Tektites as Natural Earth Satellites

Observations indicate that orbiting tektites, on entering the atmosphere, fall in a few revolutions.

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Barnes, Kopal, and Urey (*1*) criticized the theory of lunar origin of tektites as put forward by me in 1958 (*2*), in part on the ground that the distribution of tektites does not agree with this theory. Barnes and Urey argue, in particular, that if the tektites spiraled in slowly from the moon, as suggested, they would be completely distributed around the earth in a band of latitude.

In my paper I did not specify the manner in which tektites traverse the space between the earth and the moon. The argument of Barnes and Urey is incontestably correct, however, in showing that the tektites could not have crossed this space as a group of bodies. It is essential to suppose that the tektites of each strewn field crossed cislunar space as a single large body. It is also necessary, in view of the lack of small strewn fields, to suppose that there is a lower limit to the size of a body which can produce tektites efficiently.

In an attempt to account for the distribution, a study has been made of the great meteor procession of 9 February 1913, for which the name "Cyrillids" is proposed (after St. Cyril's day, 9 February). This shower cannot be named after a radiant, since it had none, nor after a comet. The precedent followed here is the naming of the Perseids the "tears of St. Lawrence," because they fall on St. Lawrence's day. It has been shown by Chant, Burns, Denning, Davidson, Pickering, Fisher, La Paz, Mebane, and me (*3*, *4*), despite objections by Hoffmeister (*5*) and Wylie (*6*), that these objects were almost certainly a group of small earth satellites moving in an orbit of low eccentricity. La Paz (*7*), Fenner (*8*), and I (*2*, *9*) have suggested that there is a connection between tektites and the Cyrillid shower.

It is therefore of interest to see whether these bodies came down all around a band of latitude, as suggested by the comments of Barnes and Urey.

Narrowness and Uniqueness of Cyrillid Orbit

All of the observations of the Cyrillids which have been obtained thus far (see Fig. 1) pertain to a single orbital revolution, in which the bodies passed over Toronto at about 9:05 P.M. EST. Since the bodies remained in the atmosphere over a distance of some 6000 miles, it follows that the orbit must have been nearly circular. The next revolution should therefore have occurred some 90 minutes, or less, later. In Fig. 2 is shown the result of displacing the trace originally drawn by Chant westward by 22.9 degrees, corresponding to an orbital period of 91.5 minutes.

To discover whether the bodies passed over this line, use has been made of the fact, discovered by Mebane (*4*), that local newspapers of the date frequently carried stories about the Cyrillids. Along the Chant trace, Mebane uncovered about two dozen stories of this kind by correspondence with editors of the local newspapers. He very kindly lent me his whole correspondence, including both positive and negative replies, and the results are plotted in Fig. 2, together with the Chant trace. As may be seen, a substantial fraction of the newspapers replying from these areas carried accounts of the shower.

Mebane's investigations, as can be seen from the figure, covered a strip some 200 kilometers wide, centered on the Chant trace. In Michigan and Minnesota, numerous accounts were found to have been published at a considerable distance from the trace, while in New York and Pennsylvania, accounts were found only in the immediate vicinity of the trace. The reason is clear: the New York and Pennsylvania areas were cloudy, and nearly all the accounts there refer only to the noises of the meteors. People in some of these localities never knew the cause of the noises; those in others had learned about the shower from the Buffalo papers before the local papers were published. The noises died out before the meteors reached New York City; the single New Jersey account (from Watchung, near Plainfield) is a visual report; here the shower was seen, apparently through a hole in the clouds.

I visited upstate New York and verified my ability to locate such stories by rediscovering several of Mebane's accounts; I even located several accounts which had been overlooked by editors who corresponded with Mebane.

Next, I visited the libraries of the state historical societies in Columbia, Mo., and Lincoln, Neb. I examined a total of 260 newspapers in these two places, with entirely negative results. Individuals recommended by the state historical societies in Nebraska, Iowa, and South Dakota were engaged to do further work, but all of their results were negative. In addition, Jesse Jameson of the State Historical Society, Wyoming, undertook to search the Wyoming files himself.

