features, would destroy a 10-m crater that is initially 3 m deep in about 3 million years. On the assumption that the erosion rate slows up when all gradients have become low, such a crater would still remain visible for a longer period, but it would appear as a shallow crater with rounded profile.

It is not our purpose to discuss possible mechanisms for erosion, but only to discuss the evidence for its occurrence. However, since one is not inclined to accept even the strongest evidence when it points towards an inconceivable occurrence, it should be mentioned that we can see no reason to discard the suggestion of dust transportation downhill by the combined action of micrometeorites liberating particles from their surface adhesion and electrostatic effects opposing their immediate return to the surface. With this combination there would then be a tendency for grains to glide for some way, greatly enhancing the effective downhill creep beyond that which mere statistics of repeated random scattering would achieve (*4*).

It appears then that a few percent, perhaps 5, of the moon's surface has been covered with craters larger than 1 m in, say, 3 million years. From this, one may derive an order of magnitude of meteoritic infall rate, but not without an assumption regarding the surface structure and thus of the size of meteorite required for the formation of a crater of given size. In a loosely cemented dust surface of much less than the compact density, craters will be much larger for a given size of meteorite than they would be in solid rock. This difference will be largest for very small craters where structural strength rather than gravity determines the size, while for very large craters the difference will be reduced to that resulting from the density factor alone.

The fact that crater formation proceeds more readily than in solid rock is also displayed by the appearance of the multitude of small secondary craters seen in the Ranger pictures. There it is certain that impact speeds are low, well below lunar orbital speed. Nevertheless most of these are also circular or only slightly deformed. This must mean that the energy liberated even at speeds of less than 1 km per second is still enough to excavate a crater that is very large compared to the projectile. In rock or any firm material this would not be the case, and the craters would mostly appear as imprints of the shapes of the projectiles or scars torn by them. In softer materials the effects of any liberation of gas at impact would be more significant. More information about these effects could be obtained by attempting to create the general appearance of lunar secondary craters by means of various projectiles shot into different terrestrial surfaces.

The Ranger pictures thus appear to show mostly a uniform, fine-grained material of low structural strength near the surface and in the first few meters below the surface. They show no hint of any transition to a different material below, such as a change in the appearance of deeper craters or an occasional outcrop of something looking like rock. It is therefore most likely that one is seeing the same type of material at all the depths excavated by the craters, but very probably in progressively greater compaction and cementation at the greater depths.

The Ranger pictures have clearly strengthened the case for dust being the main constituent of the lunar lowlands by not showing any rock formations. There is no case for discussion of a two-layer model. What structural strength can be attributed to dust sedimentation at various depths cannot be judged very well until impact probe experiments have been carried out; but without any clear signs of firm rock the pictures must lead to more concern about sinkage on impact or dust blowing in rocket exhausts in future operations on the lunar surface.

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Plutonium Dioxide: Preparation of Single Crystals

Abstract. *Well-formed single crystals of plutonium dioxide were precipitated from a silicate glass and examined as an inclusion in a glass fiber drawn from the parent material. Excellent atomic scattering factors for* Pu^{+4} *may be obtained with these specimens.*

Single crystals are desirable for precise crystallographic studies. The usual technique for the preparation of single crystals from a fused sample is not readily adaptable to the isolation of plutonium dioxide because this oxide loses oxygen rapidly below its melting point (2400°C), whether in an inert atmosphere or under reduced pressure (*1*).

We prepared well formed single crystals of this compound by the unique method of precipitation from a silicate glass. Our co-workers (*2*) at Mound Laboratory determined that up to 20 percent plutonium dioxide could be dissolved in a simple silicate glass composed of 70 percent SiO_2 and 30 percent Na_2O by weight.

To form the single crystals we dissolved plutonium dioxide in excess of 20 percent by weight, in the simple sodium silicate glass. The molten glass containing the dissolved plutonium dioxide was rapidly cooled by pouring the melt on a steel plate. This cooling process resulted in the formation of homogeneous green glass beads. Although the glass was supersaturated with plutonium dioxide, it did not devitrify on cooling. We placed the plutonium-bearing glass beads in a platinum-rhodium bushing to draw glass fibers by the monofilament process. When we heated the bushing to 1300°C, plutonium dioxide crystals precipitated in the molten glass. As the glass fibers were drawn from the bushing, the crystals emerged completely encased in the fibers.

The crystal habit was that of hoppered cubes with perfect edges, some of which were up to 60 microns long. The crystals in the glass fibers were mounted for characterization by single-crystal x-ray diffraction techniques. We took a set of MoKα precession and CuKα Weissenberg photographs of a specimen with a 30-micron edge (Fig. 1). Analysis of the photographs revealed that the hoppered cube was a monocrystal and that the internal ordering was generally good. The back reflection pattern indicated only slight evidence of imperfections. The crystal was face-centered cubic, and its unit

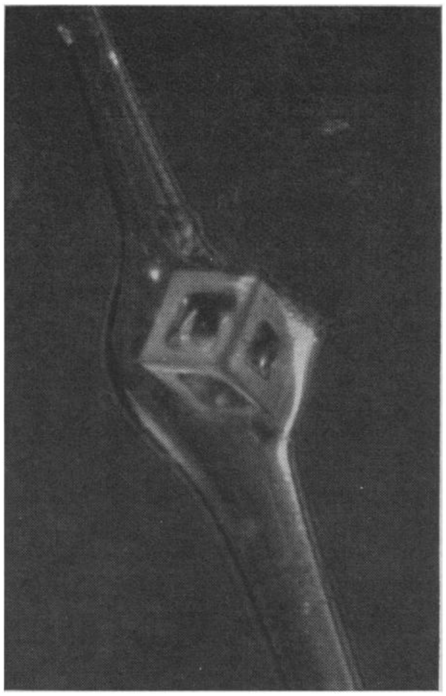

Fig. 1. A hoppered-cubic crystal of plutonium dioxide encased in the plutonium-bearing silicate glass.

