of an undifferentiated vocal repertoire which brought a new and important system of behavior within range of operant reinforcement through the mediation of other organisms (*20*).

Many efforts have been made to represent the products of both sets of contingencies in a single formulation. An utterance, gesture, or display, whether phylogenic or ontogenic, is said to have a referent which is its meaning, the referent or meaning being inferred by a listener. Information theory offers a more elaborate version: the communicating organism selects a message from the environment, reads out relevant information from storage, encodes the message, and emits it; the receiving organism decodes the message, relates it to other stored information, and acts upon it effectively. All these activities, together with the storage of material, may be either phylogenic or ontogenic. The principal terms in such analyses (input, output, sign, referent, and so on) are objective enough, but they do not adequately describe the actual behavior of the speaker or the behavior of the listener as he responds to the speaker. The important differences between phylogenic and ontogenic contingencies must be taken into account in an adequate analysis. It is not true, as Sebeok contends, that "any viable hypothesis about the origin and nature of language will have to incorporate the findings of zoosemiotics." Just as we can analyze and teach imitative behavior without analyzing the phylogenic contingencies responsible for animal mimicry, or study and construct human social systems without analyzing the phylogenic contingencies which lead to the social life of insects, so we can analyze the verbal behavior of man without taking into account the signal systems of other species.

Purpose, adaptation, imitation, aggression, territoriality, social structure, and communication—concepts of this sort have, at first sight, an engaging generality. They appear to be useful in describing both ontogenic and phylogenic behavior and to identify important common properties. Their very generality limits their usefulness, however. A more specific analysis is needed if we are to deal effectively with the two kinds of contingencies and their products.

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Luminous Phenomena in Nocturnal Tornadoes

The existence of unusual electrical discharges in the Toledo tornado is confirmed by a photograph and eyewitnesses.

B. Vonnegut and James R. Weyer

A primary and unsolved problem concerning the tornado is that of accounting for the extraordinary speed of its winds, which, according to recent evidence (*1*), may reach 200 meters per second. On the assumption that the winds of the tornado are the result of temperature contrasts between air masses in the atmosphere, one of us (Vonnegut) has calculated (*2*) that a chimney of air extending to the stratosphere would have to be at least 100°C warmer than its surroundings in order to produce such speeds. Fulks (*3*) has considered the problem on the basis of the estimated decrease in pressure in the tornado funnel and has come to the similar conclusion that "there is some means of creating large temperature differences." It is not difficult to account for the tornado-like whirlwinds that commonly accompany large fires (*4*) or volcano eruptions (*5*), for here there are unquestionably volumes of intensely heated air. It is much more difficult, however, to explain how such thermal contrasts could arise in a thunderstorm. The rate of energy production in a large thunderstorm is ample to power a tornado. The problem, as Abdullah has pointed out (*6*), is to explain the process by which a portion of the energy becomes concentrated in the tornado vortex.

A possible explanation that has been proposed (*7*) for the anomalous high-energy density in a tornado is that the tornado may derive some of its energy from the intense electrification of the tornado-producing thunderstorm, which has been estimated to be equivalent

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to a power of about 10^8 kilowatts (*8*). According to this mechanism, a portion of the tornado energy might be generated by the acceleration of air under the influence of electrical forces or by the heating of air produced by electric discharges.

Although most scientists concede that the tornado-producing storms are unusually active electrically (*9*) and that some eyewitness observations indicate luminous electric activity near the tornado, they have been reluctant to entertain the electrical explanation seriously because of the lack of good objective evidence for the presence of energetic electrical processes near the tornado funnel.

What we regard to be important new evidence was obtained on the evening of 11 April 1965. At about 9:30 p.m., one of us (Weyer), noticing spectacular lightning to the south of his home in Lambertville, Michigan, set up a 35-millimeter camera loaded with black-and-white film and took a series of photographs. To minimize vibration he used a guillotine exposure technique; that is, he held his hand in front of the lens, opened the camera shutter, and then when the first glimmer of lightning occurred made an exposure by lifting his hand. After a few seconds he terminated the exposure by lowering his hand in front of the lens and closing the shutter. With this method, it was necessary for him to keep his eyes on the camera, but although he could not see the lightning flash directly, he could detect it by peripheral vision.

A short time after the sequence of photographs had been taken, it was learned that tornadoes were sweeping a path of destruction through Toledo, Ohio, 6½ kilometers (4 miles) to the south, at about the same time. The next day, when the photographs were processed, it was found that one frame (frame 11, Fig. 1) showed no lightning sparks but, instead, two diffuse, almost vertical regions of brightness. (We believe that the bright spot at the left of this frame is the result of illumination from the window of a room adjacent to that in which the camera was set up. The patches of very bright light near the horizon are porch lights.)

The curious phenomenon captured in the photograph appears to be worth investigating from a scientific point of view, for the time and position of its appearance suggest that it may have been associated with the tornadoes. Furthermore, there are points of similarity between the phenomenon shown in the photograph and various luminous phenomena that have been described accompanying other tornadoes.

