observed. The mineral assemblages determined for asteroids span the range found for meteorites (rather than conforming to discrete classes). A continuous distribution of cosmologically occurring minerals may exist. A lengthy report on our interpretation of many more asteroid spectra further supporting and expanding these conclusions is in preparation (*11*).

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References and Notes

1. T. B. McCord, J. B. Adams, T. V. Johnson, *Science* **168**, 1445 (1970).
2. C. R. Chapman, T. B. McCord, T. V. Johnson, *Astron. J.* **78**, 126 (1973); T. B. McCord and C. R. Chapman, *Astrophys. J.*, in press.
3. M. J. Gaffey, thesis, Massachusetts Institute of Technology (1974).
4. J. B. Adams and T. B. McCord, in *Proceedings of the Apollo 11 Lunar Science Conference*, A. A. Levinson, Ed. (Pergamon, New York, 1970), vol. 3, p. 1937; *Science* **171**, 567 (1971); in *Proceedings of the Second Lunar Science Conference*, A. A. Levinson, Ed. (MIT Press, Cambridge, 1971), vol. 3, p. 2138; in *Proceedings of the Fourth Lunar Science Conference*, J. W. Chamberlain and C. Watkins, Eds. (MIT Press, Cambridge, 1973), vol. 3, pp. 163–177; J. B. Adams, T. B. McCord, P. M. Bell, J. E. Conel, H. K. Mao, D. B. Nash, *Geochim. Cosmochim. Acta* **37**, 731 (1973).
5. J. B. Adams, in preparation.
6. T. B. McCord, *J. Geophys. Res.* **74**, 3131 (1968); T. V. Johnson and T. B. McCord, *Science* **169**, 885 (1970); T. B. McCord, in *The Geophysical Interpretation of the Moon*, G. Simmons, Ed. (proceedings of a conference at the Lunar Science Institute, Houston, Texas, August 1969 and June 1970), in press; ———, M. P. Charette, T. V. Johnson, L. A. Lebofsky, C. Pieters, *J. Geophys. Res.* **77**, 1349 (1972); T. V. Johnson, C. Pieters, T. B. McCord, *Icarus* **19**, 1 (1973); T. B. McCord and J. B. Adams, *Moon* **7**, 453 (1973); C. Pieters, T. B. McCord, S. H. Zisk, J. B. Adams, *J. Geophys. Res.* **78**, 5867 (1973); M. P. Charette, T. B. McCord, C. Pieters, J. B. Adams, *ibid.* **79**, 1605 (1974); C. Pieters, T. B. McCord, M. P. Charette, J. B. Adams, *Science* **183**, 1191 (1974).
7. T. B. McCord and J. A. Westphal, *Astrophys. J.* **168**, 143 (1971); ———, J. Elias, *Icarus* **14**, 245 (1971).
8. T. B. McCord, *Science* **178**, 745 (1972); ——— and J. B. Adams, *Icarus* **17**, 585 (1972).
9. T. V. Johnson and T. B. McCord, *Icarus* **13**, 37 (1970); *Astrophys. J.* **169**, 589 (1971); ———, J. Elias, *ibid.* **165**, 413 (1971); C. R. Pilcher, S. T. Ridgeway, T. B. McCord, *Science* **178**, 1087 (1972).
10. J. B. Adams, *Science* **159**, 1453 (1968); in *Infrared and Raman Spectroscopy of Lunar and Terrestrial Minerals*, C. Kerr, Jr., Ed. (Academic Press, New York, in press); ——— and A. L. Filice, *J. Geophys. Res.* **72**, 5705 (1967); R. G. Burns, *Mineralogical Applications of Crystal Field Theory* (Cambridge Univ. Press, Cambridge, 1970); R. L. Huguenin, *J. Geophys. Res.* **78**, 8481 (1973); *ibid.*, p. 8495; *ibid.* **79**, 3895 (1974).
11. M. J. Gaffey and T. B. McCord, in preparation.
12. C. R. Chapman and J. W. Salisbury, *Icarus* **19**, 507 (1973).
13. T. V. Johnson and F. P. Fanale, *J. Geophys. Res.* **78**, 8507 (1973).
14. This work has been supported by grants NGR 22-009-583 and NGR 22-009-473 from the National Aeronautics and Space Administration. This is MITPAL Publication No. 100.

