Reports

Blowing of Lunar Soil by Apollo 12: Surveyor 3 Evidence

Abstract. *Analysis of discoloration patterns on the camera of the spacecraft Surveyor 3, after the Apollo 12 lunar module landed nearby, indicates that lunar surface particles were eroded and entrained by lunar module exhaust during the landing and were ejected almost horizontally at 70 meters per second or faster. These particles struck the Surveyor camera and whitened its surface.*

Surveyor 3 landed on the moon on 20 April 1967. Thirty-one months later, on 20 November 1969, it was visited by Apollo 12 astronauts Charles Conrad and Alan Bean. They immediately noticed that the color of the spacecraft had changed: white surfaces had become tan. This had been predicted (*1*) prior to the Apollo 12 flight, as an effect of solar ultraviolet radiation on the Surveyor white paint.

Astronauts Conrad and Bean removed the television camera from Surveyor 3 and brought it back to Earth. Ground examination showed that the surfaces that had originally been painted white showed patterns of discoloration. Some of the darker markings strongly resembled burnt-in permanent shadows of objects attached to the camera. For example, in Fig. 1 a dark marking on the painted surface looks very much like a shadow cast by the adjacent wire. The position of these dark markings remains constant, however, independent of the lighting angle. The direction from which the "shadows" were thrown was approximately that of the Apollo lunar module (LM) (*2*).

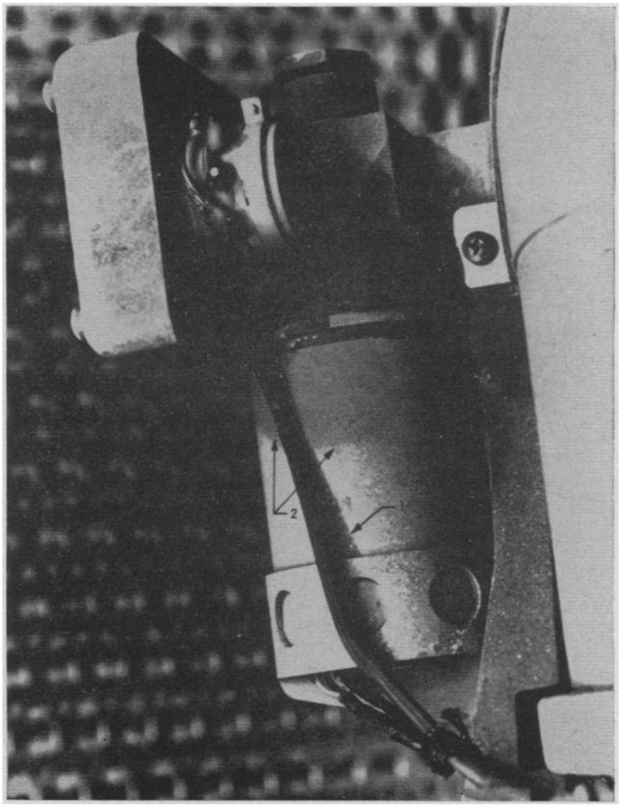

Fig. 1. Housing of Surveyor 3 television camera [NASA photograph; contrast enhanced photographically]. (1) "Permanent shadow" cast by adjacent wire (wire has been moved). (2) "Permanent shadow" cast by rectangular cover of the elevation drive train (upper left) onto cylindrical motor housing (at center). "Shadow" covers approximately the upper one-third of the cylindrical portion (arrows). "Shadow" of the lower left corner of the cover falls on the wire.

When I examined the camera, it seemed to me that the dark upper portion of the cylindrical motor housing in the center of Fig. 1 corresponded in outline to a permanent shadow cast by the rectangular cover of the elevation drive train (top left of Fig. 1). This observation was confirmed by viewing the camera from a distance, along the proper direction. The permanent shadow of the lower outboard corner of the housing falls on the wire. The distance from the corner to its permanent shadow is about 4 cm.

