Reports

VLS (Vapor-Liquid-Solid): Newly Discovered Growth Mechanism on the Lunar Surface?

Abstract. *A probable vapor-liquid-solid (VLS) type of growth has been discovered for the first time in nature on the surface of lunar rock 15015. Scanning electron microprobe and energy dispersive x-ray data indicate that the growth occurs as metallic iron stalks from about 0.015 to 0.15 micrometer in diameter, with bulbous tips consisting of a mixture of iron and sulfur and measuring from about 0.03 to 0.2 micrometer in diameter. The stalk length is two to ten times the bulb diameter.*

On the Apollo 15 mission astronauts David Scott and James Irwin collected a blocky, angular, largely glass-covered breccia (15015) almost 30 cm long and weighing 4.5 kg (*1*). The sample is the third largest one returned, and no other rock of comparable size was in the collection area. It was collected approximately 20 m west of the + Z footpad of the lunar module.

A glass-covered surface (62 mm²) on a fragment of breccia 15015 (15015,36) was coated with a thickness of approximately 150 Å of gold and selected areas were studied by scanning electron microscope (SEM), scanning electron microprobe (SEMP), and energy dispersive x-ray (EDX) techniques (*2*). The chemical and morphological nature of the surface features in the selected areas, including numerous mounds of both metallic iron and complex mixtures of metallic iron and iron sulfide, have been described in detail by Carter (*2*). He also noted peculiar patches that ranged from 0.4 to 400 μm in the longest dimension, and consisted of stalks with bulbous tips that distorted the SEMP secondary electron image. In this report I examine the nature of these patches and suggest that they are the result of the vapor-liquid-solid (VLS) type of growth (*2–4*).

An investigation (*2*) of the siliceous glass surface of rock 15015 by means of montages and stereoscopic SEM photographs reveals that the patches occur on (i) "high" areas (Fig. 1, A and B); (ii) minerals that protrude through the glass surface (Fig. 1A); and (iii) irregularly shaped metallic iron mounds that surround the silicate mineral "islands." Patches do not occur on the surface of the intervening siliceous glass. The high areas are surface expressions of high points on the rock substrate that were covered by a thin layer of siliceous melt which quenched faster than the thicker areas of melt. Examination of patches at high magnification reveals that they are composed of a series of stalks with bulbs on their tips (*2, 4*) (Fig. 1, C and D). The bulbs vary in diameter from less than 0.03 to 0.2 μm and the stalks from less than 0.015 to 0.15 μm. The stalk length varies from two to ten times the bulb diameter.

From the SEMP and EDX data, the bulbs are probably a mixture of iron and sulfur, whereas the stalks are metallic iron. However, because of the extremely small size of these structures it is not possible to ascertain precisely their chemistry. However, the chemical data and the morphological relationships are consistent with the stalks and bulbs being the result of a VLS type of growth mechanism operating in the lunar environment during a meteoritic impact event. This type of growth mechanism involving vapor, liquid, and solid phases was proposed by Wagner and Ellis (*3*) to explain many observations of the effect of impurities on crystal growth from a vapor in laboratory experiments. Crystals formed in this way are usually of very pure composition and structure.

This proposed VLS-type growth on the surface of lunar rock fragment 15015,36 is the first recognized in nature. Since the metallic iron stalks are either single domain or pseudo-single domain due to shape anisotrophy, they may affect strongly the magnetic