As shown in Fig. 2, all of these searches along the hypothetical path of the second revolution of the Cyrillids gave negative results, although in my opinion they were just as thorough as those along the Chant trace, and they involved many more newspapers. In a few cases, the search turned up a wire-service report from Buffalo referring to the passage over that city. These cases gave reassurance about the alertness of the searchers.

In a further effort to locate the second pass, a special request was made to the Weather Bureau Records Office, at Asheville, N.C., for a search of their records. The results of the search are shown in Fig. 3; the Weather Bureau had already made all of the positive

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Fig. 1. Observations of the Cyrillids to date.

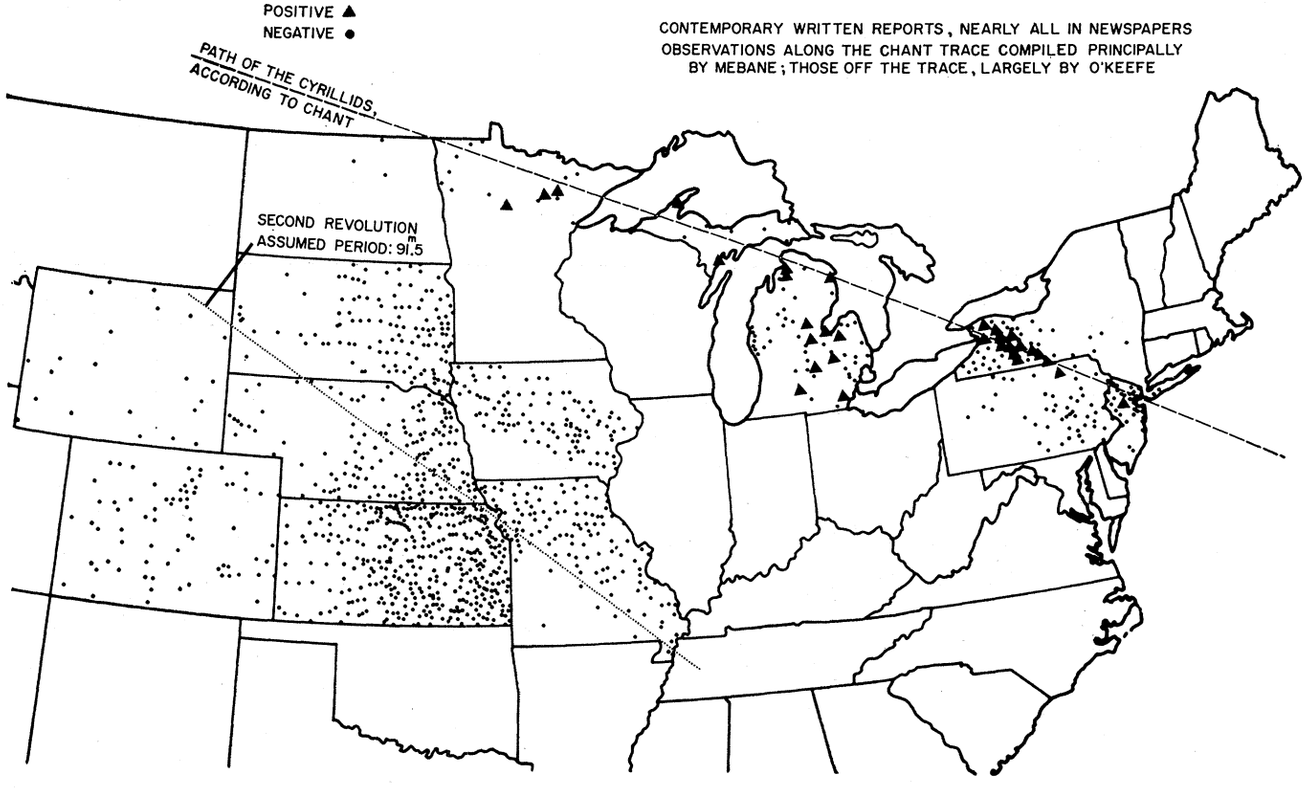

Fig. 2. Observations of the Cyrillids reported in local newspapers in the United States.

