More comprehensive reports, in which other new species will be described, are in preparation.

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References and Notes

1. The site was discovered by Newell F. Joyner, Regional Museum Curator, National Park Service, Omaha, Nebraska, and the families of Donald C. Beckman and Eugene Kuszmaul of Ft. Peck, Montana. Collections have so far been made by or for the St. Paul Science Museum (S.P.S.M.), The American Museum of Natural History (A.M.N.H.), and Minnesota (U.M.V.P.), Harvard, Princeton (P.U.), Kansas (K.U.), Yale, Montana State, and Nebraska Universities. Similar but slightly later Cretaceous mammals, now at A.M.N.H., were first found in this region in 1938 by Darwin Harbicht, then of Ft. Peck, and an untraced Mr. Moseley. It was while searching for their locality (now named Harbicht Hill) that we were led to the Bug Creek site.
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18 December 1964

Stratospheric Tapping by Intense Convective Storms: Implication for Public Health in the United States

Abstract. *The observation of a cloud-free vortex in the top of a violent convective storm over Oklahoma suggests a mechanism whereby large quantities of air may be brought directly from the lower stratosphere to the lower troposphere in the central part of such storms. That this mechanism, in combination with the torrential rains frequently generated by these systems, is capable of producing radioactive "hot spots" on the ground is pointed out. Climatological considerations and observations of accumulated strontium-90 in soils support the hypothesis that the Plains States are peculiarly subject to heavy contamination compared to other middle-latitude areas because of this mechanism.*

List *et al.* (*1*) report a "cause-and-effect relationship between the penetration of thunderstorms into high concentrations of nuclear debris in the lower stratosphere and the subsequent amount of iodine-131 in milk." I write primarily to point out a possible mechanism, on the basis of observations made in May 1962, for direct tapping of debris from the lower-stratosphere reservoir. It should, however, be clear that torrential rains are fully capable of concentrating the debris contained by tropospheric air by the selfsame convergent-flow mechanism that serves to concentrate water substance locally to form such rains. Therefore I do not wish to enter into controversy (*2*) as to the source of the observed iodine-131 contamination of milk.

Basically, the scavenging of stratospheric debris by rain is a logistics problem which requires that certain conditions be fulfilled in succession:

1) The radioactive particles must become attached to or contained in raindrops.

2) They must at some time be brought into close proximity to adequate water substance as vapor, liquid, or ice.

3) There must be an active mixing process between (i) the stratospheric (hence dry) air that contains the radioactive particles; and (ii) tropospheric air which contains sufficient water substance to produce rain.

4) The particles to be scavenged must have size and mass appropriate for the envisioned collection process. (i) For diffusive collection by cloud droplets they must be of size comparable to the stratospheric aerosol *but* they must then be associated with the cloud droplets for an extended time, and in a part of the cloud which converges toward the rain generating region. (ii) For impact collection by raindrops (washout), they must be very large, by 10 to 50 times, compared to the stratospheric aerosol.

For the production of rain, the flux of moist low-level air through a horizontally convergent system requiring uplift, condensation, and storage of condensed water in a cloud mass is necessary. All such flow systems in nature are characterized by a divergence of the processed air above the level of water storage. To the extent that the generation of rain characterizes a developing and strengthening cyclonic storm, the divergence aloft must remove a larger mass of air from the storm center than that which low-level convergence brings in. The tops of most rain-producing storm systems are therefore in the divergent flow, and cloud particles present at these levels are not likely to become associated with the precipitation particles. They are rather more likely to move away from the raining system aloft and evaporate downstream, leaving behind aggregated nuclei suitable for the generation of rain in a subsequent storm.

In particular, convective storms are characterized by horizontal divergence in their tops, which is more or less proportional to the intensity of their development. Since only the most intense are expected to penetrate the lower stratosphere, these are particularly divergent in their uppermost levels. Stratospheric debris collected by the cloud particles that penetrate to these levels is therefore not well located for incorporation in the rain produced at, and falling from, the lower portions of the storm.

Several mechanisms have been proposed whereby convective clouds may entrain air from their environments as they grow (*3*). These serve mainly to dilute the clouds with slightly drier tropospheric air, and each has important limitations for the required transfer of stratospheric debris to the rain-generating region. The mechanism suggested by Squires (*4*), on the other hand, provides for the downward penetration of dry air entrained on the top of a cloud by virtue of instability induced by evaporative cooling. Although this mechanism might bring stratospheric air into the rain-generating region of convective storms, whether its effect could be large enough to explain the observations reported (*1*) is dubious. In addition, the observed pattern of radioactive content of rain samples from strong convective storms (*5*) is usually quite different from that which must result from the broad process of cloud-top entrainment operating in a uniform debris reservoir.

Fortunately, the midwest storm of 24 May 1962, which is one of those mentioned (*1*), has been observed and studied in some detail; unique findings for this storm are available. Not only did it breed tornadoes, but one of these passed directly over the meteorological recording station at Newton, Kansas. A careful study of the aspects of this storm at low levels has been reported (*6*).

