

15418

Heavily-shocked and brecciated Granulite

1141 grams

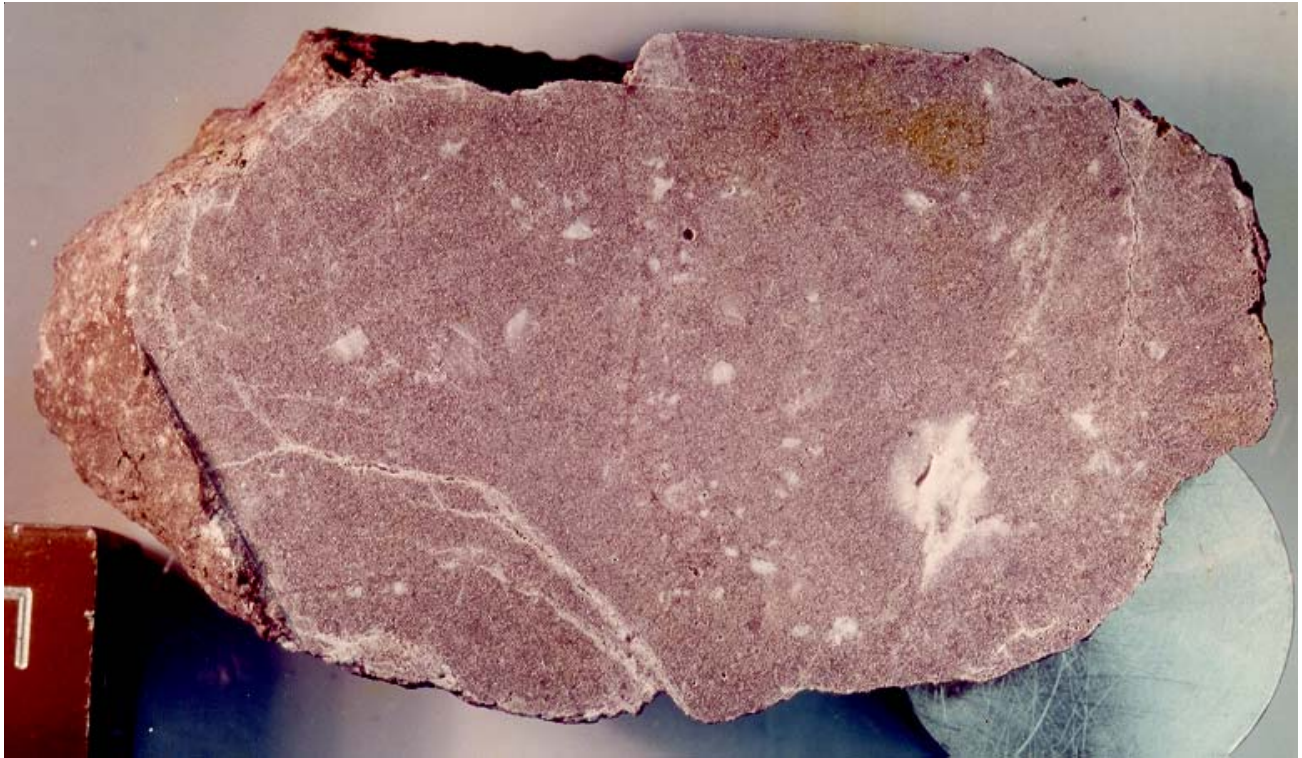


Figure 1: Sawn surface of 15418,27. Note sealed fractures. Sample is 12 cm long. Cube is 1 in. NASA S75-33763.

Introduction

Lunar sample 15418 is a highly-shocked, granulitic breccia that has a chemical composition of “gabbroic anorthosite” – and has, from time to time, been considered as representative of a portion of the original lunar crust. Although this sample has had a complicated history, the original metamorphic mineralogy with two pyroxenes can be identified. 15418 is highly aluminous ($\text{Al}_2\text{O}_3 = 26\%$) and the potassium content is low ($\text{K} = 0.01\%$). Lindstrom and Lindstrom (1986) have reviewed lunar granulites, in general, and 15418, in particular.

15418 has been dated at 4.04 b.y., with an exposure age of 250 m.y. It has micrometeorite craters on all sides.

Petrography

Four lithologies have been identified in 15418 (Nord et al. 1977, Cohen et al. 2004). The interior and main

mass (figures 1 and 6) is a highly shocked, and previously brecciated, lunar granulite composed of ~70% anorthite and ~30% mafic (augite, orthopyroxene and olivine). In places within the rock the shock-melted, plagioclase has partially reacted with the mafic minerals (figure 2). Part of the sample is coated with aluminous glass which has recrystallized in places (figure 5). An area of highly vesicular glass is found on one side (figure 10). A penetrating fracture separated a high vesicular part of the rock from a more dense portion (figure 4). Vesicles in this outer zone, were up to a cm in size. This smaller piece (.1 to .6) is what was initially studied in PET and from which most of the thin sections and initial reports were made.

Sample 15418 was extensively studied to characterize microstructures in minerals and glass (Heuer et al. 1972, Christie et al. 1973, Gleadow et al. 1974, Nord et al. 1977). At high magnification it was found that many mineral grains in 15418 have a high density of