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Volcanic Dust and Meteor Rates

Abstract. A worldwide increase in radar meteor echo rates in 1963 correlates with the injection of massive quantities of volcanic dust into the upper atmosphere by the explosion of Mount Agung in Bali in March 1963. The consequent change in atmospheric radiative heating most probably produced the increase by changing the air density gradient.

During the years 1960 to 1965 meteor rate surveys were conducted at the University of Canterbury, Christchurch, New Zealand (43°S, 173°E). A patrol radar with all-sky coverage was maintained in continuous operation for 3½ years during this period to gather information on the total meteor influx into the earth system. The data derived from this radar, which operated at 69.5 Mhz with a peak pulse power of 81 kw, has been reported by Ellyett and Keay (*1*) and Keay and Ellyett (*2*).

Examination of the recorded rates for 1963 showed a considerable excess in the meteor count compared to corresponding months of a previous year (*3*). Although this apparent increase amounted to some 3×10^5 echoes in 1963, it did not appreciably alter the form of the diurnal rate variation. That is, the diurnal variation for corresponding months of each year was very similar. With the year 1961 as a basis of comparison, the excess rates for 1963 were computed and are plotted in Fig. 1A.

A similar increase in radar meteor rates was also reported from Ottawa, Ontario (45°N, 76°W) (*4*), where a patrol radar was operated continuously from 1958 to 1966 at 32.7 Mhz with a peak power of 20 kw (*5*). The excess rates for the years 1963 to 1966 are plotted in Fig. 2, where the 1958–1962 rates are taken as the basis of comparison. The standard deviation shown in the pre-1963 data is also plotted on the same graph. It can be seen that the excess rates here are not as spectacular as those recorded in New Zealand, but are still well above the standard deviation values for the months of May through September.

Echoes with durations greater than 8 seconds were separated in the Canadian data, and it was shown that there was no statistically significant increase for these echoes (*4*). That is, the anomalous increase observed was restricted to the smaller meteors.

In both New Zealand and Canada the observed phenomena seem to be periodic, with an annual recurrence. The effect was first apparent in the Southern Hemisphere at the end of March 1963 and displayed a winter maximum in the months of June and July, which recurred on successive years, but with reduced magnitude. The year 1964 looks anomalously low in a series of possibly decaying peaks. In the Northern Hemisphere the effect occurred initially in May 1963, but on following years recurred in the winter months January through March or April, with 1964–1965 also being anomalously low.

The possible causal agencies of the effect are exhausted if we consider the following three spheres: extraterrestrial, man-made, or terrestrial. An extraterrestrial cause implies an increased particulate influx to the atmosphere. This influx, restricted to the smaller particles, would have had to extend over a period of some months. Although it is conceivable that planetary perturbations may have shifted the course of a single shower so that the earth now swept through its high-density core, it is difficult to imagine an agency whereby the influx was increased by the magnitude and for the duration observed. It also does not explain the fact that the recurring variations seem to be 6 months out of phase between opposite hemispheres. Furthermore, the facts that the form of the monthly mean diurnal variation remained unchanged and the ratio of maximum to minimum diurnal rates showed little scatter from year to year (*2*) seem to exclude the possibility of an increased particle influx as the cause of the rate increase.

A man-made agency suggested as a possible cause for the phenomenon was the reentry of orbiting dipoles or needles. In an experiment titled "Project West Ford," 22.7 kg of copper dipoles were dispensed into a short-lived, near polar orbit on 12 May 1963 (*6*). The objection to this explanation is that the observed increase at Christchurch commenced before the orbital injection of the dipoles, and recurred long after all trace of the dipoles had vanished (*7*). The diurnal variation of the observed rates would also be expected to show pronounced peaks every 12 sidereal hours as the observing station passed beneath the orbit.

This was not observed. Altogether, the magnitude of the rate increase was too great to be explained by any known man-made phenomenon.