Photographic Data

The data concerning the photographs are as follows. The camera, a Honeywell Pentax with a 28-millimeter wide-angle lens set at *f*/5.6 and loaded with Tri-X film, was placed on the sill of an open window of a darkened room whose doors had been closed. We are unsure of the length of the exposure but estimate it to be between 1 and 5 seconds. A total of 15 exposures were made. In frames 2 to 6, the camera was pointed to the west. In frame 11

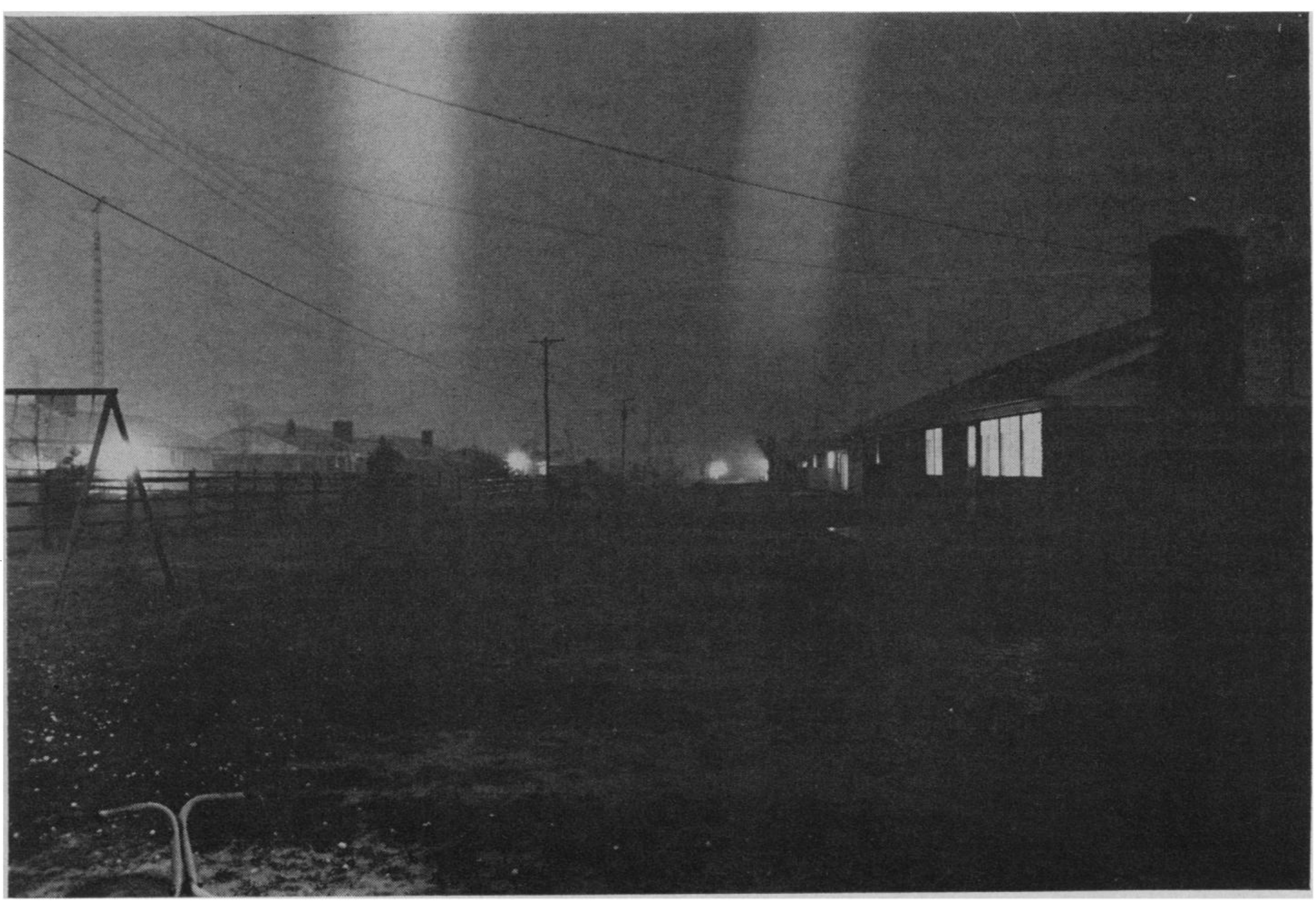

Fig. 1. Photograph showing unusual illuminated vertical pillars observed at the time of the Toledo tornado of 11 April 1965.

and in the four preceding frames the camera was pointed south, and in frames 12 to 17 it faced north. All the pictures in the sequence show illumination that is doubtless due to lightning, and frames 13, 14, and 15 show clear, well-defined lightning discharges.

The horizontal angle subtended by all of the photographs is 57 degrees. From the location of the houses and power lines showing in Fig. 1, we have determined the orientation of the camera and have indicated the field of view by the shaded triangle on the map in Fig. 2. We have indicated by the unshaded areas within the triangle the azimuths of the bases of the two bright pillars shown in Fig. 1.

From some eyewitness reports and from portions of the paths of destruction, it appears that at least part of the time there were two tornadoes that followed more or less the same path. The checkered arrow in Fig. 1 illustrates the approximate path of the tornadoes as determined by the areas of destruction. It can be seen that the azimuths of the two bright pillars in the photograph were close to the positions where the damage began.

The two bright regions in the photograph on the same azimuths as the tornadoes gave rise to the question of whether there were any eyewitnesses to these or other luminous phenomena. By interviewing people who lived close to the tornado paths and by soliciting information through local newspapers and radio and television stations we obtained over a dozen eyewitness accounts, many of which indicate various kinds of luminosity, presumably of an atmospheric electrical origin. We have selected the more interesting portions of these descriptions and have arranged them in sequence from west to east along the tornado paths. The position of each observer is indicated by the corresponding letters on the map in Fig. 2.

A. The twister came through here up high. From southwest to northeast. . . . There was hard wind. I was outside. Suddenly there was no wind. My eardrums felt like they would burst, very intense. I heard a far away roar and at the same time it was all around me. . . . Then a great wall of white came. There was hard wind and all white. I could not see through the white. There was very little damage here (*10*).

B. The lights went off. . . . The tornado struck and as the windows blew in, the place lit up just like daylight even though there was no electricity (*11*).

