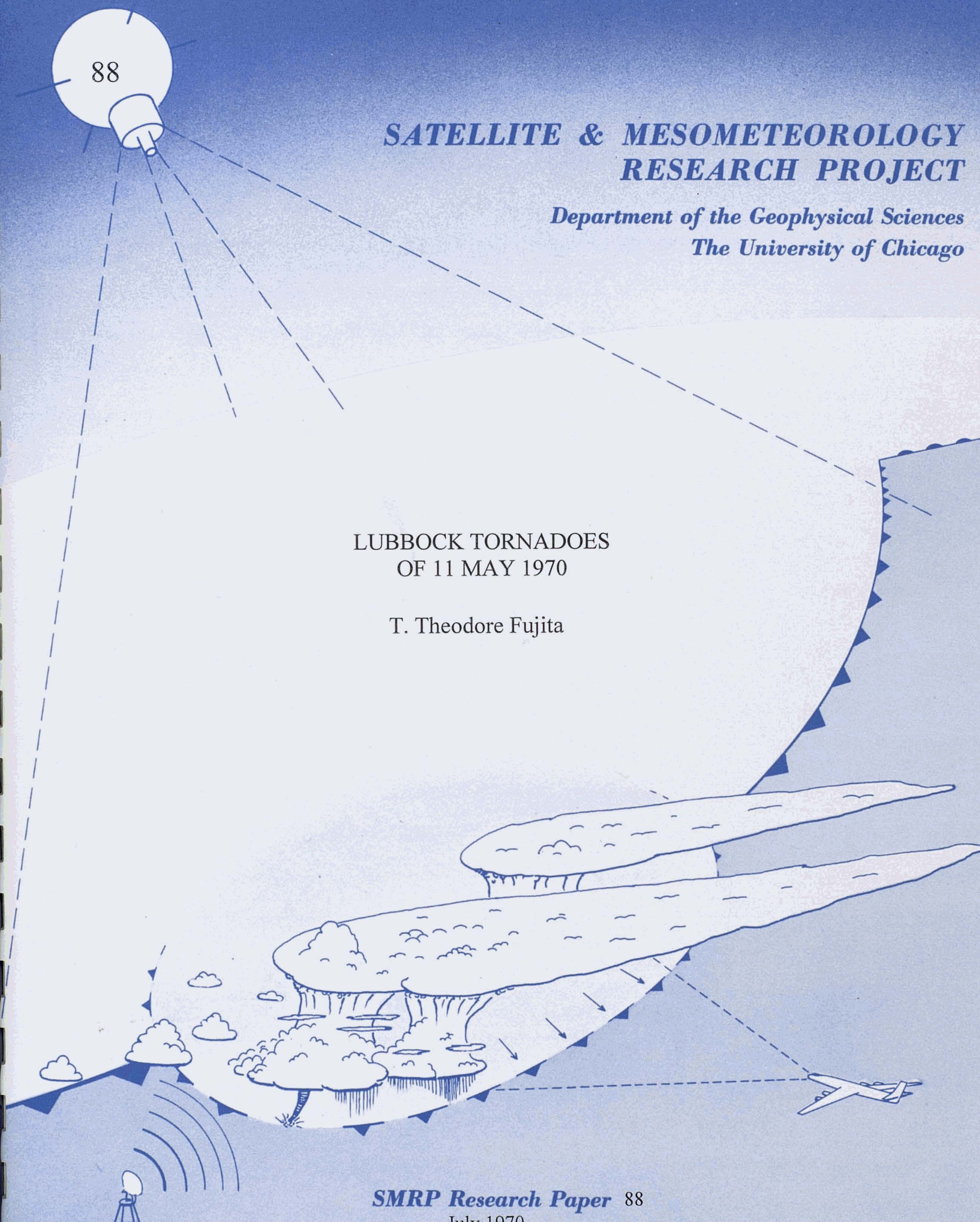
**SATELLITE & MESOMETEOROLOGY RESEARCH PROJECT**

***Department of the Geophysical Sciences***
***The University of Chicago***


# LUBBOCK TORNADOES OF 11 MAY 1970

T. Theodore Fujita


***SMRP Research Paper*** 88
July 1970

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by

Tetsuya Theodore Fujita

(Preprint of draft to be published in Weatherwise)

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# LUBBOCK TORNADOES[1]

Tetsuya Theodore Fujita
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After 70 years of immunity, Lubbock, Texas, a city of 170,000, was hit by two tornadoes on 11 May 1970; a small one at about 8:45 pm CDT and a giant one around 9:45 pm CDT. The latter one left a path of devastating damage between the downtown area and Lubbock Municipal Airport. According to the latest statistics of severe local storm occurrences by ESSA (1969), there have been 49 verified tornado occurrences in the $1^{o}$ square around Lubbock in the 13-year period 1955-1967 and 54 in the $1^{o}$ square around Amarillo. The area between these two cities reported a much greater frequency of tornado occurrences.