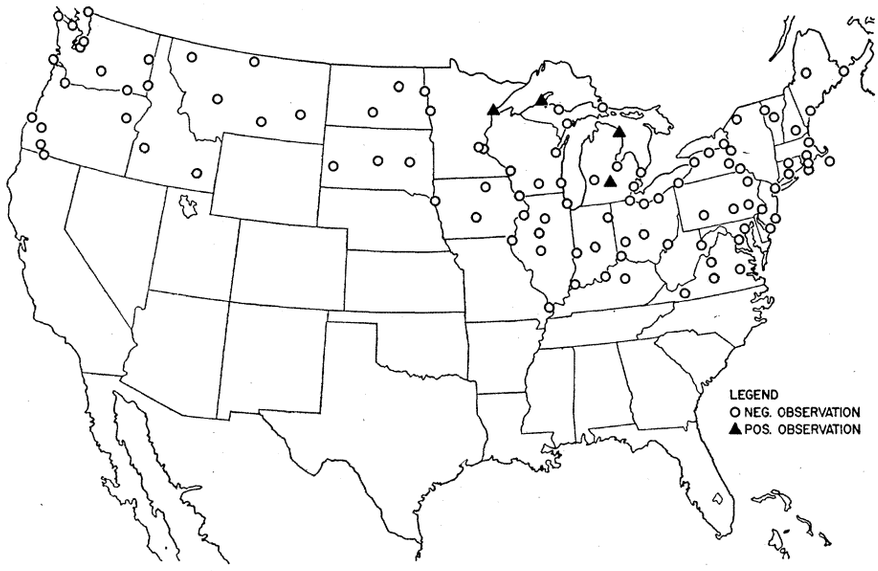

Fig. 3. Weather Bureau observations of the Cyrillids.

results available, either to Pickering (the ship observations) or to Mebane (the land observations), except for a precise and valuable account from Duluth. The Weather Bureau search covered the Pacific and the whole North Atlantic. It is clear from the results that the Cyrillids were visible only along the Chant trace.

As a final effort, an examination was made of some 200 metropolitan daily newspapers, filed at the Library of Congress, for the week of 9 February 1913 (see Fig. 4). Four accounts were located, three in Michigan papers and one in a Buffalo paper. Alertness in searching was indicated by the discovery in about 16 papers of reprints of the original reports carried by the wire services. In addition, accounts were found in New York and Philadelphia papers, for Saturday, 15 February, coming from ship observations allegedly made on 10 or 11 February. The latter were apparently misdated; the locations, however, were on or near the Chant trace at sea, so far as could be determined from crude accounts. The logs of these ships cannot be located. Whether or not the ship accounts are included, this homogeneous survey indicates once more that accounts of the Cyrillids cannot be found except along the original Chant trace. It demonstrates that the night of 9 February 1913 was not a night of general meteoric activity, as suggested by Hoffmeister and Wylie.

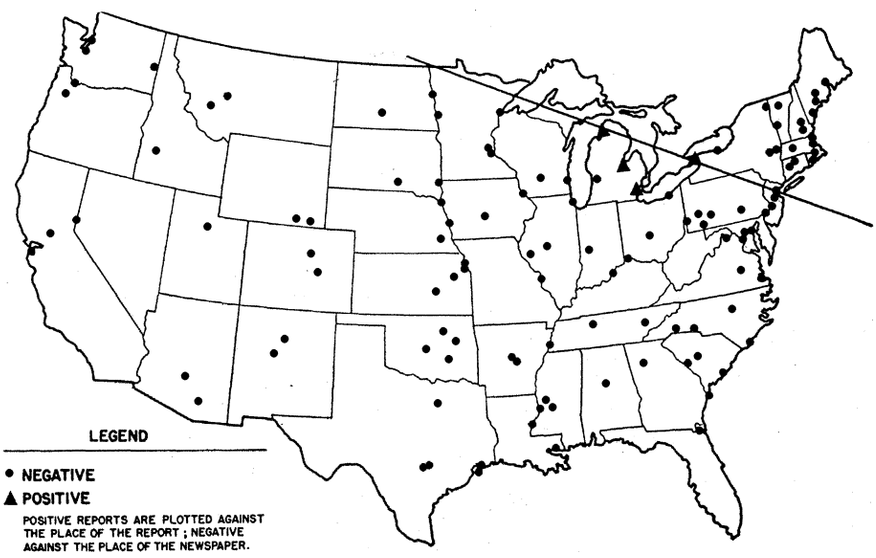

Fig. 4. Results of a survey of U.S. metropolitan newspapers in Library of Congress files (chiefly daily papers), made to locate accounts of the Cyrillid shower.

