more systematic pattern of deuterium concentration than do individual storm samples because the snowpack integrates the entire season's snowfall.

On the basis of this study, plus theoretical considerations, we suspect that differences in the isotopic composition of snow cores collected annually at the same place will show differences that may be used as a rapid means of characterizing the climate of the entire winter relative to the winter climate of other years.

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References and Notes

1. I. Friedman, A. C. Redfield, B. Schoen, J. Harris, *Rev. Geophys.* **2**, 177 (1964).
2. W. Dansgaard, *Tellus* **16**, 436 (1964).
3. I. Friedman, L. Machta, R. Soller, *J. Geophys. Res.* **67**, 2761 (1962); A. H. Woodcock, and I. Friedman, *ibid.* **68**, 4477 (1963).
4. It should be noted that some drainage divides in the Sierra Nevada lie east of the ridges that exert the most influence on precipitation patterns and storm tracks.
5. We thank K. Hardcastle and J. Gleason, both of the U.S. Geological Survey, for their aid in carrying out the deuterium analysis; H. Klieforth of the Desert Research Institute in Reno for the snow samples and for his stimulating discussions and help in understanding the climatology of the Sierra Nevada; V. Lemons of the California Department of Water Resources; and agencies and individuals (including J. Harmoning, O. Evans, C. Horton, J. Birchim, A. Miller, D. McAndrews, D. Rhodes, M. Stewart, Jr., H. Evans, R. Leake, Jr., and H. Cammack) participating in the California Cooperative Snow Surveys who collected samples for us.

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Apollo 11: Exposure of Lower Animals to Lunar Material

Abstract. *Lunar material returned from the first manned landing on the moon was assayed for the presence of replicating agents possibly harmful to life on earth. Ten species of lower animals were exposed to lunar material for 28 days. No pathological effects attributable to contact with lunar material were detected.*

Astronauts Armstrong, Aldrin, and Collins collected samples of lunar material on Apollo 11 mission and returned these samples to earth on 24 July 1969. Described here are the results of exposing selected species of fish and invertebrates to representative samples of lunar material for 28 days. The pooled sample used for the biological tests was composed of approximately 50 percent glass or glasslike material, contained from 0 to 10 parts per million (ppm) of indigenous organic material, and was free of water (*1*). Other tests revealed this sample to be only slightly soluble (about 2 ppm) in water.

Tests were designed to detect extraterrestrial replicating agents possibly harmful to life on earth (*2*). No pathological effects or evidence of the presence of replicating organisms were detected in any of the exposed experimental animals. Neither daily observations of general health nor periodic histopathological examinations revealed deleterious effects attributable to contact with, or ingestion of, lunar material. Microscopic examination of the lunar sample utilized in these studies revealed that much of the lunar material was in the form of tiny beads. Ingestion of this material by the various species did not result in abrasion of the epithelial lining of the gastrointestinal tract.

The lunar material used in these studies was a portion of the pooled conventional sample (consisting of surface fines and rocks) that had been ground to a mean particle size of 2 μm. One-half of each sample was sterilized with dry heat at 160°C for 16 hours at ambient pressure before use.

Animals of ten species selected for exposure to lunar material were maintained in class III glove cabinets inside the biological barrier system at the Lunar Receiving Laboratory. Optimum temperatures, photoperiods, feed, containers, and substrates were provided for each species to the extent possible.

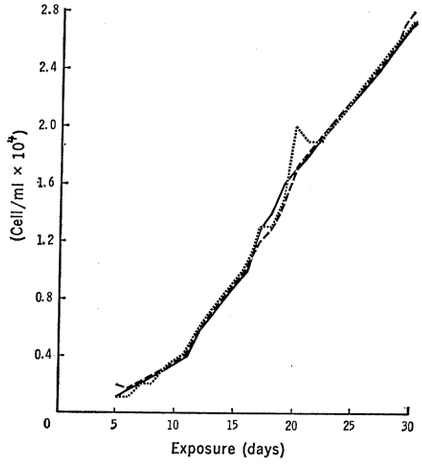

Fig. 1. Population growth in *Euglena gracilis*. Solid line, lunar sample; dashed line, sterilized lunar sample; dotted line, control.