With a theodolite it was possible to align visually the outboard side edge and outboard bottom edge of the cover with the case shadow and to determine the direction of the "ray" casting the shadow. Two sets of measurements gave, for the direction in Surveyor camera coordinates: azimuth, 90.0° ± 1.0°; elevation, 28.7° ± 0.5°.

The lunar directions are obtained by use of the appropriate coordinate transformation: bearing, 46.8° ± 0.8° west of north; zenith angle, 88.2° ± 0.9°. [This transformation takes into account both the camera orientation during Surveyor operations (*3, 4*) and subsequent rotation caused by sagging of the landing gear (*5*).]

Various reports (*6–9*) of the landed positions of Surveyor 3 and of the Apollo 12 LM, in the same coordinate system, are discrepant to the extent of about 10 m in their relative positions. By what appear to be the latest determinations (*7, 9*), a line through the Surveyor camera at the bearing and zenith angles derived above passes 3 ± 3 m horizontally and 1 ± 2 m vertically from the point on the lunar surface directly under the center of the LM. (This point is 155 m away and 4.3 m higher than the Surveyor camera.) The agreement is well within the discrepancies mentioned. Evidently the discoloration pattern measured on the Surveyor camera was produced by the Apollo LM, when the LM was very close to its surface position. In areas within line of sight of the LM, the Surveyor surface was whitened. When the Surveyor camera was inspected under a microscope by Cour-Palais (*2*), a number of shallow white craters were noted, predominantly on the side toward the LM; he attributed the surface whitening to these craters, and the craters to sandblasting by lunar particles ejected by LM exhaust during its landing.

To reach the Surveyor camera in a ballistic trajectory from the lunar surface directly below the LM, and to arrive with the zenith angle mentioned above, requires a particle velocity of 70 m/sec or greater and an emission angle at or slightly below the horizontal.

It is true that particles entrained by LM exhaust would not initially follow a ballistic trajectory, but this is probably a good approximation away from the LM. The sharpness of the "permanent shadows" on the Surveyor camera shows that the incident particles were well collimated.

Thus, the discoloration pattern on the Surveyor 3 camera not only provides excellent evidence that the camera surface was whitened by the impact of particles blown from the lunar surface by the exhaust of the LM as it landed but also indicates the velocity and direction at which these particles were ejected. Many of the lunar particles moved at very low angles to the horizontal.

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References and Notes

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10. I thank J. J. Rennilson for providing the transformation matrix relating Surveyor 3 camera coordinates to lunar coordinates and for other aid, and W. F. Carroll for helpful discussions. This report presents the results of one phase of research carried out at Jet Propulsion Laboratory under NASA contract NAS 7-100.

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Solvent Dependence of the Luminescence of N-Arylaminonaphthalenesulfonates

Abstract. N-*Methyl,*N-*phenyl-2-aminonaphthalene-6-sulfonate, a fluorescence probe, adsorbs to cycloheptaamylose with a stoichiometry of 1 : 1. The fluorescence of the complex is similar to that observed when the dye is dissolved in organic solvents. Similar fluorescence is observed with the dye in ice. The results are interpreted in terms of "solvent" relaxation during the excited state lifetime of the dye.*

Since the observation by Weber and Laurence (*1*) that *N*-arylaminonapthalenesulfonate dyes adsorb to bovine serum albumin with fluorescence enhancement, these dyes have been shown to adsorb to functionally important sites on several proteins (*2*). In addition they have been used in studies of nerves (*3*) and mitochondrial membranes (*4*). The fluorescence quantum yields of these compounds are low in polar solvents. When they are dissolved in nonpolar solvents or adsorbed to proteins, their quantum yields and average energies of fluorescence increase and the half-maximum bandwidths of emission decrease (*5–7*). Because the spectroscopic properties of these dyes adsorbed to proteins mimic those in nonpolar solvents, they have been used as probes for hydrophobic regions in protein molecules.

In homogeneous solutions, the fluorescence of these dyes reflect the polarity of the solvent (*5–7*). The question arises, however, to what extent the heterogeneous character of a protein or a membrane surface may be approximated by the homogeneous solvents in which the spectral characteristics of the chromophores have been investigated.