These observations exclude the possibility that a large display was made on the revolution following the one studied by Chant and the others (*3, 4*). They do not necessarily exclude the possibility of a minor display on the previous revolution. The display would presumably have occurred near the perigee point. From the manifestations which are available, it appears that the perigee point lay somewhere between the latitudes of Toronto and the Equator. The corresponding part of the previous revolution fell along a line from Labrador over the eastern Atlantic, in a region not much favored by British or American shipping.

From these observations we can conclude that there exists a mechanism by which bodies entering the atmosphere from a satellite orbit may fall in one or a few revolutions, without covering a complete band of latitude. Possible mechanisms are discussed below, but it is important to see that the existence of some such mechanism is a matter of observation, regardless of whether or not it can be explained.

Eccentricity of Orbits of Cyrillids and Tektites

It appears clear at once that the sharp cutoff of the Cyrillids implies that they had not been in orbit for a long time as separate bodies. If they had been, then the differences in drag between them would have caused a considerable number to survive into the next revolution. They probably became separated from the parent body at perigee on the revolution prior to the one on which they were observed.

In this case, the parent body must have had a measurable eccentricity. This follows from the fact that the daughter bodies would be expected to return to the same perigee height at which they were separated, and, at the same time, all daughter bodies would have shorter periods than the main body. If the main body had been in a very nearly circular orbit with a low perigee, any daughter body would fall to the earth at once. On the other hand, if the main body had a small eccentricity, say 0.02, then the daughter bodies could have a range in eccentricity from this value to zero, as shown in Fig. 5. With this choice of eccentricity, the range in period is about 3.3 minutes, a figure in agreement with the

statements of witnesses that the shower took about this long to pass a given point. Larger eccentricities are possible, but difficult to reconcile with the great length of the path and with the statements of witnesses everywhere that the path was nearly level.

The hypothesis of nonzero eccentricity for tektite orbits is also helpful in understanding the breadth of some of the strewn fields, such as the australite strewn field. Fenner (*8*) mentioned that if the australites had been derived from an event such as the Cyrillid shower, they would have had "a distribution much narrower than the observed" 2500 kilometers minimum width. If, however, the australites arrived in an orbit whose eccentricity was 0.5 or more, then the distribution can be understood. Suppose that the outermost ellipse in Fig. 5 represents the orbit of the main body on its last revolution. Inner ellipses represent the orbits of drops sprayed from the main body during its pass through the atmosphere on the previous revolution. These will all return at approximately the same perigee height, but the smaller bodies will precede the main body to perigee by amounts up to $P-90$ minutes, P being taken as the period of the main body and 90 minutes, as an approximation to the minimum value for the period of one of the smaller bodies. During the period $P-90$ minutes, the rotation of the earth will widen the strewn field by $(P-90)/4$ degrees of longitude. Since the actual breadth of the Australian continent is some 60°, it is clear that no very improbable values of P are demanded. Of course there would also be a spread along the orbit resulting from the range in drag coefficients among the droplets. The two ranges combined would yield the broad yet sharply cut off distribution which has been such a puzzle.

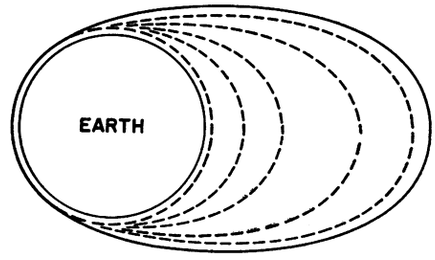

Fig. 5. Orbits of the Cyrillids. Solid lines, orbits of main body; dashed lines, orbits of daughter bodies.