Each species, with the exception of the protozoa and planaria, were divided into four test groups. At the time of inoculation, all test and control animals had been acclimated to the cabinet environment for as long as 2 weeks where appropriate. One group was inoculated with unsterilized material; a second group was inoculated with sterilized material; a third group was maintained within the cabinetry as an uninoculated control; and the fourth group was maintained in the normal animal colony as a cabinetry environment control group.

Because of differences in cultural methods for aquatic and terrestrial species, the methods of providing exposure to the lunar samples differed (Table 1). The seven aquatic species were exposed by adding lunar material to the medium in which the animals were living. The three insect species were exposed by mixing the samples with their food.

Exposure of *Euglena gracilis* (Fig. 1) and *Paramecium aurelia* to lunar material did not affect their growth rates. During the first 3 days after exposure, the activity of exposed protozoans was subjectively judged to be less than that of the control cultures. Subsequently, locomotion by both species, the avoidance response in the *Paramecium*, and metaboly in the *Euglena* were judged to be normal. Permanent slides were prepared from samples collected on day 14 and day 28. Examination with the light microscope revealed no gross morphological changes.

No mortality or morphological changes occurred in any of the groups of planaria (*Dugesia dorotocephala*). For reasons that remain unknown, the animals in the fingerbowl inoculated with heat-sterilized lunar material traveled at the water surface more frequently than the animals in either of the other groups.

Daily observation and histopathological examination of German cockroaches (*Blattella germanica*) at 1 and 3 weeks showed these insects to be in excellent condition throughout the exposure period. The symbiotic bacteria in the fat bodies and ovaries were present in the normal distribution and abundance, and the gut lining (Fig. 2) was not abraded by the lunar material. There was also an apparent slight acceleration of the development of exposed cockroaches as compared with the control groups, which further indicated the lack of ill effects. However, these developmental differences were not statistically significant.

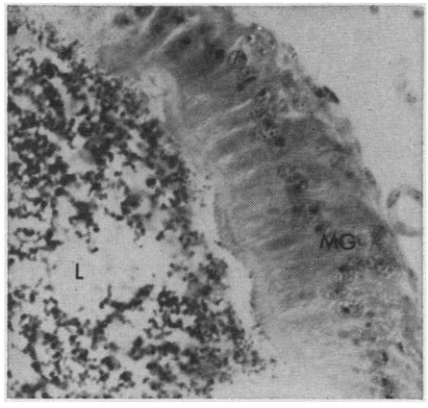

Fig. 2. Midgut epithelium (*MG*) of German cockroach with no evidence of abrasion by lunar material (*L*) in lumen.

Neither gross nor histopathological changes were detected in either the larval or the adult house flies (*Musca domestica*) exposed to lunar material. Several specimens from each group were killed after exposure for examination by both light and electron microscopy. No deleterious effects were found.

The response of greater wax moth (*Galleria mellonella*) larvae to lunar material in their diet was essentially the same as that of the other insects. Gross observations and histopathological findings showed the insects to be normal. Slightly higher survival ratios occurred in the lots exposed to lunar material, but these differences were not statistically significant.

Severe mortality occurred in all groups of oysters (*Crassostrea virginica*). Deaths may have been due to the fact that the test was conducted during the spawning season and the animals' condition was poor. No unusual microorganisms or histopathological changes were detected in tissue sections prepared from control oysters or from those exposed to lunar samples. These histological examinations included oysters that became moribund or died during the 28-day exposure as well as the ten survivors killed and examined at the end of the test. Five of the survivors had been exposed to unsterile lunar material. Oysters from all groups were emaciated and completely "spawned out." There were no indications that exposure to lunar material was responsible for the high mortality.

Brown shrimp *Penaeus aztecus* exposed to the lunar samples showed no abnormal behavior or mortality. All body tissues were healthy, and the shrimp in all groups were in excellent physical condition throughout the test.

The fathead minnow *Pimephales promelas* is quite sensitive to toxic agents. Six days before exposure to lunar material, a spill of sodium hypochlorite in the laboratory caused the loss of approximately 50 percent of the fathead minnows being acclimated. Dead fish were replaced, but slight losses continued throughout the test. At day 14 and day 28 of the exposure period, histopathological examination of these specimens showed no indication of

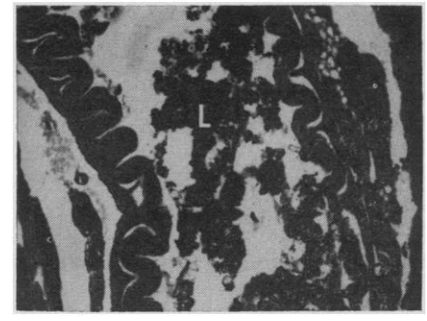

Fig. 3. Cross section of intestine of fathead minnow with no pathological effects caused by ingested lunar material (*L*) in lumen.

pathologic changes associated with their exposure to lunar material (Fig. 3). Residual pathology, which apparently represented long-term changes created by the hypochlorite spill, was noted in the gill tissues of some individual fish.