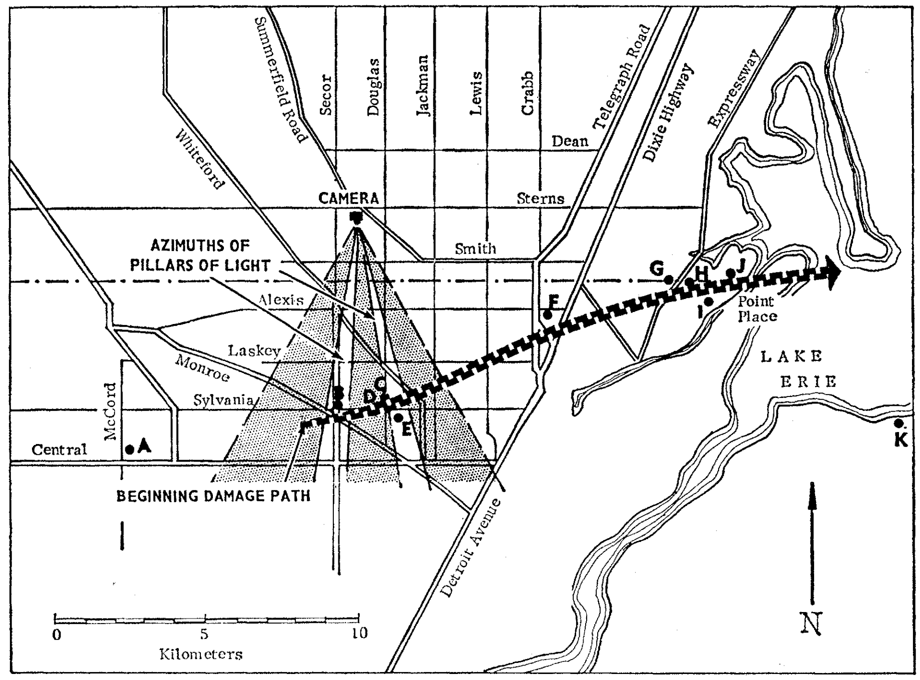

Fig. 2. Map of parts of Toledo and Oregon, Ohio, and Lambertville, Michigan, showing the field of view of the camera, the location of the pillars shown in Fig 1, and the approximate path of the damage caused by the tornados. For key, see text.

C. Just after the tornado struck, I was inside of the house looking out. I saw something very bright about the size of a basketball about six feet away from me and about five feet off the ground. It was white, blue and yellow in color and coming slowly toward me . . . at less than the speed a person would walk. . . . when it seemed to hit the door, it made the door sound like it was singing (*12*).

When the tornado struck, there was a big boom just like a bomb. There was fire around, probably from a power line that came down . . . There were also lights of different kinds of colors mixed up in the clouds (*13*).

D. . . . suddenly it turned white outside. This whiteness definitely was NOT fog. I would say it appeared to be giving off a light of its own (*14*).

E. My husband and I went out into our back yard and watched it pass through about three blocks over. . . . The phenomenal thing about it was the streaks of lightning in the cloud itself. They were shooting straight ahead like arrows (*15*). [See Fig. 3 for illustration furnished by this witness.]

F. We were shaken up and our trailer along with others was dented badly from hail the size of baseballs. The beautiful electric blue light that was around the tornado was something to see, and balls of orange and lightning came from the cone point of the tornado. The cone or tail of the tornado reminded me of an elephant trunk. It would dip down as if to get food then rise up again as if the trunk of an elephant would put the food in his mouth. While the trunk was up the tornado was not dangerous, just when the point came down is when the damage started. My son and I watched the orange balls of fire roll down the Race Way Park then it lifted and the roof came off one of the horse barns. The second tornado or twin at the same time damaged a factory badly plus the Toledo Scale Co. and Glass Bowl Lanes (*16*). [See Fig. 4 for illustration furnished by this witness.]

G. The storm hit unexpected—all sorts of things were falling about. The most interesting thing I remember is a surface glow—some three or four feet deep—rolling noise etc. . . . there was sort of a general brightness for a few seconds—some static on radio etc. (*17*).

H. We thought we saw searchlights all around us, but there were no light beams shooting up to the clouds from the ground. The lights darting around in the clouds were sort of luminous and appeared to be more round in shape than anything else, also they were quite large. The lights were not as bright as a stroke of lightning, but they were above a dense layer of clouds, and bluish white in color. . . . they were shooting around. We could see the lights in the west, northwest, north, and northeast from 8:00 p.m. on. . . . We did not have much stroke lightning and I do not recall hearing thunder. Our electricity was knocked out at 9:32 p.m., and that is when we saw one black funnel. The reason we could see it is because there was a slight glow coming from the sides of it. It came from due west (*18*).

I. There was very bad crackling static and I could not get anything on my transistor radio. . . . I was facing West side of the house at the time of the tornado, when all of a sudden the lights of the house started blinking and blinking for about 5 minutes. Then when I looked out I saw the lightning coming closer and closer to the house and it was very low instead of high like I saw before. Then all around me was red flashing lights constantly right in my kitchen. Then all the windows started to come out (*19*).

J. It was 9:30 p.m. . . . I went to the back door . . . and all I could see was this huge reddish yellow light, making the remark, "It looks like some one's house is afire." I turned around and that was the last I knew (*20*).

K. I was standing in my backyard about 9:00 p.m. looking at the sky toward the west to north about 15°. The sky was really black . . . All at once a big hole opened up in the sky with a mass of cherry red. The opening looked about ¼ mile long and about the same height. It had a yellow tinge in the center and the edges were a darker cherry red with black spots in the edges. This opening opened up complete in about 6 seconds, stayed open about 10 to 12 seconds then closed in 6 seconds. The sky was completely black again. It was about 30° to 35° up. [The following part is in reference to the drawing furnished by this witness shown in Fig. 5.] The black spots that I referred to were small portions of dark clouds like balls, just a few on the right of the sketch and the lower left. They were rolling some, always working toward the outer sides. The cherry red had some vibration to it, very little. The upper center . . . had a very fast quiver. Also a motion like hot steel melting in a pot. This motion was very small but fast (*21*).

