15445 FINE-GRAINED IMPACT MELT WITH PRISTINE CLASTS 287.2 g

INTRODUCTION: 15445 is a very fine-grained impact melt of Mg-rich low-K Fra Mauro composition and contains clasts of metamorphic and plutonic pristine igneous rocks such as spinel troctolite and norite (Fig. 1) giving it its early designation of "black and white breccia." Clasts of surficial origin are absent. 15445 is very similar to 15455 which was collected nearby, and both rocks have been interpreted to be fragments of melt rock produced in the Imbrium event (Ryder and Bower, 1977). 15445 was studied in detail by the Imbrium Consortium (leader J.A. Wood) following some earlier studies. Imbrium Consortium reports are abbreviated here as ICR 1 (=1976) and ICR 2 (=1977).


Figure 1. Macroscopic view of 15445, post-chipping (1972). Clast designations shown. Scale is in centimeters, cube is 2 cm. S-72-15938

15445 was found lying near a 1.5 x 0.6 m boulder that contained white clasts. It was collected because the astronauts believed it was likely to have once been a part of the boulder, which in turn was interpreted as Spur Crater ejecta (Bailey and Ulrich, 1975). The sample is tough, blocky, and angular, with a few zap pits on "T", "B", 'IN", and "SI,"

with none on "E." The matrix is uniformly dark gray and fine-grained. Discontinuous veins of matrix of varied thickness cut some of the clasts. Vugs constitute perhaps 3% of the matrix.

PETROLOGY: 15445 consists of about 25% white lithic clasts in a dark gray, coherent, fine-grained impact melt matrix (Figs. 1 and 2). Locally the matrix contains tiny vesicles, and mineral fragments are ubiquitous. The lithic clasts tend to be pristine igneous, and do not include polymict breccia fragments or surface-derived fragments such as basaltic-textured clasts. Simonds et al. (1975) listed 15445 as a black and white rock "macroscopically similar to several Apollo 16 rocks" but 15445 does not have the mutually intrusive components nor the dimict nature of the Apollo 16 black and white rocks (now "dimict breccias;" Stoffler et al., 1980).

MATRIX: The matrix is an aggregate of mineral class and minerals that crystallized at least partly from a silicate melt, as demonstrated in particular by the presence of euhedral, skeletal olivines (Fig. 3a). It has been described by Ryder and Bower (1977) and in ICR 1 and ICR 2. Imbrium Consortium reports refer to the matrix as Lithology 45A. In a few areas, vesicles are elongated and roughly aligned, and elsewhere the matrix is roughly stratified (ICR 1). The siderophile element abundances are within the normal range for meteoritic contaminated highlands breccias (Gros et al., 1976) and the matrix is therefore most certainly a fragment-laden impact melt. Engelhardt (1979) lists the 15445 matrix as granular, in a group "without any signs of a sequential order of crystallization" whose members are "granoblastic products of solid state recrystallization," i.e., metamorphic.

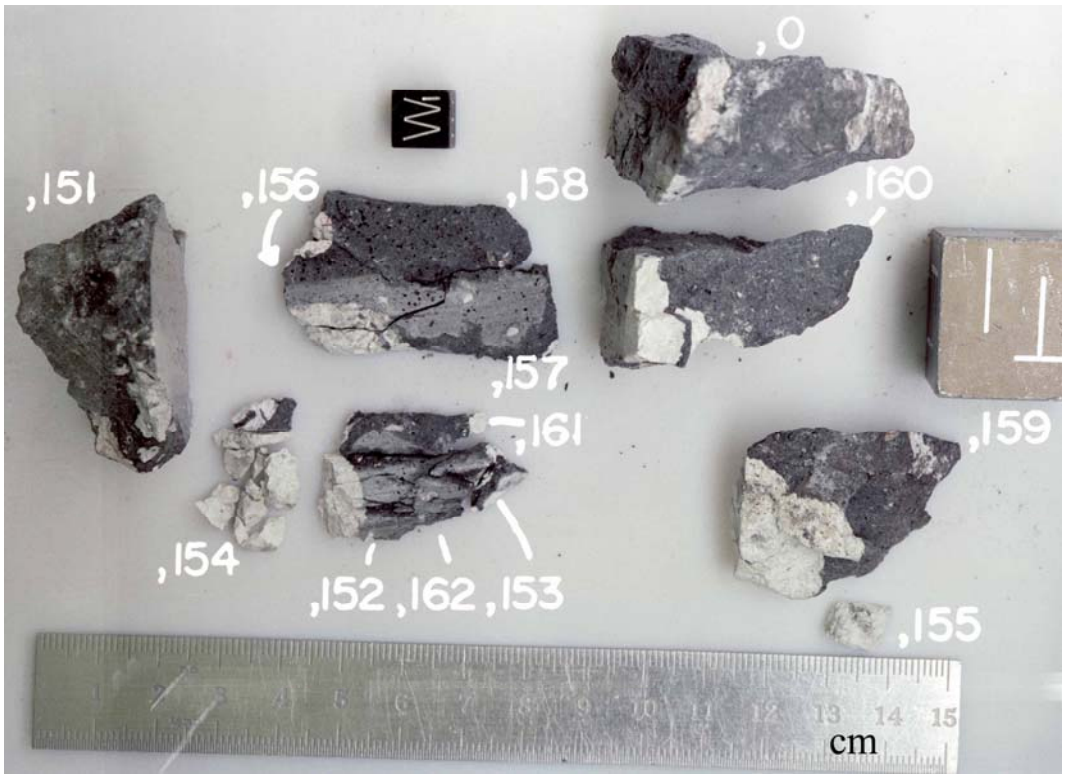


Figure 2. Dissection of slab sawn through 15445, with clast designations. Cube is 2 cm. S-75-33433

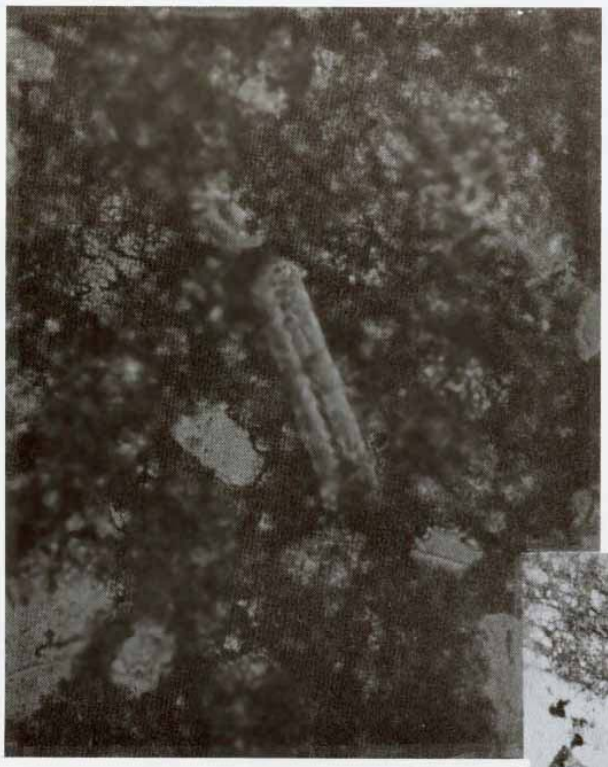


Fig. 3a

Fig. 3b

Figure 3. Photomicrographs of 15445.
a) hollow euhedral olivine in matrix of 15445,133, indicating melt origin.
Width about 125 microns. Transmitted light.
b) spinel troctolite clast A (left) and matrix (right) in 15445,133.
Width about 2 mm. Transmitted light.
c) norite clast B (right) and matrix in 15445,133.
Width about 2 mm. Transmitted light.
d) polygonal olivine clast in 15445, 147.
Crossed polarizers. Width about 2 mm.