## First Tornado, A Small Forerunner

A funnel cloud related to the first tornado was reported by an off-duty policeman at 8:10 pm; meanwhile, a small hook echo was detected by the WSR-1 radar at the Lubbock Weather Bureau station. The hook echo was tracked by the radar until 8:45 pm when a funnel cloud was reported 3 miles east of the city limits (Fig. 1). The first tornado appeared to be a forerunner of the second and was strong enough to blow down fences and billboards in directions indicating a cyclonic circulation. The width of the damage caused by estimated 75 mph gusts was about 2 miles. The strongest wind inside this tornado occurred as it moved over the U. S. 82 and Parkway Drive interchange. According to the Lubbock Avalanche Journal, "At this site, 13 beams, weighing 109,000 pounds each--each in place with a concrete dowel and doubly weighted with claims--blew from atop the overpass under construction." The size of the damaged concrete structure is seen in comparison with a man standing in the picture (Fig. 2). When an aerial picture of the overpass is examined in detail, it becomes evident that the damage is not uniform to all 35 beams. Instead, the 13 affected beams happened to be

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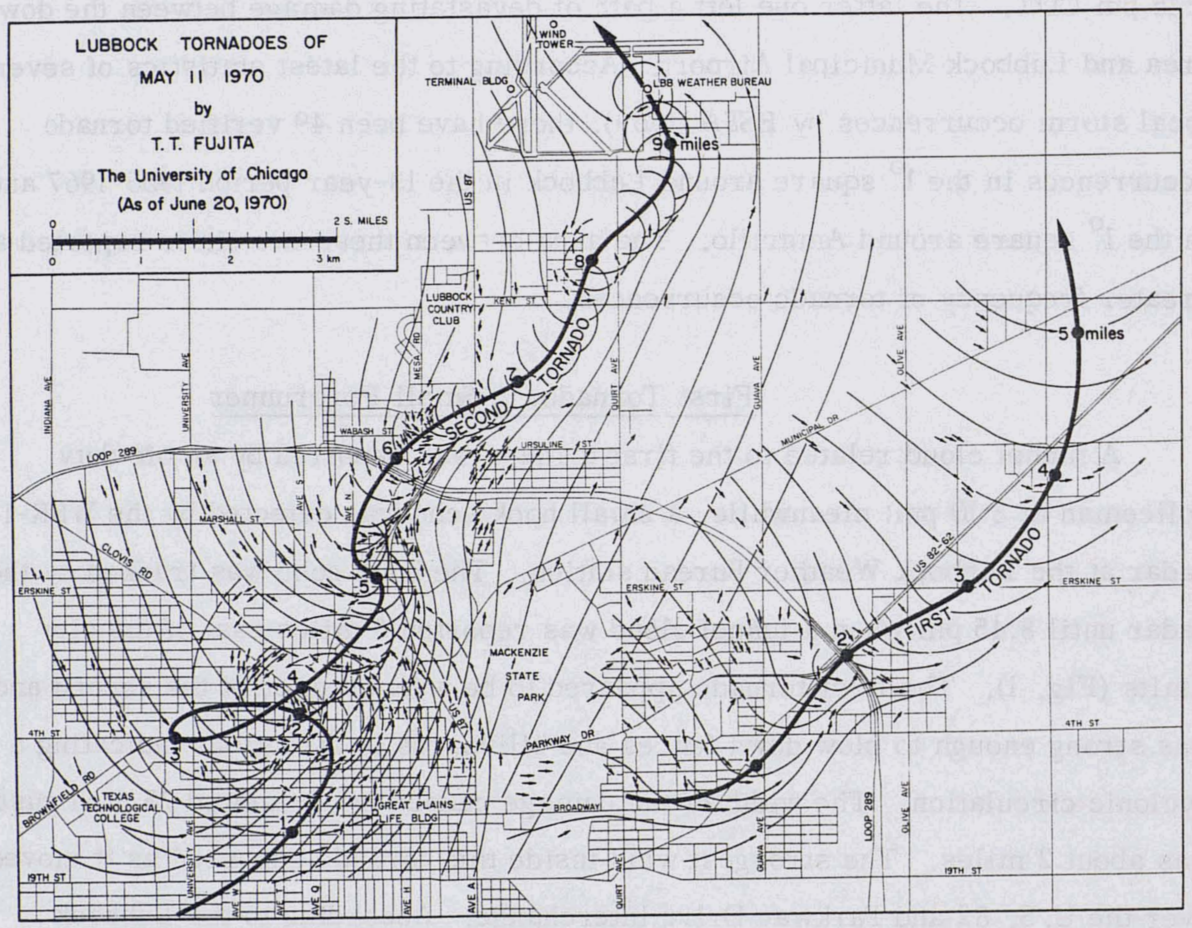


Fig. 1. Paths of two Lubbock tornadoes with distance traveled in miles. The first tornado moved over the northeast section of the city between 8:10 and 8:45 pm. The second, a giant tornado, struck the downtown area around 9:45 pm. Directions of damaging winds are shown by short arrows.



