Reports

Lunar Sample 14425: Characterization and Resemblance to High-Magnesium Microtektites

Abstract. *Measurements by energy-dispersive x-ray analysis of the surface of lunar sample 14425, a large glass bead, yield a noritic composition enriched in aluminum and magnesium and, as compared with other norites, depleted in iron and especially calcium. The sample is close in composition to the most basic microtektites. Spherical inclusions of nickel-iron, flattened where they protrude, are found to be enriched in sulfur and phosphorus, at least at the surface. The inclusions form approximately 1 percent of the volume.*

Tektites, unlike stony or iron meteorites, cannot originate outside the earth-moon system because they lack the isotopic indications—that is, adequate levels of ^{10}Be, ^{26}Al, and so on—of exposure to primary cosmic rays over periods of 10^6 to 10^7 years (*1, 2*). From their distribution on the earth, it is clear that, whether terrestrial or lunar, they were launched by a powerful mechanism, presumably either volcanism or some kind of impact event. Earth volcanism is too feeble to produce the observed strewn fields of tektites, up to halfway around the earth (*3*), and impact on the moon would yield objects with much the same composition (anorthositic gabbro or basalt) as most of the lunar crust. We are thus left with two alternatives for their origin: namely, meteorite impact on the earth or volcanic ejection from the moon.

The two alternatives lead to different explanations of the extinctions that appear to be associated with at least some tektite falls (*3*). If tektites are terrestrial, the extinctions may have been due to dust clouds in the atmosphere, thrown up by an impact event, as implicitly suggested by Alvarez *et al.* (*4*) and Ganapathy (*5*). If, however, they are of lunar origin, then it would be expected that the ash particles that missed the earth would organize themselves into Saturn-like rings around the earth and that the rings would be quantitatively sufficient to make significant climatic changes (*6*).

Geochemists (*7*) generally favor origin from the earth because tektites are closer to earth rocks than to most returned lunar samples in several respects, particularly in age, potassium-uranium ratios, rare-earth abundances, and oxygen isotopes. Some geophysicists, on the other hand, find that a terrestrial origin appears to conflict with basic aerodynamic principles (*8*) and with the physical principles that underlie the practice of glassmaking (*9*). Clearly this paradox would be illuminated if a tektite should be found among the returned lunar samples. We describe the close chemical resemblance of lunar sample 14425 to the high-magnesium, low-silica microtektites of the Australasian strewn field (*10*).

The sample's diameter of 8.006 ± 0.006 mm is constant within about 0.1 percent over the surface. Its mass, 0.78410 ± 0.00002 g, implies a specific gravity of 2.917 ± 0.002. The glass is black in some parts and brown in others. The surface is decorated with mounds that have a metallic luster, the largest being about 0.9 mm in diameter. By x-ray (Sperry model SPX, 200 kV, working at 60 kV, 4 mA) it is found that the interior contains spherules up to 0.7 mm in diameter; the mounds result when these spheres protrude through the glass surface (Fig. 1). The total volume of the spherical inclusions that are larger than 0.1 mm in diameter is estimated at 0.6 percent of the volume of the sample.

The surface composition of the glass was examined with a Cambridge 150 scanning electron microscope together with energy-dispersive x-ray analysis at the University of Delaware and by similar analysis with the Philips PSEM 500 electron microscope and an EDAX 9100 at Goddard Space Flight Center. In order to preserve the surface, the sample was not ground and polished, nor was it coated (for example, with carbon); it was used as found, and we relied on the smoothness of much of the surface. At both laboratories the sample was held in place with a brass holder, which produced spurious lines of copper and zinc at both places and lead at Delaware. These lines disappeared when an aluminum holder was substituted at Goddard, but this produced anomalous aluminum values that could not be corrected because of the aluminum in the sample. All of these effects, in addition to some