No pathologic changes of an unknown or unidentifiable character were noted during daily observation of behavioral and morphological features in the mummichog *Fundulus heteroclitus*. This marine minnow appeared to be especially hardy, and exposed groups appeared to be unaffected by the presence of the lunar material or by the spill of sodium hypochlorite in the laboratory. Histopathological examinations of sampled mummichogs at 14 and 28 days indicated that these fish were in excellent condition.

The nature of the lunar samples to

Table 1. Test facilities, environmental conditions, and lunar sample inoculation data.

Organism	Type of container	Number of containers per test group	Number of animals per container	Total containers	Diet	Medium	Photoperiod (hours light/hours dark)	Temperature (°C)	0.220 g lunar material per:
Euglena	250-ml flask	16	1.0×10^3 to 2.8×10^4	48	Provided by medium	Inorganic medium	16/8	22	Flask
Paramecium	125-ml flask	25	1.0×10^3 to 1.6×10^4	75	*Aerobacter aerogenes*	Lettuce leaf infusion	16/8	22	Flask
Planaria	300-ml fingerbowl	1	50	3	Calf liver	Aged tap water	16/8	22	Bowl*
Brown shrimp	20-liter aquarium	2	20	8	Live brine shrimp	Seawater 25 ppt	16/8	27	Shrimp
Oyster	1-liter jar	10	1	40	None	Instant ocean 21 ppt	16/8	22	Oyster
German cockroach	500-ml jar	3/3†	20/15	9/9	Mouse diet‡		16/8	25	Jar
House fly	500-ml jar	3/2§	25/25	9/6	Compounded diet ||		16/8	25	Jar
Greater wax moth	500-ml jar	3	25	9	Compounded diet ¶		Total darkness	25	Jar
Fathead minnow	20-liter aquarium	2	20	8	Live brine shrimp	Aged tap water	16/8	22	Fish
Mummichog	20-liter aquarium	2	20	8	Live brine shrimp	Instant ocean 21 ppt	16/8	22	Fish

* 3.30 g per bowl. † Nymphs/adults. ‡ Charles River prefortified rat-mouse diet. § Larvae/adults. || Sugar, albumen, sodium oleate, Wesson salts, B vitamins. ¶ Pablum, sugar, glycerol, water, B vitamins.

which the fish and invertebrates were exposed is probably the major factor responsible for the uniformly negative results that were obtained in this testing program. The inertness and associated insolubility, discovered in chemical and physical tests, was clearly of major significance.

A physical difference was noted between the sterilized and unsterilized lunar samples when these materials were added to the aquatic environment. Unsterilized lunar material was easily wetted and sank immediately to the bottom of the container. The dry, heat-sterilized material was cohesive and hydrophobic and required considerable stirring to suspend it in the water. Earth soils similarly sterilized react in the same way.

The results of these tests provided no information that would indicate that the lunar samples returned by the Apollo 11 mission contained replicating agents hazardous to life on earth. The lunar rocks and fines were released from quarantine on 12 September 1969 for further investigation.

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References and Notes

1. Lunar Sample Preliminary Examination Team, *Science* **165**, 1211 (1969).
2. W. W. Kemmerer, Jr., J. A. Mason, B. C. Wooley, *Bioscience* **19(8)**, 712 (1969).

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Jupiter's Clouds: Structure and Composition

Abstract. *Recent infrared radiometric observations of Jupiter have disclosed local temperatures in the North Equatorial Belt far in excess of those at the level of the solid ammonia clouds, and visual observations reveal an orange-brown coloration within this belt. We suggest that, in a multilayer cloud model, solar ultraviolet photolysis of hydrogen sulfide in regions where ammonia clouds are sparse or absent should lead to the production of substantial quantities of inorganic chromophores.*

As a result of a study of the chemistry of Jupiter's atmosphere, Lewis (*1*) has suggested that distinct cloud layers other than the well-known solid NH_3 clouds should be found at lower altitudes. He particularly emphasized the importance of a layer of NH_4HS clouds with maximum density at the 229°K level, and clouds composed of aqueous NH_3 solution with maximum density near the 309°K level. Calculations of cloud masses and structures for a model of Jupiter characterized by a solar composition and wet adiabatic equilibrium suggested that the NH_3 cloud layer may be partially transparent.