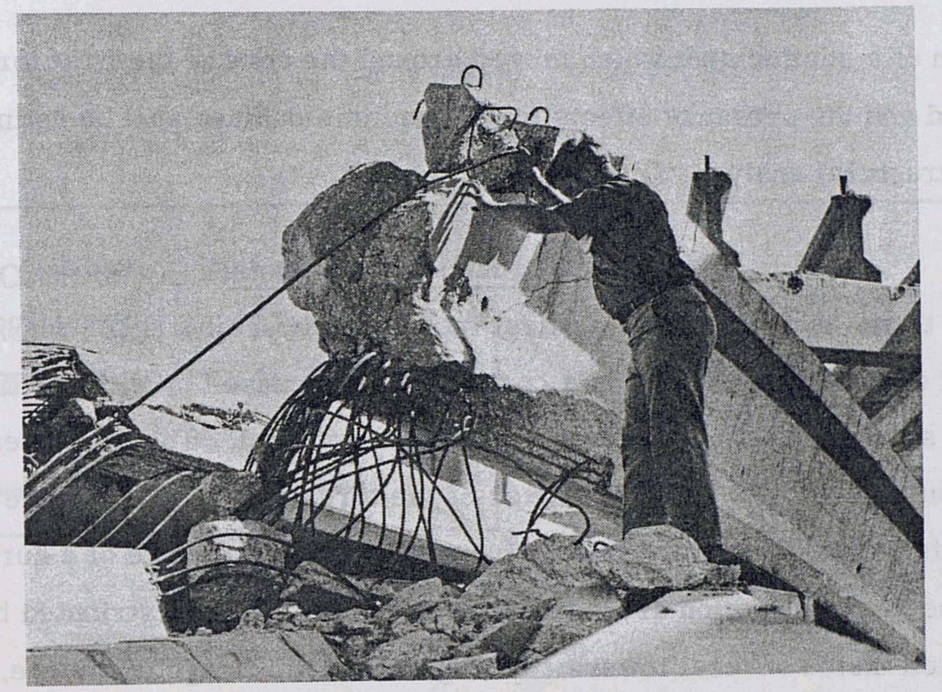

Fig. 2. Sections of 109,000 lb. beams at U. S. 82 and Parkway Drive interchange which were blown down by the first tornado. (Courtesy of Mr. Milton Adams, Lubbock Avalanche Journal photographer)

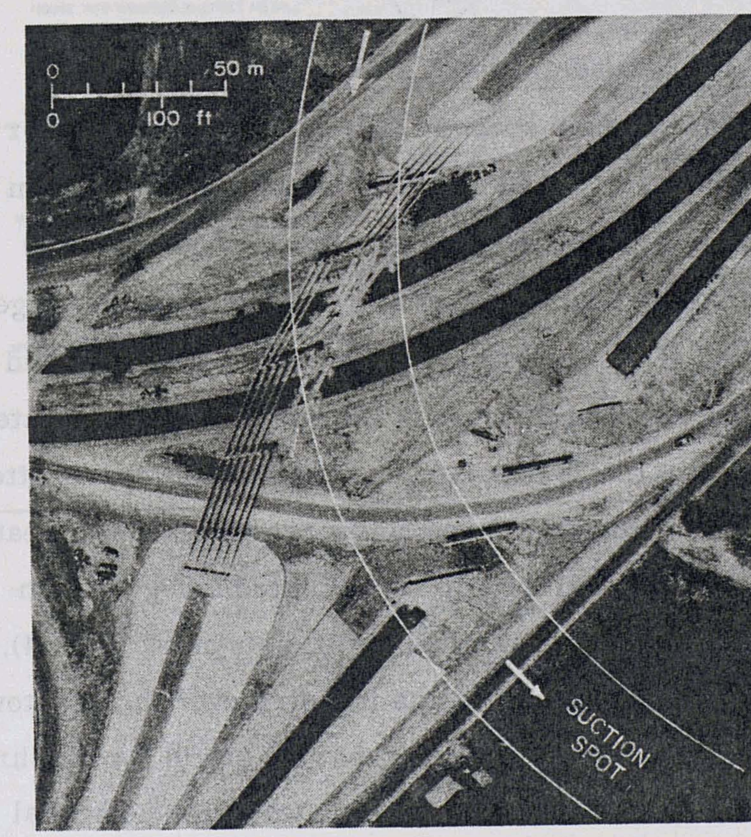


Fig. 3. Aerial view of the damaged interchange structure. Localized damage pattern indicates existence of a suction spot about 30 meters in diameter which moved over the structure from north to south. (Photograph by NASA)

in the path of a suction spot which moved around the core of the first tornado. The wind speed and the pressure effects to produce this damage will be estimated later through structural analyses (Fig. 3).