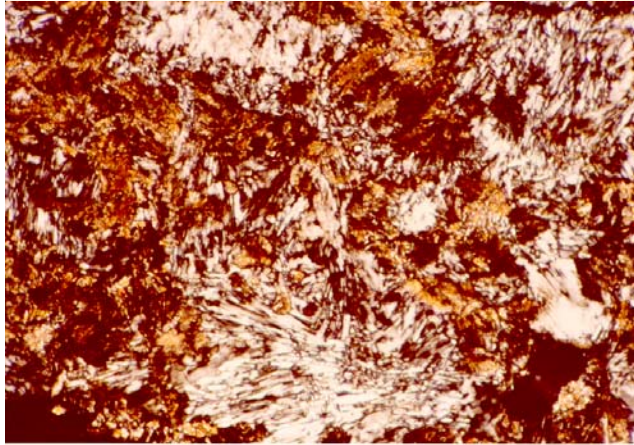
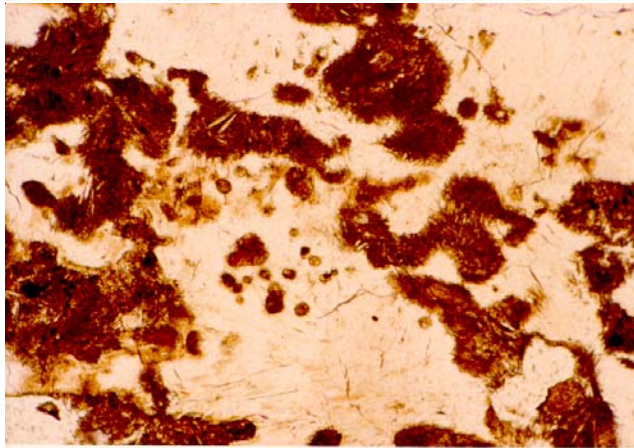
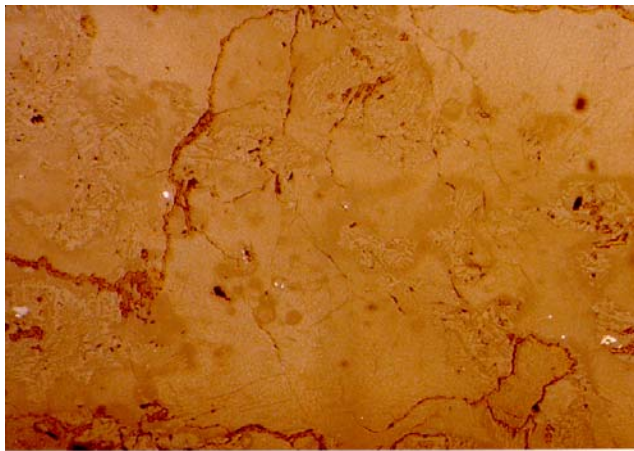


Figure 2: Photomicrographs of thin section 24 from 15418. Scale is 1.3 mm across. NASA #S79-27452-454. Top is reflected light, middle is transmitted light, bottom is with crossed-polarizer.

tiny pores (an unusual feature). The substructures of the minerals in 15418 suggest severe shock deformation.

The interior portion of 15418 has a texture of a shocked granulitic breccia that originally had a relatively coarse granoblastic texture (Cohen et al. 2004). In places

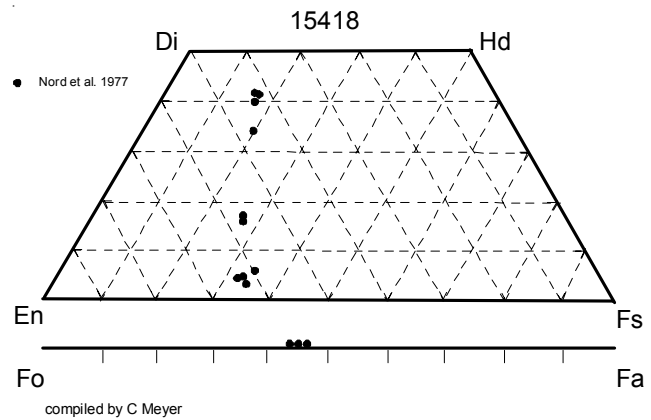


Figure 3: Pyroxene and olivine composition of 15418 (from Nord et al. 1977).

(zones), this original texture is obscured by subsequent shock-heating events. The outermost zone (rind) has a subophitic-intergranular texture and may represent a portion of a thicker rind that is no longer present (Cohen et al. 2004).

The part of the exterior of 15418 that was originally described by LSPET (1972) is different from the interior of the sample. It includes an outer zone of flow-banded glass, with various areas of devitrification and recrystallization (figure 5).

According to Cohen et al. (2004), “15418 was originally a relatively-coarse grained granoblastic granulitic breccia”. The main mass of 15418 was shocked to an extent that all the plagioclase was converted to maskelynite (30-40 GPa). Later it was coated by a high-temperature, high-shock-pressure, aluminous melt that caused the interior maskelynite to partially recrystallize and caused small vesicles in the resulting plagioclase.

Mineralogy

Olivine: The chemical composition of olivine is $Fe_{0.52-0.57}$ (Nord et al. 1977). Olivine grains are found to have a high density of dislocations (Heuer et al. 1972).

Pyroxene: Nord et al. (1977) and Cushing et al. (1999) reported the composition of pyroxene pairs in 15418. The compositions of primary augite and orthopyroxene are plotted in figure 3.

Plagioclase: Some plagioclase crystals in 15418 have aggregate extinction between crossed polarizers, resembling single crystals, but at higher magnification



Figure 4: Original photo of 15418 showing a few zap pits and a penetrating fracture. Note the portion of a very large vesicle on the bottom. NASA S71-44865. Sample is 11 cm long.

have a fine-grained polycrystalline structure (Heuer et al. 1972). Much of the plagioclase has been shocked to maskelynite and/or to glass. The composition of plagioclase is uniform at An₉₆₋₉₇.

Glass: Anorthite glass has recrystallized, often in spherulitic or rounded fibrous structures (Heuer et al. 1972). According to Cohen et al. (2004) the bulk composition of the glass is not the same as for the whole rock.

High-pressure phases: Although, Cohen et al. (2004) find that the outer portion of 15418 may have been shocked to greater than 100 GPa, no relict, high-pressure phases have been reported.

Chemistry

Laul et al. (1972), Bansal et al. (1972), Taylor et al. (1973), Lindstrom and Lindstrom (1986), Weismann and Hubbard (1977) and others reported chemical analyses (table 1, figure 8).

The sample is highly aluminous with low trace element content. Ganapathy et al. (1973) found that the pieces they analyzed were high in meteoritic siderophiles (Ir

and Au). It is important that chemical composition be correlated with the portion of the rock studied.

Schonfeld (1975) used the composition of 15418 to model the composition of the lunar crust.

Radiogenic age dating

Stettler et al. (1973) dated 15418,50 by the Ar/Ar plateau technique at 4.04 ± 0.06 b.y. (figure 9).

