# Reports

## Deuterium Content of Snow Cores from Sierra Nevada Area

Abstract. *The relative deuterium content was measured on 37 snow cores collected in April 1969 in the Sierra Nevada. The deuterium content varies inversely with altitude of collection (approximately 40 per mil per 1000 meters) but is unrelated to latitude. The altitude relationship is particularly well defined west of the crest of the range but is not well defined east of the crest. However, samples from east of the crest tend to be depleted by about 10 to 15 per mil relative to samples collected at the same elevation west of the crest. We propose that the deuterium content of snow cores, collected so as to include the total winter's precipitation, can be used as a climatic indicator to compare the climate of one winter with that of another.*

This report is a result of a larger study concerned with deuterium variations in precipitation of the Sierra Nevada as an index to the present climatic regime. Deuterium (D), the isotope of hydrogen with a molecular weight twice that of ordinary hydrogen (H), occurs on an average in a ratio of about one atom of D to every 6700 atoms of H. It is known from previous studies (*1*, *2*), however, that the deuterium concentration in rain, snow, and hail varies from place to place. These variations are attributed chiefly to the history of isotopic fractionations that occurred during changes in state of $H_2O$ between vapor, liquid, and solid. In general, the extent of fractionation is controlled by the following factors:

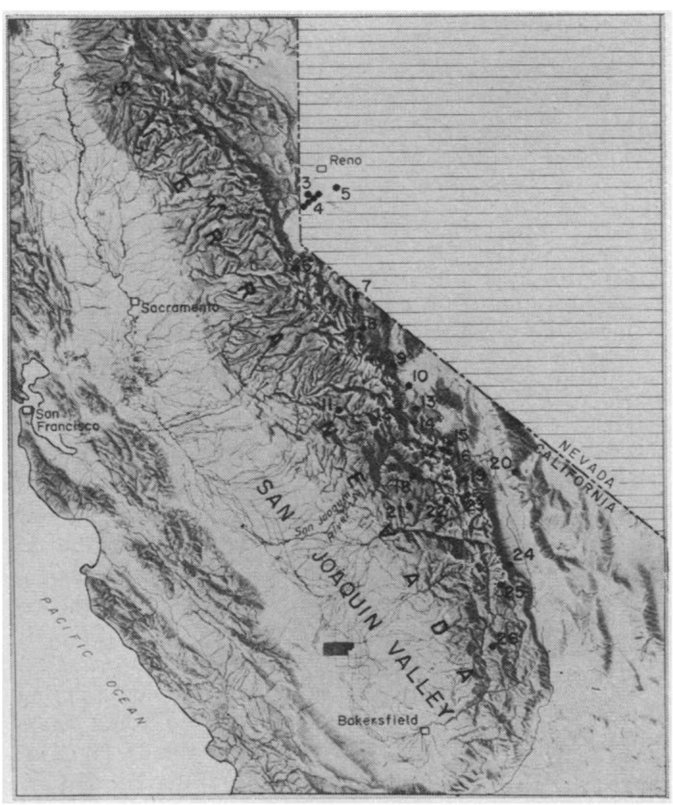
1) The temperature at which evaporation originally occurred.

2) The history of the storm between the time it leaves the ocean and the time condensation occurred.

3) The temperature at which condensation occurred in the air mass.

4) The evaporation and exchange that occurred between the time the moisture was precipitated and the time it was collected at the ground.

Most winter storms reaching the area of our study originate in the same parts of the Pacific, and thus temperature of evaporation (factor 1) is fairly constant. Variations in the conditions represented by factors 2, 3, and 4 are therefore most likely to explain the differences in deuterium content that occur from one storm to the next and between one place and the next.



