were used, lead to the same marked differences. For example, analyses of the precipitation records of single stations verify the reality and persistence of the lunisolar effect (or some closely related cycle of unknown cause). Distributions of the synodic decimals for the 1000 dates of heaviest rainfall, throughout full 91-year histories of such stations as New York City, Washington, Boston, and Toronto, clearly exhibit the same lunar-month pattern of fluctuation.

In pursuit of the vital question whether this lunar effect is globally discernible, we communicated with E. G. Bowen in the hope of arousing interest in similar work with data from the Southern Hemisphere. The unexpected outcome from this inquiry led to the accompanying report (*6*).

In summary, it can be stated that when dates of excessive precipitation are plotted in terms of the angular difference between the moon and sun, a pronounced departure from normal expectancy becomes conspicuous. There is a marked tendency for extreme precipitation in North America to be recorded near the middle of the first and third weeks of the synodical month, especially on the third to fifth days after the configurations of both new and full moon. The second and fourth quarters of the lunation cycle are correspondingly deficient in heavy precipitation, the low point falling about 3 days previous to the date of an alignment of the earth-moon-sun system. There is a demonstrable persistence of this lunisolar effect in U.S. weather records throughout the history of official meteorological observation (*7*).

These results should not be interpreted to mean that the position of the moon can be used as a reliable predictor of day-to-day rainfall. Rather, their immediate import is for atmospheric research. There is no assurance that the unknown mechanisms responsible for the effects presented here can be easily discovered; but to the extent that a search stimulates additional basic research, the prospects for a better understanding of the physical processes of the atmosphere are enhanced (*8*).

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References and Notes

1. G. Schübler, *Einfluss des Monds auf die Veränderungen unserer Atmosphäre* (Baumgärtners, Leipzig, 1830); H. Mineur, *Compt. Rend.* **233**, 1426 (1951); ———, *Ann. Geofis.* **8**, 294 (1952).
2. V. van der Bijl, *Compt. Rend.* **235**, 22 (1952).
3. J. W. Mauchly, "Lunar influence on precipitation" (1954), private distribution.
4. A. H. Jennings, "Maximum 24-hour precipitation in the United States," *U.S. Weather Bur. Tech. Paper No. 16* (1952).
5. T. H. Carpenter, *Decimal Ephemeris of Sun and Moon 1870–1962* (U.S. Weather Bureau, Washington, D.C., 1962).
6. E. E. Adderley and E. G. Bowen, *Science* this issue.
7. D. A. Bradley, *Astronomical Links with Weather* (Research Div., New York Univ. College of Engineering, New York, 1962).
8. Research supported by the Atmospheric Sciences Program. National Science Foundation, under grant G8213.
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13 June 1962

Lunar Component in Precipitation Data

The influence of the moon in producing tides in the upper atmosphere and the appearance of a lunar component in daily temperature in certain parts of the world are comparatively well known, but the effects are extremely small and difficult to detect. The possibility of a large effect on rainfall first came to our notice in 1960 with the chance reading of a paper by Rodés (*1*). Rodés showed what appeared to be a connection between rainfall in the Spanish peninsula and both the declination and the position of apogee and perigee of lunar motion. An investigation was therefore made of the rainfall data in our possession, and it was apparent that it contained a strong lunar component. However, it was also clear that this was connected with the phase of the moon rather than with the parameters used by Rodés.

At this point a decision was taken not to publish the data immediately, but to reserve it for a later date. The reason for doing so was that our work on singularities in rainfall was still being treated with disbelief in meteorological circles, and to suggest a lunar effect on rainfall would simply not have met with the right response.

We were not surprised therefore when we received a communication from Bradley, Woodbury, and Brier (*2*) indicating a pronounced lunar effect in U.S. rainfall. The effect is matched by similar effects in the Southern Hemisphere. A curve showing the heaviest falls of the month for 50 stations in New Zealand, plotted in the same way as the U.S. data are plotted, is given in Fig. 1. It shows variations of a magnitude comparable with those in the U.S. and closely related in phase.