Cosmogenic isotopes and exposure ages

Stettler et al. (1973) determined an exposure age of 250 m.y. by ³⁷Ar. Keith et al. (1972) determined cosmic ray induced activities of ²⁶Al = 120 dpm/kg., ²²Na = 27 dpm/kg., ⁵⁴Mn = 8 dpm/kg., ⁵⁶Co = 1.9 dpm/kg. and ⁴⁶Sc = 0.8 dpm/kg.

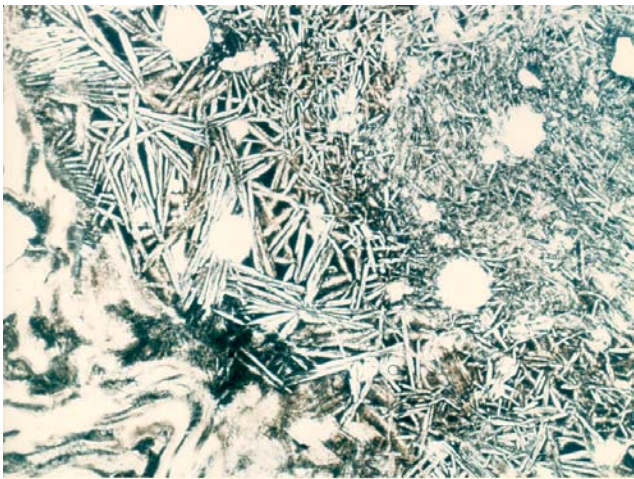


Figure 5: Recrystallized glass from 15418. NASA S71-51743.

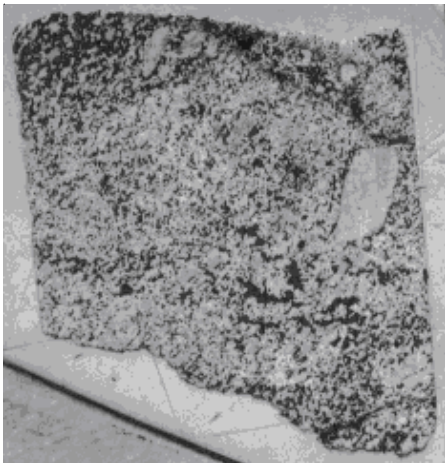


Figure 6: Thin section 15418,152. Scale 1 cm.

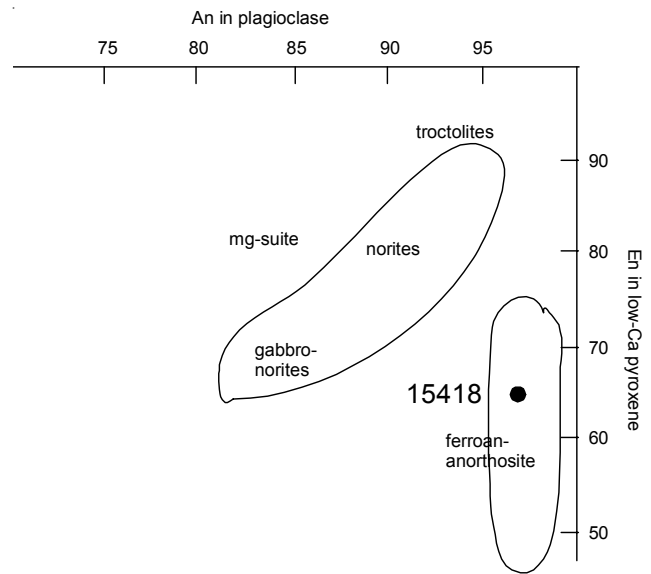


Figure 7: Composition of plagioclase and mafic minerals in 15418.

Other Studies

- | | |
|--------------------------------|-------------------------|
| Ahrens et al. 1973 | shock measurements |
| Allen et al. 1973 | 204Pb |
| Baldrige et al. 1972 | thermal expansion |
| Cukiermann and Uhlmann 1972 | glass flow |
| Hutcheon et al. 1972 | gas bubbles |
| Huffman et al. 1972 | Mossbauer |
| MacDougall et al. 1973 | no solar flare tracks |
| Nagata et al. 1972, 1973, 1975 | magnetic properties |
| Nyquist et al. 1972, 1973 | Sr isotopes |
| O'Keefe and Ahrens 1975 | equation of state |
| Richter et al. 1976 | microcracks |
| Schwerer et al. 1973 | Mossbauer |
| Schwerer et al. 1974 | electrical conductivity |
| Tatsumoto et al. 1972 | Pb isotopes |
| Todd et al. 1973 | seismic velocity |
| Uhlmann et al. 1974 | glass flow |
| Wang et al. 1973 | seismic velocity |
| Yinnon et al. 1980 | glass flow, DTA |