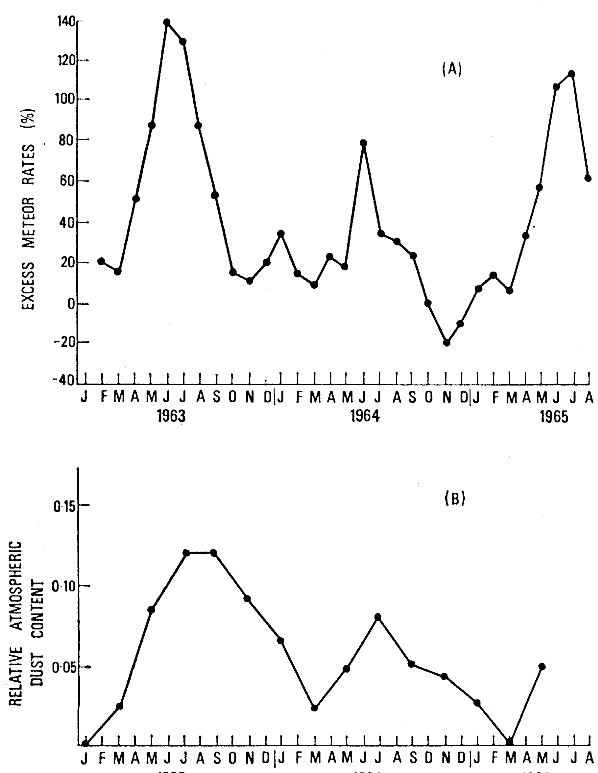
The most plausible mechanism for the meteor rate increase is a global variation in the atmospheric parameters that govern the ionization occurring in the meteor trails. This could influence the observed meteor rate without affecting the form of the diurnal variation. The parameter of most interest here is the atmospheric scale height or density gradient.

Lindblad (*8*), at Onsala in Sweden (58°N, 12°E), used intermittent radar and visual meteor records to show that the 1963 increase was worldwide and that there was also an inverse correlation between solar activity and meteor rates over an 11-year period. This relationship, also found to be significant in a statistical correlation by Ellyett (*9*), was shown to be related to atmospheric density gradient changes. Lindblad's measurements showed that the height of first appearance of meteors from a given shower remained at around 110 km, whereas the average end point rose by about 11 km from 85.2 km in 1956 to 96.0 km in 1963. These results agreed well with atmospheric density values for the range 70 to 120 km during 1961 to 1964 (obtained by measurements on falling spheres ejected from rockets), with maximum density and highest end point both occurring in 1963. Thus, a variation in meteor rates of atmospheric origin was shown to exist. This variation appears to be controlled to a large extent by the solar cycle of activity, but the anomalous 1963 increase (1964 was the year of minimum solar activity) remains unexplained.

It is now proposed that the factor responsible for the increase in scale height of nonsolar origin was the injection of massive quantities of volcanic dust into the upper atmosphere by the eruption of Mount Agung on the island of Bali (8°S, 115°E) on 17 March 1963 (*10*) and the subsequent spreading and distribution of this dust cloud throughout the world (*11–13*). A summary of the available data (*14*) shows that the effects of the dust cloud were evident in the Southern Hemisphere quite soon (on the order of weeks) after the eruption in March, whereas reports from the Northern Hemisphere showed smaller effects which were not evident until later. This correlates well with both the time and intensity of the meteor rate effect as observed in opposing hemispheres. It was observationally shown (*14*) that an equatorial dust reservoir formed (or was much enhanced) after the explosion. During the winter months in each hemisphere there is then a poleward transport of the stored material. This again agrees with the 6-month phase difference observed in the meteor rates between New Zealand and Canada in following years.

Arguments for this hypothesis must be limited to temporal and spatial correlations between observations of the volcanic dust cloud and detection of the excess meteors, because of the paucity of global atmospheric density observations in the mesosphere (just below meteor ablation heights). One quantitative measurement of total atmospheric dust content (*11*) made at Aspendale, Victoria (38°S, 144°E) is shown in Fig. 1B. This is reasonably close (geographically) to Christchurch, and the dust content shows a marked resemblance to the excess meteor rate of Fig. 1A.

The exact heating mechanism in the atmosphere required to produce the observed density changes is not known. It is necessary, however, that the density predominantly increase in the meteor ablation region only. If the air density increased uniformly at all higher altitudes, it would merely cause the same ablation at greater heights. The density gradient must be increased if a larger electron line density is to result from a particular meteoroid and thus allow smaller meteoroids to come within the radar detection range. The relation between the maximum electron line density produced by a particular meteoroid and the atmospheric scale height is given by Kaiser (*15*). Although this shows the essential inverse relation be-