Fig. 3c

Fig. 3d

The finest mineral clastic material and coarsest melt mineral products overlap in grain size, and are difficult to distinguish. The melt phase (approximately 70% of the matrix) crystallized plagioclase, olivine, at least some low-Ca pyroxene, and opaque phases. Metal and sulfide grains are present, locally in the vesicles. Plagioclase grains less than 50 microns in diameter (dominantly melt-produced) have compositions $An_{96-82}$ with a peak about $An_{90}$, and are more sodic than larger, clastic plagioclases (Fig. 4). Small olivines (less than about 50 microns) have compositions of $Fo_{86-71}$, peaked at about $Fo_{79}$ (Fig. 4). Skeletal varieties are zoned, approximately $Fo_{85-80}$, and all small olivines are more Fe-rich than the obviously clastic olivines.

Mineral fragments form about 30% of the matrix. Most plagioclase fragments are $An_{97-93}$, with a range $An_{97-65}$ (Fig. 4). No primary zoning of grains is apparent, but zoning from reaction with the matrix occurs in the outer few microns. Olivine fragments also show minor reaction border zoning, but no primary zoning. The total compositional range is $Fo_{95-65}$ (Fig. 4), wider than observed in lithic clasts in 15445. Augite is a rare clastic phase. None of the augite clasts is larger than about 50 microns in diameter. Ridley et al. (1973) noted rare orthopyroxene in the matrix, but that study did not distinguish a melt phase. Essentially, low-ca pyroxene fragments are conspicuous by their absence, in contrast to the abundance of orthopyroxene in some of the lithic clasts in 15445. Other mineral fragments include pleonaste spinel and chromite.

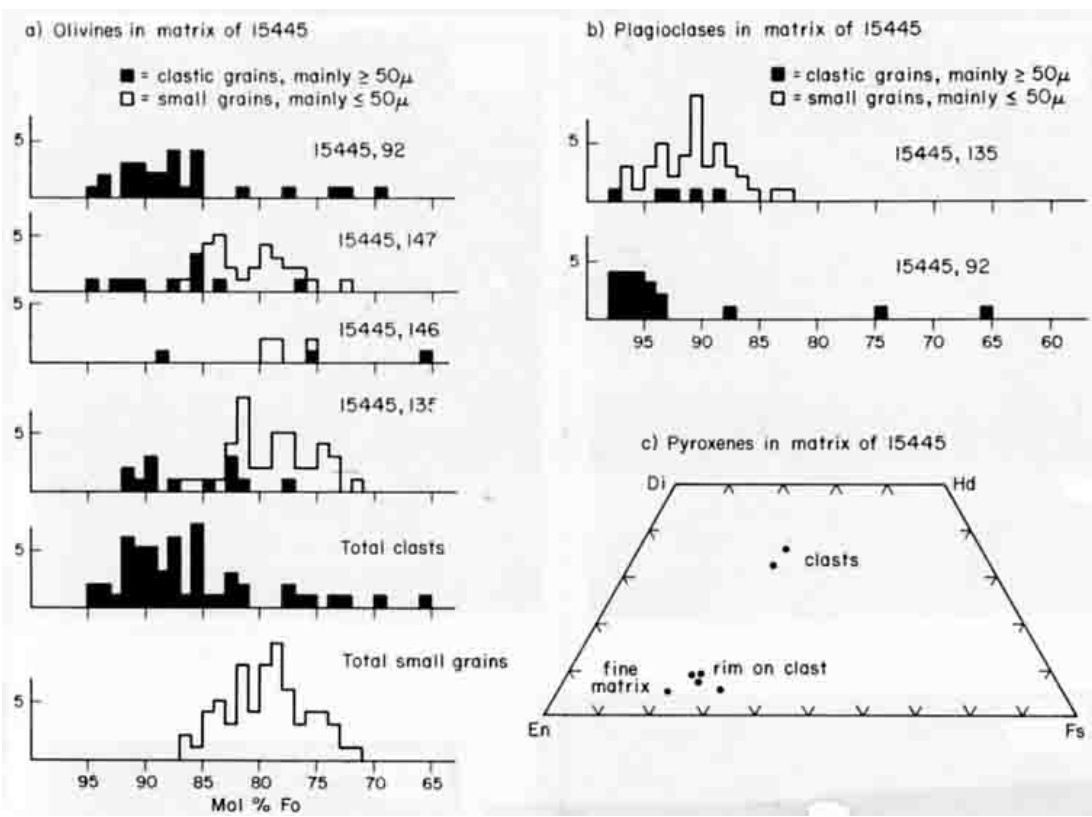



Figure 4. Compositions of minerals in matrix of 15445 (Ryder and Bower, 1977).

LITHIC CLASTS: Several types of lithic clasts occur in 15445. The larger ones all appear to be pristine plutonic igneous rocks. These were labeled as individual clasts and described in Ryder and Norman (1979). Specific clasts have been labeled A, B .... , etc. (not to be confused with type A, B of Ridley et al., 1973). Separate designations were used by the Imbrium Consortium. Comparisons of clast designations are listed in Table 15445-1.

1) Spinel Troctolite: Several of the clasts in 15445 consist of a cataclastic assemblage of olivine, plagioclase, aluminous spinel, and aluminous orthopyroxene, e.g., Clast A (Fig. 3b). The clasts are friable, once coarse-grained (>2 mm), notable for their Mg-rich olivine and Mg-Al spinel, and are generally believed to be from plutonic pristine igneous or metamorphic sources. Clast A at least is free of meteoritic contamination (Gros et al., 1976). The spinel troctolites have been described, with mineral analyses, by Ridley et al. (1973), Anderson (1973), Ridley (1977), Reid et al. (1977), Ryder and Bower (1977), Baker and Herzberg (1980), and in ICR 1 and ICR 2. Further detailed mineral analyses, particularly olivine, have also been reported by Steele and Smith (1975) (olivine; microprobe), and Steele et al.(1980) (plagioclases; ion microprobe). Steele et al. (1974) plotted armalcolite and olivine compositions. Clast A has beer, referred to as a peridotite (e.g., Anderson,1973) but Ryder and Bower (1977) suggest a mode with 30 to 40% plagioclase, about 50% olivine, and 10 to 20% pleonaste.

TABLE 15445-1

| CLAST DESIGNATION | LITHOLOGY (Imbrium Consortium) | RIDLEY et al. (1973) |
|---|---|---|
| Clast A | 45E | Type B |
| Clast B | 45D | Type A |
| Clast E | 45B | - |
| Clast F | 45C | Type B |

Clast H contains about 65% olivine, 25% plagioclase, and 10% spinel (Baker and Herzberg, 1980). A few percent aluminous orthopyroxene is present in these spinel troctolite clasts, as well as opaque phases including rutile (?) and armalcolite.

