### References and Notes

1. W. Dansgaard, *Geochim. Cosmochim. Acta* **6**, 241 (1954).
2. R. P. Sharp and S. Epstein, *Proc. Int. Ass. Sci. Hydrol. Chamonix Publ.* **47**, 359 (1958); W. Dansgaard, *Medd. Grønland* **165**, No. 2, 1 (1961); W. Ambach, W. Dansgaard, H. Eisner, J. Møller, *Tellus* **20**, 595 (1968).
3. C. Lorius, *Comité National Français des Recherches Antarctiques (CNFRA) Rept., No. 8* (1963).
4. C. Lorius, R. Hagemann, G. Nief, E. Roth, *Earth Planet. Sci. Lett.* **4**, 237 (1968).
5. S. Epstein and R. P. Sharp, *Trans. Am. Geophys. Union* **40**, 81 (1959); R. Gonfiantini, V. Tagliatti, E. Tongiorgi, W. de Breuck, E. Picciotto, *J. Geophys. Res.* **68**, 3791 (1963); S. Epstein, R. P. Sharp, I. Goddard, *J. Geol.* **71**, 698 (1963); S. E. Wilgain, E. Picciotto, W. de Breuck, *J. Geophys. Res.* **70**, 6023 (1965); S. Epstein, R. P. Sharp, A. J. Gow, *ibid.*, p. 1809; C. C. Langway, Jr., *U.S. Army Cold Region Research and Engineering Laboratory (CRREL) Rep.* **77**, 1 (1967); E. Picciotto, R. Cameron, G. Crozaz, S. Deutsch, S. Wilgain, *J. Glaciol.* **7**, 273 (1968).
6. H. Ueda and D. Garfield, *U.S. Army Cold Region Research and Engineering Laboratory (CRREL) Spec. Rep.* **126**, 1 (1968).
7. B. L. Hansen and C. C. Langway, Jr., *Antarctic J. U.S.* **1**, 207 (1966); temperature profile published by J. Weertman, *J. Geophys. Res.* **73**, 2691 (1968).
8. P. F. Scholander, W. Dansgaard, D. C. Nutt, H. de Vries, L. K. Coachman, E. Hemmingsen, *Medd. Grønland* **165**, 1 (1962); C. C. Langway, Jr., H. Oeschger, A. Renaud, B. Alder, *Nature* **206**, 500 (1965); H. Oeschger, B. Alder, H. Loosli, C. C. Langway, Jr., *Earth Planet. Sci. Lett.* **1**, 49 (1966).
9. H. Oeschger, B. Alder, C. C. Langway, Jr., *J. Glaciol.* **6**, 939 (1967); H. Oeschger, B. Stauffer, C. C. Langway, Jr., B. L. Hansen, International Quaternary Antarctic Congress, Paris, France, abstr. (1969).
10. S. J. Johnsen and W. Dansgaard, in preparation.
11. W. Dansgaard and S. J. Johnsen, *J. Glaciol.* **8**, 215 (1969).
12. G. Crozaz and C. C. Langway, Jr., *Earth Planet. Sci. Lett.* **1**, 194 (1966).
13. W. Dansgaard and S. J. Johnsen, *J. Geophys. Res.* **74**, 1109 (1969).
14. H. Craig, *Science* **133**, 1833 (1961).
15. P. Bergthorsson, *Vedrid*, Reykjavik **12**, 55 (1967).
16. W. S. Broecker, E. A. Olson, J. Bird, *Nature* **183**, 1582 (1959); H. de Vries, *Kon. Ned. Akad. Wetensch. Proc.* **13**, 61 (1958).
17. E. H. Willis, H. Tauber, K. O. Münnich, *Am. J. Sci. Radiocarbon Suppl.* **2**, 1 (1960).
18. H. E. Suess, *J. Geophys. Res.* **70**, 5937 (1965).
19. J. Mercer, *Geogr. Rev.* **55**, 390 (1965).
20. F. Bourdier, *Le Quaternaire du Bassin du Rhône* (C.N.R.S., Paris, 1963), vol. 2.
21. J. N. Rosholt, C. Emiliani, J. Geiss, F. F. Koczy, P. J. Wagersky, *J. Geol.* **69**, 162 (1961).
22. R. Fairbridge, Ed. *Physics and Chemistry of the Earth* (Pergamon, New York, 1961), vol. 4, chap. 3.
23. T. V. D. Hammen, G. C. Maarleveld, J. C. Vogel, W. H. Zagwijn, *Geol. Mijnbouw* **46**, 79 (1967).
24. R. P. Goldthwait, A. Dreimanis, J. L. Forsyth, P. F. Karrow, G. W. White, in *The Quaternary of the United States*, H. E. Wright, Jr., and D. G. Frey, Eds. (Princeton Univ. Press, Princeton, N.J., 1965), p. 737.
25. C. Emiliani, *Science* **154**, 851 (1966).
26. A. van Woerkom, in *Climate Change*, H. Shapley, Ed. (Harvard Univ. Press, Cambridge, Mass., 1953), p. 147; W. S. Broecker, *Science* **151**, 299 (1966).
27. W. Dansgaard, *Tellus* **16**, 436 (1964).
28. L. A. Lliboutry, "Ice flow law from ice sheet dynamics," *Int. Symp. Antarctic Glaciol. Expl. 1st* (Hanover, N.H., Sept. 1968), in press.
29. This does not mean that isotopic change of seawater (due to binding of large amounts of isotopically light ice) is unimportant for the paleotemperature scale developed by Urey (*30*), Epstein *et al.* (*31*), and Emiliani (*32*); on the contrary, Emiliani's estimate of this effect seems to be much too low (*33*; see *34*).
30. H. C. Urey, *J. Chem. Soc.* **47**, 562 (1947).
31. S. Epstein, R. Buchsbaum, H. Lowenstam, H. C. Urey, *Bull. Geol. Soc. Amer.* **64**, 1315 (1953).
32. C. Emiliani, *J. Geol.* **63**, 538 (1955).
33. E. Olausson, *Progr. Oceanogr.* **3**, 221 (1965); N. Shackleton, *Nature* **215**, 15 (1967); W. Dansgaard and H. Tauber, *Science*, in press; W. S. Broecker, in *Quaternary of the United States*, H. E. Wright, Jr., and D. G. Frey, Eds. (Princeton Univ. Press, Princeton, N.J., 1965), p. 737.
34. C. Emiliani, *J. Geol.* **74**, 109 (1966).
35. R. Haefeli, *J. Glaciol.* **4**, 1133 (1961).