It should not be assumed from this that a lunar component will be found in all rainfall records. It is already apparent that there are distinct variations

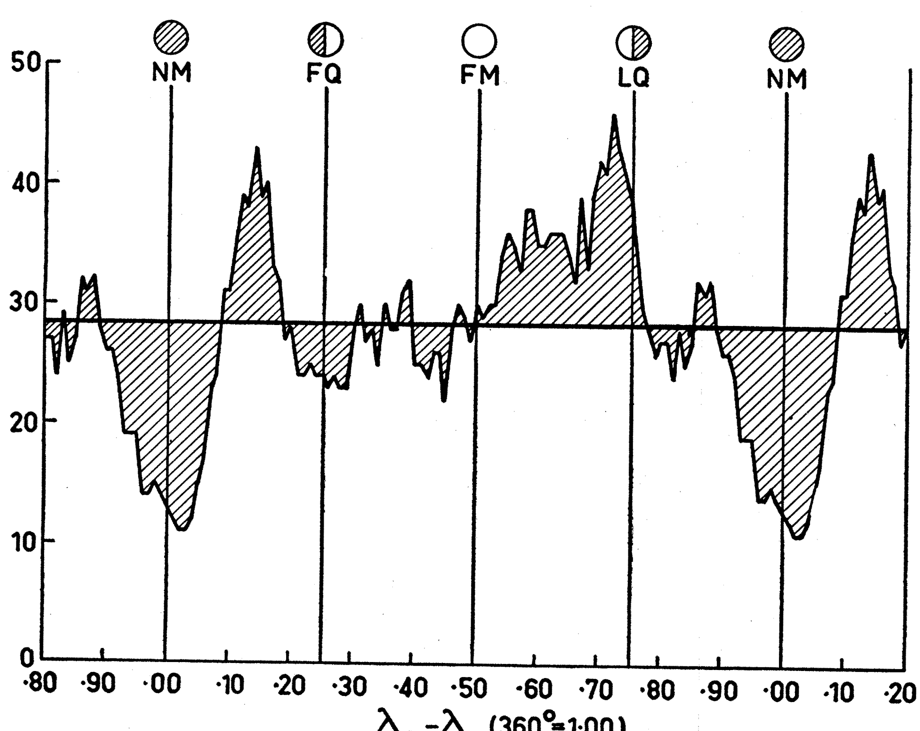

Fig. 1. Ten-unit moving totals of the heaviest falls of the month, for 50 New Zealand stations for the years 1901–1925, plotted against the synodic decimal.

in harmonic content of the curves with geography and, in addition, some shifts of phase. But the effect is sufficiently widespread in the land masses of the Southern Hemisphere to warrant further investigation.

It is not yet possible to advance a physical explanation of the phenomenon, but it is clearly not incompatible with the meteor hypothesis. Meteoritic dust reaching the earth is known to be distributed in orbits, the majority of which are in the plane of the ecliptic. The moon's orbit is also close to the ecliptic and, as the moon revolves around the earth, it could impose a lunar modulation on the amount of dust reaching the earth. However, a calculation of the magnitude of such an effect shows that it is unlikely that gravitational forces alone could produce a variation in rainfall as large as that shown by the accompanying curves. It may therefore be necessary to look for some other explanation for the phenomenon.

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References

1. L. Rodés, "Influye la luna en el tiempo," *Memorias del Observatorio del Ebro No. 7* (Tortosa, Spain, 1937).
2. D. A. Bradley, M. A. Woodbury, G. W. Brier, *Science*, this issue.

25 June 1962

Alveolar Epithelial Cell Mitochondria as Source of the Surface-Active Lung Lining

Abstract. We propose that the surface-active lining of the mammalian lung is formed in the mitochondria of the alveolar epithelial cells. Findings supporting this hypothesis are the presence of strong surfactant uniquely in the washed mitochondrial fraction of mammalian lung, almost complete loss of mitochondrial lamellar forms accompanying loss of lung surface activity after vagotomy, and the absence of strong surface activity from the lung extracts of animals whose alveolar lining cells show no lamellar forms.

Several investigations have suggested that a substance possessing characteristic surface activity (surfactant) lines the internal surface of the lungs (*1, 2*) and helps to stabilize the air spaces. There is some evidence that a lipoprotein containing phospholipid as a major component may be the stabilizing factor (*3*).

