P.504

LUNAR MAFIC GREEN GLASSES, HOWARDITES, AND THE COMPOSITION OF UNDIFFERENTIATED LUNAR MATERIAL by Ursula B. Marvin, J. B. Reid, Jr., G. J. Taylor, and J. A. Wood,* Smithsonian Astrophysical Observatory, Cambridge, Massachusetts 02138.

Our general survey of coarse fine particles from the Apollo 14 soil samples is summarized in the abstract we originally submitted to the Lunar Science Conference and will be published in the Proceedings Volumes. In our talk and this amended abstract, we wish to dwell on one particularly interesting class of soil particle.

Fig. 1 shows the normative mineralogy of all particles of non-mare lunar material, from lunar soil samples, analyzed by our group to date. The distinction between mare and non-mare materials is not always easy to make; we assumed particles containing > 2% $TiO_2$ were mare-derived, and excluded them from the plot. Three classes of non-mare material can be distinguished: plagioclase-rich anorthositic particles, norites rich in K and P (normative orthoclase, apatite), and a small group of pale green glasses (arrow) consisting of about one-third normative plagioclase and two-thirds normative mafic silicate minerals.

We have found these pale green mafic glasses in < 1-mm fines samples from the Luna 16 and Apollo 14 core tubes. These glasses are relatively rare in the lunar soils, but not so rare as Fig. 1 indicates. They are sufficiently rare that there is little likelihood of finding them among the small numbers of > 1-mm soil particles allocated for study; and they have escaped notice among < 1-mm soil particles because few investigators make detailed chemical studies of individual particles in "fine fines" samples.

The lunar mafic green glasses are compositionally similar to howardites, one of the Ca-rich classes of meteorites. The comparison is drawn in columns three and four of Table I. Averaged values in these two columns sometimes do not match very closely, but both howardites and lunar green glasses are variable in composition, and for all oxides but CaO the compositional ranges overlap. A comparison between the

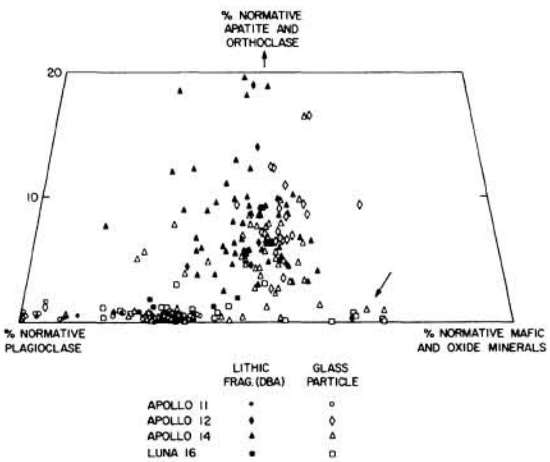


Fig. 1. Normative compositions (microprobe analyses) of non-mare particles analyzed by us in lunar soil samples. Arrow: mafic green glasses.

*Speaker.

P.508

normative mineralogy of Ca-rich meteorites and howardites is drawn in Figs. 2 and 3. Mineral compositions and abundances do not match perfectly for howardites and lunar green glasses, but the difference is small.

Four interpretations of the significance of howarditic glass in the lunar soil can be considered:

(1) The glass is derived from howarditic meteorites that have bombarded the Moon. This is unlikely: ordinary chondrites, ~30× more abundant among terrestrial meteorite falls than howardites, are not found in the lunar soil, either intact or impact-melted; evidently stony meteorites are, with rare exceptions, melted on impact and mingled beyond recognition with lunar materials.

(2) Howarditic meteorites are derived from the Moon (a possibility suggested by Duke and Silver, Geochim. Cosmochim. Acta 31, 1637, 1967). Also unlikely: if impacts on the Moon deliver howardites to us as meteorites, they should also deliver anorthositic rocks, KREEP-rich norite, and Ti-rich basalt.

(3) Howarditic material is developed by a complex process of igneous differentiation, brecciation, and mixing (as indicated by textures) in at least two places: in the Moon and in one or more parent meteorite planets elsewhere in the solar system. We regard it as too much of a coincidence that this chain of events would produce such similar end products on two planets in the solar system; textures notwithstanding, it seems to us that the howarditic composition has some fundamental geochemical significance that carries over from one planet to another.

(4) The special importance of this composition does not have to do with melting relationships in silicate systems; howardites do not lie near the eutectic composition in the system anorthite-forsterite-silica. We suggest that howardites are a fair approximation to the raw material from which some of the inner planets or pre-planetary masses accreted. These included our Moon; and while it seems that almost the entirety of the Moon has been partially melted and differentiated, some small proportion of its original substance must have survived more or less unfractionated, to serve later as a source for the lunar green glasses.

Fig. 2

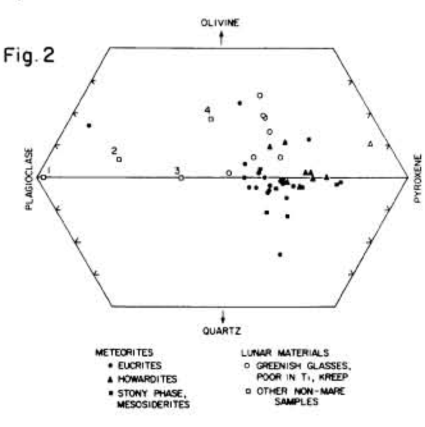


Fig. 3

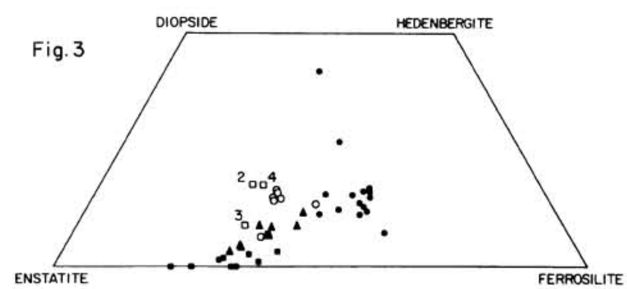


Fig. 2. Comparison of proportions of major minerals in the norms of Ca-rich meteorites, green glasses, and other lunar materials: 1, 15415 (the Genesis Rock); 2, gabbroic anorthosite 15418; 3, igneous norite 14310; 4, "green clod" 15923.