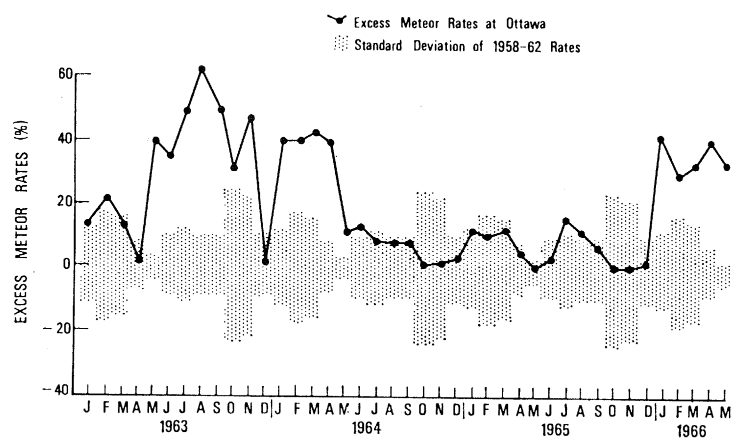


Fig. 1 (left). (A) Excess meteor rates at Christchurch plotted monthly for the years 1963 to 1965. The ordinate is calculated as (mean monthly meteor rate − base rate for same month)/base rate, and is expressed as a percentage. The base rate year was taken as 1961. (B) Dust content in the atmosphere above Aspendale, Victoria, for the same period [after Dyer and Hicks (*11*)]. The ordinate is equal to the total number of aerosols $\eta\Delta h$ in a vertical path Δh, times a scattering coefficient K. Fig. 2 (right). Excess meteor rates at Ottawa, Canada, plotted monthly for the years 1963 to 1966. The ordinate is calculated as in Fig. 1, but here the base rates are the monthly means of the 1958–1962 rate data. The shaded portion indicates the standard deviation shown in these monthly means.

tween electron density and scale height, it also contains the mean pressure to the third power in the numerator, and it is not at all sure that this is constant under the conditions described.

One possible mechanism for the volcanic dust–atmosphere interaction is the absorption of solar radiation by an aerosol layer and the consequent heating of the immediate atmosphere. The lowered air density in this region may then create an increase in the atmospheric density gradient at higher altitudes.

There seem to be two regions where the required changes could have occurred. The first is around 20 km, where the largest concentration of aerosols, or primary dust cloud, was reported. However, this is a considerable distance below the mesopause, and radiosonde measurements (*16*) did not indicate the temperature differences thought necessary to produce the required scale height changes. A secondary layer in the mesosphere (*12*) is closer to the meteor ablation region than the primary stratospheric layer and could conceivably exert a greater influence on this region. Although temperature measurements at these heights are sparse, it has been observed (*17*) that in 2½ hours these altitudes can undergo a temperature change of 60°C. The presence of aerosols will increase the absorption cross section of the atmosphere to solar radiation. Reradiation of the absorbed energy will produce a neighboring temperature increase. For a given solar energy input per unit area, the lower density in the mesosphere means that a larger temperature increase will result, and the appropriate density changes follow.

Although there now seems to be little evidence for the existence of a large-scale aerosol concentration in the mesosphere, it is interesting to note that the reappearance of the excess meteor rates every alternate year correlates with a biennial oscillation of the equatorial stratospheric winds (*14*), which could conceivably cause injection of fine particles into the mesosphere on alternate years.

Another mechanism producing atmospheric heating with the correct seasonal phase is the summer penetration of solar ultraviolet radiation to a lower level at the present mid-latitude observational sites (*18*). The required heating may have been produced by volcanic augmentation of the SO_2 or SO_3 in the thermosphere (*19*), plus an increase in solar ultraviolet due to the drop in ozone concentration observed at the same time as the presence of the aerosols (*20*). Even if the presence of a mesospheric dust layer is not confirmed, heating of the lower atmospheric layers by these two effects might well cause an upward progression of the expansion to meteor heights.

Our aim in presenting this report was to show that there is a strong correlation between the increased meteor rates and volcanic dust at high altitudes. We hope that atmospheric dynamicists might be sufficiently interested by this report to investigate in greater detail the actual mechanisms involved in this interaction.