Discussion of Photograph

The close association in time and azimuth of the phenomena shown in the photograph and the tornado, coupled with the accounts of luminosity along the tornado path, indicate that we may be justified in assuming that the luminous phenomena in the photograph were at about the same distance from the camera as the tornado. On this assumption, it can be calculated that the bases of the luminous pillars are approximately 500 meters in diameter. If it is assumed that the pillars are vertical, then their altitude at the top of the photograph is a little more than 2 kilometers.

According to observations made at 9:00 p.m. by the U.S. Weather Bureau at the Toledo Airport (about 20 kilometers southwest of the beginning of the paths of destruction), the elevation of the cloud ceiling was about 4 kilometers. It is therefore possible that the bright pillars may have extended down from a cloud base that would probably have been somewhat above the level of the top of the photograph. It is of course also possible that they may have come from the side of the cloud or conceivably even been independent of any cloud at all.

There appear to be several possible explanations for the columns of light shown in Fig. 1. They may be two tornado funnels illuminated externally by lightning; they may be some kind of luminous electrical discharge; or they may be tornado funnels illuminated by lightning or some other kind of electrical discharge within the vortex. We doubt the first of these possibilities on the grounds that if there were external lightning capable of illuminating the clouds, we should see evidence of illumination on the ground or objects in the foreground. Thus we are inclined to favor either of the two latter explanations.

We do not know whether the two bright regions were illuminated steadily or only briefly by momentary flashes. If the illumination was steady, it must have been fairly dim, and the actual width of the pillars may have been somewhat less than it appears to be in the photograph, which would probably have been smeared because of motion of the pillars during the exposure.

The change in illumination that presumably prompted the termination of the exposure may well have been a change in the luminosity of the funnel, but it could equally well have been the result of lightning flashes elsewhere that were evidently still taking place. Since frame 11 was the last one to be taken looking in a southerly direction, where the tornadoes were in progress, we have no photographic evidence on which to judge whether the luminous pillars continued and moved by or whether they were only a transient phenomenon.

We have given some thought to the possibility that we might extract quantitative information from the photograph concerning the brightness of the luminous pillars. However, we have decided that data obtained in this way would be of doubtful value in view of the uncertainty in the duration of the exposure and of the luminosity. It seems from comparisons between the brightness of the pillars and the brightness of the lights in the windows of nearby homes that the pillars were not particularly bright.

The two bright pillars shown in the photograph bear some similarity to atmospheric phenomena that have been described elsewhere (*22*). For example, the photograph may illustrate the phenomenon designated by the Latin word *prester*, defined as "a fiery whirlwind that descends in the form of a pillar of fire" (*23*).

There are several descriptions, by apparently well-qualified observers, of luminous phenomena associated with tornadoes that seem to be similar to that shown on the photograph. For example, Peltier (*24*) quotes a description of a tornado by M. Debrun: "It was of a grayish hue and was traversed from top to bottom by a tube as luminous as the moon." More recently,

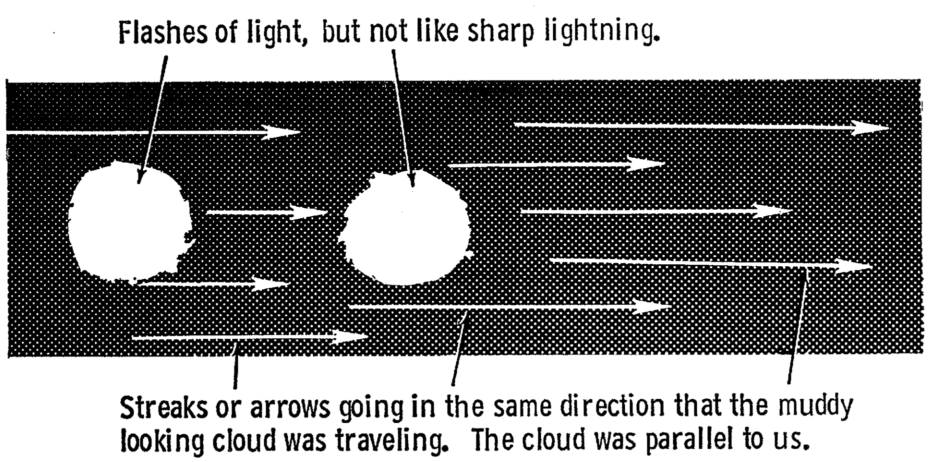

Fig. 3. Drawing of her observations furnished by Mrs. Kenneth E. Pyle (witness E). [Black-and-white rendering by J. Tolford]

W. S. Houston observed an apparently similar phenomenon from Champaign, Illinois, on a summer afternoon in 1942 (*25*):

> I was looking . . . up at the clouds when I saw something that looked like a searchlight beam extend out of the cloud and reach to the skyline. It seemed a bit brighter than the cloud background. Edges were sharp, overall intensity even, sides parallel. Width about a degree of arc. No movement or turbulence evident. The phenomenon was interesting enough so I took out my Polaroid glasses and observed this "ray" through them, twisting the lens to look for polarization. No polarization was noted. This ray was obvious enough so that passerbys on the street were staring at it. All this took, say, 60 to 120 seconds (or more). Then abruptly the ray was instantly replaced by a normal tornado funnel. No transition stage was noted. The funnel *did not* descend from the cloud layer. It appeared over all, in situ. At this time I was a student at the Army Weather School at Chanute Field.