Fig. 3. Comparison of composition of normative pyroxenes in Ca-rich meteorites and lunar materials. Symbols and number key as in Fig. 2.

Table I. Comparison of average compositions (and compositional ranges) of Ca-rich meteorite classes and lunar mafic green glasses. Analyses recalculated to sum 100%.

| | Stony Phase, Meteorites[a] | | | Particles from Lunar Soils | | | | Lunar Rocks | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Eucrites[b] | Mesosiderites[c] | Howardites[d] | Mafic green glasses[e, f] | Genesis Bean[f] | MSC Glasses[g] | "Howardite" (110-48)[f] | 15923 Green clod | 15076 Basalt | 15556 Basalt |
| $SiO_2$ | 48.97 (47.94–49.96) | 53.61 (49.27–60.59) | 50.20 (48.14–51.10) | 46.68 (44.84–50.74) | 49.26 | 46.22 | 42.56 | 45.41 | 49.27 | 45.67 |
| $TiO_2$ | 0.47 (0.07–0.75) | 0.48 (0.22–1.09) | 0.35 (0.03–0.79) | 0.77 (0.47–1.50) | 0.60 | 0.65 | 1.10 | 1.15 | 1.47 | 2.79 |
| $Al_2O_3$ | 12.83 (11.05–15.57) | 8.86 (5.83–11.69) | 8.67 (5.10–11.35) | 11.38 (9.25–17.43) | 8.98 | 9.11 | 11.84 | 15.14 | 9.39 | 9.55 |
| $Cr_2O_3$ | 0.39 (0.06–0.88) | 0.53 | 0.62 (0.04–1.35) | 0.54 (0.37–0.70) | 0.56 | – | 0.47 | 0.40 | – | – |
| FeO | 18.42 (15.02–20.41) | 13.77 (9.28–17.95) | 17.08 (15.29–18.48) | 17.03 (12.83–19.46) | 16.79 | 18.65 | 22.08 | 13.79 | 18.80 | 22.53 |
| MnO | 0.42 (0.21–0.78) | 0.53 (0.40–0.62) | 0.51 (0.22–0.72) | 0.28 (0.22–0.34) | 0.29 | – | 0.30 | 0.18 | 0.27 | 0.29 |
| MgO | 7.42 (6.47–8.67) | 15.18 (12.22–22.61) | 15.27 (11.27–20.50) | 13.13 (9.73–15.43) | 13.76 | 16.24 | 14.24 | 12.20 | 9.55 | 7.83 |
| CaO | 10.42 (8.62–11.48) | 5.72 (2.92–7.89) | 6.89 (3.88–8.63) | 9.72 (8.98–11.37) | 9.15 | 8.74 | 7.22 | 11.17 | 10.92 | 10.96 |
| $Na_2O$[h] | 0.45 (0.40–0.53) | 0.53 (0.47–0.57) | 0.29 (0.18–0.40) | 0.38 (0.35–0.42) | 0.41 | 0.24 | 0.05 | 0.36 | 0.26 | 0.26 |
| $K_2O$[h] | 0.05 (0.02–0.08) | 0.02 (0.01–0.02) | 0.02 (0.02–0.03) | 0.05 (0.00–0.10) | 0.10 | 0.15 | 0.02 | 0.11 | 0.03 | 0.03 |
| $P_2O_5$ | 0.14 (0.06–0.27) | 0.78 (0.26–1.47) | 0.10 (0.01–0.21) | 0.04 (0.00–0.16) | 0.10 | – | 0.10 | 0.09 | 0.03 | 0.08 |

[a] Eucrites and howardites contain < 1%, mesosiderites 40 to 60%, of metal and sulfide phases.

[b] Average of Bereba, Cachari, Jonzac, Juvinas, Luotolax, Macibini, Moore County, Pasamonte, Peramiho, Petersburg, Stannern, Chervony Kut, and Sioux County; analyses referenced in Mason (1967) and Urey and Craig (1953).

[c] Average of stony phases of Patwar (Jarosevich and Mason, 1969), Crab Orchard, Vaca Muerte, Estherville, Hainholz, Veramin, Lowicz, Morristown, and Bondoc (Powell, 1971).

[d] Average of Frankfort, Binda, Pavlovka, Chaves, Bununu, Yurtuk, Le Teilleul, Kapoeta, and Brient; analyses referenced in Mason (1967).

[e] Average of Genesis Bean and demi-Genesis Bean, from 14230, 2; pale-green glasses (306-214), (306-75), and (306-145) from level G, Luna 16; and pale-green glasses (257-21) and (260-67) from 14230, 30 and 14230, 2, respectively.

[f] Our microprobe analyses.

[g] Average of ten "mare derived glasses" containing <1.0% $TiO_2$, from <1 mm fines sample 14259 (Brown et al., 1971).

[h] Only post-1950 values for meteorites are used; supplemented by Edwards and Urey (1955) and Schmitt (1966).