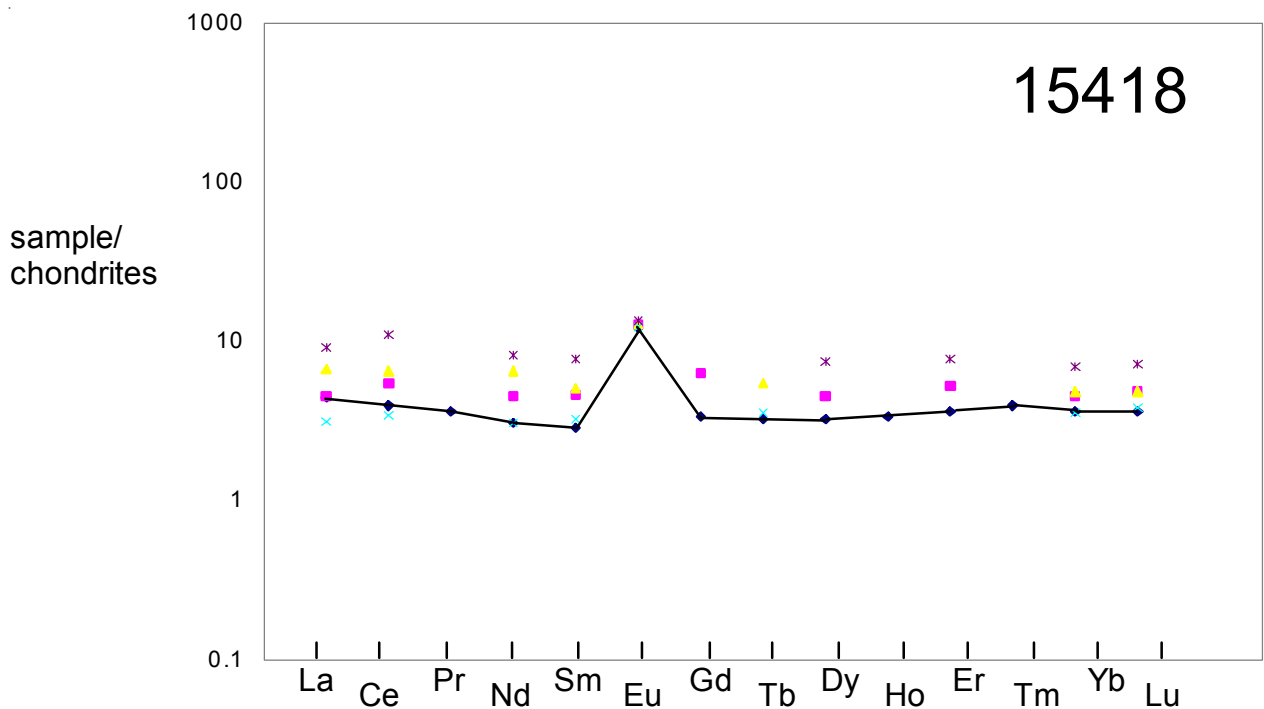


Figure 8: Normalized rare earth element diagram for 15418 (data from Taylor et al. 1973 connected. Additional data from Wiesmann et al., Bansal et al., Laul et al. and Lindstrom and Lindstrom - see table).

Processing

A bandsaw was used in a dry nitrogen cabinet to cut a slab (,28) which was further subdivided into a column (,31) and end pieces (figure 11). The width of the slab was ~1.5 cm and the width of the column (,31) was ~2 cm. The column was split lengthwise (,32 and ,33) and cut into cubes with many fine cuts (figures 13 and 14). Thin sections were made from different parts of 15418, show different lithologies (see diagram). Figures 1 and 6 illustrate the main shocked granulitic lithology.

Ryder (1985) gives a full description of the research performed on 15418 up to that time. It is apparent that 15418 needs to be studied in “consortium mode” – as was done for complicated samples in later missions. Cohen et al. (2004) compared 15418 with one of the lunar meteorites (Dhofar 026). This comparison strengthens the case that 15418 may be representative of the lunar crust. But, clearly, the main interior lithology of 15418 deserves a more coordinated and methodical study.

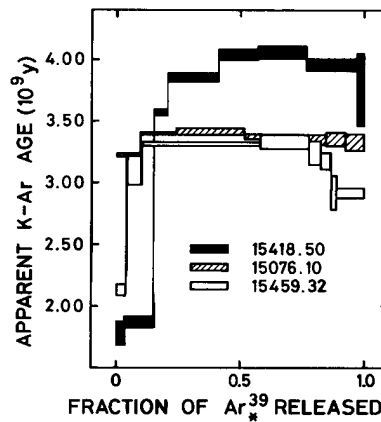


Figure 9: Ar/Ar plateau age for 15418,50 (from Stettler et al. 1973).

Summary of Age Data for 15418

| | Ar/Ar |
|----------------------|---|
| Stettler et al. 1973 | 4.04 ± 0.06 b.y. (intermediate temperature plateau) |
| Stettler et al. 1973 | 3.99 ± 0.07 |

Table 1. Chemical composition of 15418.