The phenomenon as described by Houston seems quite similar to that shown in Fig. 1 except that it was seen by day instead of at night, there was only one bright region instead of two, and the angle subtended was only 1, instead of 5, degrees of arc.

Although there are, as far as we know, no other photographs of a luminous tornado funnel, there is the drawing according to Hall (*26*), shown in Fig. 6, which may illustrate a similar phenomenon. Here again there is an illuminated pillar, in this case quite clearly shown to be a hollow funnel cloud, illuminated from within by some variety of rather brilliant electrical phenomena. The estimated diameter of Hall's cloud appears to be about one-fourth that of the luminous pillars shown in the photograph.

A very recent account of a tornado including a mention of luminosity is that of D. B. Munro of the U.S. Weather Bureau near Jackson, Mississippi. He says, concerning the tornado that occurred during the late afternoon of 3 March 1966, that several observers commented that the funnel appeared to be lighted from the inside (*27*).

Discussion of Observations

Scientists investigating the luminous effects that are sometimes observed to accompany tornadoes face several difficulties. Because of the rarity and unpredictability of tornadoes, they must of necessity rely heavily on observations made by untrained observers, often during periods of great stress. Furthermore, most tornadoes occur during the daylight when it may be difficult or impossible to see the luminosity of an electrical discharge.

These difficulties are further compounded because the phenomena at-

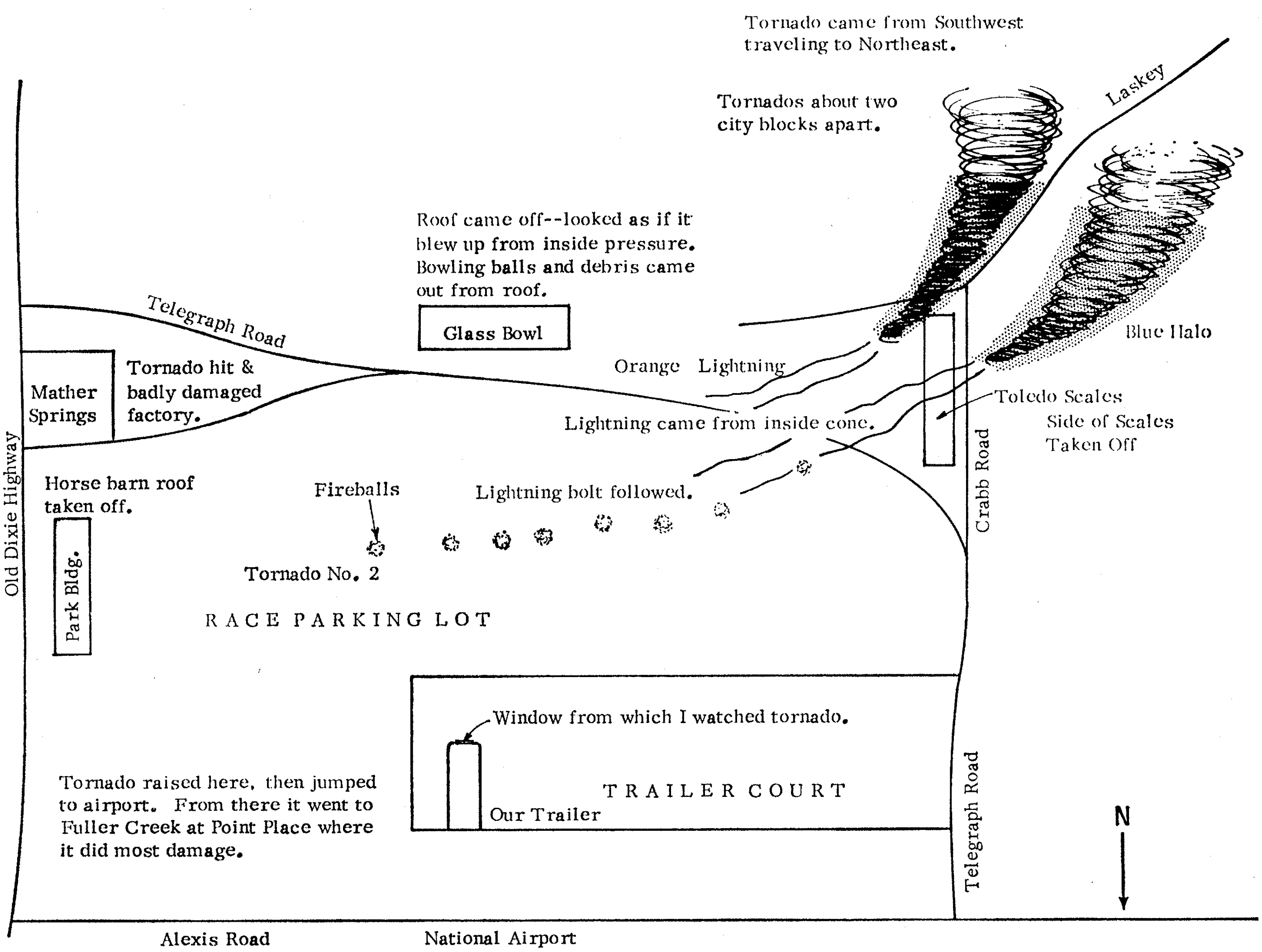

Fig. 4. Map showing her location and the appearance of twin tornadoes, furnished by Mrs. L. R. Highiet (witness F). [Black-and-white rendering by J. Tolford]

tending the tornado are sometimes so bizarre that they often tax the credulity of scientists accustomed to the ordinary variety of weather phenomena. There is reason to believe that some tornado observations may have been subject to a kind of scientific censorship. This is evident from the following note that an editor of a meteorological magazine felt obliged to insert beneath an article that presented a particularly lurid description of a tornado (*26*, p. 65):

> Except to shorten some less important details, no attempt has been made to edit this eyewitness account to obtain more complete consistency and agreement with general meteorological theory."