## Tornado Suction Spots

The term "suction spot" was first introduced by Fujita (1967) who concluded that a number of cycloidal marks left in a corn field were caused by three to five spots where the suction effects of a tornado were concentrated. The size of each suction spot was only about 1/20 of the diameter of the tornado's core. In some respects, these suction spots resemble convective towers around the eye of a hurricane, because the vertical motion around the eye is not uniformly distributed but is concentrated inside several towers rotating around the fringe of the eye. There are evidences that suction spots are in a state of slow rotation while moving around the fringe of a tornado core, where the rotational wind of a tornado as a whole reaches a maximum.

## The Second Tornado, A Giant Tornado

To inspect the damage caused by the second Lubbock tornado, the major one which originated in the downtown area, the author made an aerial survey from a helicopter. He made an intensive search for damage patterns which could be related to the paths of suction spots. During a few hours of surveying, a large number of semicircular patterns of severe damage were observed which could have been caused by suction spots around the core of the second tornado. Later, when the locations of occurrence of the 28 deaths due to the tornado were plotted on a map with suction spot paths, a remarkable coincidence was found; all deaths and fatal injuries except one, or 95% of all fatalities, occurred along the path of suction spots which may be called a suction swath or suction mark (Fig. 4).

The pattern of suction swaths of the tornado as it moved over the downtown area consisted of concentric semicircles, suggesting that the storm's core shrank very rapidly from a diameter of about 2 miles to 0.4 mile while the rotational wind speed increased due to the shrinking core diameter.



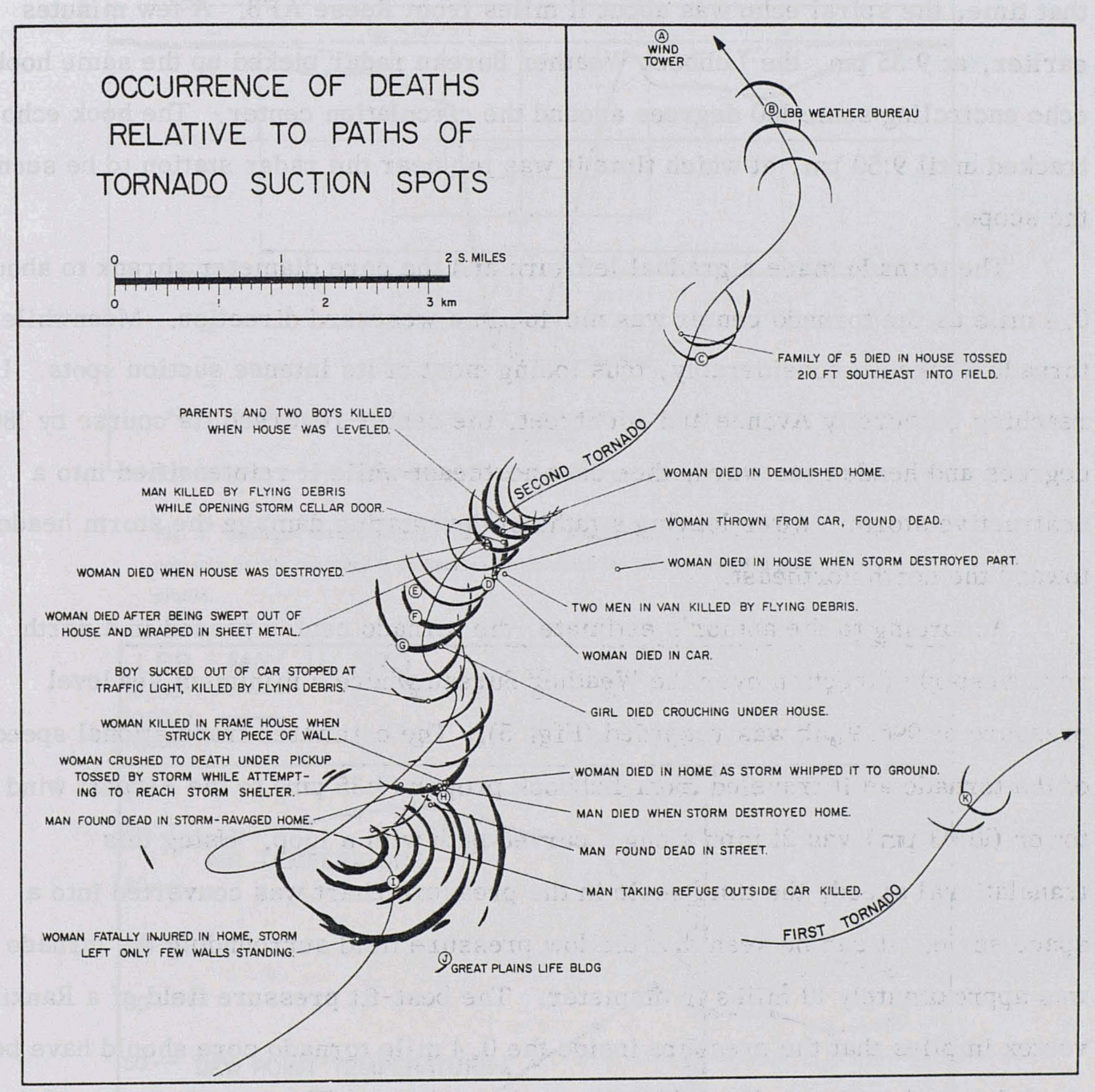


Fig. 4. Location of occurrence of 26 deaths resulting from the second tornado, two at unknown locations are not included. Note that fatalities occurred within narrow swaths of suction spots or suction marks. For suction marks see Fujita, Bradbury, and Van Thullenar (1970).