Recently Jupiter's North Equatorial Belt (NEB) has changed color to a distinct orange-brown, and infrared emission measurements made by Gillett *et al.* (*2*) at 5 μ have disclosed a temperature of 225°K for this belt. Some local breaks in this uniform cloud layer have also been detected, within which, according to Westphal (*3*), emission measurements at 5 μ have disclosed brightness temperatures up to 310°K.

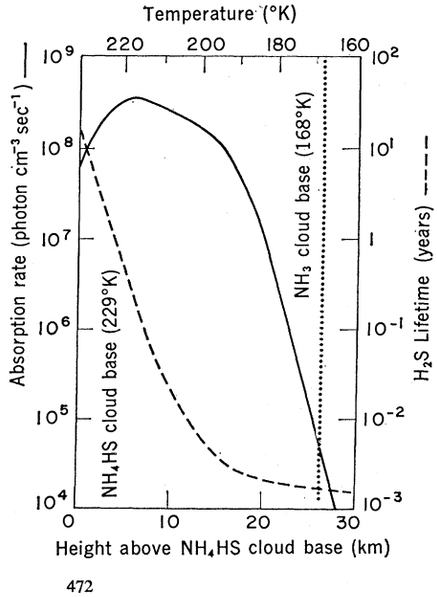

Fig. 1. Rate of solar ultraviolet photolysis of H_2S and H_2S lifetimes in the atmosphere of Jupiter. The solid curve gives the rate of photolysis as a function of height above the NH_4HS cloud layer for a model in which the H_2S vapor density is determined by the dissociation equilibrium of solid NH_4HS. The dashed curve gives the lifetime of this amount of H_2S in the presence of normally incident solar ultraviolet flux. The atmosphere must undergo convective overturn on a time scale shorter than this lifetime in order that significant amounts of H_2S may be present at a given altitude. For a convection time scale of ~1 year essentially no H_2S will be present above the 220°K level.

It has been suggested independently by Owen (*4*) and by Lewis that these NH_4HS clouds might contain the yellow-orange solid $(NH_4)_2S$, but the available thermodynamic data on $(NH_4)_2S$ are insufficient to permit one to decide whether or not it might be stable. Also, the yellow color of laboratory-synthesized $(NH_4)_2S$ is due entirely to the oxidation by atmospheric oxygen of sulfide to elemental sulfur; the colored product is in fact ammonium polysulfide, $(NH_4)_2S_x$. An appropriate chemical oxidizing agent is surely absent on Jupiter.

Wildt (*5*), however, pointed out long ago that gaseous H_2S will readily undergo photolysis by solar ultraviolet radiation to produce free sulfur. This photolytic oxidation obviates the necessity for free oxygen.

To investigate the feasibility of the solar ultraviolet photolysis of H_2S, we have carried out a calculation for the case where the NH_3 cloud cover is optically very thin or absent. We have used a scattering phase function

$$\Phi(Y) = 1 + a_1 \cos(Y)$$

as discussed by Chandrasekhar (*6*) and Sobolev (*7*), where a_1 is the forward-scattering parameter and Y is the scattering angle, to solve the equation of radiative transfer for a semi-infinite absorbing and scattering atmosphere composed of plane parallel layers, with normal incidence of solar radiation. We have obtained the total radiation intensity and hence the total absorption rate of the absorbing gases H_2, He, CH_4, NH_3, and H_2S as a function of depth in the atmosphere. Such calculations by Prinn (*8*) have shown that the solar flux shortward of 2200 Å is totally absorbed by H_2, He, CH_4, and NH_3 before it reaches the NH_3 cloud level. We have considered here only the radiation from 2200 to 2700 Å, the latter being the long-wavelength absorption limit for H_2S. In this spectral region H_2, He, and CH_4 do not absorb, NH_3 absorbs a little (*9*), and H_2S absorbs considerably (*10*). The Rayleigh scattering cross sections used