In addition, a different subsystem of this storm was viewed and photographed from above by a U-2 aircraft (Air Force Cambridge Research Laboratory) flying at an altitude of about 19.5 km (*7*). The composite of the photo reconnaissance shows a cloud-free vortex of about 6.5 km (3.6 nautical miles) diameter at 15.3 km. Photogrammetric rectification and radar cross sections indicate that the vortex extended and tapered down to a diameter of about 1.85 km (1 nautical mile) at 12.0 km.

There is a meteorological analog, which is pertinent, in the known structure and behavior of a hurricane (*8*). It is well known that the upper central part of a hurricane vortex is a region of strongly descending air. A similar effect is noted in laboratory-simulated vortices (*9*). The production of this effect appears to depend upon a very high degree of organization of the convergent and upward moving air currents and an associated organizing effect upon downward convection initially of the type described by Squires (*4*). It is conceivable that relatively few intense convective storms are capable of achieving this degree of organization.

In any case, the observation of the upper vortex suggests a powerful mechanism for drawing the radioactivity-laden air from the lower stratosphere directly into such a well-organized storm system. This air should be expected to descend well into the lower troposhere in the central vortex downdraft. At levels below 1.5 km or less, the downdraft should tend to be destroyed by the lower boundary conditions, and a divergence into the peripheral updraft, with consequent mixing of the stratospheric air into the rain-generating cloud, should be expected. The stratospheric aerosol would then be so placed as to be efficiently scavenged by both the diffusive and the impact mechanisms.

Quantitative evaluation of this mechanism in terms of the amount of stratospheric air it might bring directly into the rain-producing system must await a more complete analysis of the dynamics of such storms. Its potential for producing radioactive "hot spots" on the ground by the concentrated precipitation of stratospheric debris is obvious.

In addition, climatological evidence indicates that this particular form of stratospheric tapping is not at all likely to be evenly distributed in middle latitudes. On the assumption that tornado-breeding storms are the most likely to display the required high degree of organization, reference may be made to existing data on tornadoes. The highest frequency anywhere in the world is found in the months of March to June over Oklahoma, Arkansas, Kansas, Nebraska, and Iowa (*10*). Whereas storms that are called tornadoes occur in West Africa, India, and Australia, none of these tornadoes have the extreme development found in those of the Plains States (*11*). As a result, these states should be uniquely subject to the radioactive "hot spots" produced by these violent vortices and their associated intense rains if this mechanism operates effectively.

Reports of the amounts of radioactive iodine in milk do not provide adequate information to test the hypothesis. This is true both because iodine-131 is a short-lived, and therefore noncumulative, isotope and because it may be carried to earth from either the stratosphere or the troposphere. The accumulation of strontium-90 in soils is a better indicator because of its long life and its firm identification with the stratospheric reservoir. A recent report of strontium-90 accumulation in soils shows an impressive maximum in an area nearly congruent with that of maximum tornado activity (*12*) in the United States.

There is little doubt that atmospheric exchanges of much larger scale take place between the stratosphere and the troposphere, and that these probably account for a large fraction of worldwide fallout. The paucity of data on troposphere-stratosphere exchanges in polar and equatorial latitudes at present makes quantitative estimation of their effectiveness impossible. The "stratospheric extrusion" mechanism (*13*) of middle latitudes has been studied by Reiter (*14*) who has estimated that it could do the entire stratospheric cleansing job without the help of other exchange mechanisms. Although this is obviously an overestimation, it is indicative of the relative significance of the larger-scale atmospheric processes. It is noteworthy that this overestimation is based upon studies of Danielsen's (*13*) mechanism over the United States. The implication that this mechanism is less effective over the rest of the middle-latitude belt of the Northern Hemisphere should not be overlooked.

Taken together, then, one should expect a broad and relatively even earth contamination by fallout attributable to the large-scale exchange processes, upon which are superimposed fallout components attributable to progessively more localized processes, the most intense of which, for stratospheric debris, may be that of direct tapping of the lower stratosphere by highly organized and intense convective storms. The last, because of its ability to concentrate radioactivity in "hot spots," constitutes the greatest health hazard, and is peculiar to a limited but agriculturally important part of the United States.

Modern conventional techniques for observing weather, complemented by appropriate radar monitoring of the severe storm situations of the Plains States, might readily give initial indications of the locations of such radioactive "hot spots." More specific identification of the areas affected could be made by prompt field checks which would then serve as a basis for segregating the "hot farms" from the rest of their respective milksheds or produce areas. The "hot" produce could then be separately processed so as to minimize the impact of its radioactivity upon human health.

Appropriate collaboration of the Weather Bureau, the Atomic Energy Commission, the Public Health Service, and the Department of Agriculture in the development and use of such preventive procedures could thus provide real safeguards for our populace.