An observer's sketch of the echo seen on the AN/FPS-77 radar scope at Reese AFB clearly indicated a hook echo spiraling around a core with a diameter of one mile and centered to the northwest of the Great Plains Life Building. At that time, the spiral echo was about 11 miles from Reese AFB. A few minutes earlier, at 9:35 pm, the Lubbock Weather Bureau radar picked up the same hook echo encircling some 180 degrees around the circulation center. The hook echo was tracked until 9:50 pm, at which time it was too near the radar station to be seen on the scope.

The tornado made a gradual left turn and the core diameter shrank to about 0.4 mile as the tornado center was moving in a westward direction. Meanwhile, the tornado weakened considerably, thus losing most of its intense suction spots. Upon reaching University Avenue and 4th Street, the center reversed its course by 180 degrees and headed eastward, then east northeast while it reintensified into a destructive storm. After leaving swaths of devastating damage, the storm headed toward the north northeast.

According to the author's estimate, the tornado center passed in a north northwesterly direction over the Weather Bureau where a minimum sea level pressure of 996.9 mb was recorded (Fig. 5). The estimated translational speed of the tornado as it traveled from Lubbock proper (9:35 pm) to the Airport wind tower (10:03 pm) was 21 mph along a curved path with a loop. Using this translational speed, the time scale in the pressure chart was converted into a space scale. It can be seen that the low pressure field surrounding the tornado was approximately 10 miles in diameter. The best-fit pressure field of a Rankine vortex implies that the pressure inside the 0.4 mile tornado core should have been much lower than that indicated by the pressure trace. The core diameter of the tornado vortex as it moved over the Weather Bureau was between 0.3 and 0.4 mile. Suction-spot paths were found on both north and south sides of the Weather Bureau, without breaking any windows.

## Weather Situation

On 11 May 1970 the sky over Lubbock was clear until around 3:00 pm CDT. Dew-point temperatures were near $40^{\circ}$F which is too low to support any severe convective



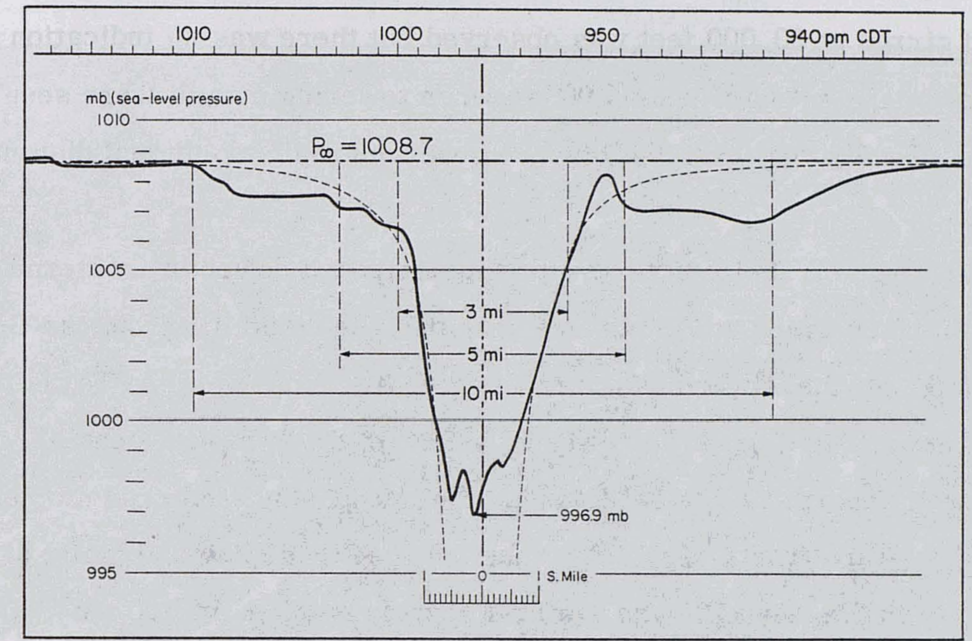


Fig. 5. Enlarged barograph trace from Lubbock Weather Bureau. Dashed line represents pressure profile computed from Rankine vortex which best fits to recorded pressure profile.

