# 12002

*Revised*

## Olivine Basalt

1529 grams

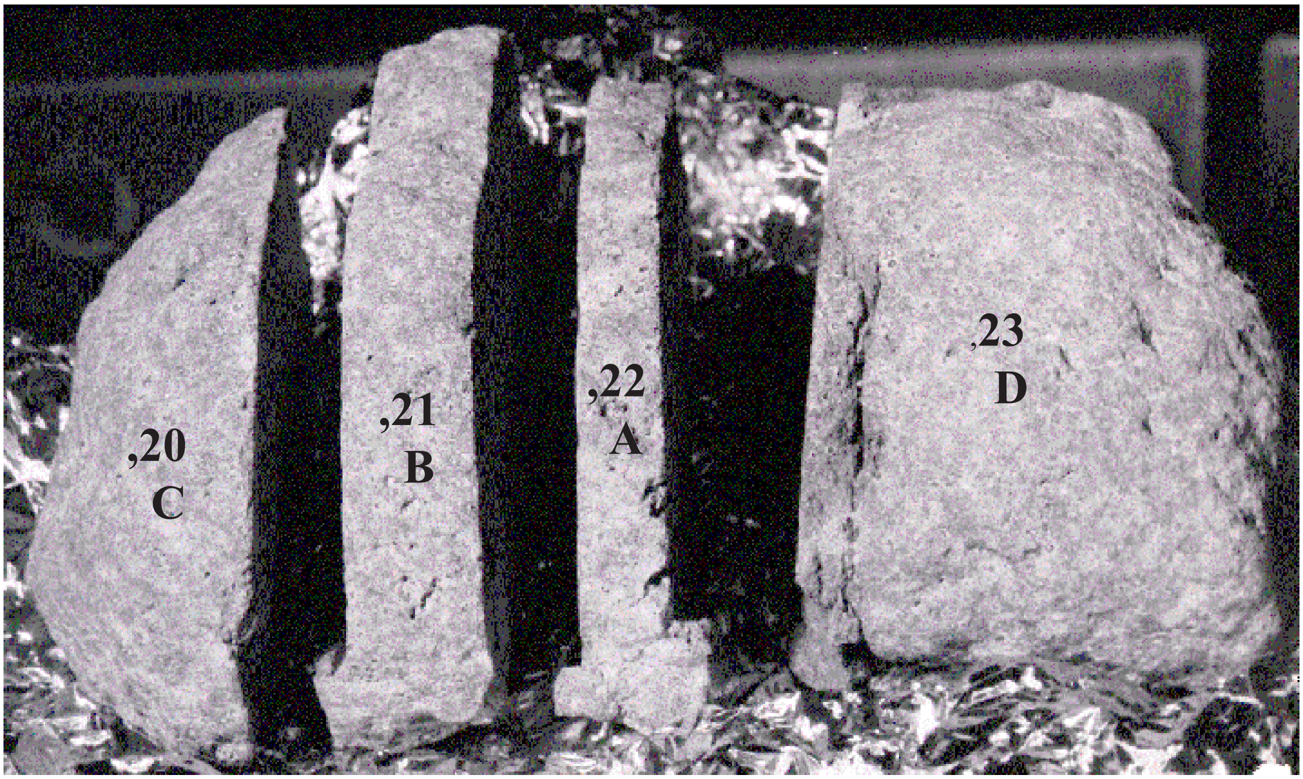



*Figure 1: Lunar basalt 12002 after first two saw cuts in 1970. NASA# S70-38479. Sample is 8 cm across.*

## Introduction

12002 is one of the important samples for the study of depth variation of cosmogenic nuclides in a lunar surface rock due to solar and cosmic ray interactions (figure 1). The top surface of 12002 was identified by Ernie Schonfeld using high $^{58}$Co (O'Kelly et al. 1971) and slabs were cut accordingly to give accurate depth profiles (Alexander et al. 1971, Finkel et al. 1971 and others). These studies showed that the sample had not tumbled in the soil and allowed the study of nuclear reactions caused by high energy cosmic rays, solar flares and resultant neutron fluxes.

## Petrography

Lunar sample 12002 is a medium-grained porphyritic basalt containing phenocrysts of olivine and clinopyroxene (figure 2) (Grove et al. 1973). Phenocrysts often have melt inclusions (now crystallized) indicating that they formed as skeletal crystals and grew to include the melt (figure 5). The matrix contains intergrown pyroxene and plagioclase often forming acicular radiating bundles and lath-shaped ilmenite. The plagioclase sometimes has hollow cores (intrafasciculate) and is reversed zoned in composition (figure 6). The mesostasis is glassy and contains irregular shaped vugs.

## Mineralogy

***Pyroxene:*** Pyroxene is sector zoned. Pigeonite cores are compositionally zoned towards augite in one sector while zoning towards iron rich in the other direction (figure 4).

***Olivine:*** Grove et al. (1973) give the olivine composition as $Fo_{61-76}$. Taylor et al. (1971) determined the trace element composition of olivine separates (Ni =150 ppm).

***Plagioclase:*** Plagioclase is sometime intrafasciculate (figure 6, hollow cores, like straws). Grove et al. (1973)

*Figure 2: Photomicrograph of thin section of 12002,7. Field of view is 1.7 cm. NASA # S70-31576.*

found that plagioclase was often reverse zoned ($An_{90}$ to $An_{95}$) due to metastable crystallization.

***Opaques***: Ilmenite is present as laths growing in the outer zones of pyroxenes. Chromite inclusions are found in the cores of olivine and pyroxene (figure 9). Chromite found in the mesostasis is rimmed with ulvöspinel with blebs of metallic iron (figure 7) (El Goresy et al. 1971).