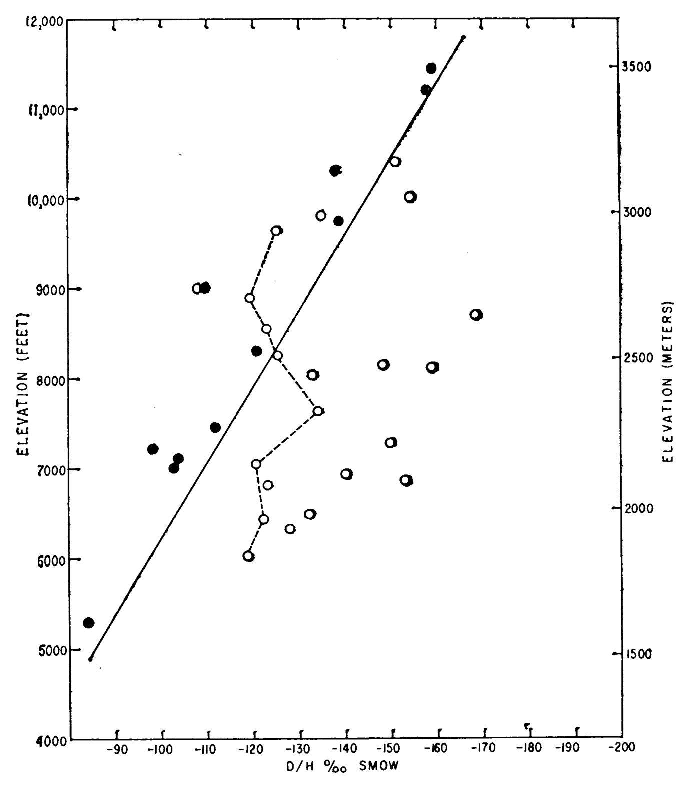




Fig. 1 (left). Index map of central California showing locations of sample sites: 1, Mount Dyer No. 1; 2, Blue Canyon; 3, Mount Rose; 4, Mount Rose profile (eight stations); 5, Geiger Grade; 6, Echo Summit; 7, Monitor Pass Road; 8, Sonora Junction; 9, Conway Summit; 10, Mono Craters; 11, Gin Flat; 12, Gem Pass; 13, Deadman Summit; 14, Mammoth Midstation; 15, Rock Creek No. 1; 16, Rock Creek No. 3; 17, Mono Pass; 18, Badger Flat; 19, Bishop Creek; 20, Westgard Pass; 21, Fred Meadow; 22, Blackcap Basin; 23, Bishop Pass; 24, Whitney Portal Road; 25, Big Whitney Meadow; 26, Round Meadow. Fig. 2 (right). Relation between elevation and deuterium content of snow cores collected on or about 1 April 1969. Filled circles, samples collected west of the Sierra Nevada drainage divide; open circles, samples collected east of the divide. Solid line parallels the trend indicated by the filled circles and separates them from most of the open circles. Dashed line connects values from Mount Rose profile cores. Radius of circles is experimental uncertainty (±1 per mil).

While a storm is being generated and moving over ocean areas, isotopic equilibrium is approached between the moisture that is added to the air mass by continued evaporation and the moisture that is lost by precipitation. However, once the mass leaves the ocean, it begins to lose deuterium, which is preferentially concentrated in the rain or snow that is left behind. The longer the storm trajectory is prior to reaching a given station, the greater is the depletion of deuterium in the air mass and the lower is its concentration in precipitation.

The temperature at which condensation occurs in an air mass (factor 3) is a function of many meteorological parameters; it generally varies from storm to storm, as well as during a single storm.

The evaporation and exchange that occur during the falling of raindrops from a cloud (*3*) and between the time they reach the ground and the time they are collected (factor 4) introduce many variables that are difficult to evaluate. However, snow and hail do not evaporate to a significant extent, nor do they exchange with water vapor during their fall; thus they preserve a better record than rain of the isotopic composition of the moisture in the air mass at the time of condensation. The deuterium concentration of snow therefore reflects quite accurately the concentration in the moisture of the storm-producing air masses at the time they reached a given station.

Snow cores that effectively integrate the winter's snowpack at 34 sites were collected. All but five of the 37 samples were collected within a few days of 1 April 1969, and thus they represent a composite of almost the entire winter's accumulation of snow at these sites. One sample was collected from the Mammoth Midstation on 21 April but is here considered as part of the 1 April suite. Four cores were collected along the Mount Rose profile on 30 April for comparison with earlier samples.

The snow cores were emptied into large plastic bags, the tops of the bags were tied securely to prevent evaporation, and the snow slowly melted. At all stages, care was taken to prevent any evaporation or contamination of the samples. Deuterium analyses were made by techniques previously described (*1*).

All deuterium values are given as D/H ratios in per mil of standard mean ocean water (SMOW): a value of −100 indicates that the sample has 100 per mil (10 percent) less deuterium than does a sample of SMOW. All laboratory results are precise to ±1 per mil.