Astounding though the Toledo eyewitness reports may be, we believe them to be reliable, for they seem consistent with the photographic evidence and are similar in many respects to previous descriptions of tornadoes. Machiavelli, for example, describes violent luminous displays that occurred during a tornado in Italy in 1456 (*28*), and modern, experienced, and scientifically qualified observers report the same kinds of phenomena. Floyd Montgomery (*29*), a U.S. Weather Bureau observer in Blackwell, Oklahoma, has stated, "As the funnel was east of me, the fire near the top of the funnel looked like a child's 4th of July pin wheel." Montgomery (*30*) has also provided the sketch shown in Fig. 7, which in some respects resembles that shown in Fig. 4. The bright area of illumination described by Willett, and illustrated in Fig. 5, may be similar to the "circular patch of light on the side of the cloud structure" that has been reported near tornadoes by Jones (see *31*).

Another example is W. Hiser's account (*32*) of what he saw during the Miami tornado of 17 June 1959:

> [The] lower extremity [of the funnel] was continuously illuminated with a blue-green light flashing like an electric welding torch. A part of this was no doubt produced by the tornado disrupting . . . power lines . . . However, the tornado was associated with a thunderstorm which had an extreme amount of electrical activity with almost continuous cloud to cloud and cloud to ground lightning strokes . . .

Recent observations of tornadoes in France that have been reported by Dessens (*33*) parallel some of the observations of the Toledo eyewitnesses. In his tabulation of French tornadoes, Dessens notes reports of ball lightning and a red column and states, "It is indeed undeniable that often (about one time out of two, according to the above table) either the tornado is furrowed by lightning or the bottom of the tornado "vomits" balls of fire, or in short, the tornado is luminescent at one place or another."

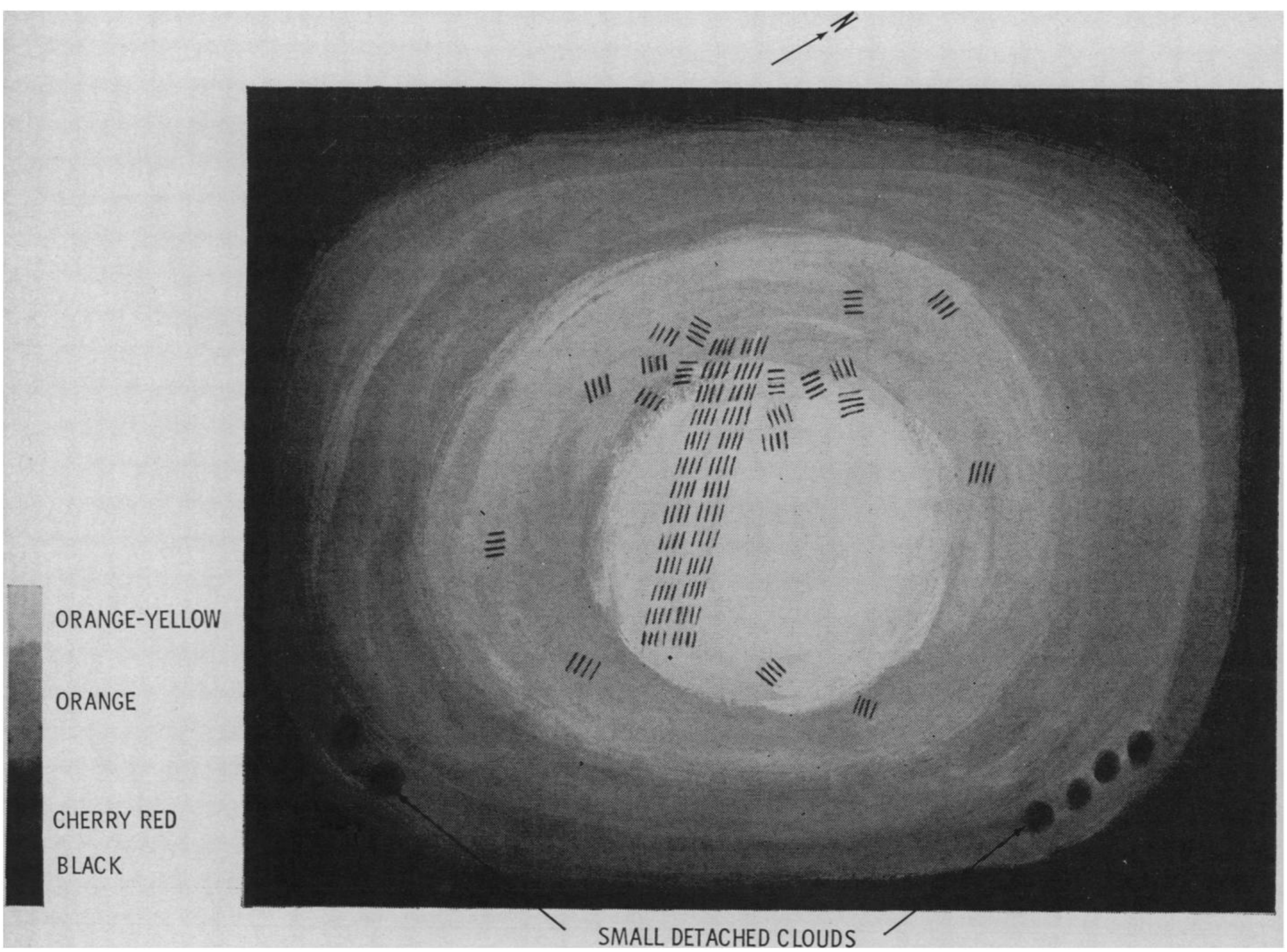

Fig. 5. Drawing furnished by Myron Willet (witness K), showing appearance of luminosity in sky. [Black-and-white rendering by J. Tolford]