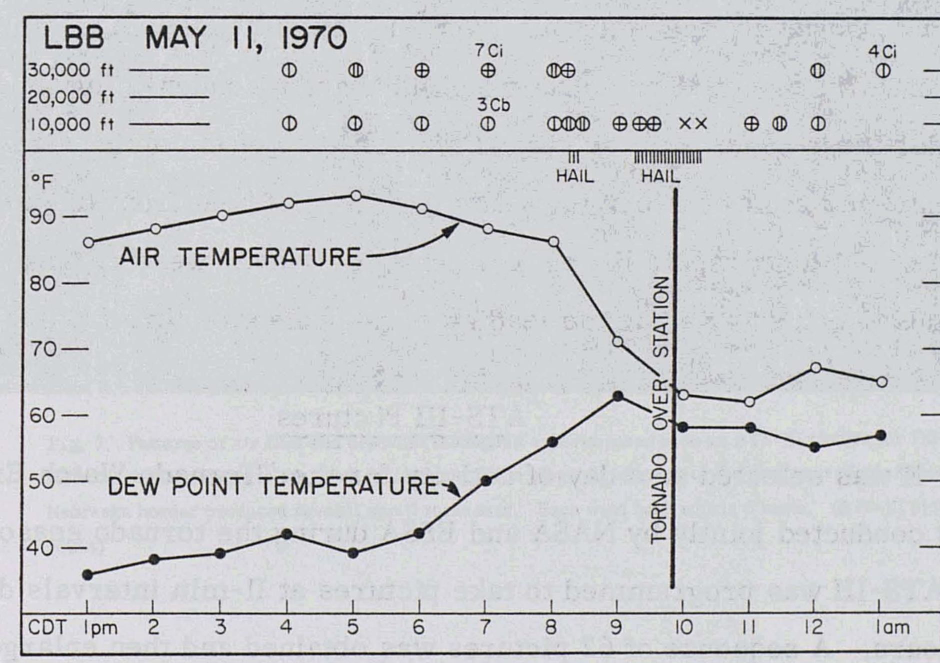


Fig. 6. Air and dewpoint temperatures and cloud cover reported by the Lubbock Weather Bureau on 11 May 1970. The station is 5 miles north-northeast of downtown area. The two hail periods began shortly before the two tornadoes struck.

activity (Fig. 6). By 4:00 pm some cumuli with bases at 8000 feet had developed and scattered cirrus at 30,000 feet was observed but there was no indication of major vertical development until near 6:00 pm when towering cumuli were seen in all quadrants. By 7:00 pm cumulonibi were observed to the south and distant north northeast.

An enlarged ATS-III picture with superimposed dewpoint isotherms in dashed lines and surface winds at 7:00 pm reveals that the moist air from the Gulf was pushing north northeastward with a front extending from western Texas and central Kansas to Iowa (Fig. 7). A southwesterly flow of dry air from central Mexico extended as far north as central Kansas, thus producing a marked moisture gradient along the moisture front. The difference between these dry and moist air masses is seen clearly in the Amarillo and Midland soundings taken at 7:00 pm CDT. Lubbock is located halfway between these two stations. Over Amarillo there was a dry-adiabatic layter of 42°C potential temperature extending up to 13,000 ft. MSL, but with the condensation level at 16,000 ft.,cumulus growth was prohibited in this dry air. Over Midland, however, the moist air from the Gulf extended up to 10,000 ft. MSL, showing a uniform potential temperature of 41°C and a condensation level at 11,000 ft. MSL. Under these conditions the virtual temperature of the moist air will exceed that of the dry air aloft by receiving a small amount of heat from the underlying ground. A slight topographic lifting of the moist air over western Texas will result in a vigorous overturning along the leading edge of the moisture front.

## ATS-III Pictures

May 11 was selected as a day of activity for the "Tornado Watch Experiment" which was conducted jointly by NASA and ESSA during the tornado season of 1970. Thus the ATS-III was programmed to take pictures at 11-min intervals during the daylight hours. A sequence of 62 pictures was obtained and then enlargement of the area was made into pictures of highest possible resolution. Those taken at 6:00, 7:00, and 8:00 pm CDT (Fig. 8) are shown with superimposed surface reports. A distance scale in each picture shows that we can see 2- to 3-mile size clouds. A front between the dry air to the northwest and the moist air to the southeast is