cell edge a_0 was 5.397 Å, a value which compared favorably with the accepted lattice parameter for PuO_2, that is a_0 equal to 5.3960 Å (*3*). Because of this similarity in space group, *Fm*3*m*, and unit cell size, the crystal was identified as PuO_2, the apparent primary phase for the given composition.

The structure of PuO_2 has been established by powder diffraction techniques as being of the fluorite type, C 1 (*4*). With these single crystals of relatively simple habit and high internal symmetry, experimental atomic scattering factors for x-rays can be accurately calculated as Pu^{+4} as a function of the scattering angle (*5*). Roof (*6*) obtained such an experimental function from PuO_2 powder data, but no comparable single crystal values are available.

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Electron Microscopy of Meteoritic and Artificially Shocked Graphite

Abstract. *Samples of graphite, partly converted to diamond by shock, and meteoritic graphite were studied by transmission electron microscopy. The shocked graphite remained in the form of single crystals and was mildly deformed while the diamond which had formed was anhedral and polycrystalline. The meteoritic graphite contained minor amounts of troilite (FeS) and elemental sulfur but no detectable carbon phase other than graphite.*

As an adjunct to an x-ray crystallographic study of meteoritic diamonds (*1*) we have studied the morphology of the phases present in meteoritic graphite, and in graphite which has been artificially shocked at pressures high enough (300 kbar) to produce diamond (*2*).

Samples of the starting material, high-purity graphite (*3*), as well as the resulting shock-product, and graphite from the interior of a 1.1-g graphite nodule from the Canyon Diablo iron meteorite were crushed to 100 mesh. Slurries in ethanol were then placed in an ultrasonic generator for 5 minutes to disperse the sample uniformly. The suspensions were placed on Formvar, collodion, or carbon substrates for examination in a Hitachi HU-11 electron microscope. Phases were identified by electron diffraction of selected areas with gold and palladium as standards.

Figure 1*a* shows a typical graphite-diamond intergrowth from the artificially shocked graphite. All of the diamonds formed in this manner were anhedral and polycrystalline. The graphite flakes seemed mildly deformed although they remained single crystals. Figure 1*b* shows a typical graphite flake from the starting material.

In both the starting material and shock product the only other phase that we found was in the form of euhedral cubes (Fig. 2) which were single crystals of uncertain origin. The cell dimension of these simple cubic crystals (a_0 = 5.55 Å) corresponds very closely to that of the "carbon II" phase (a_0 = 5.545 Å) reported by Aust and Drickamer (*4*). Inasmuch as the cubes were present in very small numbers (<<1 percent) in both the starting material and product we cannot say that they were produced by shock or, in fact, that they were composed of carbon. It seems very unlikely that some extraneous material would possess exactly the same cell dimension and crystallographic habit as "carbon II". Yet the cubes' euhedral appearance, the general perfection of these crystals, and their low abundance suggest that they were contaminants and not shock-formed. It could also be that these cubes were, indeed, "carbon II" which had grown relatively slowly during preparation of the original artificial graphite block. Unfortunately, all three alternatives (contamination, shock-formation, or slow growth) seem equally unlikely and it is impossible to decide among them with the available data.

The anhedral morphology of the artificial diamond might be expected from the short time available for crystal growth under the experimental shock conditions. Shocks generated

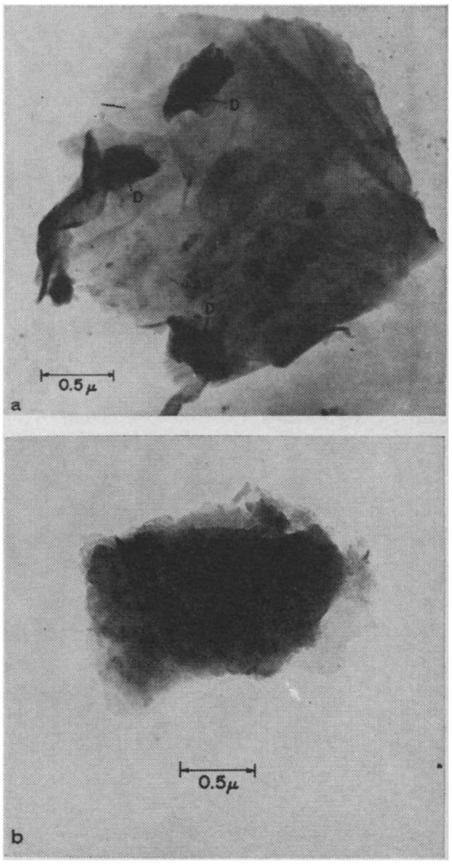

Fig. 1. (*a*) Diamond-graphite intergrowth in artificially shocked graphite. Note the anhedral morphology of the larger diamond grains (*D*). (*b*) Typical flake from the graphite starting material. The texture of this flake may be compared with that of the untransformed graphite in (*a*).