Electricity and Tornadoes

The weight of evidence indicating the presence of extraordinary electrical activity in some tornadoes has now reached the point that the question to be answered is no longer whether unusual electrical activity occurs but instead what is its origin, nature, and role in the tornado. In previous discussions one of us (*34*) has shown that a vortex can have a stabilizing effect on a high-voltage electrical discharge and has considered three classes of explanations for the association between tornadoes and electricity; (i) that the association was fortuitous; (ii) that the tornado produced the electricity; and (iii) that the electricity produced the tornado. Unquestionably, there is no single, simple explanation, for there is a wide variety of tornadoes, and the role of electrification varies from one storm to another. For example, during the vigorous whirlwinds that were observed to accompany the phreatic eruptions of volcano Surtsey, there was also electrification as evidenced by occasional lightning discharges (*35*). However, all the evidence suggests that this association was fortuitous. A calculation shows that the volcano was producing electrical power of about 100 kilowatts and this appears to be far too little to account for the whirlwinds. There seems little doubt that electrical energy was only of secondary importance in these whirlwinds, for they often continued even when there seemed to be very little electrical activity. It is even possible, as Wilkins (*36*) has demonstrated by laboratory experiments, that under some conditions, instead of promoting a vortex circulation, an electric discharge can have an inhibiting effect.

In some circumstances, the tornado very probably serves as a strong electrical generator. Quite frequently tornado winds stir up heavy clouds of dust particles from the ground or spray droplets from bodies of water. These particles or droplets without a doubt are sometimes highly electrified, and when they are carried up by the air moving into the tornado funnel, this flux of charge constitutes a vigorous electrical charging current. That such a process can take place is demonstrated by Freier's observations (*37*) of the electrification that takes place in an ordinary dust devil. A related phenomenon has recently been reported by Lavan and Fejer (*38*), who observed in laboratory experiments that the low-pressure region of a supersonic vortex of air can become luminous under the influence of the electrical discharges resulting from the electrification of condensed water drops.

A third explanation for the electrical effects observed with tornadoes is that the electricity may somehow be giving rise to the tornado. A number of possibilities have been discussed. For example, Lucretius (*39*) suggested that the tornado was heated by lightning. Hare (*40*) and Peltier (*41*) suggested that the tornado was an electric wind. Rathbun (*42*) suggested that the electromagnetic forces started the tornado rotation, and Silberg (*43*) and Carstoiu (*44*) have suggested that magnetohy-