The clasts are very magnesian, with olivines $Fo_{92}$. Plagioclases ($An_{95-89}$) are generally not as calcic as those in ferroan anorthosites, although Ridley et al. (1973) reported $An_{98}$. The orthopyroxenes ($En_{92}$) contain up to 5 wt% $A1_2O_3$ (e.g., Ridley et al, 1973). There is more grain-to-grain variation in Clast H-- than in Clast A (Baker and Herzberg, 1980) e.g., minor elements in orthopyroxene. The very low CaO contents (0.010-0.014%, Steele and Smith, 1975; 0.03%, Baker and Herzberg, 1980) are the lowest reported among lunar samples and require a slow cooling or a very low Ca potential. Smith et al. (1980) suggested equilibration at temperatures as low as 400° C for the CaO in these olivines, according to an empirical model. Most authors agree that the spinel troctolite clasts are probably from cumulates that underwent slow cooling and possibly some post-crystallization equilibration, although Bence and McGee (1976) have proposed that such assemblages are the residuum of partial melting deep in the crust. Anderson (1973) concluded that the petrology was consistent with initial igneous accumulation at

moderate pressure (e.g., 2 Kb) followed by partial recrystallization during granulation at 950 ± 50° C and a pressure greater than or equal to 1.3 ± 0.5 kilobars. Similarly, Herzberg (1978) used subsolidus thermodynamic calculations to estimate and $P_{min}$ of 960° C and nearly 2 Kb respectively (i.e., lower crust or upper mantle) for the 15445 spinel troctolite assemblage, and concluded that the phase equilibria require spinel accumulation.

MacDougall et al. (1973) studied grains from Clast A using high voltage electron microscopy (HVEM) techniques. No recrystallized zones, deformed crystals, multiple twinning, micro-fracturing, or other metamorphic features were observed in grains from the clast.

2) Norite: Clast B, the largest in 15445, consists of 60-65% plagioclase ($An_{94-95}$) and 35-40% low-Ca pyroxene (Fig. 5) ($En_{77-81}$, Ryder and Bower, 1977; $En_{80-85}$, Ridley et al., 1973). The clast is cataclasized (Fig. 3c) but is free of meteoritic contamination (Gros et al., 1976). It has been described by Ridley et al. (1973), Ryder and Bower (1977), and in ICR 1 and ICR 2. Macroscopically, its pyroxene is green. Mori et al. (1982) stated that they studied pyroxenes with ATEM, XRD, and microprobe techniques, but no data were reported.

The pyroxenes contain approximately 1.5% $Al_2O_3$, not unlike terrestrial plutonic norites. Silica and an opaque mineral (ilmenite ?) (Ryder and Bower, 1977) and armalcolite and ilmenite (Ridley et al., 1973) have been reported as accessory phases. A minor vein system of Fe-metal (possibly secondary) cuts the pyroxene locally. Relict textures suggest that the norite was originally coarse-grained (>l mm) and may have been poikilitic. The mineralogy is broadly similar to the 78235 norite and the 15455 norite, but it lacks the numerous minor phases present in the latter two samples. Other small fragments of norite occur in the sample, but low-Ca pyroxene is not a part of the monomineralic clast population of the matrix. James and Flohr (1982) list the norite as a member of the Mg-norite suite. MacDougall et al. (1973), using HVEM, found that crystals exhibited dislocations and twinning indicative of mild shock.

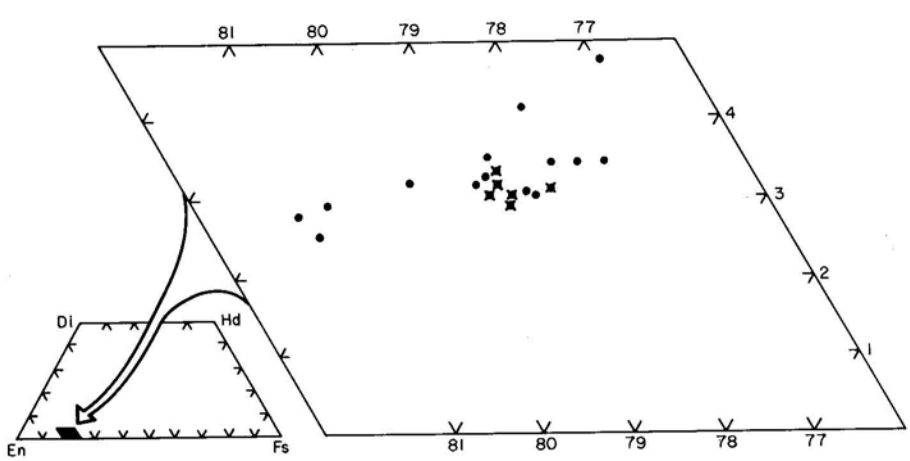



Figure 5. Compositions of pyroxenes in norite clast B (Ryder and Bower, 1977).

3) Anorthosite: A few small clasts consist entirely of brecciated and subsequently annealed plagioclase grains. The large size of some suggests that they are from anorthosites per se or very coarse-grained multiphase rocks.

4) "Gabbroic" Clasts: Marvin (ICR 1) observed rare "gabbroic" clasts containing yellow-brown pyroxene, but these clasts do not appear in thin sections.

5) Clast E: Clast E is unique and enigmatic. Macroscopically it is white, and free of pink spinel or green mafic minerals. One thin section (2 x 3 mm) consists of more than 95% plagioclase. A second thin section documented as from the clast is heterogeneous and consists of zones of crystalline plagioclase ($An_{93-97}$) + olivine ($Fo_{82-84}$), and crystalline plagioclase ($An_{93-97}$) + low-Ca pyroxene ($En_{80-82}$). The whole is injected by a brownish glass. Hence this is a complex clast. Warren and Wasson (1978) found a split from Clast E to be meteorite-free, but thought it to be polymict. While some of the discrepancies might result from erroneous documentation, the splits are clearly complex.

6) Others: Most other clasts are small and are monomineralic aggregates (Ryder and Bower, 1977). Polygonalized olivines (Fig. 3d) consist solely of olivine. The largest observed has a diameter of 3 mm. The two analyzed have olivine of $Fo_{87-88}$. Spherulitic plagioclase masses up to 1 mm diameter, are mainly round and smooth. Some clearly recrystallized in situ from the rim inwards. Rare feldspathic granulites are small and have a typical triple-junction, polygonal texture.

CHEMISTRY: Chemical analyses of matrix and clasts are listed in Tables 2 to 5, and rare earths are plotted in Figure 6 a,b,c. Jovanovic and Reed (1972) reported additional data on halogens and Te for matrix samples which were leached in the laboratory, as well as similar analyses for the leaches themselves. Keith et al. (1972) report gamma-ray-measured U (0.63 ± 0.08 ppm), Th (2.40 ± 0.18 ppm), and K (0.106 ± 0.014 ppm) abundances for the entire rock which are similar to those derived from analyses of the matrix alone (Table 3).

MATRIX: The matrix of 15445 (Tables 2 and 3) is contaminated with meteoritic siderophiles (Gros et al., 1976) grouped as 1L by Hertogen et al. (1977), the same as the 15455 matrix. It has a magnesian low-K Fra Mauro composition with rare earth abundances higher than any of the lithic clasts contained within it (Fig. 6a). Ridley et al. (1973) noted that its composition is difficult to interpret in terms of mixing of Apennine Front materials, and it appears to represent a chemically distinct unit. It was interpreted by Ryder and Bower (1977) as melt created by the Imbrium impact. The high Pb (Unruh and Tatsumoto, 1976) requires a lot of pre-analysis contamination, but if the data are real then the non-radiogenic Pb is difficult to account for.