The sample localities are plotted in Fig. 1. The results of the analyses of 1 April cores are given in Table 1 and are plotted in Figs. 2 and 3. In Fig. 2 we have plotted deuterium concentration of these snow cores against the altitude at the collection point. For samples collected west of the Sierra Nevada divide, there is a clear relation between the deuterium concentration and the altitude of collection; samples collected at the lowest elevations have 75 per mil more deuterium than samples collected at the highest elevations. The trend, which is parallel to the solid line shown on Fig. 2, has a slope such that there is a decrease of approximately 40 per mil deuterium for each thousand meters of increased elevation. However, samples from areas east of the divide, including the eight samples from the Mount Rose profile (locality 4, Fig. 1; connected in Fig. 2 by a dashed line), suggest only a vague relation between deuterium content and altitude. This result may be attributable to much additional turbulence created as the air masses moved across the highly irregular Sierra Nevada crest; this turbulence destroyed the relatively systematic relation between isotopic ratios and altitude indicated by samples from the west slope.

It is doubtful that the altitude-deuterium relation found on the west side is due to a longer period of melting and refreezing for the samples from lower altitudes. The extent and nature of changes in the deuterium content of a snowpack due to poststorm recrystallization are illustrated by data in Table 1. Three of the stations (A-2, C-1, and G) on Mount Rose that were cored during the 1 April survey were cored again about 1 month later; the D/H ratios indicate increases in deuterium of 1, 5, and 8 per mil, respectively. Part of the observed increase in deuterium is due to new snow that fell during storms from 5 to 6 April and from 22 to 24 April; samples of the 22 to 24 April storm (the larger of the two) from stations G, N, and O on Mount Rose were notably high in deuterium for that area (D/H

Table 1. Sample localities, collection data, and D/H ratios of snow samples collected on or about 1 April 1969 (arranged in order of decreasing elevation). Numbers in parentheses after station names in the first column refer to the California snow courses.

| Station name | Elevation | | Latitude (N) | Longitude (W) | Average snow depth (cm) | D/H (‰ SMOW) |
|---|---|---|---|---|---|---|
| | Feet | Meters | | | | |
| Mono Pass (182) | 11,450 | 3,490 | 37°26.3′ | 118°46.4′ | 401 | −159 |
| Bishop Pass (222) | 11,200 | 3,415 | 37° 6.0′ | 118°33.4′ | 449 | −158 |
| Gem Pass (281) | 10,400 | 3,170 | 37°46.8′ | 119°10.2′ | 391 | −151 |
| Blackcap Basin (223) | 10,300 | 3,140 | 37° 4.0′ | 118°46.2′ | 397 | −138 |
| Rock Creek No. 3 (209) | 10,000 | 3,050 | 37°27.0′ | 118°44.5′ | 247 | −154 |
| Mammoth Midstation | 9,800 | 2,990 | 37°38.6′ | 119° 2.1′ | 404 | −135 |
| Big Whitney Meadow (257) | 9,750 | 2,970 | 36°26.4′ | 118°15.3′ | 260 | −139 |
| Mount Rose S | 9,650 | 2,940 | 39°18.4′ | 119°53.0′ | 182 | −125 |
| Round Meadow (258) | 9,000 | 2,745 | 35°57.9′ | 118°21.6′ | 390 | −109 |
| Mount Rose (334) | 9,000 | 2,745 | 39°21.0′ | 119°52.0′ | 450 | −108 |
| Mount Rose C-1* | 8,885 | 2,710 | 39°18.1′ | 119°53.9′ | 335+ | −119 |
| Rock Creek No. 1 (211) | 8,700 | 2,650 | 37°29.5′ | 118°43.0′ | 183 | −164 |
| Mount Rose A-2† | 8,500 | 2,590 | 39°17.9′ | 119°55.1′ | 384+ | −123 |
| Badger Flat (346) | 8,300 | 2,530 | 37°15.9′ | 119° 6.5′ | 413 | −121 |
| Mount Rose G‡ | 8,245 | 2,515 | 39°19.6′ | 119°53.1′ | 325 | −125 |
| Conway Summit | 8,140 | 2,480 | 38° 5.3′ | 119°11.0′ | 157 | −148 |
| Bishop Creek | 8,120 | 2,475 | 37°15.0′ | 118°34.8′ | 124 | −159 |
| Deadman Summit | 8,020 | 2,445 | 37°46.5′ | 119° 0.9′ | 244 | −133 |
| Mount Rose K | 7,610 | 2,320 | 39°20.3′ | 119°52.4′ | 226 | −134 |
| Echo Summit (108) | 7,450 | 2,270 | 38°49.7′ | 120° 2.2′ | 385 | −112 |
| Westgard Pass | 7,275 | 2,215 | 37°16.3′ | 118° 9.2′ | 71 | −150 |
| Fred Meadow (239) | 7,200 | 2,195 | 37° 2.3′ | 119° 4.8′ | 311 | −98 |
| Mount Dyer No. 1 (48) | 7,100 | 2,165 | 40°14.6′ | 121° 2.1′ | 258 | −104 |
| Mount Rose N | 7,035 | 2,145 | 39°20.5′ | 119°51.4′ | 157 | −121 |
| Gin Flat (179) | 7,000 | 2,135 | 37°45.9′ | 119°46.4′ | 395 | −103 |
| Sonora Junction | 6,910 | 2,105 | 38°20.9′ | 119°27.5′ | 99 | −140 |
| Mono Craters | 6,855 | 2,090 | 37°54.9′ | 119° 2.6′ | 43 | −153 |
| Geiger Grade | 6,800 | 2,070 | 39°21.5′ | 119°39.7′ | 66 | −123 |
| Monitor Pass Road | 6,480 | 1,975 | 38°39.3′ | 119°35.5′ | 56 | −132 |
| Mount Rose O | 6,420 | 1,955 | 39°21.0′ | 119°51.2′ | 90 | −122 |
| Whitney Portal Road | 6,320 | 1,925 | 36°35.5′ | 118°11.9′ | 69 | −128 |
| Mount Rose 2 | 6,015 | 1,835 | 39°22.0′ | 119°51.0′ | 43 | −119 |
| Blue Canyon | 5,290 | 1,610 | 39°17.2′ | 120°41.1′ | 251 | −84 |