**Mineralogical Mode 12002**

| | Grove et al. 1973 | Neal et al. 1994 |
|---|---|---|
| Olivine | 17 vol. % | 22.2 |
| Pyroxene | 49 | 41.1 |
| Plagioclase | 16 | 27.9 |
| Opaques | 11 | |
| Ilmenite | | 0.9 |
| Chromite + Usp. | | 4.1 |
| mesostasis | 5 | 2.3 |

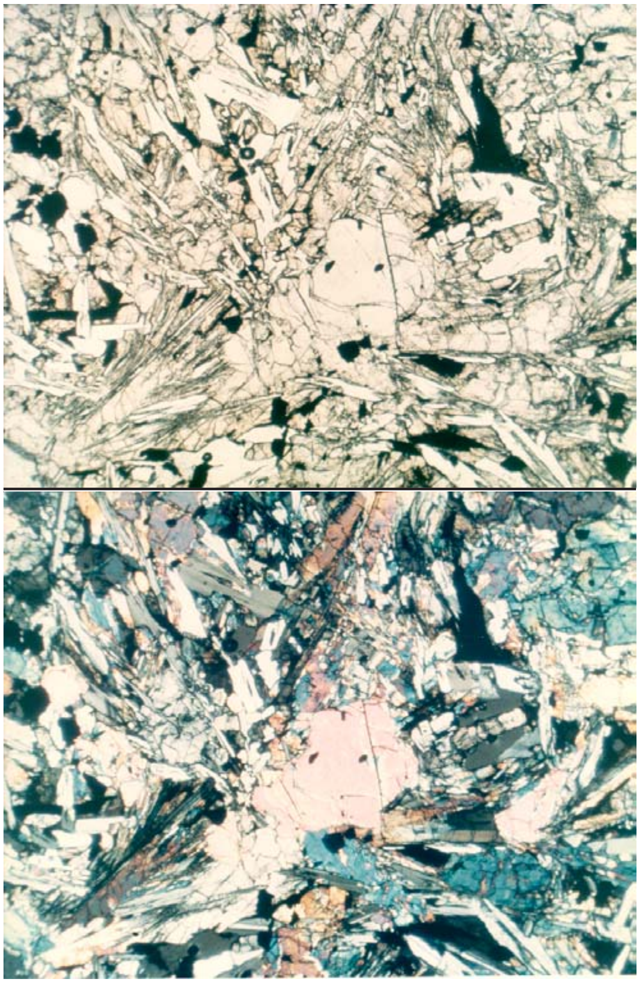


*Figure 3: Thin section photomicrographs with partially-crossed nicols (top) and fully-crossed nicols (botom). The olivine in the center includes three small melt inclusions. Field of view is 2.6 mm. NASA # S70-16778-16779.*

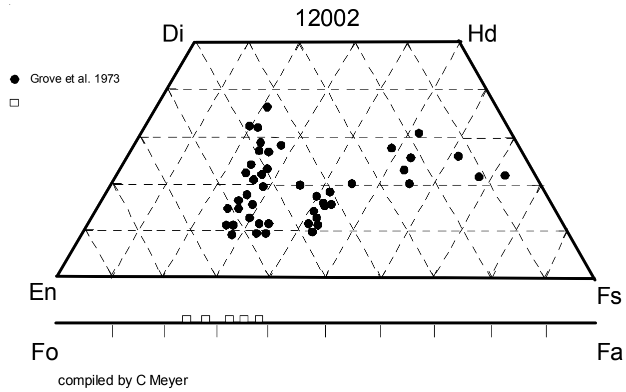



*Figure 4: Pyroxene and olivine composition diagram for 12002 (replotted from Grove et al. 1973).*

***Metallic iron:*** The Ni content of metallic iron grains in 12002 was about 6 wt. % and found to be the same in all mineral associations unlike other Apollo 12 rocks (figure 8).

## Chemistry

Gast and Hubbard (1970), Willis et al. (1971), Wänke et al. (1971) and others determined the chemical composition of 12002 (table 1). The composition is typical of other Apollo 12 basalts (figures 10, 11).

## Radiogenic age dating

12002 has been dated by Turner (1971), Alexander et al. (1972) and Papanastassiou and Wasserburg (1970) (figure 12).

## Cosmogenic isotopes and exposure ages

O'Kelly et al. (1971b) reported the concentrations of radioactive elements from recent solar flares ($^{22}$Na, $^{26}$Al, $^{54}$Mn, $^{58}$Co and $^{60}$Co). They found elevated concentrations in the surface slab 12002,30 confirming the lunar orientation. Rancitelli et al. (1971) determined $^{22}$Na and $^{26}$Al as a function of depth. Finkel et al. (1971) also carefully studied the activities of short-lived, cosmic-solar-ray produced radionuclides as a function of depth in the 12002 (Table 2). 12002 was used for $^{53}$Mn depth profile (Finkel et al. 1971, Imamura et al. 1973) and for $^{14}$C depth profile (Boeckl 1972). The depth profile for $^{53}$Mn and $^{26}$Al could be fit by the same solar, cosmic ray (SCR) parameters as for other rocks (Kohl et al. 1978). Small subsamples have been more carefully prepared in 1997 for fine scale, $^{14}$C depth profile by accelerator mass spectroscopy (figure 16).

The exposure age of 12002 was determined as 94 ± 6 m.y. by the $^{81}$Kr method by Marti and Lugmair (1971), 92 m.y. by Bogard et al. (1971) and 144 ± 10 m.y. by the $^{38}$Ar method by D'Amico et al. (1971). Alexander et al. (1971) determined 161 ± 20 m.y by $^{3}$He and 77 to 105 by $^{130}$Xe. The suntan age (from etched solar flare track studies) is 2.2 m.y. (Bhandari et al. 1971).

## Other Studies

Grove et al. (1973) and Walker et al. (1976) experimentally determined the phases that crystallize at various pressures and determined that the liquid basalt came for a depth of ~300 km (figure 13). They were also able to generally reproduce the crystallization sequence observed in the thin sections.


*Figure 5: "Melt inclusion" in pyroxene phenocryst (now crystallized).*


*Figure 6: Hollow plagioclase "straws" in cross section in 12002.*

Fleischer et al. (1971) determined the nuclear track densities in pyroxene and estimated the surface residence time.

Hartung et al. (1975) studied the details of micrometeorite pits on the surface of 12002, including solar flare track densities in the spall areas of relatively large zap pits, to try to get the age of zap pits. They also studied micromounds of metallic iron on the surface, concluding that they were of meteorite origin by the Ni and Co contnet.

Herzenberg et al. (1971) determined the Mössbauer spectrum of 12002 (figure 14), showing a high abundance of olivine and no evidence for ferric iron.

Wang et al. (1971) measured the velocity of sound as a function of pressure and also determined the compressibility of 12002. Katsube and Collett (1971) and Chung et al. (1971) determined the dielectric properties (dielectric constant, loss tangent and dielectric conductivity as a function of frequency).

Marti and Lugmair (1971) and Alexander et al. (1971) determined the isotopic composition of rare gases in 12002.

## Processing

12002 is one of the lunar samples featured in the Lunar Petrographic Educational Thin Section Package (Meyer 2003).