TABLE 15445-2. Chemistry of 15445 matrix

| | | ,25 | ,25 | ,118 | ,123 | ,122 | ,125 |
|---|---|---|---|---|---|---|---|
| Wt % | SiO2 | 44.6 | | | | | |
| | TiO2 | 1.47 | 1.49 | | | | |
| | Al2O3 | 16.66 | 16.2 | | | | |
| | FeO | 9.83 | 10.2 | 10.0 | | | |
| | MgO | 16.0 | 15.5 | | | | |
| | CaO | 10.04 | 9.6 | | | | |
| | Na2O | | 0.55 | 0.54 | | | |
| | K2O | | .164 | | | | |
| | P2O5 | 0.21 | | | | | 0.17 |
| (ppm) | Sc | | | 17.6 | | | |
| | V | | | | | | |
| | Cr | | 1750 | | | | |
| | Mn | 1085 | | | | | |
| | Co | | | 47.4 | | | |
| | Ni | | | 550 | 396 | | |
| | Rb | 3.56 | | | 4.02 | | |
| | Sr | 160 | | | | | |
| | Y | | | | | | |
| | Zr | | 315 | | | | |
| | Nb | | | | | | |
| | Hf | | 10.5 | 7.4 | | | |
| | Ba | 237 | | | | | |
| | Th | | | 2.4 | | | |
| | U | | .800 | | .788 | | 0.56 |
| | Pb | | | | | 13.3 | |
| | La | 22.1 | | 20.4 | | | |
| | Ce | 57.6 | | 54 | | | |
| | Pr | | | | | | |
| | Nd | 35.7 | | | | | |
| | Sm | 10.1 | | 10.3 | | | |
| | Eu | 1.85 | | 1.64 | | | |
| | Gd | 11.9 | | | | | |
| | Tb | | | 2.4 | | | |
| | Dy | 13.2 | | | | | |
| | Ho | | | | | | |
| | Er | 7.71 | | | | | |
| | Tm | | | | | | |
| | Yb | 6.90 | | 7.2 | | | |
| | Lu | 1.02 | | 0.98 | | | |
| | Li | 14.1 | | | | | |
| | Be | | | | | | |
| | B | | | | | | |
| | C | | | | | | |
| | N | | | | | | |
| | S | 600 | | | | | |
| | F | | | | | | |
| | Cl | | | | | | |
| | Br | | | | .096 | | |
| | Cu | | | | | | |
| | Zn | | | | 2.5 | | |
| (ppb) | I | | | | | | |
| | At | | | | | | |
| | Ga | | | | | | |
| | Ge | | | | 630 | | |
| | As | | | | | | |
| | Se | | | | 91 | | |
| | Mo | | | | | | |
| | Tc | | | | | | |
| | Ru | | | | | | |
| | Rh | | | | | | |
| | Pd | | | | 17.4 | | |
| | Ag | | | | 2.0 | | |
| | Cd | | | | 5.3 | | |
| | In | | | | 0.32 | | |
| | Sn | | | | | | |
| | Sb | | | | 244 | | |
| | Te | | | | 4.7 | | |
| | Cs | | | | 177 | | |
| | Ta | | | 1100 | | | |
| | W | | | | | | |
| | Re | | | | 0.668 | | |
| | Os | | | | 7.44 | | |
| | Ir | | | | 6.21 | | |
| | Pt | | | | | | |
| | Au | | | | 6.02 | | |
| | Hg | | | | | | |
| | Tl | | | | 0.59 | | |
| | Bi | | | | 0.24 | | |
| | | (1) | (1) | (2) | (3) | (4) | (5) |

**References and Methods:**

(1) Ridley et al. (1973); isotope dilution, XRF, AA. (also partial publication in Church et al. (1972); Nyquist et al. (1972b, 1973); Hubbard et al. (1974; Wiesmann and Hubbard (1975).

(2) Blanchard et al.; in ICR 2; INAA.

(3) Gros et al. (1977), in ICR 1; RNAA.

(4) Tatusmoto and Unruh, in ICR 1; isotope dilution.

(5) Jovanovic and Reed (1977) and ICR 1; INAA (U), colorimetry ($P_2O_5$).

TABLE 15445-3. Microprobe defocussed beam analyses of matrix
(Ryder and Bower, 1977; ICR 2)

| | | | |
|---|---|---|---|
| Wt % | SiO2 | 45.7 | 45.3 |
| | TiO2 | 1.56 | 1.70 |
| | Al2O3 | 17.3 | 17.5 |
| | FeO | 7.9 | 9.5 |
| | MgO | 13.4 | 15.7 |
| | CaO | 11.5 | 9.7 |
| | Na2O | 0.62 | 0.81 |
| | K2O | 0.22 | 0.18 |
| | P2O5 | 0.18 | 0.27 |
| ppm | Cr | 1230 | 1030 |
| | Mn | 850 | 1240 |

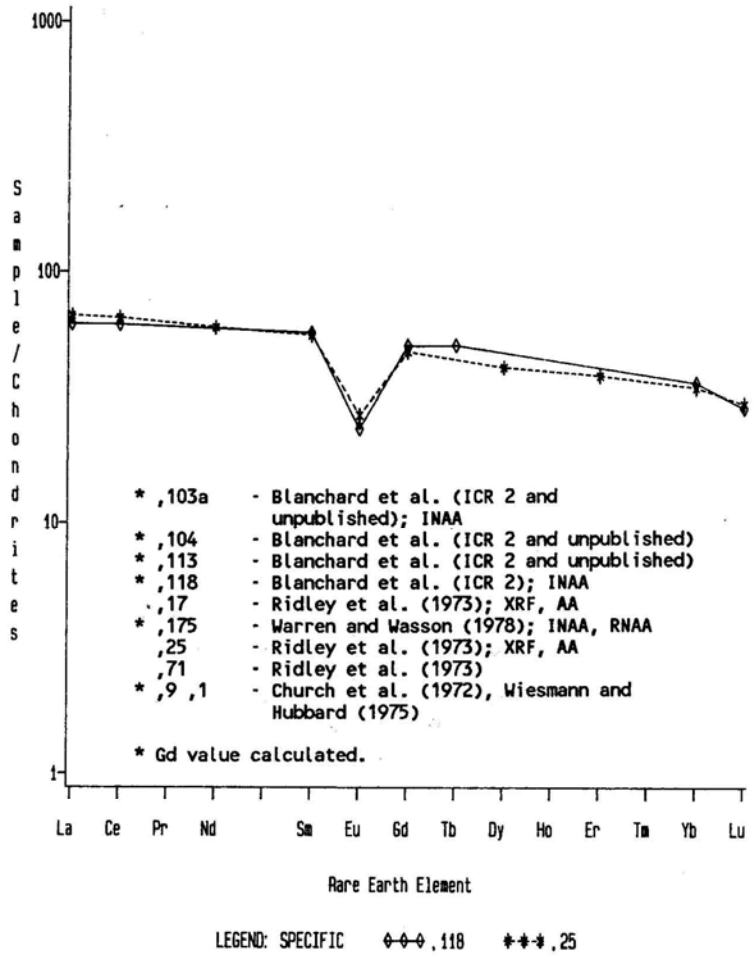
LITHIC CLASTS:

1) Spinel Troctolites: The small size of the analyzed splits of the spinel troctolite samples are a disadvantage in their interpretation, but they do seem to be ultrabasic, with more than 30% MgO (Table 4). The rare earths for Clast G are substantially different from those for Clast A (Fig. 6b). The enriched heavy REEs (a unique pattern for a lunar sample) of Clast A reported by Ridley et al. (1973) were interpreted by the authors as indicating the former presence of garnet in the rock, but a second analysis of the same split (Wiesmann and Hubbard, 1975) showed no such enrichment and in fact appeared similar to the analysis of Clast G (or F) by Blanchard et al. (in ICR 1). Gros et al. (1976) note the very low siderophile content of Clast G (,102). According to Gros et al. in ICR 1, the levels are slightly enriched above the expected indigenous, an enrichment which could be explained by 5% matrix contamination. They suggested that the high Ni abundance they measured is spurious.