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13 January 1965

Microelectrophoresis with Alternating Electric Fields

Abstract. *Electrophoretic mobility of microscopically visible particles is measured from photographs of their oscillatory migration in a low frequency electric field. The measurements are inherently free of gravitational or thermal-convective drifting. Many measurements may be made from one photograph. An automatic timing circuit insures reproducibility and determines the sign of the particles' charge.*

A method, which is free of drift, for measuring the electrophoretic mobility of microscopically visible particles has been developed. In a cell of simple design, the suspension of particles is exposed to an alternating, electric field (1 to 10 cy/sec). Particles having a net charge experience a force varying with time. The resulting movement of the particles is photographed in such a way that the mobility can be calculated from measurements on the photographic record.

In the d-c method of microelectrophoresis, particles, suspended in a liquid and subjected to a d-c electric field, are observed microscopically as they move a measurable distance in a fixed length of time, say 5 seconds. However, the same displacement may be due partially to gravity or to thermal convection in the liquid. The thermal convection is caused by drafts in the room, insufficient thermal equilibration of the apparatus, or uneven heating of the sample by the microscope lamp. At best, the d-c method requires many serial measurements, each on one particle, to obtain a consistent average.

In the a-c method of microelectrophoresis, problems of drifting are obviated by measuring the amplitude of the particle's oscillatory migration in an alternating electric field. Gravitational and thermal drifts, being nonoscillatory, do not contribute to the quantity being measured. Observation is made photographically, so that measurements for many particles may be obtained from one picture.

At the low frequencies used, 1 to 10 cy/sec, forces of electric origin are very large compared to inertial forces on micron-sized particles (*1*). Therefore, one may consider that the particles instantaneously assume a velocity proportional to the time-varying, applied electric field, $\mathcal{E}(t)$. Thus, if $v(t)$ is the particle's velocity and $x(t)$ is its displacement,

$$v(t) = \mu\mathcal{E}(t)$$

and

$$x(t) = \mu\int\mathcal{E}(t)\,dt$$

where μ is the mobility. If $\mathcal{E}(t) = E \sin \omega t$, where E is the amplitude and ω is the angular frequency of the applied, sinusoidal electric field, then

$$x(t) = -\frac{\mu E}{\omega}\cos \omega t,$$

where $A = \mu E/\omega$ is the amplitude of the oscillatory migration. Thus

$$\mu = \omega A/E.$$

The value of A is measured from a photograph of the motion. However, the entire cell must be moved perpendicularly both to the applied field and to the line of view in order to display the oscillatory migration on a time base (Fig. 1). This artifice resolves the motion into an oscillatory migration about a slowly drifting origin, thus separating electric from nonelectric migrations.

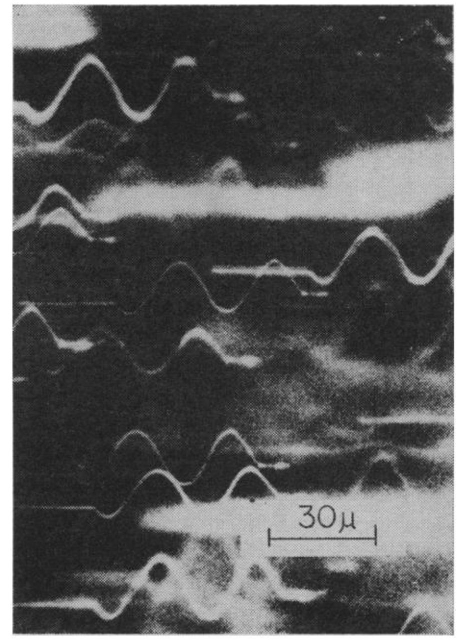

Fig. 1. Electrophoresis patterns of polystyrene spheres (1 micron in diameter) subjected to 340 volt/cm, 10 cy/sec. The "artificial" horizontal component of the motion is the result of moving the stage of the microscope during the exposure. Each pattern has two "tails," since the field is applied for less time than the illumination.

The frequency of the applied voltage should be high enough to cause the particle to oscillate rapidly about an origin which may be slowly drifting. It should also be low enough to give a large, easily measured amplitude, A. When these requirements are balanced and E is kept small to minimize heating, frequencies between 1 and 10 cy/sec are usually the most useful.

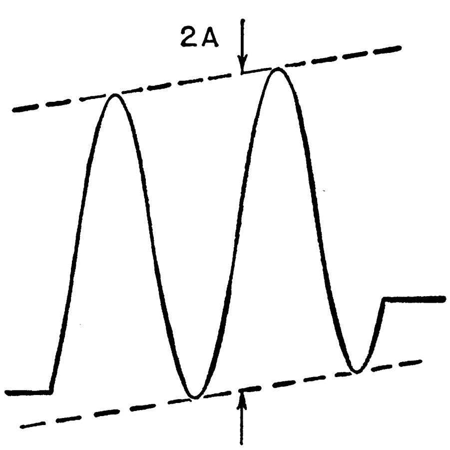

Fig. 2. Method for measuring amplitude, A, of a particle's alternating migration from the photographic record.