Figure 15 shows the position of the first slab (,22A) and surface piece (,34) initially cut from 12002 in 1970 for detailed cosmic ray studies by the La Jolla group (Arnold consortium). A second slab (,21B) was cut into three columns and two end pieces. One of the butt ends (,23D) was sliced parallel to the lunar surface. Figure 16 shows the careful cutting of a fourth column (from ,25) in 1997 for extended, fine-scale, cosmic ray studies.

12002,182 is on public display in Wales, England (figure 17).

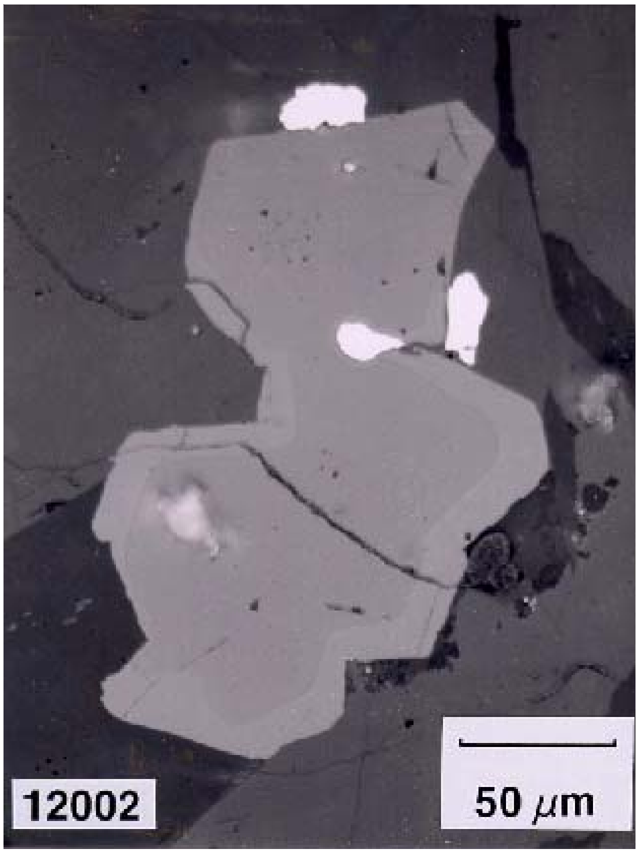



*Figure 7: Chromite rimmed with ulvospinel in 12002. Bright grains are metallic iron that crystallized as Cr and Ti changed valance.*

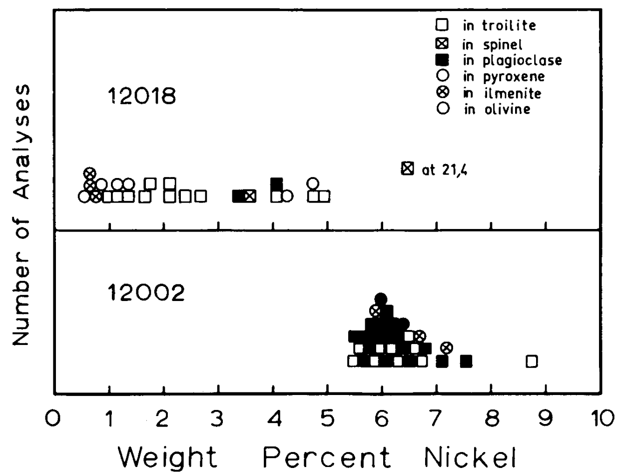



*Figure 8: Composition of iron in 12002 and 12018 (ElGoresy et al. 1971, after Reid et al. 1970).*

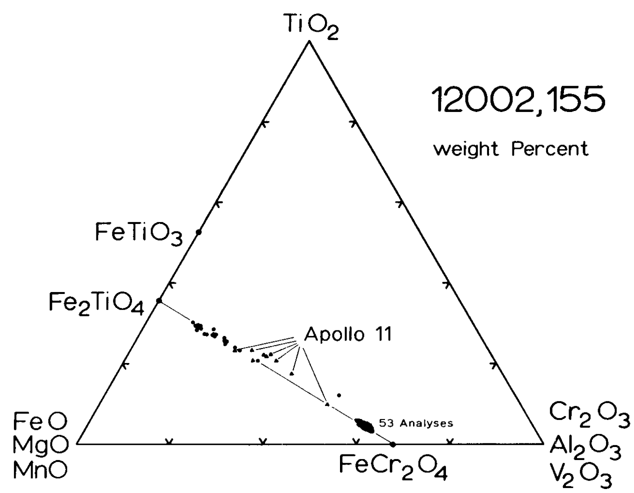



*Figure 9: Composition diagram for chromite-ulvospinel in 12002 (from ElGoresy et al. 1971).*

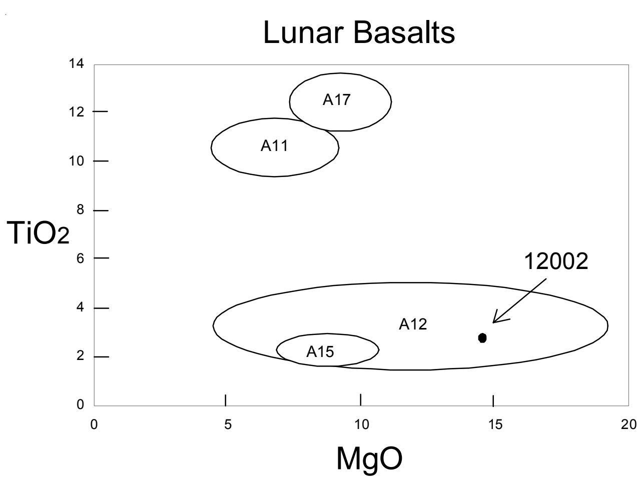



*Figure 10: Composition of lunar basalts showing 12002.*

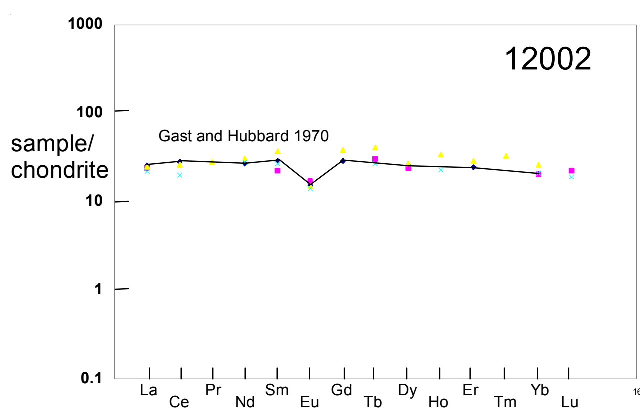



*Figure 11: Normalized rare-earth-element diagram for 12002 (data from table 1).*