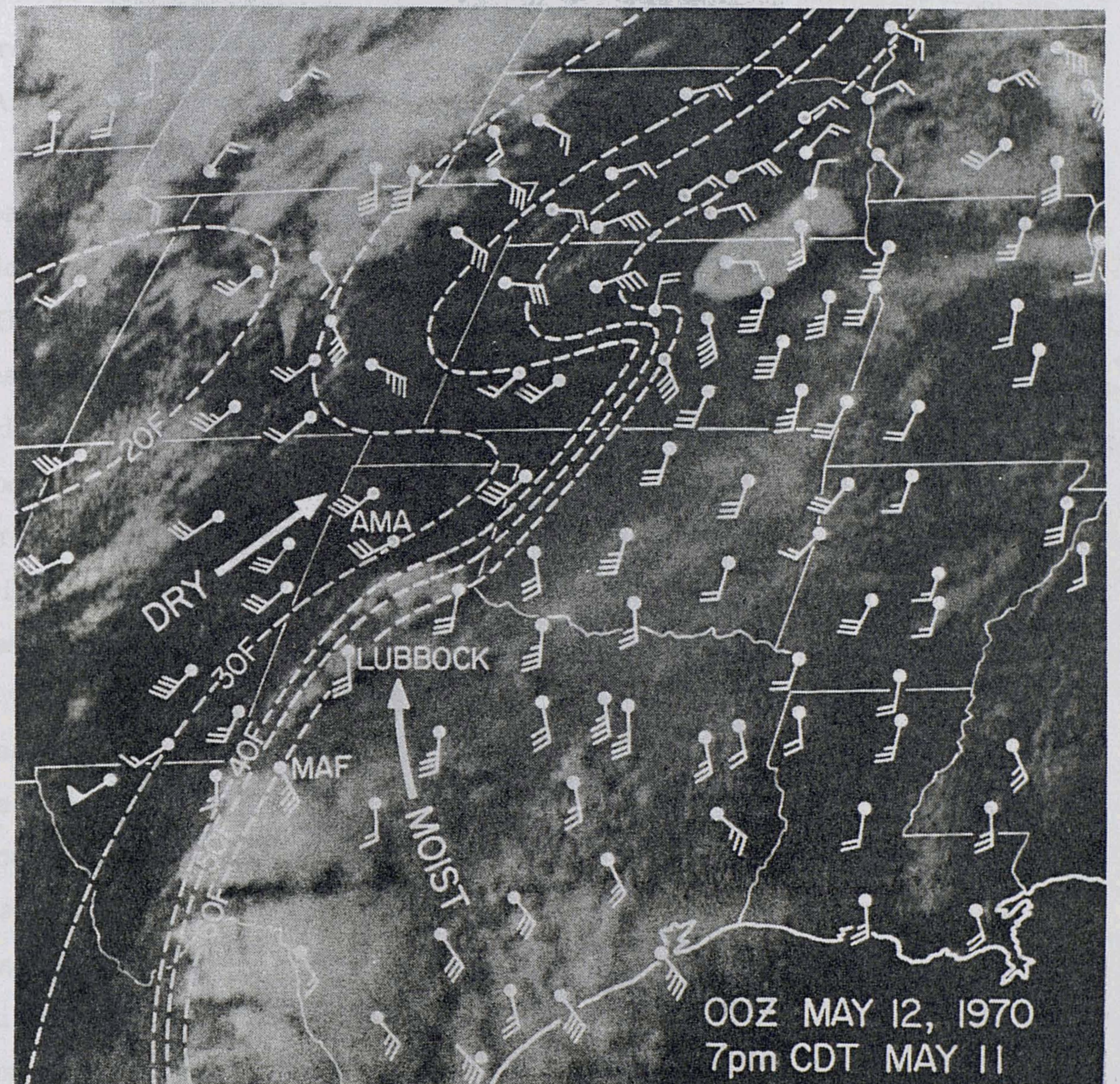


Fig. 7. Patterns of air flow and dewpoint isotherms superimposed upon an ATS-III picture for 7:00 pm. Note the tornado cloud to the south of Lubbock. The large cloud mass to the northeast of the Kansas-Nebraska border produced several small tornadoes. Each wind barb equals 5 knots. (ATS-III picture by NASA)