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## Atmospheric Aerosols


Abstract. *Measurements of particle counts and size distributions of atmospheric aerosols have been made at various locations by use of an instrumented aircraft. The number of atmospheric particulates is related to the visibility.*


Investigations have been made to determine the fate of atmospheric pollutants subsequent to their release from man-made sources such as power stations, smelters, and pulp mills as well as from natural sources such as forest fires. Gaseous and particulate concentrations have been measured in effluent plumes and in relatively clear air by flying an instrumented Cessna 182 aircraft in a series of plume-tracking patterns. We report here some of the findings with respect to particle numbers and sizes for various atmospheric regimes.

Sample air is taken in through a rubber tube protruding from the leading edge of the aircraft wing, and airflow rates are reduced by use of a number of inverted Y's. A dust counter (Bausch & Lomb) detects, classifies according to size, and counts the particulates. The dust counter was calibrated in the laboratory by the use of polystyrene latex particles with a refractive index of 1.56. Thus, the reported particle diameters are "equivalent diameters" based upon the laboratory calibrations (*1*).

Figure 1 shows an array of curves depicting particle size distributions found in various flights. Instrumental capabilities allowed for particle counting in the size ranges noted on the abscissa (Fig. 1). The upper counting limit is 36 particles per cubic centimeter, and the lower limit, although not so clearly established, is about 0.03 particle per cubic centimeter.