| reference weight | sawdust | | sawdust | | | | | | sawdust | | | |
|--------------------------------|----------|-------------------|---------|--------------|-------|-------|-------|-------|----------------------|-------|-------|-----------|
| | LSPET 72 | Laul 72 147 mg | Laul 83 | Lindstrom 86 | | | | | Wiesmann 77 56 mg | 50 mg | 54 mg | |
| SiO ₂ % | 44.97 | (c) | | | | | | | | | | |
| TiO ₂ | 0.27 | (c) 0.37 | 0.3 | 0.41 | 0.25 | | | 0.25 | (a) 0.27 | 0.23 | 0.27 | (b) |
| Al ₂ O ₃ | 26.73 | (c) 26.4 | 26.4 | 25.7 | 26.8 | | | 28.4 | (a) | | | |
| FeO | 5.37 | (c) 7.5 | 7 | 4.9 | 6.44 | 6.84 | 6.52 | 5.11 | (a) | | | |
| MnO | 0.08 | (c) 0.086 | | 0.077 | 0.09 | | | 0.077 | (a) | | | |
| MgO | 5.38 | (c) 5.3 | 6 | 6.4 | 5.5 | | | 4.3 | (a) | | | |
| CaO | 16.1 | (c) 15.8 | 15.7 | 15.4 | 15.6 | 15.4 | 15.7 | 16.5 | (a) 15.8 | | | (b) |
| Na ₂ O | 0.31 | 0.282 | 0.29 | 0.39 | 0.29 | 0.27 | 0.27 | 0.3 | (a) 0.27 | 0.32 | 0.3 | (b) |
| K ₂ O | 0.03 | 0.011 | | | | | | | (a) 0.013 | 0.02 | 0.024 | (b) |
| P ₂ O ₅ | 0.03 | (c) | | | | | | | | | | |
| S % | 0.03 | (c) | | | | | | | | | | |
| sum | | | | | | | | | | | | |
| Sc ppm | | 12.7 | 12 | 9.11 | 11.8 | 13.4 | 13.5 | 10.5 | (a) | | | |
| V | | 42 | | | | | | | | | | |
| Cr | 752 | (c) 1916 | 1920 | 818 | 690 | 870 | 882 | 639 | (a) | 614 | 628 | (b) |
| Co | | 77 | 70 | 15.7 | 11 | 13.5 | 14.7 | 7.8 | (a) | | | |
| Ni | | | 700 | 125 | 36 | 65 | 45 | 26 | (a) | | | |
| Cu | | | | | | | | | | | | |
| Zn | | | | | | | | | | | | |
| Ga | | | | | | | | | | | | |
| Ge ppb | | | | | | | | | | | | |
| As | | | | | | | | | | | | |
| Se | | | | | | | | | | | | |
| Rb | | | | | | | | | | 0.17 | 0.361 | 0.489 (b) |
| Sr | 152 | (c) | | 161 | 138 | 150 | 135 | 149 | (a) 140 | 148 | 139 | (b) |
| Y | | | | | | | | | | | | |
| Zr | 67 | (c) | | 110 | 25 | <50 | <50 | <45 | (a) 18 | 30 | 35 | (b) |
| Nb | | | | | | | | | | | | |
| Mo | | | | | | | | | | | | |
| Ru | | | | | | | | | | | | |
| Rh | | | | | | | | | | | | |
| Pd ppb | | | | | | | | | | | | |
| Ag ppb | | | | | | | | | | | | |
| Cd ppb | | | | | | | | | | | | |
| In ppb | | | | | | | | | | | | |
| Sn ppb | | | | | | | | | | | | |
| Sb ppb | | | | | | | | | | | | |
| Te ppb | | | | | | | | | | | | |
| Cs ppm | | | | 0.11 | <0.05 | <0.05 | | <0.05 | (a) | | | |
| Ba | | 70 | 30 | 100 | 19 | 15 | 14 | 15 | (a) 19.2 | 24.4 | 28.9 | (b) |
| La | | 1.2 | 1.6 | 8.02 | 0.759 | 0.756 | 0.812 | 0.719 | (a) 1.07 | 1.73 | 2.19 | (b) |
| Ce | | | 4 | 20.8 | 2.1 | 2.05 | 2.22 | 1.86 | (a) 3.31 | | 6.78 | (b) |
| Pr | | | | | | | | | | | | |
| Nd | | | 3 | 12.5 | 1.4 | 1.6 | 1.2 | 1.3 | (a) 2.09 | 3.15 | 3.75 | (b) |
| Sm | | 0.69 | 0.75 | 3.74 | 0.485 | 0.499 | 0.541 | 0.437 | (a) 0.688 | 0.94 | 1.16 | (b) |
| Eu | | 0.73 | 0.726 | 0.911 | 0.697 | 0.698 | 0.699 | 0.696 | (a) 0.726 | 0.764 | 0.762 | (b) |
| Gd | | | | | | | | | | 1.25 | 1.25 | (b) |
| Tb | | 0.18 | 0.2 | 0.88 | 0.129 | 0.149 | 0.15 | 0.129 | (a) | | | |
| Dy | | 1.2 | | | | | | | (a) 1.12 | 1.49 | 1.84 | (b) |
| Ho | | | | | | | | | | | | |
| Er | | | | | | | | | | 0.85 | 1.04 | 1.24 (b) |
| Tm | | | | | | | | | | | | |
| Yb | | 0.81 | 0.8 | 2.9 | 0.593 | 0.628 | 0.65 | 0.55 | (a) 0.74 | 0.907 | 1.12 | (b) |
| Lu | | 0.12 | 0.12 | 0.444 | 0.094 | 0.102 | 0.105 | 0.085 | (a) 0.12 | 0.143 | 0.176 | (b) |
| Hf | | 0.8 | 0.7 | 2.78 | 0.36 | 0.4 | 0.42 | 0.32 | (a) 0.5 | 0.8 | 0.6 | (b) |
| Ta | | 0.09 | | 0.32 | 0.033 | 0.031 | 0.04 | 0.026 | (a) | | | |
| W ppb | | | | | | | | | | | | |
| Re ppb | | | | | | | | | | | | |
| Os ppb | | | | | | | | | | | | |
| Ir ppb | | | <5 | 3.8 | 2.2 | 1.8 | 1 | 1 | (a) | | | (b) |
| Pt ppb | | | | | | | | | | | | |
| Au ppb | | | 3 | 1.6 | <1 | <1 | <1 | <1 | (a) | | | (b) |
| Th ppm | | | 0.25 | 1.27 | 0.046 | 0.049 | 0.064 | 0.024 | (a) | | | (b) |
| U ppm | | | | 0.33 | <0.09 | <0.1 | <0.1 | <0.06 | (a) 0.045 | | | (b) |

technique (a) INAA, (b) IDMS, (c) XRF

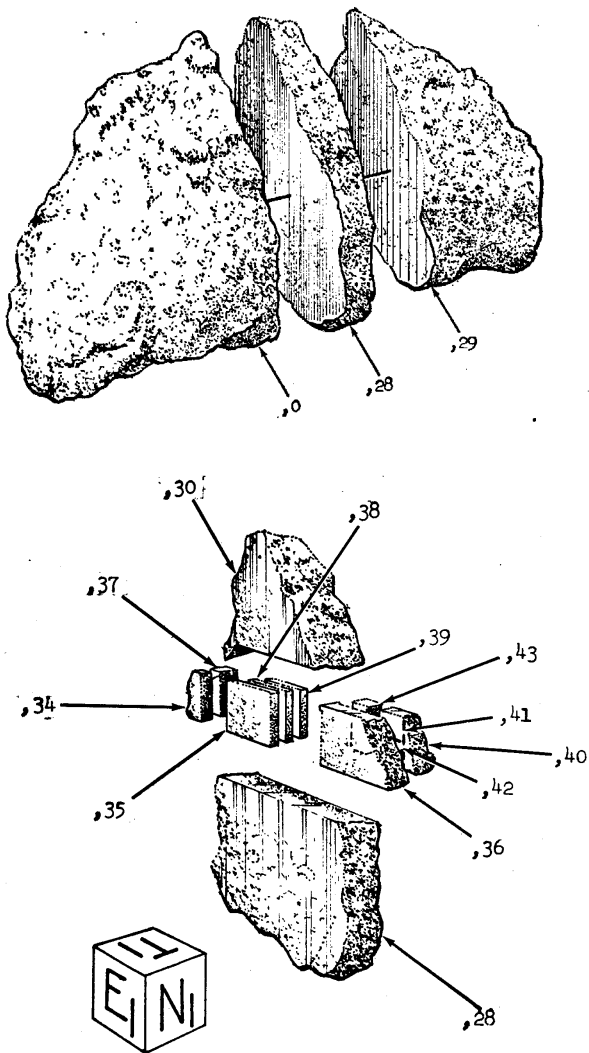
Table 1b. Chemical composition of 15418.