## Table 1a. Chemical composition of 12002.

| *reference* | Gast 70 | | Willis 1971 | | | Brunfelt et al. 71 | | | | Anders 1971 | | Baedecker 71 | | Goles 71 | | Taylor 71 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *weight* | | | | | | | | | | | | | | | | | |
| SiO2 % | | | 43.56 | (c ) | | | | | | | | | | 44.93 | (a) | | |
| TiO2 | 2.83 | (e) | 2.6 | (c ) | | 2.62 | 2.5 | 2.75 | (a) | | | | | 2.25 | (a) | | |
| Al2O3 | | | 7.87 | (c ) | | 8.92 | 7.14 | 7.49 | (a) | | | | | 8.09 | (a) | | |
| FeO | | | 21.66 | (c ) | 21.23 | 22 | 21.23 | 20.58 | (a) | | | | | 21.1 | (a) | | |
| MnO | | | 0.283 | (c ) | | 0.27 | 0.28 | 0.27 | (a) | | | | | 0.24 | (a) | | |
| MgO | | | 14.88 | (c ) | | | | | | | | | | | | | |
| CaO | | | 8.26 | (c ) | | | | | | | | | | 6.72 | (a) | | |
| Na2O | 0.21 | | 0.23 | (c ) | | 0.2 | 0.22 | 0.21 | (a) | | | | | 0.2 | (a) | | |
| K2O | 0.057 | (e) | 0.051 | (c ) | | | | | | | | | | | | | |
| P2O5 | | | 0.11 | (c ) | | | | | | | | | | | | | |
| S % | | | 0.062 | (c ) | | | | | | | | | | | | | |
| *sum* | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Sc ppm | | | 45 | (d) | 41.7 | 45 | 42.1 | 43.9 | (a) | | | | | 38.3 | (a) | 41 | (f) |
| V | | | 175 | (d) | | 223 | 212 | 227 | (a) | | | | | | | 190 | (f) |
| Cr | | | 6570 | (c ) | | 6780 | 5650 | 5450 | (a) | | | | | 5620 | (a) | 5000 | (f) |
| Co | | | 62 | (d) | 58.7 | 59.8 | 58.3 | 58.1 | (a) | | | | | 65.8 | (a) | 67 | (f) |
| Ni | | | 64 | (c ) | | | | | | | | | | | | 100 | (f) |
| Cu | | | 4.6 | (c ) | | 5.9 | 6.5 | 5.3 | (a) | | | | | | | 5 | (f) |
| Zn | | | 1.5 | (c ) | | 3.4 | 2.9 | 7.2 | (a) | 0.7 | (b) | 1.2 | (b) | | | | |
| Ga | | | | | | 3.1 | 2.9 | 2.6 | (a) | 2.4 | (b) | 2.9 | (b) | | | | |
| Ge ppb | | | | | | | | | | | | 57 | (b) | | | | |
| As | | | | | | | | | | | | | | | | | |
| Se | | | | | | | | | | 0.14 | (b) | | | | | | |
| Rb | 1.04 | (e) | 1.25 | (c ) | | | | | | 0.97 | (b) | | | | | | |
| Sr | 101 | (e) | 86 | (c ) | | | | | | | | | | | | 95 | (f) |
| Y | | | 39 | (c ) | | | | | | | | | | | | | |
| Zr | | | 106 | (c ) | | | | | | | | | | <100 | (a) | 110 | (f) |
| Nb | | | 8.5 | (c ) | | | | | | | | | | | | 4.5 | (f) |
| Mo | | | | | | | | | | | | | | | | 0.05 | (f) |
| Ru | | | | | | | | | | | | | | | | | |
| Rh | | | | | | | | | | | | | | | | | |
| Pd ppb | | | | | | | | | | | | | | | | | |
| Ag ppb | | | | | | | | | | 0.81 | (b) | | | | | | |
| Cd ppb | | | | | | | | | | 1.4 | (b) | 2 | (b) | | | | |
| In ppb | | | | | | | | | | 1.9 | (b) | 0.6 | (b) | | | | |
| Sn ppb | | | | | | | | | | | | | | | | 230 | (f) |
| Sb ppb | | | | | | | | | | | | | | | | | |
| Te ppb | | | | | | | | | | 10 | (b) | | | | | | |
| Cs ppm | | | | | | | | | | 0.039 | (b) | | | | | 60 | (f) |
| Ba | 67.2 | (e) | 66 | (c ) | 66 | 58 | 65 | 48 | (a) | | | | | 80 | (a) | 57 | (f) |
| La | 6.02 | (e) | | | | 5.8 | 5.6 | 5.1 | (a) | | | | | 5.34 | (a) | 5.9 | (f) |
| Ce | 17 | (e) | | | | 22 | 21 | 19 | (a) | | | | | 12 | (a) | 16 | (f) |
| Pr | | | | | | | | | | | | | | | | 2.5 | (f) |
| Nd | 12.3 | (e) | | | | | | | | | | | | 13 | (a) | 14 | (f) |
| Sm | 4.24 | (e) | | | | 4.38 | 5.5 | 4.32 | (a) | | | | | 3.94 | (a) | 5.4 | (f) |
| Eu | 0.853 | (e) | | | | 0.91 | 0.82 | 0.86 | (a) | | | | | 0.8 | (a) | 0.84 | (f) |
| Gd | 5.65 | (e) | | | | | | | | | | | | | | 7.5 | (f) |
| Tb | | | | | 0.84 | 0.93 | 1.22 | 0.79 | (a) | | | | | 1 | (a) | 1.5 | (f) |
| Dy | 6.34 | (e) | | | | 7.5 | 10.6 | 6 | (a) | | | | | | | 6.5 | (f) |
| Ho | | | | | | | | | | | | | | 1.3 | (a) | 1.9 | (f) |
| Er | 3.89 | (e) | | | | | | | | | | | | | | 4.6 | (f) |
| Tm | | | | | | | | | | | | | | | | 0.8 | (f) |
| Yb | 3.36 | (e) | 4.3 | (d) | | *7* | *12.8* | *5.9* | (a) | | | | | 3.45 | (a) | 4.2 | (f) |
| Lu | | | | | | *1.11* | *2.07* | *0.86* | (a) | | | | | 0.459 | (a) | | |
| Hf | | | | | 2.9 | 3.3 | 3.1 | 3.1 | (a) | | | | | 2.49 | (a) | 3.5 | (f) |
| Ta | | | | | | 0.35 | 0.37 | 0.37 | (a) | | | | | 0.28 | (a) | | |
| W ppb | | | | | | 140 | 290 | 200 | (a) | | | | | | | | |
| Re ppb | | | | | | | | | | | | | | | | | |
| Os ppb | | | | | | | | | | | | | | | | | |
| Ir ppb | | | | | | | | | | 0.62 | (b) | 0.05 | (b) | | | | |
| Pt ppb | | | | | | | | | | | | | | | | | |
| Au ppb | | | | | | | | | | 0.024 | (b) | | | | | | |
| Th ppm | | | | | 0.6 | *2.5* | *9.3* | *2.3* | (a) | | | | | 0.91 | | 0.65 | (f) |
| U ppm | | | | | 0.19 | *2.1* | *8.5* | *1.7* | (a) | | | | | | | 0.15 | (f) |