Curves 1, 2, and 3 illustrate the particle sizes and counts observed under conditions of excellent visibility in Santa Fe, New Mexico; Cedar Key on the Gulf of Florida; and Douglas, Arizona. Curve 4 shows the particle size distribution found at Bronson, Florida, which is about 35 miles inland from Cedar Key.

Data for Cedar Key and Bronson were taken within a 20-minute interval and illustrate the buildup in particulate concentrations that occurred over the Florida land mass. In this instance, there was a 12-fold increase in the number of particles 1 $\mu$m in diameter or larger from the coast to this inland location. Winds were from the south parallel to the coast at 15 knots, and there was substantial turbulence at the sampling altitude of 760 m.

Curve 5 shows the influence of urban air pollution in the metropolitan area of Houston, Texas. Measurements were made about 37 km downwind and at an altitude of 1800 m. These early-afternoon measurements were below the top

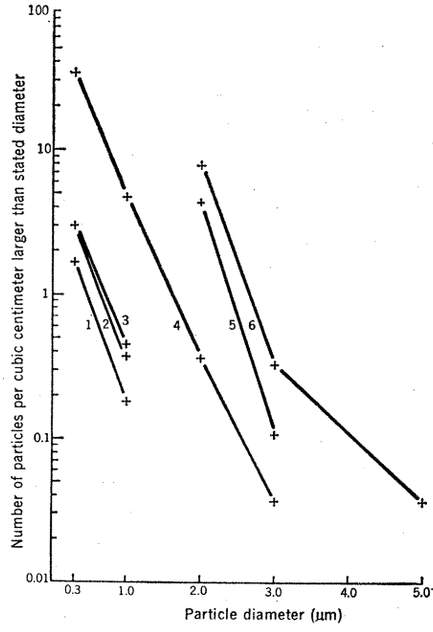


Fig. 1. Particle size distribution of natural and man-made aerosols. Data represent airborne samples from the following sources: curve 1, Santa Fe, New Mexico, 24 September 1968, 0920 hours, 2250 m; curve 2, Cedar Key, Florida, 19 December 1968, 1035 hours, 760 m; curve 3, Douglas, Arizona, 19 September 1968, 0715 hours, 1700 m; curve 4, Bronson, Florida, 19 December 1968, 1045 hours, 760 m; curve 5, 32 km north of Houston, Texas, 25 September 1968, 1300 hours, 1800 m; curve 6, Four Corners, New Mexico (in plume 6.5 km from power station), 23 September 1968, 0900 hours, 1800 m.

Fig. 2. Power station at Four Corners, New Mexico.

of the mixing layer and were associated with a visibility of approximately 9.5 km (*2*).

Data for curve 6 were developed from a circular flight pattern through the plume of a coal-fired power station at Four Corners, New Mexico. Samples were taken about 6.5 km from the point of emission; visibility in the plume was estimated at less than 1.5 km. Figure 2 illustrates this plume. The photo was taken about 30 minutes prior to the sampling activities.

Although suspended particulates have been traditionally sampled and reported on a mass basis in air-pollution investigations, it is useful to know more about their size distribution and abundance (*3*). This is especially true when one considers the effects of aerosols on visibility and the resulting hazards to both air and ground traffic.

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**References**

1. K. T. Whitby and R. A. Vomela, *Environ. Sci. Tech.* **1**, 801 (1967).
2. G. C. Holzworth, *J. Appl. Meteorol.* **6**, 1039 (1967).
3. U.S. Department of Health, Education, and Welfare, Division of Air Pollution, *U.S. Public Health Serv. Publ. APTD 68-9* (1966); M. Corn, in *Air Pollution*, A. C. Stern, Ed. (Academic Press, New York, 1968), p. 47; C. E. Junge, *Air Chemistry and Radioactivity* (Academic Press, New York, 1963).