| <i>reference weight</i> | Bansal 72 | Taylor 73 | Hubbard 74 | Ganapathy 73 | Tatsumoto 72 sawdust | Nyquist 73 | Keith 72 |
|--------------------------------|-----------|-----------|------------|-----------------|----------------------|-----------------|---------------|
| SiO ₂ % | 44.2 (c) | | 45.53 (c) | | | | |
| TiO ₂ | 0.27 (c) | | 0.29 (c) | | | | |
| Al ₂ O ₃ | 26.6 (c) | | 25.98 (c) | | | | |
| FeO | 6.65 (c) | | 6.66 (c) | | | | |
| MnO | | | 0.1 (c) | | | | |
| MgO | 5.08 (c) | | 6.09 (c) | | | | |
| CaO | 16 (c) | | 15.63 (c) | | | | |
| Na ₂ O | 0.27 (c) | | 0.31 (c) | | | | |
| K ₂ O | 0.013 (c) | | 0.03 (c) | | 0.015 | | 0.0104 (f) |
| P ₂ O ₅ | | | 0.03 (c) | | | | |
| S % | | | 0.03 (c) | | | | |
| <i>sum</i> | | | | | | | |
| Sc ppm | | 7 (d) | | | | | |
| V | | 18 (d) | | | | | |
| Cr | | 1150 (d) | | | | | |
| Co | | 10 (d) | | | | | |
| Ni | | 54 (d) | | | | | |
| Cu | | 2 (d) | | | | | |
| Zn | | | | 0.82 0.49 (e) | | | |
| Ga | | 2.2 (d) | | | | | |
| Ge ppb | | | | 65 17 (e) | | | |
| As | | | | | | | |
| Se | | | | 56 25 (e) | | | |
| Rb | 0.17 (b) | | | 0.8 0.03 (e) | 0.263 | 0.162 0.361 (b) | |
| Sr | 140 (b) | | | | 134.6 | 140.1 147.8 (b) | |
| Y | | | | | | | |
| Zr | | | | | | | |
| Nb | | 0.43 (d) | | | | | |
| Mo | | | | | | | |
| Ru | | | | | | | |
| Rh | | | | | | | |
| Pd ppb | | | | | | | |
| Ag ppb | | | | 0.59 1.4 (e) | | | |
| Cd ppb | | | | 1.7 2.4 (e) | | | |
| In ppb | | | | 0.29 0.18 (e) | | | |
| Sn ppb | | | | | | | |
| Sb ppb | | | | 0.5 0.16 (e) | | | |
| Te ppb | | | | 3.7 1.9 (e) | | | |
| Cs ppm | | | | 0.04 0.008 (e) | | | |
| Ba | 19.2 (b) | 20 (d) | | | | | |
| La | 1.07 (b) | 1.06 (d) | | | | | |
| Ce | 3.31 (b) | 2.4 (d) | | | | | |
| Pr | | 0.33 (d) | | | | | |
| Nd | 2.09 (b) | 1.41 (d) | | | | | |
| Sm | 0.688 (b) | 0.43 (d) | | | | | |
| Eu | 0.726 (b) | 0.69 (d) | | | | | |
| Gd | 1.25 (b) | 0.67 (d) | | | | | |
| Tb | | 0.12 (d) | | | | | |
| Dy | 1.12 (b) | 0.8 (d) | | | | | |
| Ho | | 0.19 (d) | | | | | |
| Er | 0.85 (b) | 0.59 (d) | | | | | |
| Tm | | 0.1 (d) | | | | | |
| Yb | 0.74 (b) | 0.6 (d) | | | | | |
| Lu | 0.12 (b) | 0.09 (d) | | | | | |
| Hf | | 0.16 (d) | | | | | |
| Ta | | | | | | | |
| W ppb | | | | | | | |
| Re ppb | | | | 0.38 0.13 (e) | | | |
| Os ppb | | | | | | | |
| Ir ppb | | | | 5.4 2.2 (e) | | | |
| Pt ppb | | | | | | | |
| Au ppb | | | | 1 0.26 (e) | | | |
| Th ppm | | 0.1 (d) | | | 0.208 0.127 0.1377 | | (b) 0.102 (f) |
| U ppm | 0.045 (b) | | | 0.185 0.024 (e) | 0.058 0.038 0.0394 | | (b) 0.043 (f) |

technique (a) INAA, (b) IDMS, (c) XRF, (d) ssms, (e) RNAA, (f) radiation counting



Figure 10: Photo of 15418,1 illustrating vesicularity. Large piece is 2 cm across. NASA S72-32321.



List of Photo #s for 15418

| | |
|-----------------|------------------|
| S71-51743 | TS color |
| S71-52203 | TS |
| S71-52498 | TS |
| S71-43656 – 661 | color mug |
| S71-44890 – 865 | color mug |
| S71-45266 – 297 | B&W mug |
| S71-59176 – 206 | processing |
| S71-59591 – 610 | processing |
| S71-59894 – 918 | processing |
| S72-34093 | ,0 B&W |
| S72-32321 | ,1 vesicular |
| S75-33598 | ,27 vesicular |
| S75-33763 | ,27 sawn surface |
| S76-21675 | ,0 B&W |
| S79-27452 – 454 | TS color |
| S81-29176 – 180 | ,167 color |
| S81-29203 – 209 | ,179 color |