Cycloheptaamylose forms complexes with a variety of organic compounds (*8*). In the case of *N*-methyl,*N*-phenyl-2-aminonaphthalene-6-sulfonate, the interaction is indicated by a large increase in the quantum yield of fluorescence and a blue shift in the emission maximum. The fluorescence spectrum of the complex is shown in Fig. 1 and may be contrasted with the low fluorescence shown in water. The change of the fluorescence quantum yield was used to determine the stoichiometry and affinity between the dye and the sugar. A Scatchard (*9*) analysis indicated that one dye molecule bound to one sugar molecule with a Gibbs free energy of −6 kcal/mole.

The structure of cycloheptaamylose is well known (*8*) and shows the presence of hydroxyl groups both in the cavity and on the outside of the cyclic sugar. Thus while the sugar surface may be less polar than water, it does not represent what a protein chemist would usually refer to as a hydrophobic region.

The fluorescence emission spectra of *N*-methyl,*N*-phenyl-2-aminonaphthalene-6-sulfonate in ice is also shown in Fig. 1. This spectrum was taken at a dye concentration where no concentration dependence of the emission energy was observed. In the case of ice the dye is certainly surrounded by polar molecules. The fluorescence properties of this dye in water, ice, and in the presence of cycloheptaamylose are summarized in Table 1.

We have observed that when dyes of this type are adsorbed to silica gel or when they are in a crystalline state, their fluorescence spectra are similar to those observed when the dyes are dissolved in nonpolar solvents. The fluorescence of a *hydrated* crystal of *N*-(*p*-tolyl)-2-aminonaphthalene-6-sulfonate has been reported (*10*) and showed an emission similar to that observed in fluid *polar* solvents.

We have recently investigated a series of fourteen 2,6-substituted aminonaphthalenesulfonates (*7, 11*). From the absorption and fluorescence spectra in various liquid solvents and the acid-base dependence of the spectra, we concluded that the lowest energy singlet-singlet transitions of these molecules contain significant intramolecular charge-transfer character of the type

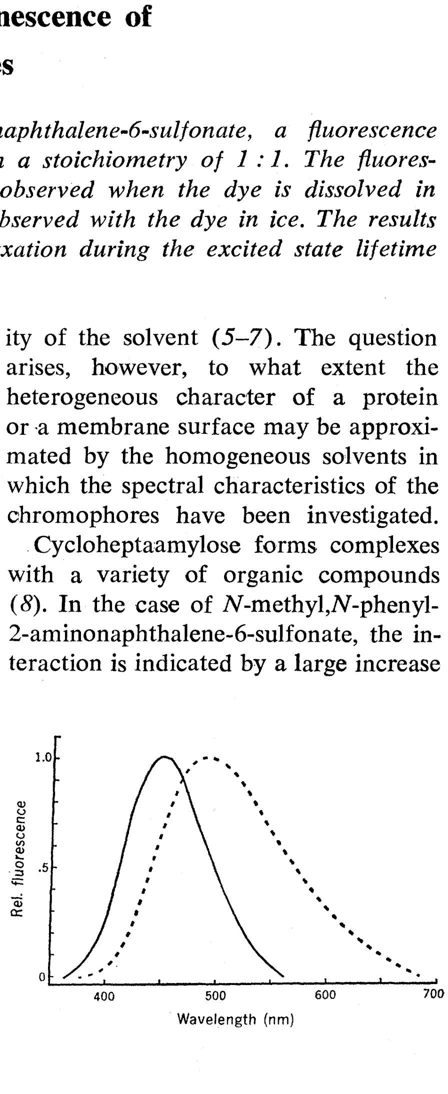

Fig. 1. Normalized fluorescence emission spectra of *N*-methyl,*N*-phenyl-2-aminonaphthalene-6-sulfonate in ice (solid curve) and adsorbed on cycloheptaamylose (dashed curve). The dashed curve was obtained from a solution containing 8.52 × $10^{-6}M$ *N*-methyl,*N*-phenyl-2-aminonaphthalene-6-sulfonate and 1.50 × $10^{-3}M$ cycloheptaamylose.