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## Alpha-Recoil Tracks in Mica: Registration Efficiency

Abstract. *Recoils from alpha-particle decay of naturally occurring radioactive nuclides have energies between 70 and 169 kiloelectron volts. It is shown that these alpha recoils register tracks in mica, observable as etch pits, with an efficiency of about 80 percent. When the recoil energy is degraded to 40 kiloelectron volts the efficiency drops to 50 percent. But, since the decay of each thorium or uranium impurity atom in natural mica is followed by a cascade of six or eight alpha particles, the overall registration efficiency must be very nearly 100 percent.*

Huang and Walker (*1*) have reported that heavy nuclei recoiling during emission of alpha particles can produce etchable tracks in mica. Samples etched in 48 percent hydrofluoric acid showed many shallow etch pits which were made visible with phase-contrast microscopy. These tracks were attributed to $\alpha$ decay of uranium and thorium series impurities. This phenomenon was suggested as the basis of a method of age determination several thousand times more sensitive than fission track dating.

In identifying the source of these tracks Huang and Walker first annealed samples of mica at 600°C for 21 hours to remove latent fossil tracks. Then they evaporated solutions of $Th^{228}$, and its decay products, on these samples. After a 20-hour irradiation and etching with 48 percent HF for 2 hours, they produced shallow pits identical in appearance with fossil pits. However, contact of annealed mica with uranium foils for up to 12 days did not yield appreciable densities of tracks. As a possible explanation of this apparent contradiction the authors suggested that radiation damage from several successive $\alpha$ recoils may be necessary to initiate growth of an etch pit. From a uranium source only a single $\alpha$ recoil is produced during the time of the experiment because the daughter products are long-lived. On the other hand, $Th^{228}$ has a series of short-lived daughter products so that about five successive $\alpha$ recoils are produced in a 20-hour exposure.

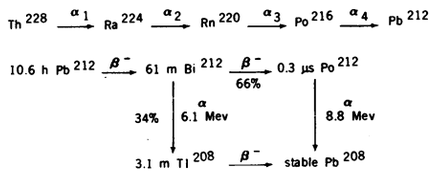


Fig. 1. The $Th^{228}$ (1.9 y) decay chain.

This study was initiated to test this interpretation and to seek answers to the following questions. How many $\alpha$ recoils are required to initiate growth of an observable etch pit at a given site? What is the ratio of pits to incident recoil particles? What is the minimum $\alpha$-recoil energy required to produce an etch pit?

The experiments were started with members of the $Th^{228}$ (1.9 y) decay chain (Fig. 1). Sources of $Pb^{212}$ (10.6 h) were collected on aluminum foils, as very thin active deposits, from decay of gaseous $Rn^{220}$ (54 s) emanated by 2 mc of $Th^{228}$ (*2*). Only one $\alpha$ particle is emitted per $Pb^{212}$ decay: either 6.1 Mev or 8.8 Mev. In the first case the recoil energy is 117 kev and in the latter it is 169 kev. By counting the activity of $Tl^{208}$ (3.1 m) it is possible to determine the number of recoils emitted by a source. Recoils from $\beta^-$ emission have energies $< 10^{-4}$ that of $\alpha$ recoils, and, therefore, they do not leave the foil in significant amount.

The $\alpha$ recoils were collected on 1.5 $cm^2$ pieces of annealed mica placed 12 mm from the source inside a vacuum system. The mica rested on a thin brass frame such that only the central area ($8 \times 8$ mm) was exposed to the source. A potential of +500 volts was applied to the frame to repel ions near thermal energy. Recoils were collected for 10-minute intervals on a series of mica squares. The air pressure in the system was varied between 0 and 10 torr so as to vary the energy of the recoils. After each 10-minute collection period the activity of $Tl^{208}$ (3.1 m) on each piece of mica was measured with a calibrated end-window proportional counter. Thus the number