2) Norite: Clast B is an anorthositic norite according to its major elements (Table 5), and has a conspicuous positive Eu anomaly (Fig. 6c) consistent with plagioclase accumulation (Ridley et al., 1973). Hubbard et al. (1974) gave it "conditional membership" in an anorthositic series but gave no real discussion of it. Both Gros et al. (1976) and Tatsumoto and Unruh (ICR 1) and Unruh and Tatsumoto (1976) erroneously referred to this lithology as olivine and spinel-bearing, i.e., spinel troctolite, and it is also erroneously referred to as 15455,107 in one place in the text of Gros et al. (1976). The norite is free of meteoritic contamination. The high Pb abundance, nonradiogenic, cannot be accounted for by their own possible laboratory contamination, but might be from previous sample handling, according to Unruh and Tatsumoto (1976).

3) Clast E: Chemical analyses by Blanchard et al. (ICR 2, and unpublished) and by Warren and Wasson (1978) are not in good agreement (Table 5), presumably because of small sample sizes and the apparent complexity of the clast. The analysis by Warren and Wasson is of a more mafic split; it is free of meteoritic contamination, but Ge is very high. The rare earth pattern is KREEPy, and Clast E may well be polymict. Wanke et al. (1983) plotted 15445 on a diagram of pristine rocks; the data appear to be that of Warren and Wasson (1978) for Clast E.

**Fig. 6a**


1000
100
10
1
Sample/Chondrites
* ,103a - Blanchard et al. (ICR 2 and unpublished); INAA
* ,104 - Blanchard et al. (ICR 2 and unpublished)
* ,113 - Blanchard et al. (ICR 2 and unpublished)
* ,118 - Blanchard et al. (ICR 2); INAA
,17 - Ridley et al. (1973); XRF, AA
* ,175 - Warren and Wasson (1978); INAA, RNAA
,25 - Ridley et al. (1973); XRF, AA
,71 - Ridley et al. (1973)
* ,9 ,1 - Church et al. (1972), Wiesmann and Hubbard (1975)
* Gd value calculated.
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Rare Earth Element
LEGEND: SPECIFIC ,118 ,25

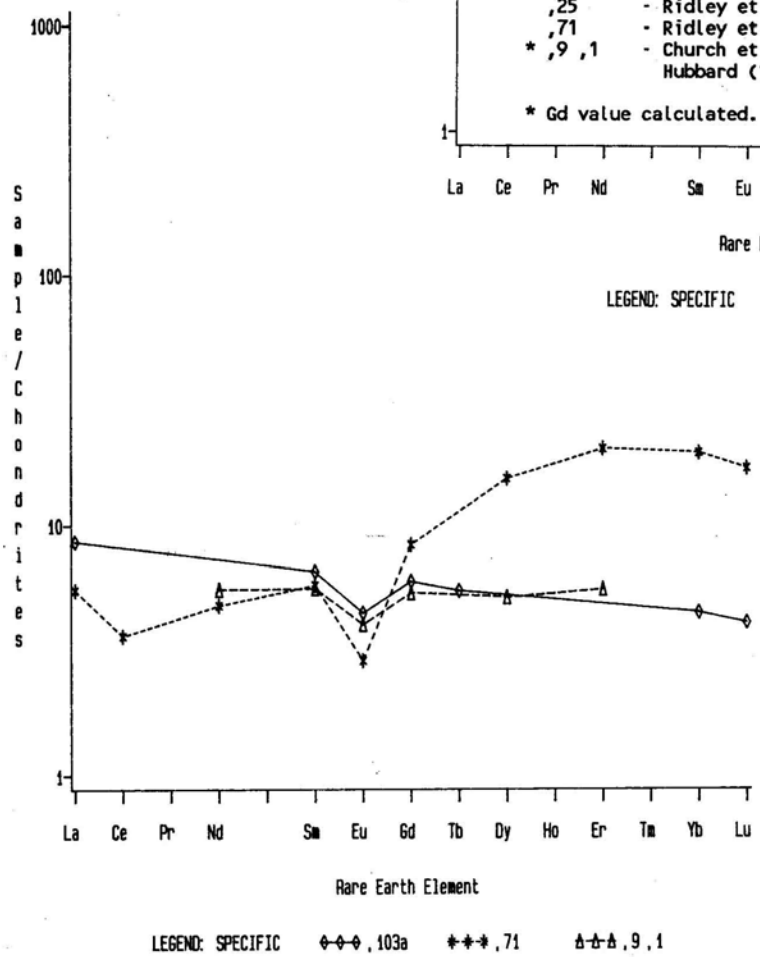

1000
100
10
1
Sample/Chondrites
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Rare Earth Element
LEGEND: SPECIFIC ,103a ,71 ,9 ,1