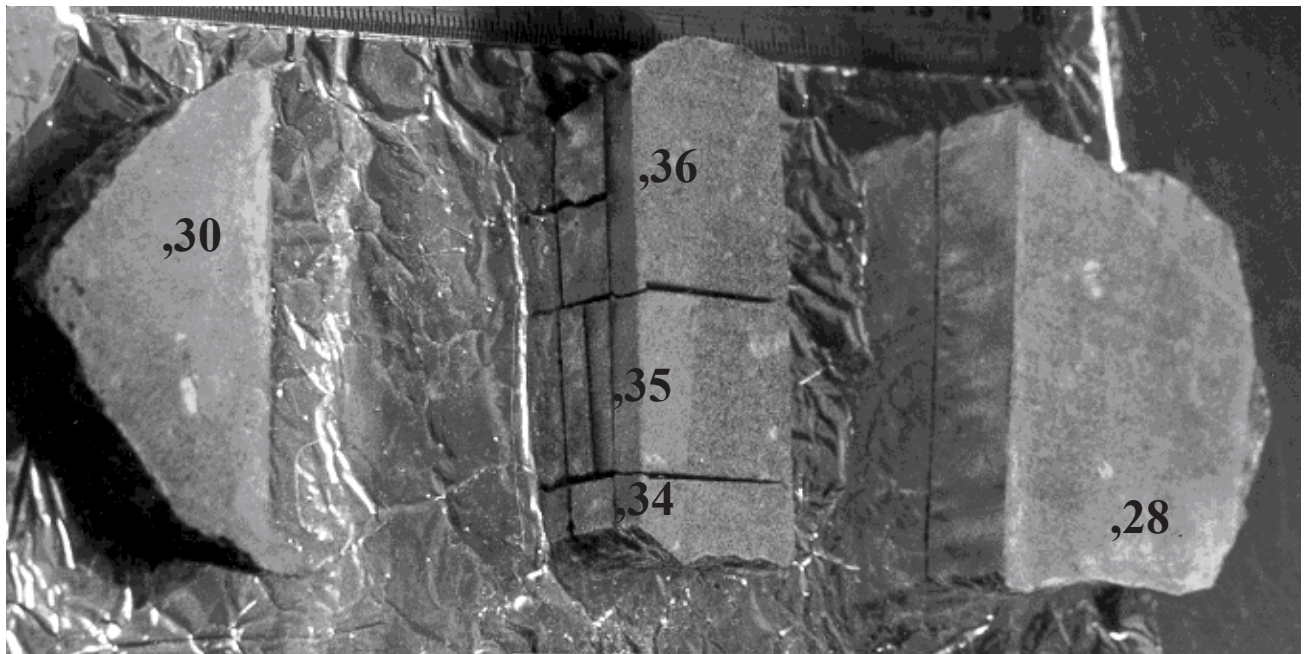


Figure 11: Subdivision of slab 15418,28. NASA S71-59606. Column is 2 cm wide.

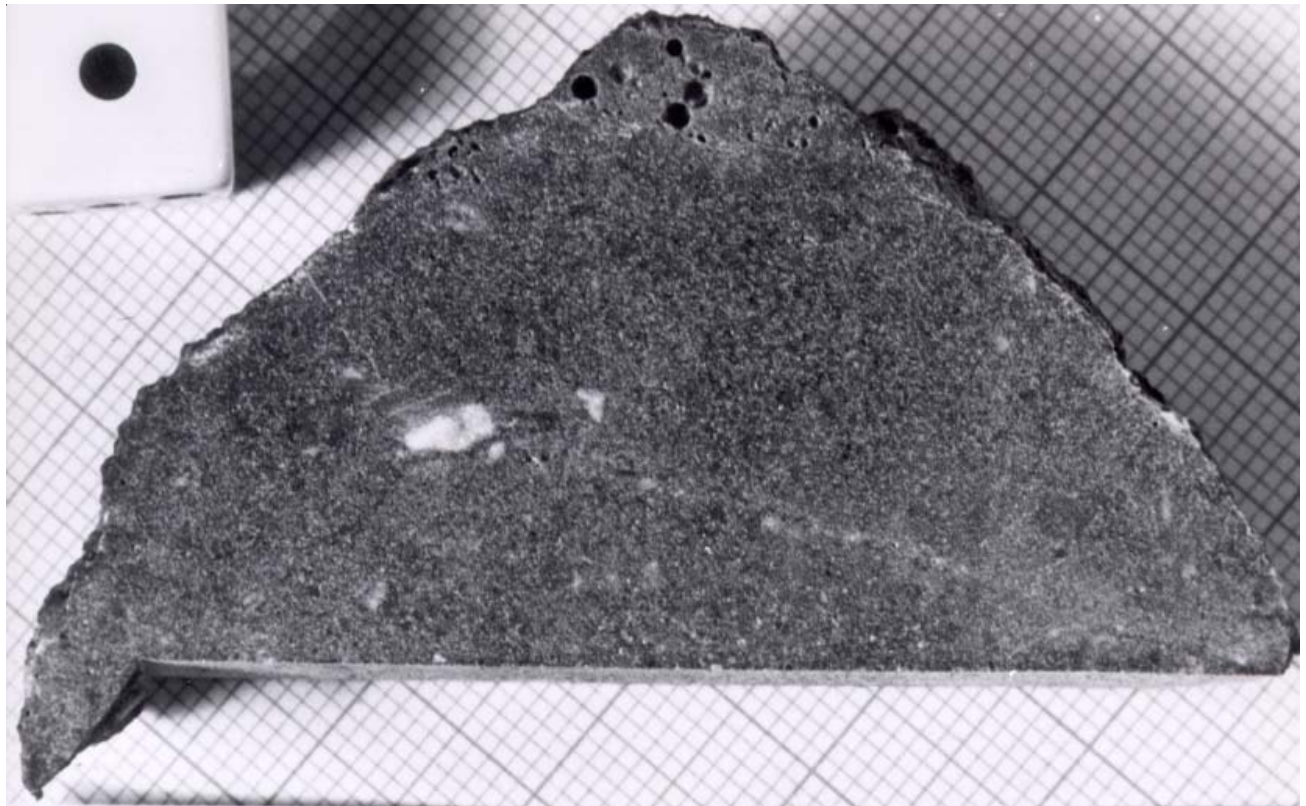


Figure 12: Mini-slab of 15418,30. Cm graph paper for scale. Photo by Tatsumoto.