History of Parent Bodies

A measurable eccentricity (and, even more, a large eccentricity) on the last revolution implies that the perigee of the orbit was low in the atmosphere—perhaps under 100 kilometers—throughout the history of orbital decay. This is a serious difficulty since only a small fraction of the particles ejected from the moon could possibly have initial perigee heights as low as 100 kilometers. A probable explanation is that the orbit was initially different, and that it was subjected to strong lunar perturbations, as would be the case with any body coming from the moon. The perturbations would continue for a considerable time, since the effect of a close encounter would be to change all parts of the orbit except the point of the encounter. Eventually, the body would either leave the earth-moon system, or strike the earth, or strike a low layer of the atmosphere. In the latter case, the effect of atmospheric drag would be to remove the apogee from the vicinity of the moon's orbit after only a few revolutions, and thereafter the evolution would be controlled by drag.

According to remarks made by A. H. Hibbs at the Goddard conference on meteorites and the moon, such perturbations manifest themselves strongly in the case of calculations made for lunar probes. Hibbs remarked that his calculations indicated that atmospheric capture is rare as compared to direct collision with the earth.

We must, therefore, as a corollary to the eccentricity of tektite orbits, accept the probable conclusion that most of the lunar material which reaches the earth does so not as tektites but in some other, not yet recognized, form. It is possible to understand how lunar material might escape attention even if it were of the same chemical composition as the tektites and more abundant. The composition of tektites is not sufficiently different from that of terrestrial material to attract attention. Tektites (Fig. 6) attract the attention of local collectors because they are glass and, especially in the case of the australites, because of their shapes and markings. Without these peculiarities, which are the result of arrival along a grazing path, it is likely that they would get by unnoticed unless an actual fall were observed. Even in that case their acidic composition would give the meteoriticists pause; the latter have to reject about a thousand objects for every real meteorite brought in, and they rely heavily on chemical composition as a guide.

It is also necessary to understand why there are so few small strewn fields, or none at all. If we remember that the energy available for the ablation of a body is its kinetic energy, which is pro-

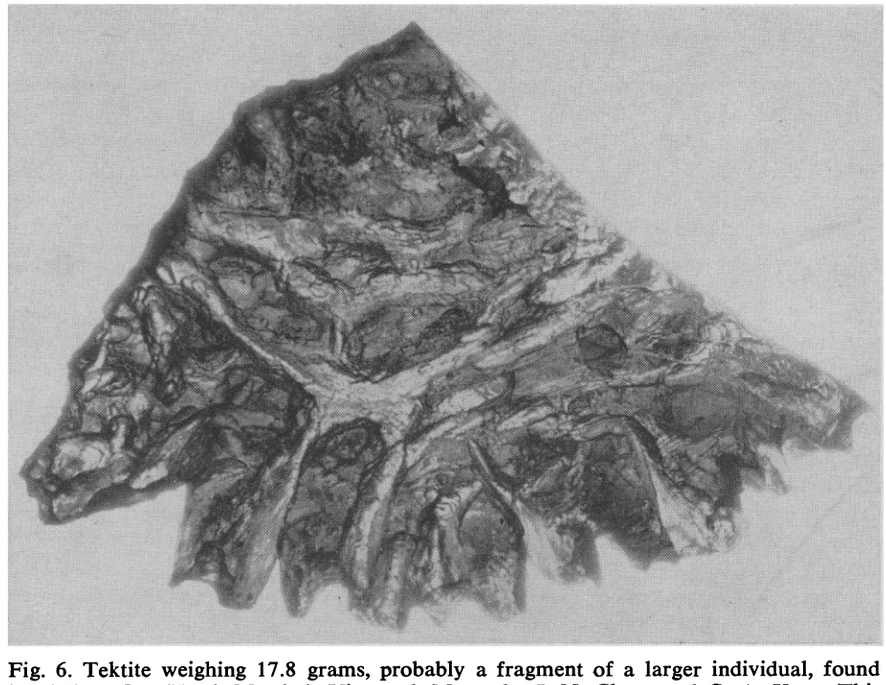

Fig. 6. Tektite weighing 17.8 grams, probably a fragment of a larger individual, found in 1959 at Gay Head, Martha's Vineyard, Mass., by J. N. Chase and C. A. Kaye. This specimen has been studied by the Smithsonian Institution, the U.S. Geological Survey, and the Massachusetts Institute of Technology (about × 2.1). [Smithsonian Institution]