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References and Notes

1. C. D. Ellyett and C. S. L. Keay, *Mon. Not. R. Astron. Soc.* **125**, 325 (1963).
2. C. S. L. Keay and C. D. Ellyett, *Mem. R. Astron. Soc.* **72**, 185 (1969).
3. C. D. Ellyett and C. S. L. Keay, *Science* **146**, 1458 (1964).
4. B. A. McIntosh and P. M. Millman, *ibid.*, p. 1457.
5. D. W. R. McKinley, *Meteor Science and Engineering* (McGraw-Hill, New York, 1961); P. M. Millman and B. A. McIntosh, *Can. J. Phys.* **42**, 1730 (1964); *ibid.* **44**, 1593 (1966).
6. W. Liller, *Nature (Lond.)* **200**, 349 (1963).
7. A. Sandage and C. Kowal, *Science* **141**, 797 (1963); W. G. Tifft, W. M. Sinton, J. B. Priser, A. A. Hoag, *ibid.*, p. 798.
8. B. A. Lindblad, *Space Research 7* (North-Holland, Amsterdam, 1967), p. 1029; in *Physics and Dynamics of Meteors*, L. Kresák and P. M. Millman, Eds. (Reidel, Dordrecht, Netherlands, 1968), p. 50.
9. C. D. Ellyett, *Essa Tech. Rep. ERL 71-ITS61* (1968).
10. W. P. Booth, *Natl. Geogr. Mag.* **124**, 436 (1963); S. W. Matthews, *ibid.*, p. 447.
11. A. J. Dyer and B. B. Hicks, *Nature (Lond.)* **208**, 131 (1965).
12. M. P. Meinel and A. B. Meinel, *Science* **142**, 582 (1963).
13. A. R. Hogg, *Aust. J. Sci.* **26**, 119 (1963); S. C. Mossop, *Nature (Lond.)* **203**, 824 (1964); H. Moreno, I. Sanduleak, J. Stock, *Science* **148**, 364 (1965); E. C. Flowers and H. J. Viebrock, *ibid.*, p. 493; F. E. Volz, *ibid.* **144**, 1121 (1964); *J. Geophys. Res.* **75**, 1641 (1970); G. Grams and G. Fiocco, *ibid.* **72**, 3523 (1967); J. M. Rosen, *ibid.* **69**, 4673 (1964).
14. A. J. Dyer and B. B. Hicks, *Q. J. R. Meteorol. Soc.* **94**, 545 (1968).
15. T. R. Kaiser, *Advan. Phys.* **2**, 495 (1953).
16. J. G. Sparrow, *Aust. J. Phys.* **18**, 579 (1955); R. E. Newell, *J. Atmos. Sci.* **27**, 977 (1970).
17. G. V. Groves, *Space Research 7* (North-Holland, Amsterdam, 1967), p 977.
18. This was suggested by a referee.
19. Much sulfurous matter was reported in U-2 particle collections by Mossop (*13*).
20. A. B. Pittock, *Nature (Lond.)* **207**, 182 (1965).
21. The Australian Radio Research Board is thanked for financial support.

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Synthesis of Cell Wall Microfibrils in vitro by a "Soluble" Chitin Synthetase from Mucor rouxii

Abstract. *A "soluble" form of chitin synthetase was separated from a membrane-rich fraction by exposure to the enzyme substrate (uridine diphosphate* N*-acetyl-*D*-glucosamine) and activator (*N*-acetyl-*D*-glucosamine). The solubilized enzyme catalyzed the synthesis of chitin microfibrils similar, if not identical, to those formed in vivo by the fungus. Cell wall microfibrils were thus abundantly formed in the absence of a living cell or its membranes.*

Microfibrils are the skeletal components of the cell walls of the vast majority of fungi, algae, and higher plants (*1*). Cellulose and chitin microfibrils occur most abundantly and have been studied most extensively. Yet, the mechanism of elaboration of cell wall microfibrils is largely unknown.

It has been repeatedly demonstrated, by using radioisotopes, that minute amounts of insoluble products with the chemical properties of chitin (*2–4*) or cellulose (*5, 6*) can be synthesized in vitro from the appropriate nucleoside diphosphate sugar. Hitherto, however, there had been no conclusive (that is, physical) evidence that microfibrils were formed in such experiments. Moreover, claims for the biosynthesis of cellulose in cell-free extracts of plants could not be confirmed by x-ray diffraction analysis (*7*).

The subcellular site of cell wall microfibril formation is also unresolved. It is considered unlikely that microfibrils are elaborated internally and then secreted in prefabricated form (*8*) except in some unusual systems (*9*). It is generally believed that microfibrils are assembled at the cell surface (*8*) and that the plasmalemma is actively engaged in their synthesis (*10*). Studies with cell-free extracts have shown that cell wall polysaccharide synthetases are associated with various membrane fractions (*3, 4, 6, 7*), but localization of the synthesizing enzymes in the wall itself has also been reported (*4, 11*). Invariably, little or no activity is found in the soluble cytoplasm. Repeated efforts to solubilize chitin synthetase failed, except perhaps that of Glaser and Brown (*2*), who not only discovered chitin synthetase but were also successful in solubilizing