*technique (a) INAA, (b) RNAA, (c ) XRF, (d) OES, (e) IDMS, (f) spark s. MS*

## Table 1b. Chemical composition of 12002.

| reference | O'Kelly 71 | | Wanke 71 | |
|---|---|---|---|---|
| *weight* | | | | |
| SiO2 % | | | 44.5 | (b) |
| TiO2 | | | | |
| Al2O3 | | | 7.8 | (b) |
| FeO | | | 22.13 | (b) |
| MnO | | | 0.29 | (b) |
| MgO | | | 14.75 | (b) |
| CaO | | | | |
| Na2O | | | 0.21 | (b) |
| K2O | 0.054 | (a) | 0.054 | (b) |
| P2O5 | | | | |
| S % | | | | |
| *sum* | | | | |
| | | | | |
| Sc ppm | | | 42.6 | (b) |
| V | | | | |
| Cr | | | 6570 | (b) |
| Co | | | 68.7 | (b) |
| Ni | | | 150 | (b) |
| Cu | | | 5.5 | (b) |
| Zn | | | | |
| Ga | | | | |
| Ge ppb | | | | |
| As | | | | |
| Se | | | | |
| Rb | | | | |
| Sr | | | | |
| Y | | | | |
| Zr | | | | |
| Nb | | | | |
| Mo | | | | |
| Ru | | | | |
| Rh | | | | |
| Pd ppb | | | | |
| Ag ppb | | | | |
| Cd ppb | | | | |
| In ppb | | | | |
| Sn ppb | | | | |
| Sb ppb | | | | |
| Te ppb | | | | |
| Cs ppm | | | | |
| Ba | | | | |
| La | | | 5.65 | (b) |
| Ce | | | | |
| Pr | | | | |
| Nd | | | | |
| Sm | | | 3.3 | (b) |
| Eu | | | 0.96 | (b) |
| Gd | | | | |
| Tb | | | 1.1 | (b) |
| Dy | | | 5.8 | (b) |
| Ho | | | | |
| Er | | | | |
| Tm | | | | |
| Yb | | | 3.33 | (b) |
| Lu | | | 0.55 | (b) |
| Hf | | | 3.6 | (b) |
| Ta | | | 0.54 | (b) |
| W ppb | | | | |
| Re ppb | | | | |
| Os ppb | | | | |
| Ir ppb | | | | |
| Pt ppb | | | | |
| Au ppb | | | | |
| Th ppm | 0.89 | (a) | | |
| U ppm | 0.23 | (a) | | |

*technique (a) radiation counting, (b) INAA*

**List of some photo #s for 12002**

S69-60370-377 B&W mug shot
S69-64082
S69-64107
S76-23966 color
S70-38479 group photo
S70-16778-779 TS
S70-31576 TS

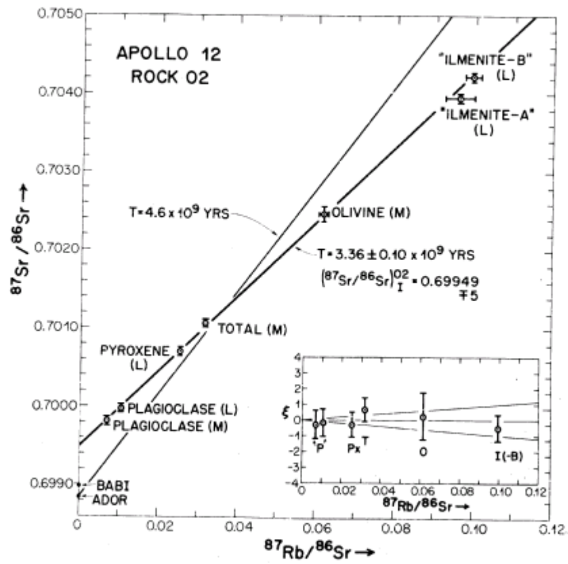



*Figure 12: Rb-Sr internal mineral isochron for 12002 (from Papanastassiou and Wasserburg 1970).*

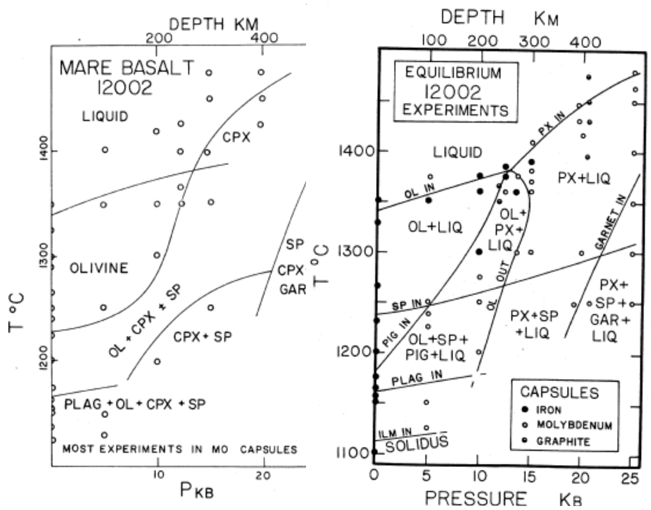



*Figure 13: Phase diagrams for 12002 showing multiple saturation at about 12 kilobars (from Grove et al. 1973 and Walker et al. 1976).*