In 1954, Macklin (*4*) suggested that the alveolar epithelial cell (sometimes called septal cell, epicyte, or pneumonocyte) secretes substances into the fluid film that lines the alveoli. He observed osmiophilic granules in the alveolar epithelial cell and on the air-liquid interface and recovered these granules from washings of the respiratory tract. Low (*5*) and Schlipköter (*6*), by means of the electron microscope, have observed mitochondria and unusual inclusion bodies in the alveolar epithelial cells. The presence of forms intermediate between mitochondria and these inclusions has led several investigators (*7, 8*) to suggest that the mitochondria of the alveolar epithelial cell can be transformed into inclusion bodies. These inclusion bodies have been called mitochondrial transformations, lamellar transformations, and lamellar forms. In changing into the lamellar form, the mitochondria appear to swell and lose their homogeneous interior, and their cristae coalesce into densely osmiophilic structures (Fig. 1).

We have noted similar structures in surface active material prepared from beef lung, fixed with osmic acid and examined with the electron microscope. Further, Buckingham and Avery (*9*) have found that the surfactant first appears in the lungs of fetal mice on the 17th to 18th day of gestation; they related this finding to the work of Woodside and Dalton (*10*), who had observed the first appearance of lamellar forms in the fetal mouse lung on the 17th to 18th day. All of these observations suggested to us that the alveolar cell mitochondria may contain the lung surfactant or its precursor and that they release this material during the process of lamellar transformation. Our report presents three experiments which attempt to locate the subcellular site of such material in the lung.

The first experiment correlates the gross occurrence of mitochondrial transformation in different species with the surface activity of extracts of the lungs in these species. Lamellar forms and characteristic surface activity have been found in the lungs of the dog, cat, rat, mouse, rabbit, and man. Toad and pigeon lungs do not have lamellar forms (*8*). To test for surface active material in these two groups, we made surface tension-area measurements on saline extracts of the lungs. Fifty milliliters of 0.9 percent NaCl was added to 3 g of minced lung, and the mixture was stirred for 30 min-

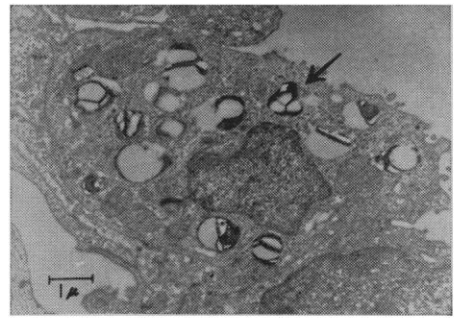

Fig. 1. Alveolar epithelial cell from a normal guinea pig, showing normal mitochondria and many lamellar forms (arrow). Osmic fixed, methacrylate embedded. (RCA EMU 3 electron microscope, × 5080)

utes. Debris was removed by filtration through four layers of cotton gauze, and surface tension measurements were made on the filtrate with a modified Langmuir-Wilhelmy trough (*11*). The area of the extract surface was reduced to one-fifth and reexpanded over a period of ½ hour. The tension-area measurements were recorded automatically and repeated until two successive tracings were duplicated. On compression of the surface of the mammalian lung extracts, surface tension characteristically drops below 10 dyne/cm (*2, 11*). Extracts prepared from 30 toad and 6 pigeon lungs, however, did not reduce surface tension below 18 dyne/cm. Miller and Bondurant (*12*) found that extracts from the chicken and frog did not reduce surface tension below 20 dyne/cm.

In the second experiment we tested whether the abundance of lamellar forms correlates with the surface activity of lung extracts in guinea pig lungs before and after bilateral cervical vagotomy, a procedure which is followed by loss of surface activity (*13*). Figure 1 is a section of a normal

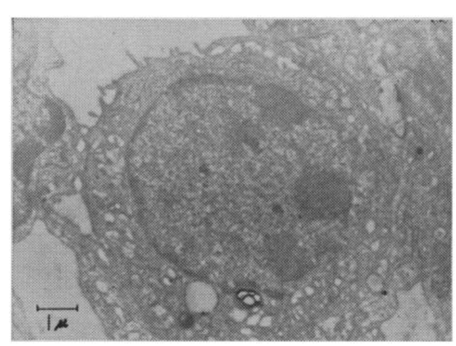

Fig. 2. Alveolar epithelial cell from a vagotomized guinea pig, showing vesiculation of the cytoplasm and only one lamellar form. (× 5250)