**Fig. 6b**

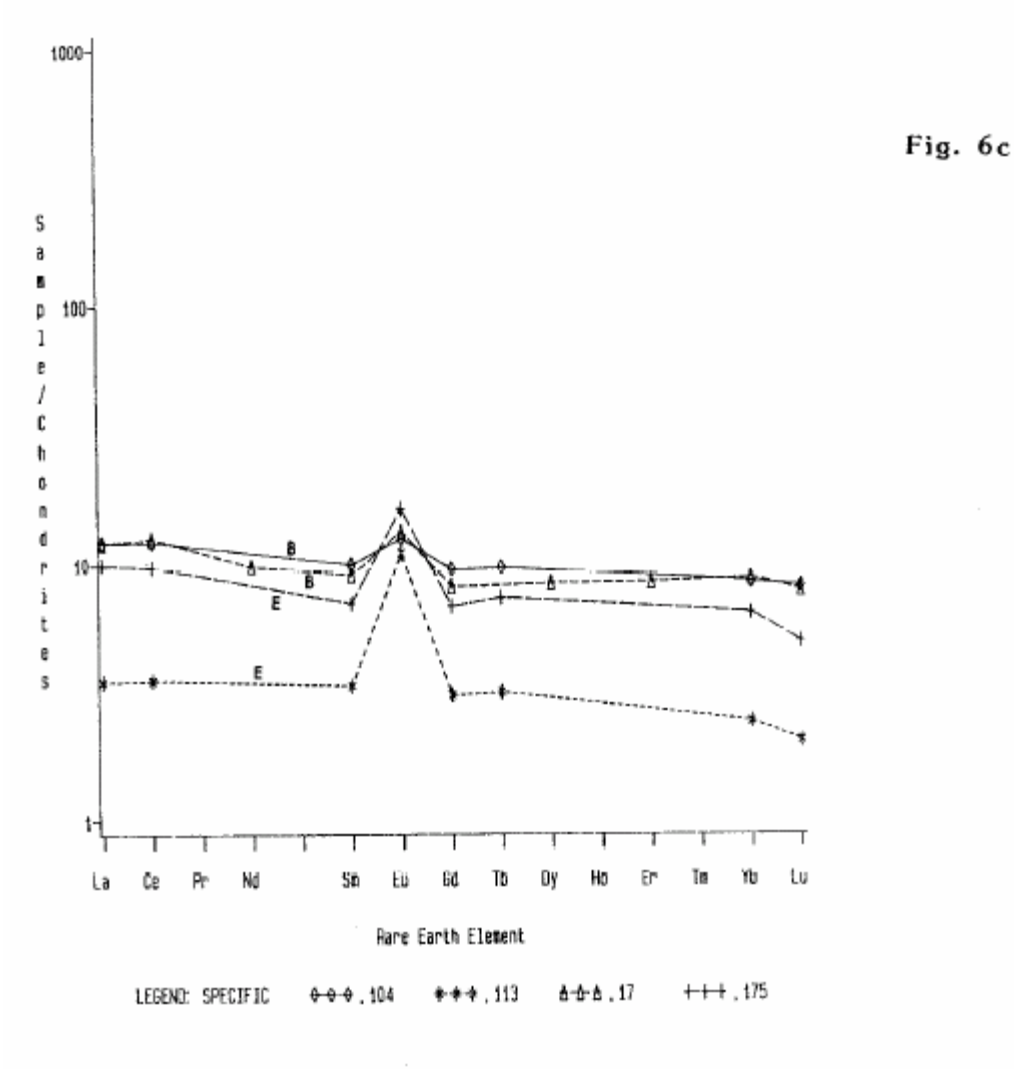



Figure 6. Rare earths in 15445.
a) matrix; b) spinel troctolites; c) norite B and clast E.

TABLE 15445-4. Chemistry of 15445 Spinel Troctolite Clasts

| | | Clast A | | | Clast G | |
|---|---|---|---|---|---|---|
| | | ,71 | ,9 | ,9,1 | ,102 | ,103a |
| Wt % | SiO2 | | | | | 37.5 |
| | TiO2 | .588 | | .154 | | 0.25 |
| | Al2O3 | 7.2 | | | | 14.7 |
| | FeO | | | | | 6.4 |
| | MgO | 31.1 | | 36.7 | | 33 |
| | CaO | 1.9 | | 4.76 | | 4.8 |
| | Na2O | 0.10 | | | | 0.14 |
| | K2O | | | .0146 | | 0.022 |
| | P2O5 | | | | | |
| (ppm) | Sc | | | | | 3.43 |
| | V | | | | | |
| | Cr | | | | | 6900 |
| | Mn | | | | | |
| | Co | | | | | 50.4 |
| | Ni | | | | 901* | 820 |
| | Rb | | .80 | | .66 | |
| | Sr | | 42.6 | | | |
| | Y | | | | | |
| | Zr | | | 35.5 | | |
| | Nb | | | | | |
| | Hf | | | <1 | | 0.74 |
| | Ba | 25.0 | | 23.6 | | |
| | Th | | | | | 0.27 |
| | U | | | .151 | .024 | |
| | Pb | | | | | |
| | La | 1.84 | | | | 2.86 |
| | Ce | 3.2 | | | | |
| | Pr | | | | | |
| | Nd | 2.89 | | 3.35 | | |
| | Sm | 1.05 | | 1.02 | | 1.19 |
| | Eu | 0.196 | | 0.275 | | 0.31 |
| | Gd | 2.09 | | | | |
| | Tb | | | | | 0.26 |
| | Dy | 4.88 | | 1.65 | | |
| | Ho | | | | | |
| | Er | 4.04 | | 1.12 | | |
| | Tm | | | | | |
| | Yb | 3.89 | | | | 0.90 |
| | Lu | 0.573 | | | | 0.136 |
| | Li | | | | | |
| | Be | | | | | |
| | B | | | | | |
| | C | | | | | |
| | N | | | | | |
| | S | | | | | |
| | F | | | | | |
| | Cl | | | | | |
| | Br | | | | .0831 | |
| | Cu | | | | | |
| | Zn | | | | 13.4 | |
| (ppb) | I | | | | | |
| | At | | | | | |
| | Ga | | | | | |
| | Ge | | | | 335 | |
| | As | | | | | |
| | Se | | | | 1.3 | |
| | Mo | | | | | |
| | Tc | | | | | |
| | Ru | | | | | |
| | Rh | | | | | |
| | Pd | | | | <1.2 | |
| | Ag | | | | 1.77 | |
| | Cd | | | | 2.0 | |
| | In | | | | 10.9* | |
| | Sn | | | | | |
| | Sb | | | | 18.9 | |
| | Te | | | | 2.7 | |
| | Cs | | | | 180 | |
| | Ta | | | | | |
| | W | | | | | |
| | Re | | | | .174 | |
| | Os | | | | .323 | |
| | Ir | | | | .340 | |
| | Pt | | | | | |
| | Au | | | | .319 | |
| | Hg | | | | | |
| | Tl | | | | 2.7 | |
| | Bi | | | | .22 | |
| | | (1) | (2) | (3) | (4) | (5) |

References and Method:

(1) Ridley et al. (1973); isotope dilution and ?
(2) Nyquist et al. (1972b, 1973); isotope dilution.
(3) Church et al. (1972) and Wiesmann and Hubbard (1975); isotope dilution.
(4) Gros et al. (1977) and in ICR 1; RNAA.
(5) Blanchard et al. in ICR 2 and unpublished; INAA.
(6) Jovanovic and Reed (1977) and in ICR 1; thermal neutron activation for U; colorimetric for $P_2O_5$.

Notes:

* suspected by analyzers of contamination
(a) listed as Clast F, which it might be