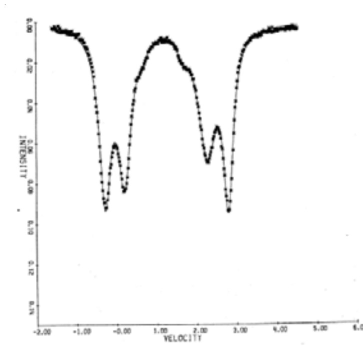


*Figure 14: Mossbauer spectra for 12002 from Herzenberg et al. (1971).*

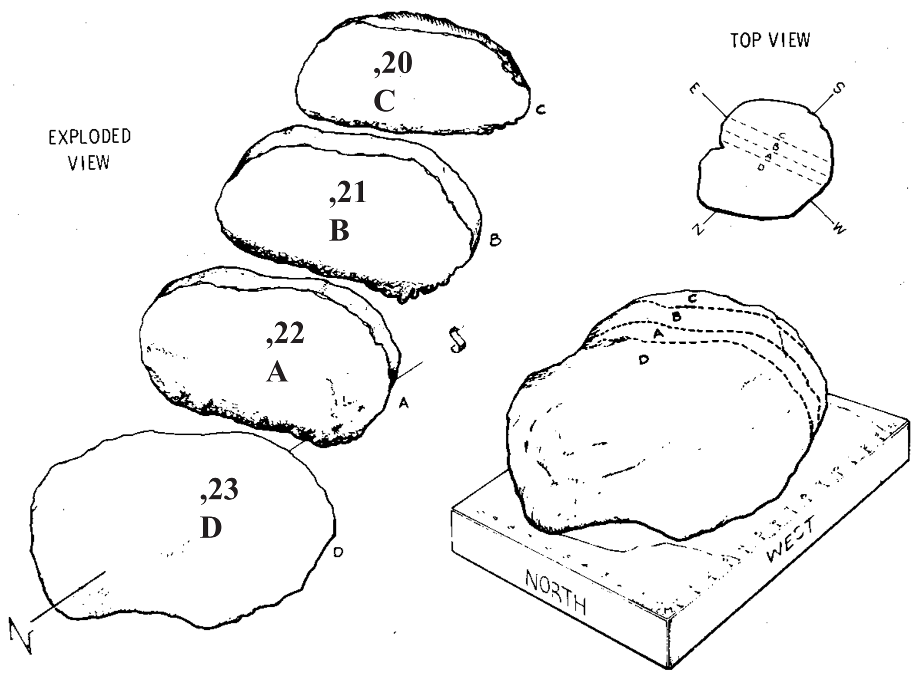
Table 2

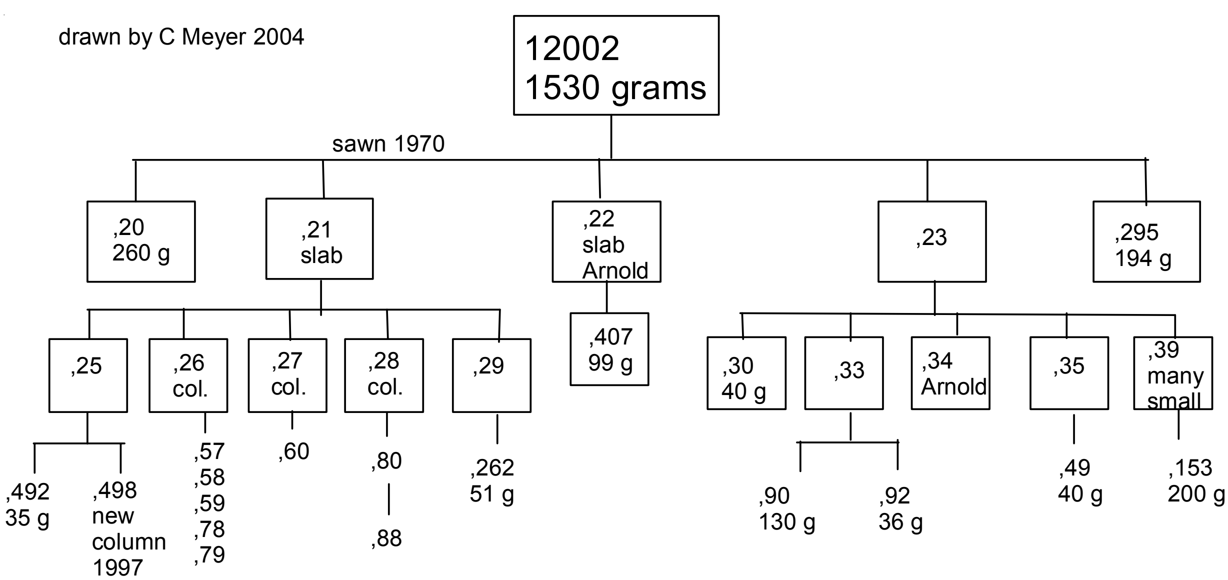
| Isotope | $T_{1/2}$ | OP–1 9.9 g (0–1 mm) | OP–2 9.5 g (1–2 mm) | OP–3 17.7 g (2–4 mm) | OP–4 25.3 g (4–9 mm) | OP–5 18.2 g (9–20 mm) | OP–6 50.4 g (20–60 mm) | OP–7 4.4 g (60 mm) |
|---|---|---|---|---|---|---|---|---|
| $Be^{10}$ | $2.5 \times 10^6$ y | | | | | 15.4 ± 3.0 | 11.5 ± 1.4 | |
| $Na^{22}$ | 2.6 y | 166 ± 18 | 122 ± 14 | 91 ± 11 | 71 ± 8 | 54 ± 7 | 39 ± 6 | |
| $Al^{26}$ | $7.4 \times 10^5$ y | 209 ± 26 | 154 ± 21 | 111 ± 16 | 91 ± 12 | 72 ± 11 | 64 ± 6 | 66 ± 11 |
| $Cl^{36}$ | $3.1 \times 10^5$ y | 13.4 ± 3.8 | | 9.7 ± 2.5 | 14.7 ± 2.4 | 8.4 ± 2.1 | 9.4 ± 1.4 | |
| $Mn^{53}$ | $3.7 \times 10^6$ y | 98 ± 6 | 86 ± 5 | 73 ± 5 | 67 ± 4 | 52 ± 3 | 47 ± 3 | 51 ± 3 |
| $Mn^{54}$ | 303 d | 98 ± 17 | 77 ± 12 | 53 ± 11 | 50 ± 9 | 39 ± 10 | 31 ± 5 | |
| $Fe^{55}$ | 2.6 y | 731 ± 68 | 454 ± 46 | 285 ± 30 | 171 ± 23 | 101 ± 17 | 56 ± 12 | |
| $Co^{56}$ | 77 d | 533 ± 70 | 205 ± 30 | 80 ± 15 | 32 ± 9 | | | |
| $Co^{57}$ | 270 d | 16 ± 6 | < 6 | | | | | |