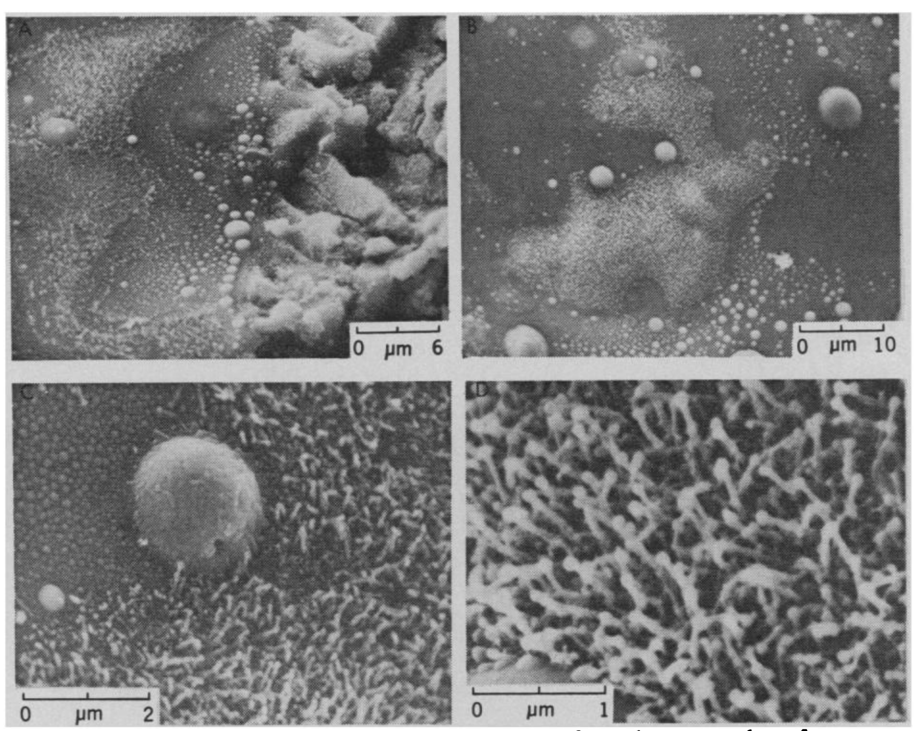

Fig. 1. Scanning electron microscope photographs of a glass-covered surface on a fragment of lunar breccia 15015. (A) Probable VLS-type growth on a "high" area and on a silicate mineral "island." (B) Relationship of probable VLS-type growth on a high area to metallic iron mounds. (C) Enlarged view of the center of (B) showing stalks with bulbous tips. (D) Details of probable VLS-type growth. The stalks are considered to be metallic iron and the bulbous tips mixtures of iron and sulfur.

properties of this rock and contribute to its hard magnetic component (5). Low-grade metamorphic breccia produced from soil containing these VLS-type stalks would then contain metallic iron needles of the single domain or pseudo-single domain type (5).

Since VLS-type growth has probably occurred in many impact situations on the lunar surface, it may have been an important growth mechanism in the early accretionary history of the earth, especially before it acquired an appreciable oxidizing atmosphere, and on other planets.

JAMES L. CARTER
Institute for Geological Sciences, University of Texas at Dallas, Dallas 75230

References and Notes

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2. J. L. Carter, in *The Apollo 15 Lunar Samples*, J. W. Chamberlain and C. Watkins, Eds. (Lunar Science Institute, Houston, 1972), p. 51; in "Proceedings of the Fourth Lunar Science Conference," *Geochim. Cosmochim. Acta*, in press.
3. R. S. Wagner and W. C. Ellis, *Appl. Phys. Lett.* 4, 89 (1964); *Trans. AIME* 233, 1053 (1965).
4. I thank D. L. Crosthwait, Jr., of Texas Instruments Inc., Dallas, for introducing me to the concept of VLS-type growth.
5. D. J. Dunlop, in *Lunar Science IV*, J. W. Chamberlain and C. Watkins, Eds. (Lunar Science Institute, Houston, 1973), p. 193.
6. I thank D. S. McKay of the Lyndon Baines Johnson Space Center, Houston, Texas, for taking the high-magnification SEM photograph shown in Fig. 1D, and J. B. Toney for technical assistance. Supported by NASA grant NGR-44-004-116. Contribution No. 235 of the Institute for Geological Sciences, University of Texas at Dallas.

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Toxic Metal Fumes from Mantle-Type Camp Lanterns

Abstract. *The mantle of a gas lantern contains about 600 micrograms of toxic beryllium metal. Most of the beryllium is volatilized and becomes airborne during the first 15 minutes of use of a new mantle. The inhalation of this quantity of beryllium can be hazardous.*

The users of mantle-type lanterns, while familiar with the fire risks associated with them, may be unaware of another very serious hazard, namely, the emission of toxic fumes from the mantle. The mantle is made up almost entirely of the oxides of thorium (95 percent), magnesium, aluminum, cerium, beryllium, and silicon. It is the presence of beryllium which poses the greatest threat.