* Re-collected 30 April 1969: depth, 361 cm; D/H = −118. † Re-collected 30 April 1969: depth, 318 cm; D/H = −118. ‡ Re-collected 30 April 1969: depth, 221 cm; D/H = −117.

= −90, −87, and −89 SMOW). The change brought about by recrystallization in the snowpack is therefore regarded as small and certainly inadequate to account for 75 per mil difference between the lowest and highest samples from the west slope of the Sierra Nevada.

Because a large percentage of the water vapor (and deuterium) had normally been lost from the air masses by the time they reached the eastern slopes of the Sierra Nevada, there is a clear relation between deuterium content and position of the sample point relative to the drainage divide. The sloping line in Fig. 2 divides most of the points that represent collection stations east of the divide (*4*) from collection stations west of it. The only exceptions are the points representing the sample from the Mammoth Midstation (2990 m), three of the eight closely spaced samples from the Mount Rose profile (connected by a dashed line in Fig. 2), and the anomalous station from Mount Rose (2745 m) that was disregarded in drawing contours on Fig. 3. When samples from the same elevation are considered, those collected east of the Sierra Nevada divide generally contain 10 to 50 per mil less deuterium than samples collected west of it at comparable altitude and latitude.

There is no clear relation between deuterium content and latitude.

Figure 3 shows the D/H ratios of samples from each station and contours representing equal D/H ratios. The divide of the Sierra Nevada is also plotted. Except in one area discussed below, the contours are generally regular. Along the west side of the highest part of the range, which lies approximately between the latitudes of the Sonora Junction on the north (D/H = −140 in Fig. 3) and Big Whitney Meadow on the south (D/H = −139), they tend to be parallel and closely spaced. North and south of these points, the contours bend eastward and cross the divide, because most storms retained a higher percentage of their moisture (and deuterium) as they moved eastward across the lower segments of the range. The contours at the south end of the range are shown wrapping around the range, instead of gradually diverging from it, on the basis of data from individual storms. The contours to the north ignore the D/H value from the 2745-m station at Mount Rose (D/H = −108) because the sample is about 15 per mil heavier than samples from any of the eight nearby Mount