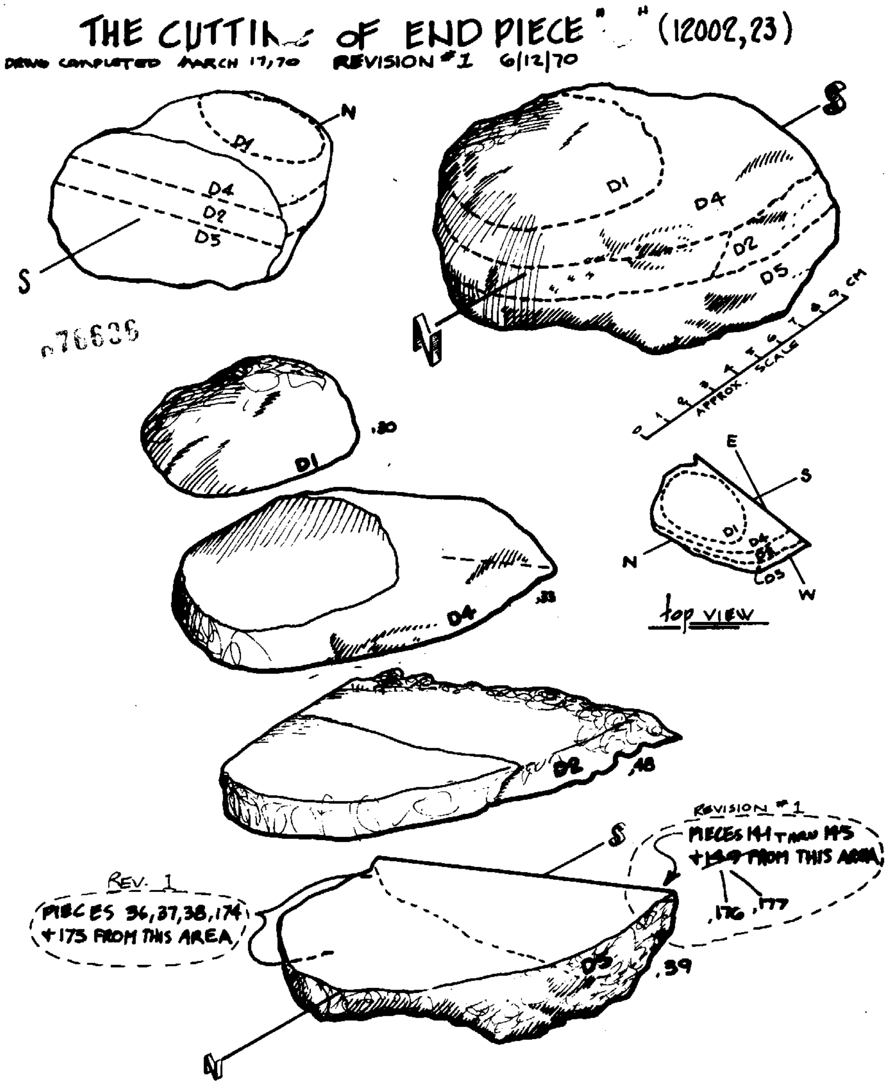
## Summary of Age Data for 12002

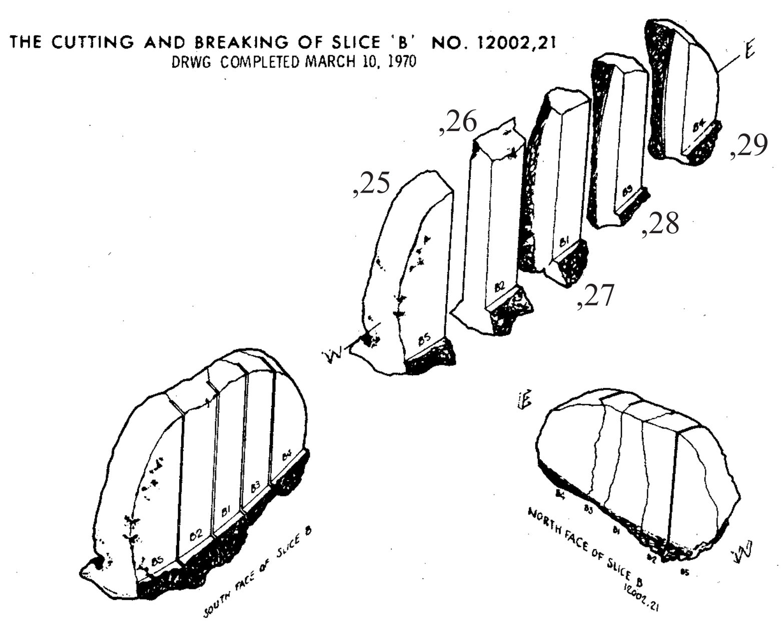
| | Ar-Ar | Rb-Sr |
|---|---|---|
| Turner 1971 | 3.24 ± 0.05 b.y. | |
| Alexander et al. 1972 | 3.26 ± 0.06 | |
| Papanastassiou and Wasserburg 1970 | | 3.36 ± 0.10 |

FIRST CUTS ON LUNAR ROCK NO. 12002,0
DRWG COMPLETED MARCH 6, 1970




THE CUTTING OF END PIECE " " (12002,23)
DRWG COMPLETED MARCH 17,70 REVISION #1 6/12/70
N
D1
D4
D2
D5
S
APPROX. SCALE
,30
,33
,48
,39
top view
REV. 1
PIECES 36,37,38,174 +175 FROM THIS AREA
REVISION #1
,176
,177


THE CUTTING AND BREAKING OF SLICE 'B' NO. 12002,21
DRWG COMPLETED MARCH 10, 1970
,25
,26
,27
,28
,29
E
W
SOUTH FACE OF SLICE B
NORTH FACE OF SLICE B
12002,21

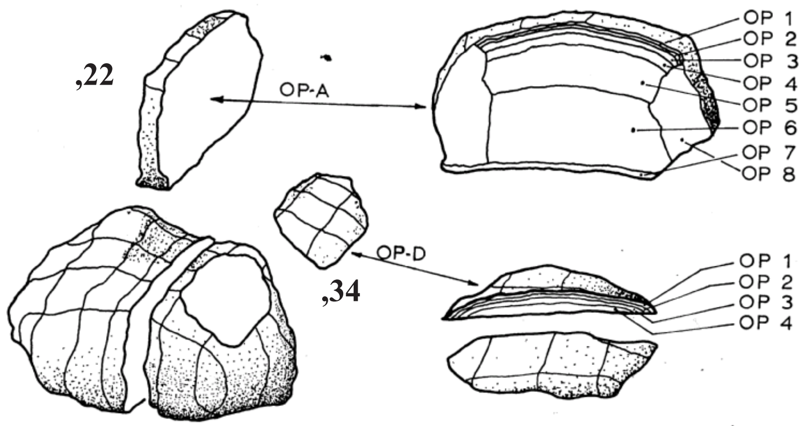



*Figure 15: Exploded parts diagram for 12002 (from paper by Finkel et al. 1971).*