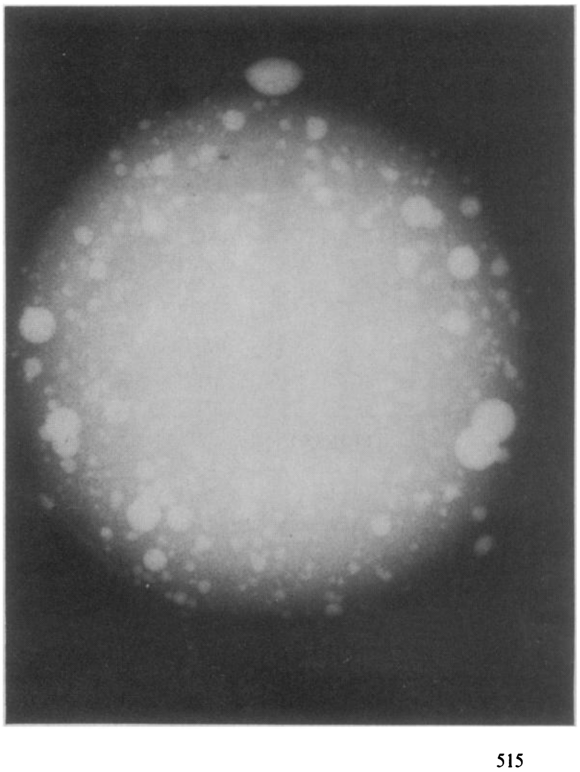

Fig. 1. X-ray of lunar sample 14425; the large mound is at top. The sample is 8.0 mm in diameter.

spurious lines of gold in the Goddard spectra, resulted from the fact that without a conducting coat, the surface charges up and repels the electron beam, which then wanders. It is believed that by comparison of the three holders, it has been possible to eliminate these effects.

In both analyses, the small peak due to sodium was difficult to separate from the adjoining magnesium peak, which was about 100 times stronger. With the use of a wavelength-dispersive Microspec system at Goddard, a value of 0.1 percent was found for Na_2O.

The means of the analyses on the glass are shown together with the standard deviations in Table 1. In Fig. 2, measurements from both laboratories are plotted against silica content, as in the Harker diagram. Measurements made with the aluminum holder failed to show any substantial difference between the light and the dark regions of the surface.

The composition of sample 14425 is different from the other known lunar samples, so far as we can find. We have examined 1200 analyses of lunar glasses (*11*), and 100 papers on lunar samples, including 50 described as referring to lunar norites. The analysis of the groundmass of lunar sample 14068 (*12*), which is one of the closest fits, is plotted in Fig. 2; it is clearly not the same material.

Table 1. Composition of glass. Mean percentages by weight of major oxides and standard deviations of the individual measures from the mean.

Oxide	Mean (%)
SiO_2	56.0 ± 1.7
Al_2O_3	18.0 ± 1.2
FeO	4.9 ± 1.5
MgO	16.9 ± 0.8
CaO	5.8 ± 0.7
Na_2O	0.1
K_2O	0.14 ± 0.07
TiO_2	0.6 ± 0.16
Cr_2O_3	0.19 ± 0.09

The small dots in Fig. 2 are plotted from a report (*13*) on bottle-green (high-magnesium) microtektites from the Australasian strewn field. The resemblance of the Australasian glasses to sample 14425 is conspicuous. Microtektites from the Ivory Coast strewn field (not shown) do not fit as well—for example, FeO averages 10 percent.

Two of the mounds with metallic luster were analyzed. The largest mound showed iron and sulfur in a 5 to 2 ratio with a few percentages each of nickel and phosphorus; a smaller mound gave iron and nickel in a 4 to 1 ratio, with small quantities of sulfur and phosphorus. A possible interpretation would be nickel-iron spherules containing schreibersite and troilite, such as have been reported for tektites (*14*) and impactites (*15*). Reid *et al.* (*16*) did not find schreibersite in nickel-iron blebs from lunar basalts. The presence of these spherules could be consistent either with impact or lunar volcanism (*17*).

In conclusion, we find a close chemical resemblance between lunar sample 14425 and the high-magnesium microtektites. However, to establish that this sample is a tektite, more data on age, isotopic composition, and trace element abundances are required. In particular, the rare earth element pattern should be studied for comparison with the data of Frey (*18*) on high-magnesium microtektites. The siderophile element abundance ratios could tell us whether the metal was derived from a meteorite or was produced by reduction of the matrix glass.