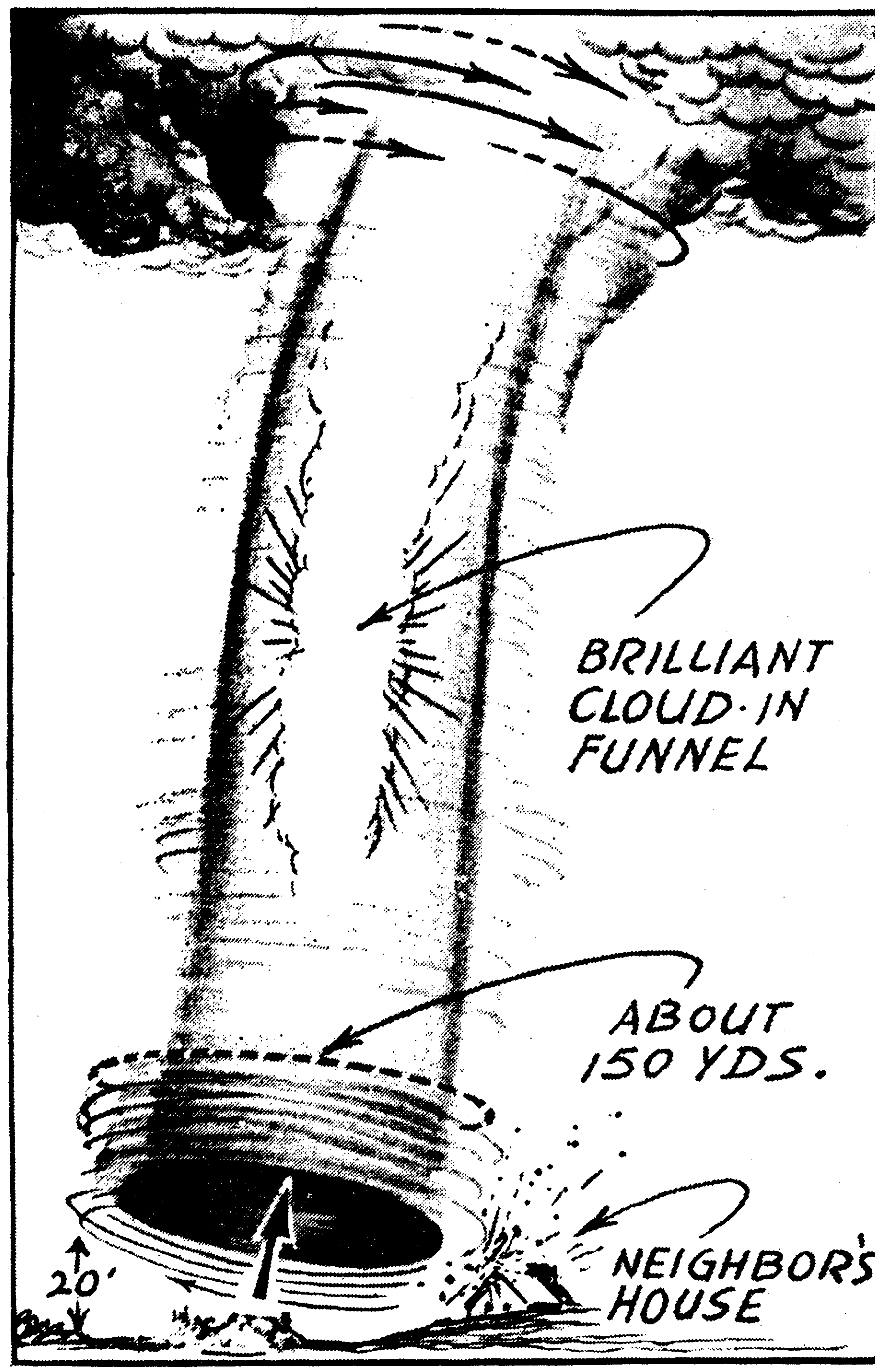

Fig. 6. Appearance of McKinney, Texas, tornado of 1948 according to Roy S. Hall (*25*, p. 65). The tornado funnel is "considered transparent for illustration purposes, and shown as if the observer had been off to one side instead of beneath it."

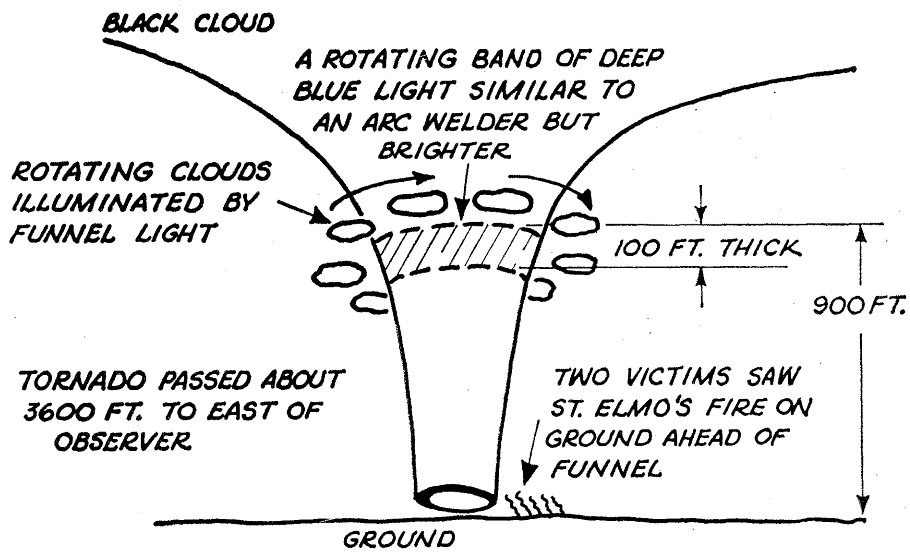

Fig. 7. Appearance of Blackwell, Oklahoma, tornado of 25 May 1955 according to Montgomery (*30*).

drodynamic phenomena may be of importance in the tornado vortex.

An appealing feature of the idea that thunderstorm electricity may provide some of the energy for the tornado is that it provides an explanation for the very high concentration of energy observed in the funnel. On the basis of this idea, electrical energy generated by the storm can be brought together and released in a relatively small volume of the atmosphere. Brook and Vonnegut (*45*) have pointed out that through the action of horizontal lightning discharges bridging many convective cells, electrical energy derived from storm systems having dimensions of 100 kilometers or more can be concentrated and released at a single location.

It is evident that some tornadoes, such as those that devastated Toledo, Ohio, on 11 April 1965 are veritable museums of unusual electrical discharges, including ball lightning. It appears that the phenomena taking place constitute an important class of atmospheric electrical phenomena and that our knowledge of atmospheric electricity and of thunderstorms will be incomplete until we understand the nature of these discharges, the magnitudes of the electric fields that prevail, and the electric currents that are flowing.

In approaching the scientific and practical problems posed by the tornado, it is important to determine whether the electrical activity is an unimportant by-product of the storm or whether it is sometimes a source of energy that is of importance in establishing or maintaining the tornado circulation. Possibly the most direct method of answering this question will be to make temperature measurements in the tornado. If electrical energy is a significant item in the budget of the tornado, we may expect to find local updrafts of air that have been heated 50°C or more by electrical discharges. Air temperatures could be measured by several techniques, such as the use of large numbers of inexpensive, recoverable probes that would be sucked up into the tornado or of instrumented drone aircraft or rockets that could be directed into the storm.

It is desirable that the electrical currents flowing in the tornado be measured. This might be accomplished by current-density determinations made either from the ground beneath the tornado or in the air above the tornado-producing cloud. Clues to the magnitude and nature of the electrical currents that are flowing might also be determined by electric, magnetic, and electromagnetic field strength measurements.

Fujita (*46*) has shown in his classical studies how it is possible from a detailed scientific analysis of photographs to learn much about the circulation of the tornado and the tornado producing storm. If the help of the general public can be enlisted to obtain detailed still and ciné photographs of the luminous activity accompanying the tornado, it may similarly be possible to secure valuable qualitative and quantitative information concerning the electrical activity that is taking place.

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47. We are indebted to the eyewitness observers of tornadoes for their descriptions; to Leroy Bruner, science editor of the Toledo *Blade*; Art Barrie, of radio station WSPD; Joe Gillis and Bruce McLaughlin of television station WTOL-TV; Chase Clements and David Drury of television station WSPD-TV, for help in locating eyewitnesses; and to Arthur D. Little, Inc., the NSF, and the ONR, whose support made this work possible. We appreciate the many constructive suggestions offered by M. Brook, E. M. Brooks, E. Dewan, P. R. Leavitt, and C. B. Moore during the preparation of the manuscript and the invaluable help of associates at Arthur D. Little, Inc.