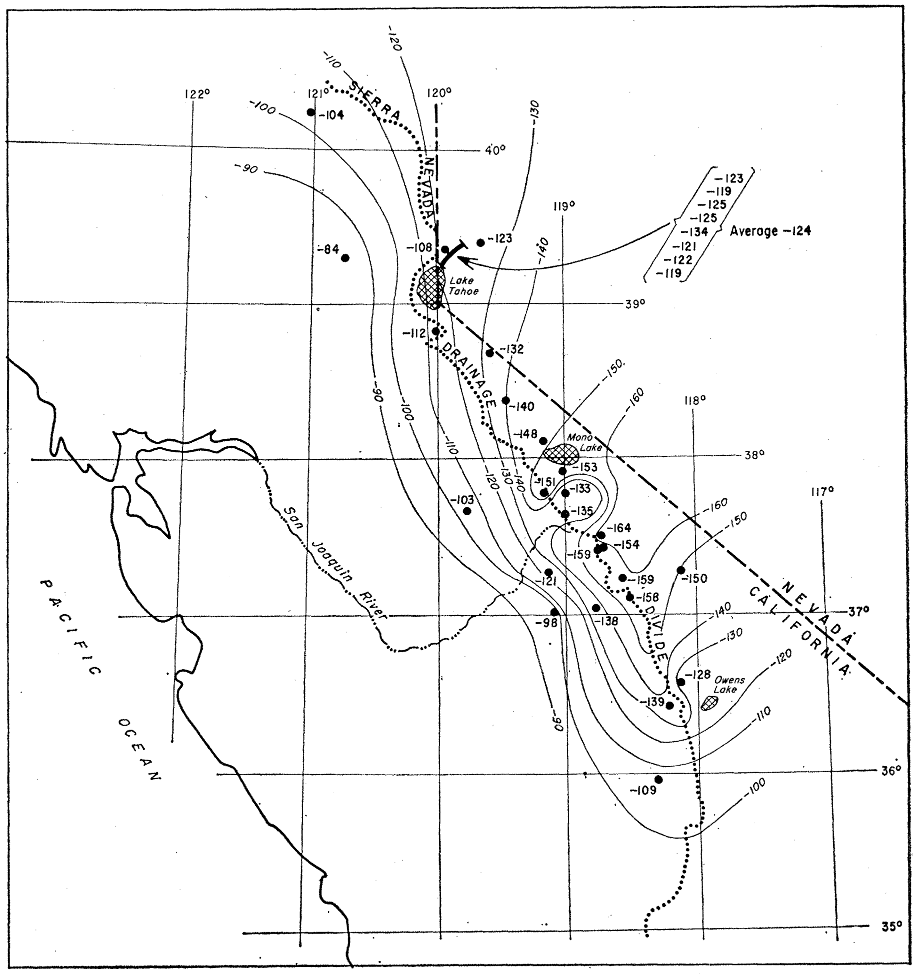



Fig. 3. Map showing contours on D/H values in study area. One station [Mount Rose (334), D/H = − 108] excluded during contouring.

Rose profile stations; this may be a result of local wind erosion preferentially removing the light powder snows, which are generally products of colder and therefore isotopically lighter storms.

Contrary to this general pattern, samples from the Mammoth Midstation (D/H = −135) and Deadman Summit (−133), east of the crest, contain much more deuterium than do samples from areas immediately north and south of them. This is attributed to the fact that the snow in those areas came from masses of moist air that flowed through the depression in the Sierra Nevada crest where the west-draining San Joaquin River forms a large reentrant into the west slope and crest of the range (Fig. 1). The air masses retained more of their moisture until they reached these two areas east of the crest than did the air masses that brought snow to other nearby segments of the east slope. The large snowfall that characterizes the Mammoth Mountain area is generally attributed to this topographic effect.

In summary, we offer the following conclusions:

1) Deuterium concentration of winter snow west of the Sierra Nevada divide is clearly a function of altitude (D/H decreasing at the rate of 40 per mil per 1000 m), but the relation east of the divide is much less clear.

2) The deuterium concentration is not a function of latitude.

3) Precipitation west of the Sierra Nevada divide tends to contain 10 to 50 per mil more deuterium than precipitation east of the divide.

4) The highest segment of the Sierra Nevada causes larger percentages of both the moisture and the deuterium to be deposited on the west slopes than do lower segments of the range to its north and south. An eastward bulge in the deuterium distribution near Mammoth Mountain is attributed to the depression in the range caused by the canyon of the San Joaquin River.

5) Although we have found that individual storms vary widely in deuterium concentration, snow cores provide a

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**

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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.

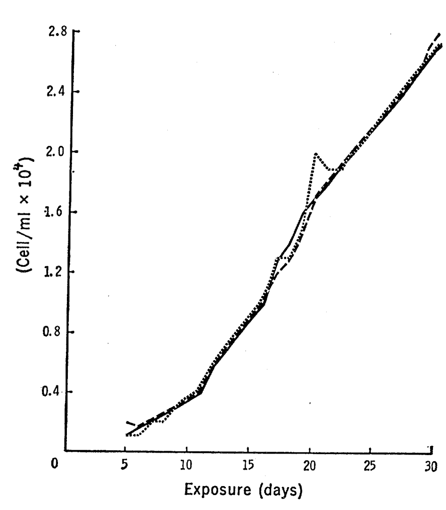


Fig. 1. Population growth in *Euglena gracilis*. Solid line, lunar sample; dashed line, sterilized lunar sample; dotted line, control.

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.