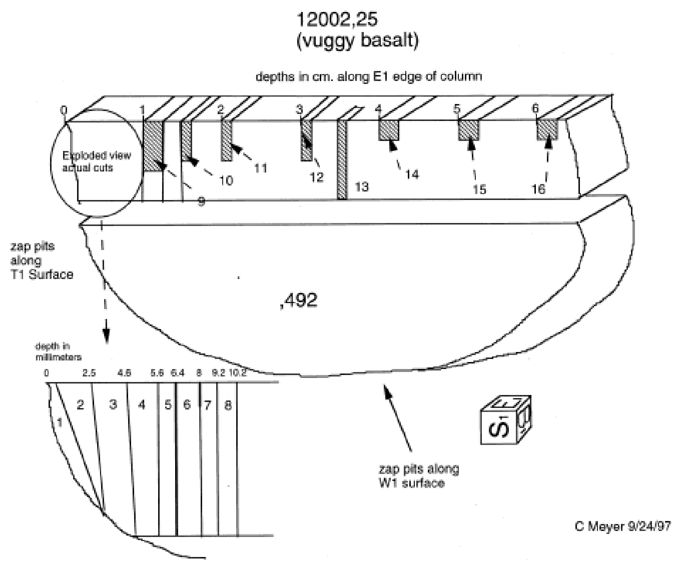
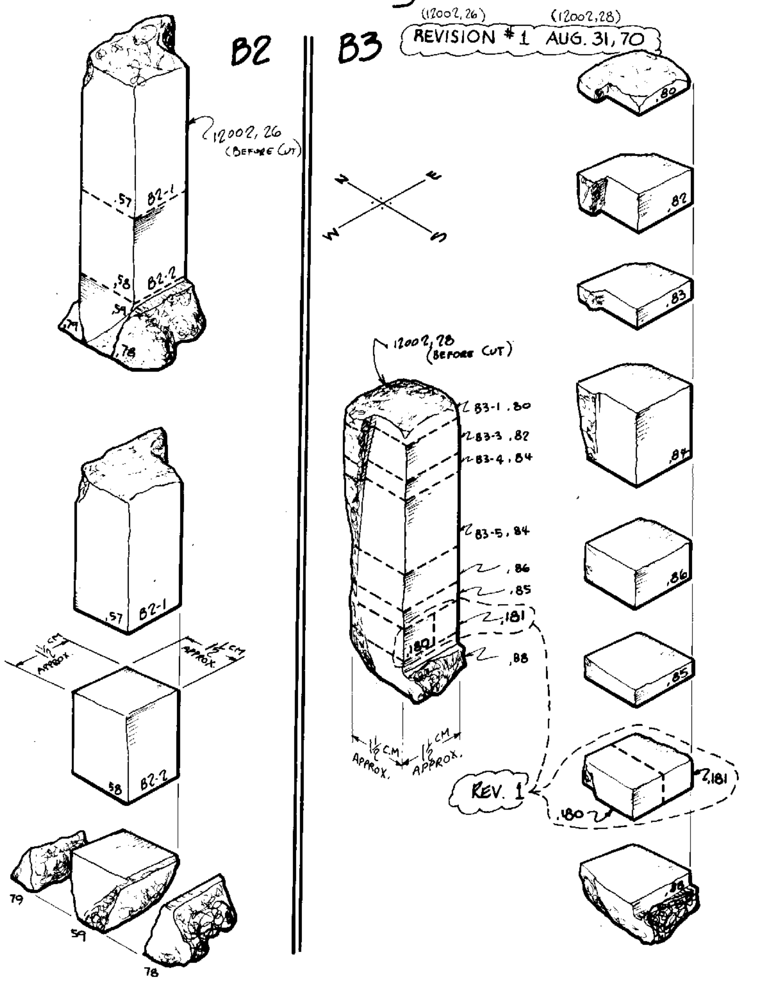



*Figure 16: Cutting diagram for detailed column cut from 12002,25 in 1997 for fine scale 14C measurements.*

the CUTTING of "B2" AND "B3"

DRWG COMPLETED MAR 13, 70




THE CUTTING AND BREAKING OF PIECE 'B1' NO. 12002,27

DRWG COMPLETED MARCH 12, 1970

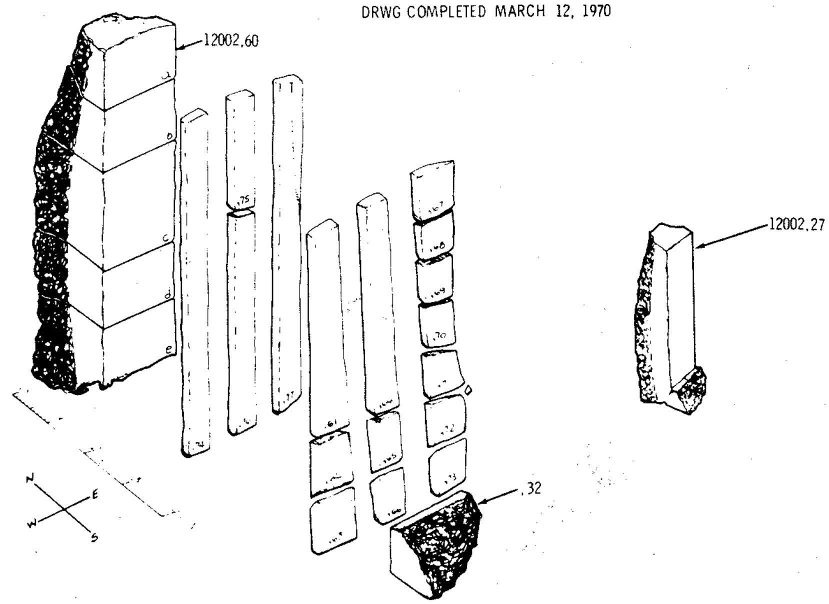



*Figure 17: Display sample 12002,182.*

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