J. A. O'KEEFE
Laboratory for Astronomy and Solar Physics, NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771
B. P. GLASS
Geology Department, University of Delaware, Newark 19716

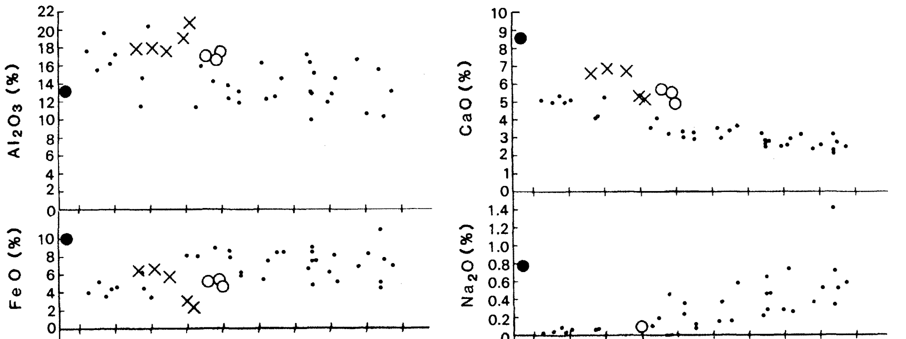

Fig. 2. Major oxides plotted against SiO_2. Large closed circles represent lunar sample 14068; open circles represent Goddard measurements on lunar sample 14425; crosses represent Delaware measurements on sample 14425; and small dots represent the data of Glass (*13*) on the high-magnesium tektites of the Australasian strewn field. Although sample 14068 is one of the best matches to 14425 among the lunar samples, it is not nearly as close as the microtektites.

References and Notes

1. J. A. O'Keefe, *Tektites and Their Origin* (Elsevier, Amsterdam, 1976), pp. 147–165.
2. B. P. Glass, *Introduction to Planetary Geology* (Cambridge Univ. Press, Cambridge, 1982), p. 166.
3. ———, M. B. Swincki, P. A. Zwart, in *Proceedings of the 10th Lunar and Planetary Science Conference*, R. B. Merrill, Ed. (Pergamon, New York, 1979), pp. 2535–2545.
4. W. Alvarez, F. Asaro, H. V. Michel, L. W. Alvarez, *Science* **216**, 886 (1982).
5. R. Ganapathy, *ibid.*, p. 885.
6. J. A. O'Keefe, *Nature (London)* **285**, 310 (1980).
7. S. R. Taylor and S. M. McLennan, *Geochim. Cosmochim. Acta* **44**, 2153 (1980).
8. D. R. Chapman and H. K. Larson, *J. Geophys. Res.* **68**, 4305 (1963).
9. J. A. O'Keefe, *Geochim. Cosmochim. Acta* **44**, 2151 (1980).
10. Microtektites are microscopic (greater than 1 mm in diameter) tektites. Each group of microtektites has been identified as belonging to one or another of the known strewn fields, on the basis of geographic location, age, and composition. The high-magnesium microtektites appear to be the low-silica end members of the sequence of high-magnesium tektites [D. R. Chapman and L. C. Scheiber, *J. Geophys. Res.* **74**, 6737 (1969)].
11. B. P. Glass, *Final Report for NASA Contract NGR 08-001-020* (University of Delaware, Newark, 1975).
12. R. T. Helz, in *Proceedings of the 3rd Lunar Science Conference*, E. A. King, Ed. (MIT Press, Cambridge, Mass., 1972), pp. 865–886.
13. B. P. Glass, *J. Geophys. Res.* **77**, 7057 (1972).
14. E. C. T. Chao, E. J. Dwornik, J. Littler, *Geochim Cosmochim. Acta* **28**, 971 (1964).
15. A. El Goresy, in *Shock Metamorphism of Natural Materials*, B. M. French and N. M. Short, Eds. (Mono Book, Baltimore, 1968), pp. 531–553.
16. A. M. Reid, C. Meyer, R. S. Harmon, R. Brett, *Earth Planet. Sci. Lett.* **9**, 1 (1970).
17. R. Ganapathy, *ibid.* **65**, 225 (1983).
18. F. A. Frey, *ibid.* **35**, 43 (1977).
19. The sample is from the holdings of the Planetary Materials Laboratory of Johnson Space Center. We thank D. P. Blanchard and J. W. Dietrich for help in obtaining the sample; R. S. Marriott and B. Parker for analyses; J. Jellison for x-ray photography; and C. C. Schnetzler, H. Thomas, and S. Sofia for helpful advice.

13 August 1984; accepted 8 November 1984