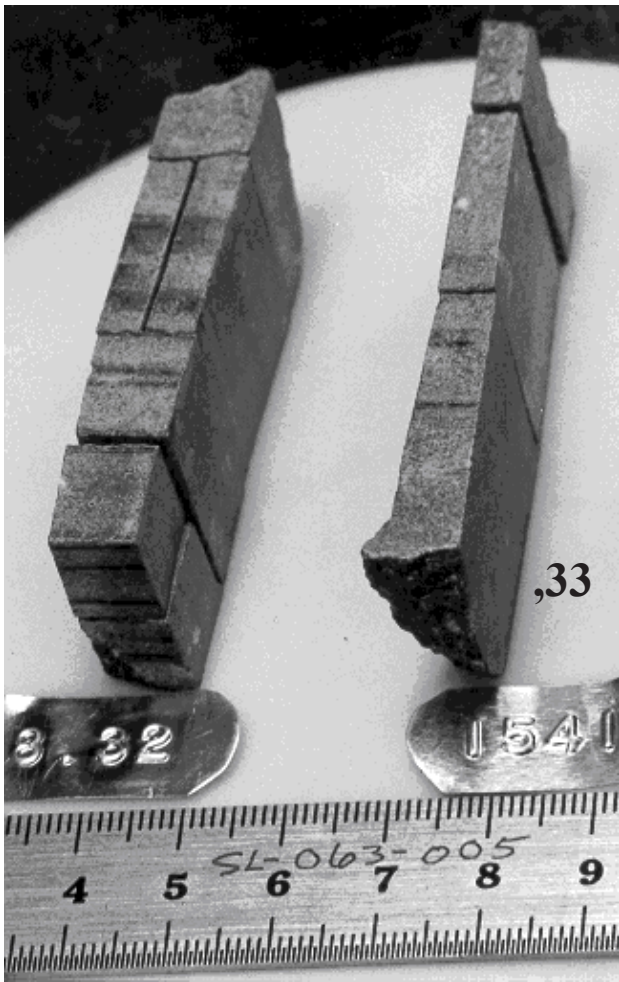


Figure 13: Splitting column 15418,31. S71-59604. Scale in cm.

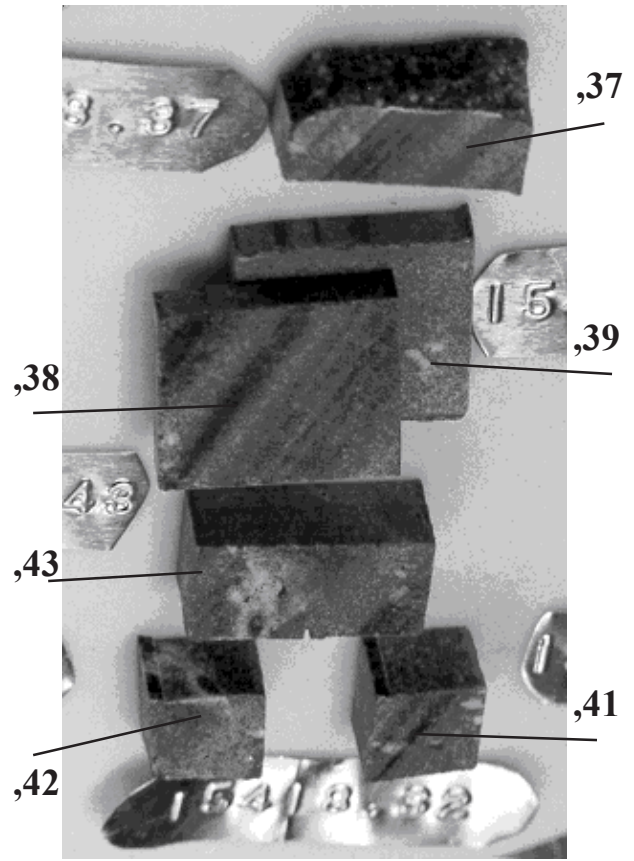
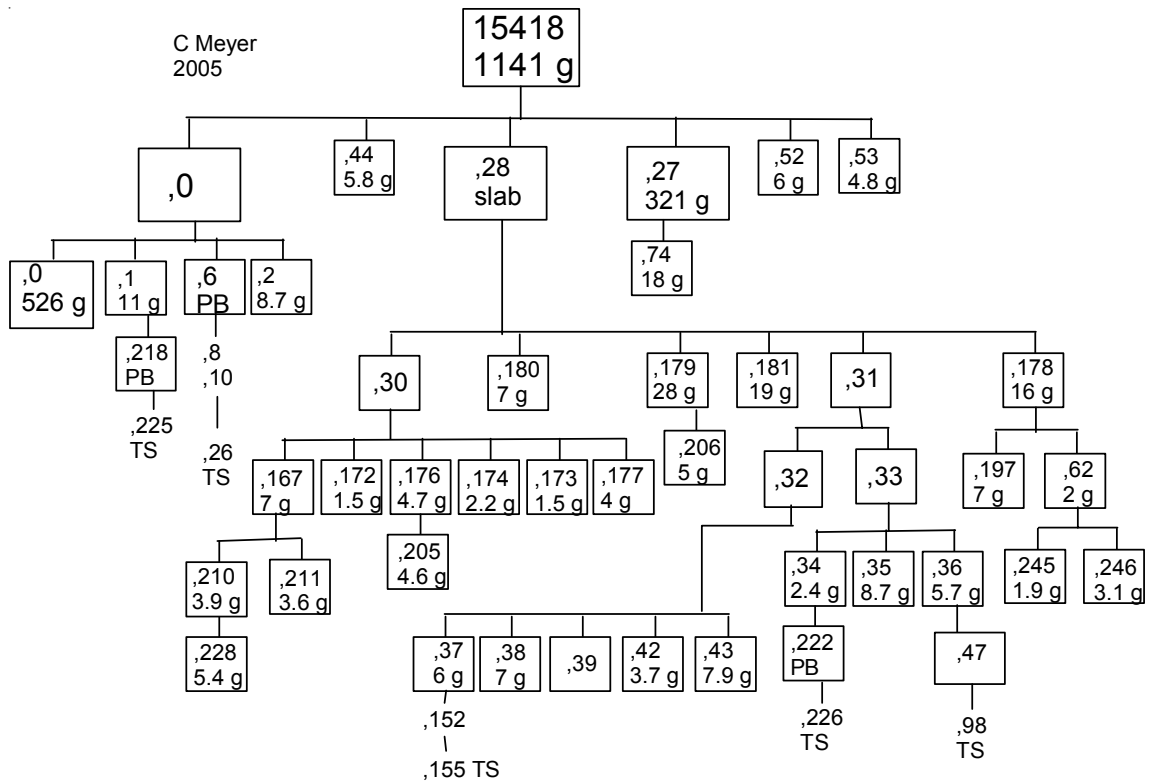


Figure 14: Cutting 15418,32 into cm cubes. S71-59918.



References for 15418

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