TABLE 15445-5. Chemistry of 15445 Norite Clast B and Complex Clast E

| | | Norite B | | | | | Clast E | |
|---|---|---|---|---|---|---|---|---|
| | | ,17 | ,17 | ,106 | ,104 | ,107 | ,113 | ,175 |
| Wt % | SiO2 | 48.7 | | | 47.7 | | 43.4 | 45.58 |
| | TiO2 | 0.15 | 0.140 | | 0.27 | | .01 | 0.07 |
| | Al2O3 | 23.76 | 20.8 | | 23.0 | | 33 | 30.43 |
| | FeO | 3.88 | 3.8 | | 3.9 | | .55 | 2.32 |
| | MgO | 9.94 | 9.7 | | 10.2 | | 1.56 | 4.70 |
| | CaO | 13.26 | 12.6 | | 12.8 | | 17.3 | 16.38 |
| | Na2O | | 0.33 | | 0.32 | | .31 | 0.36 |
| | K2O | | .070 | | 0.066 | | .045 | |
| | P2O5 | 0.03 | | | | | | |
| (ppm) | Sc | | | | 7.1 | | 1.90 | 4.3 |
| | V | | | | | | | |
| | Cr | | 1560 | | 1710 | | 228 | 890 |
| | Mn | 600 | | | | | | 292 |
| | Co | | | | 10.3 | | 2.64 | 10.1 |
| | Ni | | | | | 11 | 70 | <90 |
| | Rb | | 1.43 | | | 1.14 | | |
| | Sr | | 130 | | | | | |
| | Y | | | | | | | |
| | Zr | | 115 | | | | | |
| | Nb | | | | | | | |
| | Hf | | 4.1 | | 1.36 | | 0.60 | 1.2 |
| | Ba | | 61.9 | | | | | |
| | Th | | | 0.893 | .82 | | 0.94 | 0.68 |
| | U | | .539 | 0.160 | | .135 | | 0.18 |
| | Pb | | | 65.5 | | | | |
| | La | | 4.02 | | 4.02 | | 1.15 | 3.3 |
| | Ce | | 11.1 | | 10.8 | | 3.1 | 8.6 |
| | Pr | | | | | | | |
| | Nd | | 5.91 | | | | | |
| | Sm | | 1.65 | | 1.81 | | 0.61 | 1.28 |
| | Eu | | 0.929 | | 0.87 | | 0.77 | 1.14 |
| | Gd | | 2.05 | | | | | |
| | Tb | | | | 0.46 | | 0.15 | 0.35 |
| | Dy | | 2.69 | | | | | |
| | Ho | | | | | | | |
| | Er | | 1.72 | | | | | |
| | Tm | | | | | | | |
| | Yb | | 1.78 | | 1.72 | | 0.49 | 1.3 |
| | Lu | | 0.268 | | 0.28 | | 0.069 | 0.17 |
| | Li | | | | | | | |
| | Be | | | | | | | |
| | B | | | | | | | |
| | C | | | | | | | |
| | N | | | | | | | |
| | S | | | | | | | |
| | F | | | | | | | |
| | Cl | | | | | | | |
| | Br | | | | | .0679 | | |
| | Cu | | | | | | | |
| | Zn | | | | | 1.5 | | 0.81 |
| (ppb) | I | | | | | | | |
| | At | | | | | | | |
| | Ga | | | | | | | 4800 |
| | Ge | | | | | 5.1 | | 3820 |
| | As | | | | | | | |
| | Se | | | | | 4.6 | | |
| | Mo | | | | | | | |
| | Tc | | | | | | | |
| | Ru | | | | | | | |
| | Rh | | | | | | | |
| | Pd | | | | | 1.2 | | |
| | Ag | | | | | 0.52 | | |
| | Cd | | | | | 2.8 | | <9 |
| | In | | | | | 0.34 | | <150 |
| | Sn | | | | | | | |
| | Sb | | | | | 0.42 | | |
| | Te | | | | | <0.7 | | |
| | Cs | | | | | 267 | | |
| | Ta | | | | 130 | | 190 | 120 |
| | W | | | | | | | |
| | Re | | | | | 0.0099 | | 0.70 |
| | Os | | | | | 0.018 | | |
| | Ir | | | | | 0.072 | | 0.14 |
| | Pt | | | | | | | |
| | Au | | | | | 0.022 | | <0.035 |
| | Hg | | | | | | | |
| | Tl | | | | | 3.5 | | |
| | Bi | | | | | 0.25 | | |
| | | (1) | (1) | (2) | (3) | (4) | (3) | (5) |

References and Methods:

(1) Ridley et al. (1973); isotope dilution, XRF, AA.
(also partial publication in Church et al. (1972); Nyquist et al. (1972b, 1973);
Hubbard et al. (1974); Wiesmann and Hubbard (1975)).
(2) Tatsumoto and Unruh in ICR 1 and Unruh and Tatsumoto (1976); isotope dilution.
(3) Blanchard et al. in ICR 2 and unpublished.
(4) Gros et al. (1976) and in ICR 1; RNAA.
(5) Warren and Wasson (1978); INAA, RNAA, microprobe fused bead.

STABLE ISOTOPES: Clayton et al. (1973a, b) reported oxygen isotopic analyses of olivine from spinel troctolite Clast A, plagioclase and orthopyroxene from norite Clast B, and bulk matrix (Table 6).

The plag-opx fractionation in the norite, 0.35, is identical within experimental error of all previously reported fractionations of plag-px in lunar basalts and gabbros. It indicates equilibration at about 1200° C, but is fairly insensitive to temperature--as low as 1050° C is also compatible with the data. The olivine in the spinel troctolite, if in equilibrium with the norite, also indicates 1000° C to 1200° C, hence there is no evidence of isotopic exchange following igneous crystallization. Metamorphic equilibration within the spinel troctolite cannot be ruled out. All the separated phases have $\delta O^{18}$ TM values 0.2 to 0.3º/oo lower than their counterparts in lunar mare basalts.

RADIOGENIC ISOTOPES/GEOCHRONOLOGY: Nyquist et al. (1972b, 1973) presented whole-rock Rb-Sr isotopic data (Table 7), without specific discussion, for matrix, spinel troctolite, and norite lithologies.

Tatsumoto and Unruh (ICR 1) and Unruh and Tatsumoto (1976) presented U, Th, Pb concentrations and isotopic abundances for both matrix and for plagioclase, orthopyroxene, and whole-rock splits of norite Clast B (Table 8). They erroneously referred to the norite as an olivine-spinel-bearing white clast, and hence to the green orthopyroxene as olivine. The matrix has a high lead content with $^{206}Pb/^{204}Pb$ of 27, i.e., very non-radiogenic. Such an isotopic composition requires a lot of contamination, but if the data are real, the non-radiogenic lead cannot be accounted for. All splits of the norite are also unusually non-radiogenic with $^{206}Pb/^{204}Pb$ of 20 to 24. Again, this could result from contamination during sample handling prior to analysis.

Bernstein (1983) reported $^{40}Ar$-$^{39}Ar$ stepwise release results for a matrix sample. The pattern is disturbed with no real plateau and a drop-off at 1100° C, similar to that obtained by Alexander and Kahl (1974) for a 15455 matrix sample. A weighted average gives an "age" of 3.76 ± 0.09 b.y. for 15445.

TABLE 15445-6. Oxygen isotopic analyses of 15445
(Clayton et al., 1973b)

| SPLIT | ROCK TYPE | MINERAL | $\delta O^{18}$(SMOW) |
|---|---|---|---|
| ,14 | norite | plag | +5.67 |
| ,14 | norite | opx | +5.32 |
| ,10 | sp-troctolite | oliv | +4.89 |
| ,28 | matrix | ---- | +5.63 |

RARE GASES/TRACKS/EXPOSURE: Drozd et al. (1977) analyzed the abundances of isotopes of Ne, Kr, and Xe in ,111, apparently a matrix chip. The sample is not rich in solar wind gases and does not contain more fission xenon then expected. They calculated a $^{21}$Ne exposure age of 118 m.y. and a $^{81}$Kr exposure age of 157 ± 22 m.y. Bernstein (1983) calculated a $^{38}$Ar exposure age of 220 m.y. for a matrix sample.

Keith et al. (1972) counted cosmogenic radionuclide ($^{26}$Al, $^{22}$Na, $^{54}$Mn, $^{56}$Co, and $^{46}$Sc) disintegrations for the bulk rock. Yokoyama et al. (1974) could not decide if these data indicated saturation in $^{26}$Al activity or not.

MacDougall et al. (1973) found no preserved solar flare tracks in the spinel troctolite or the norite clasts. They did not investigate the matrix.

PROCESSING AND SUBDIVISIONS: At the Lunar Receiving Laboratory in 1971, clasts were designated A, B, D, E, and F, and pieces of them and matrix were pried or chipped off for allocation (Fig. 7), leaving many chips. Subsequent mapping and processing for the Imbrium Consortium is detailed by Marvin (ICR 1). A slab, which broke along fractures, was cut through the sample, leaving end piece ,151 and ,0. ,0 was then split into ,0; ,159; and ,160, and the slab dismembered for allocation (Fig. 2). The sample is substantially dissected.