portional to its mass, while the radiation from a body is proportional to its area, we see that, in principle, it should be possible for sufficiently small bodies to reach the earth after suffering relatively little melting. This line of reasoning is ordinarily applied to the micrometeorites, but it is clear that along grazing trajectories, where the heating is so much more gentle than in a typical meteor trajectory, the same reasoning may apply to very much larger objects. It is perhaps in this way that smaller chunks of lunar material manage to reach the earth's surface without being transformed into droplets.

In conclusion, therefore, it is found that the theory of a lunar origin for tektites can be reconciled with the criticisms of Urey and Barnes with respect to the distribution, but that to reconcile them requires us to assume, first, that the orbits are measurably eccentric; second, that the glassy form of the tektites is the result of atmospheric ablation; and third, that lunar material also reaches the earth in considerable quantity in some other, probably inconspicuous, form. The conclusion of Kopal, that some source nearer than the moon is required to account for the narrow distribution of the tektites, is valid in the sense that the breakup into separate bodies takes place in the earth's atmosphere (*10*).

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10. I wish to thank Kenneth B. Holmes of the Missouri State Historical Society, Donald F. Danker of the Nebraska State Historical Society, Edythe L. George of the South Dakota State Historical Society, Roy L. Fox, director of the National Weather Records Center, Asheville, N.C., and especially Alexander D. Mebane of New York City for kindness in supplying the information on which this article is based.

Science in the News

Kennedy's Program for Education: Teachers' Salaries; Construction; Scholarships

This week the President submitted to Congress what he described as a "modest program" for education. For the first year (fiscal 1962) it calls for spending about $700 million beyond the billion proposed in the Eisenhower budget, with built-in increases of $400 million each year for fiscal '63 and '64.

The program includes the two principal innovations Kennedy had committed himself to support: aid for teachers' salaries and a federal scholarship program. The amounts of money involved, though, are smaller than those in the bill that passed the Senate last year, and smaller still than those recommended by Kennedy's task force on education.

In general, the pattern of the education message follows that established by earlier proposals on medical care and minimum wages, to which Kennedy also attached the term "modest": he has compromised on dollar figures while holding out for innovations in principle.

The minimum wage bill, to the dissatisfaction of organized labor, abandons the request for an immediate raise from $1 an hour to $1.25, settling for an increase by steps over a period of 3 years; the medical care bill provides smaller benefits than those in the bill Kennedy and Senator Anderson sponsored during the rump session of Congress; the education bill asks for only about half as much money in the first years as the $1.5 billion a year measure that Kennedy's task force recommended. In each case, though, the really controversial point is less the dollar figures than a new legislative principle: in the case of minimum wage, an expansion of the definition of the Constitution's interstate commerce clause to cover not only businesses involved in interstate commerce but businesses merely "affecting" interstate commerce; this would cover just about every business of any consequence in the country. In the case of medical care, the new principle, of course, is the inclusion of health services under the social security system.

In the case of education, the point of controversy is money for teachers' salaries, with its clear implication, conceded by the Administration, that this involves a permanent commitment of the federal government (as opposed to a bill limited to school construction, which might be regarded as an emergency program to be terminated when the classroom shortage had been met).

In each case Kennedy is asking for expansion not merely of the amount of federal spending, but of the area in which the federal government will operate. Like the other major proposals, the education measure will face heavy conservative opposition both on the grounds that the expanded federal authority is unwise in itself and because once the new principle is accepted expansion of the program becomes virtually inevitable, even if the proposals for the first year or two are comparatively modest. The education program will almost surely pass the Senate without difficulty; indeed the Senate, as it did last year, will probably vote for a larger program than the President has asked for. But it will be quite a triumph for the Administration if it can get a bill granting money for teachers' salaries through the House.

Sam Rayburn, Speaker of the House, greeted Kennedy's message by announcing that he was still opposed to grants for teachers' salaries, and considering the close division in the House between liberals and conservatives that showed up in the vote on the Rules Committee, it is hard to see where