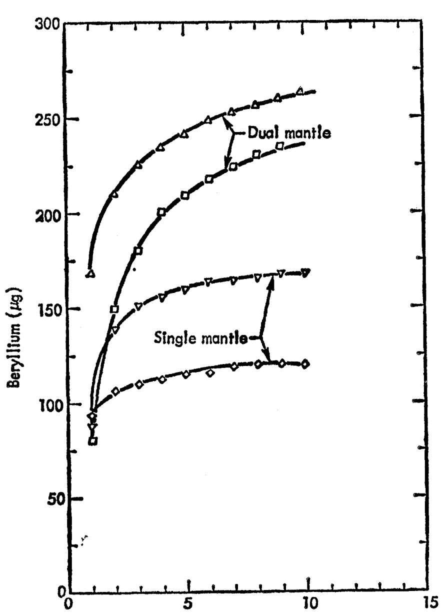

Fig. 1. A plot of airborne beryllium emission versus time for two single-mantle and two dual-mantle lanterns.

The results of an analysis of the beryllium content of eight new, unused mantles were reasonably consistent, with values ranging from 550 to 700 μg with an average content of 650 μg. After 1 hour's use in a lantern, the mantle residues were found to contain from 112 to 288 μg of beryllium, with an average content of about 200 μg. Most of the missing 400 μg of beryllium had volatilized and become airborne in the first 15 minutes of mantle use (see Table 1).

Another potential hazard arises from radioactive thorium (and its daughters), even though the mantles are in no way labeled to suggest the presence of radioactive elements. The thorium can emit from 150,000 to 300,000 alpha particles per minute. Although the thorium in the mantle does not appear to volatilize and become airborne during use, certain of the daughter products do. These products decay fairly rapidly.

It is useful to review some details of the construction and operation of these mantles. The mantle is prepared by dipping rayon fabric into a solution of the nitrates of thorium, cerium, and beryllium. Magnesium, aluminum, and silicon are also present in small quantities. The thorium is the material which incandesces when the mantle is heated to a high temperature. The cerium's function is possibly to improve upon the whiteness of this incandescence, and the beryllium is added to harden the delicate ashlike structure of the mantle. After drying, the mantle is coated with nitrocellulose to "fix" the salts to the fabric support material. The nitrocellulose also assists in the preburning of the mantle. Preburning is carried out with a match but in the absence of fuel to prepare the mantle for its initial use. This simple ignition is kindled by the combustible nitrocellulose coating and burns away the fabric support material, converting the thorium, cerium, and beryllium nitrates to their respective oxides.

I sampled the airborne beryllium content by placing the lantern in a transparent enclosure [2 cubic feet (0.056 m^3) in volume] that was open on the bottom and set over a honeycomb material to diffuse the incoming air. The chamber had an opening at the top through which air samples could be taken. Air was swept through the opening at the bottom of the container past the lantern so that any particles of beryllium in the air would be deposited on the paper in the sampler. This paper was then analyzed for beryllium by fluorometry or atomic absorption spectrophotometry, or both.

In two of these tests (tests 1 and 2, Table 1) the initial samples were taken during the preburning, during which smoke and soot are given off. I suspected that beryllium might be

Table 1. Airborne beryllium emissions from gas lanterns containing new, unused single mantles.

Sample time (cumulative) (minutes)	Beryllium collected (cumulative) (μg)	Condition
	Test 1	
30	1.25	No fuel
45	181	Fuel
66	189	Fuel
96	195	Fuel
126	198	Fuel
	Test 2	
5	0.25	No fuel
35	177	Fuel
66	182	Fuel
156	189	Fuel
	Test 3	
16	182	Fuel
32	196	Fuel
63	202	Fuel
93	205	Fuel
124	207	Fuel
155	209	Fuel
	Test 4	
33	157	Fuel
63	178	Fuel
94	183	Fuel
125	187	Fuel
175	191	Fuel