TABLE 15445-7. Rb-Sr Analyses of 15445
(Nyquist et al., 1973).

| Split | Lithology | $^{87}$Rb/$^{86}$Sr | $^{87}$Rb/$^{86}$Sr | Tm[a] | $T_{LUNI}$[b] |
|---|---|---|---|---|---|
| ,25 | matrix | .0643 ± 7 | .70322 ± 6 | 4.47 ± .11 | 4.57 ± .15 |
| ,17 | norite | .0318 ± 4 | .70122 ± 4 | 4.64 ± .15 | 4.85 ± .15 |
| ,9 | sp-troctolite | .054 ± 12 | .70238 ± 44 | 4.2 ± 1.6 | 4.4 ± 1.6 |

a) model age assuming I = 0.69910 (BABI plus lab bias)
b) model age assuming I = 0.69900
$\lambda = 1.39 \times 10^{-11} \times yr^{-1}$

TABLE 15445-8. U, Th, Pb analyses of 15445
(Tatsumoto and Unruh, ICR 1).

| Sample | Fraction | Weight[1] (microgram) | Run[2] | Concentrations U (ppm) | Concentrations Th (ppm) | Concentrations Pb (ppm) | Atomic Ratios $^{232}$Th/$^{238}$U | Atomic Ratios $^{238}$U/$^{204}$Pb | Lead Isotopic Composition: Observed Ratio[3] $^{206}$Pb/$^{204}$Pb | Observed Ratio $^{207}$Pb/$^{204}$Pb | Observed Ratio $^{208}$Pb/$^{204}$Pb | Corrected Ratio[4] $^{206}$Pb/$^{204}$Pb | Corrected Ratio $^{207}$Pb/$^{204}$Pb | Corrected Ratio $^{208}$Pb/$^{204}$Pb | Corrected Ratio $^{207}$Pb/$^{206}$Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15445,106 | whole rock | 753.0 | P | | | | - | | 23.39 | 17.75 | 42.08 | 23.47 | 17.83 | 42.32 | 0.760 |
| ~~olivine-spinel bearing white clast~~ | | 404.6 | C | 0.160 | 0.893 | 65.5 | 5.78 | 0.168 | 22.43 | 17.55 | -- | 22.43 | 17.55 | -- | 0.782 |
| Norite | plagioclase (matrix) | 814.6 | P | | | | | | 21.24 | 17.73 | 40.93 | 21.32 | 16.81 | 41.19 | 0.788 |
| | | 426.8 | C | 0.207 | 1.177 | 33.3 | 5.88 | 0.434 | 21.30 | 16.79 | -- | 21.44 | 16.84 | -- | 0.785 |
| | ~~olivine~~ opx | 104.0 | P | | | | | | 20.84 | 16.58 | 39.90 | 21.03 | 16.70 | 40.03 | 0.789 |
| | | 66.5 | C | 0.054 | 0.262 | 16.95 | 5.03 | 0.216 | 20.79 | 15.93 | -- | 21.02 | 15.97 | -- | 0.760 |
| 15445,122 matrix | whole rock | 134.0 | P | | | | | | 26.98 | 20.11 | 45.98 | 27.10 | 20.22 | 46.28 | 0.746 |
| | | 768.0 | C | -- | -- | 13.3 | -- | -- | 26.61 | 19.91 | -- | 27.10 | 19.54 | -- | 0.721 |

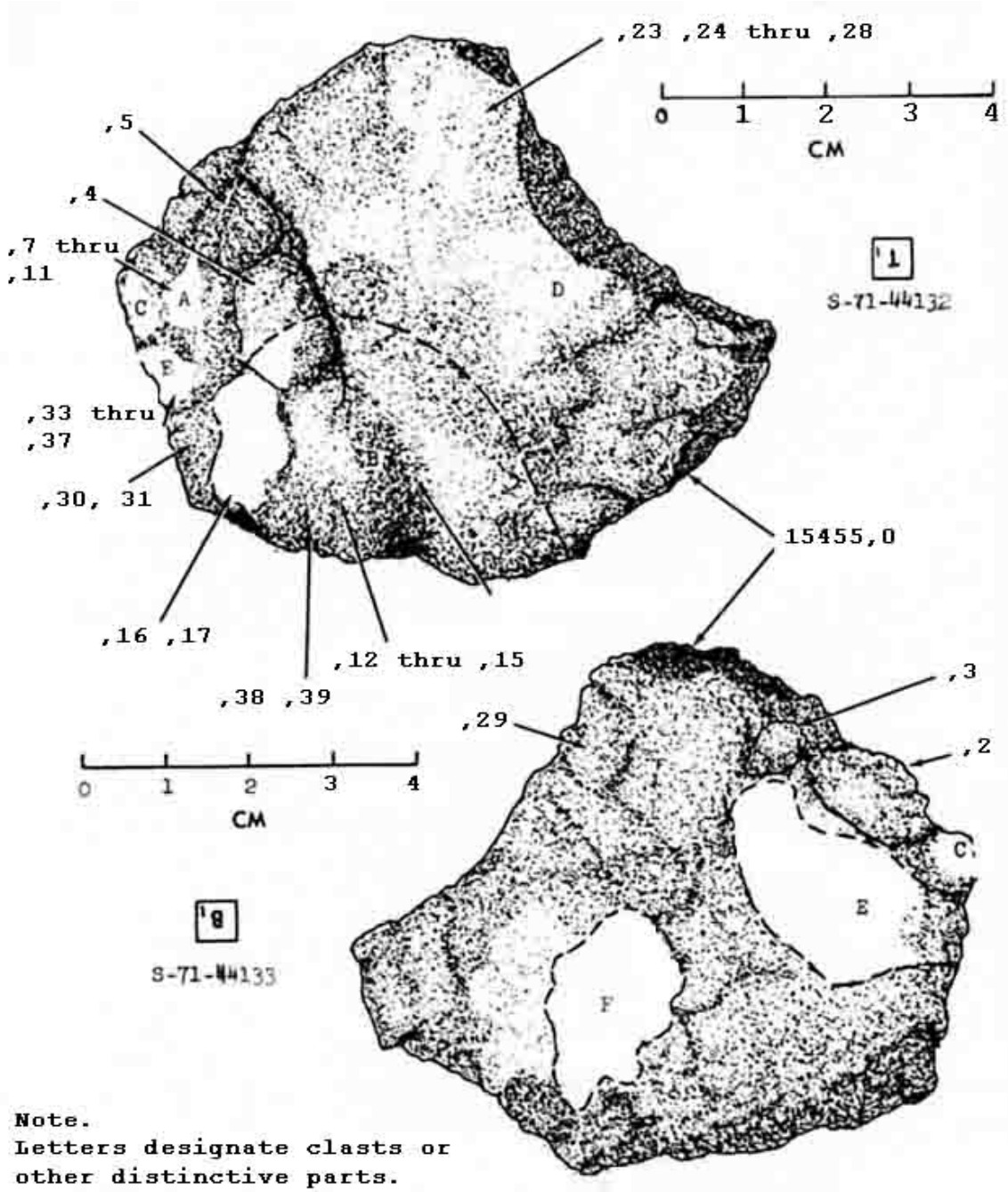



Figure 7. Original chipping and clast designations of 15445.