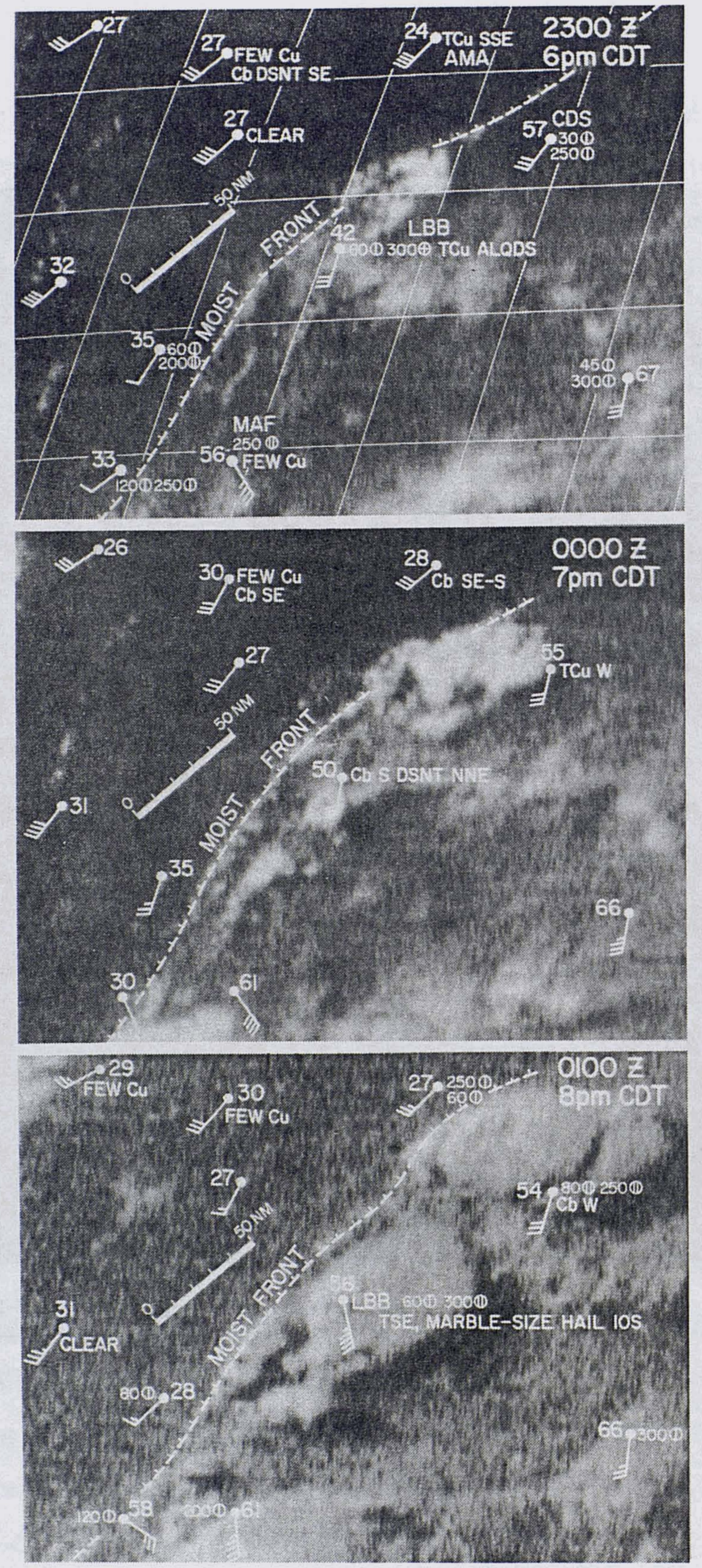


Fig. 8. Three satellite pictures showing the development of the Lubbock tornado cloud. Upper picture has a superimposed one degree latitude-longitude grid. The advancing front of moist air from the Gulf is indicated as "moist front." Each wind barb equals 5 knots. (8X enlargement satellite pictures by NASA)



readily seen as a cumulus line separating the dark area to the northwest from the gray area.

An analogy may be made here between the moisture front and temperature front. That moisture front where moist air replaces dry air is termed a moist front and where dry air replaces moist air is a dry front. These correspond to the warm and cold fronts.

These pictures show that at 6:00 pm, Lubbock was in the moist air mass about 15 miles southeast of the moist front while Amarillo was deep inside the dry air mass with a dewpoint temperature of 24°F. Most of the white to gray clouds east-southeast of Lubbock are cirrus moving from WSW at 25 to 28 knots. A few thunderstorms can be seen to the northeast but no cumulonimbi clouds of greater diameter than 5 miles are visible in the 6:00 pm picture. By 7:00 pm the moist front reached a point about 20 miles northwest of Lubbock and a circular anvil cloud, 13 miles in diameter, formed to the south, with its northern edge approaching near to Lubbock. A close observation of the picture shows two overshooting tops of cumulonibi near the western edge of the anvil cloud. By 8:00 pm, 10 min before a funnel was reported by an off-duty policeman, the circular-shaped anvil cloud had rapidly expanded into an elliptical shape. In fact, the downwind edge of the anvil cloud expanded at a rate of 53 knots, which is 40% higher than the Amarillo windspeed and 30% higher than the Midland windspeed at 250 mb. Such an explosive expansion is the result of the storm's vigorous outflow field which is an indication of the violent convection taking place within the area of the anvil. At 8:00 pm the Lubbock Weather Bureau reported a thunderstorm to the southeast and marble size hail about 10 mi south of the station.

Unfortunately, because of darkness, the last ATS-III picture was taken at 8:00 pm. These pictures did show, nonetheless, that the first Lubbock tornado cloud originated shortly after 6:00 pm some 25 miles to the south of Lubbock, 15 to 20 miles behind the moist front moving northwest. The storm cloud did not form, as in many cases, in a region where warm moist air was plowed by advancing cold air. Instead, it orginated just behind an advancing moist front with small temperature difference between the two air masses.

## WSR-57 Radar Pictures

Amarillo was the only WSR-57 radar station near enough to the tornadic activity to detect the Lubbock storms. A collection of radar scope pictures at 30-min intervals reveals that there was no echo from the expected location of the storm cloud. At 6:30 pm the radar picture shows a rapidly growing echo to the south of Lubbock, which changed into a double-celled structure by 7:00 pm. At this time the northern edge of the echo was only a few miles from Lubbock. By 8:00 pm the major echo and two smaller ones to the west-southwest had split forming three echo pairs. The location of the first tornado is shown in the 8:30 and 9:00 pm pictures in small circles. There were no characteristic hook echoes visible in these pictures because of the great distance of the storm from Amarillo (Fig. 9).

Between 9:00 and 10:30 pm a significant echo convergence took place. This is approximately the time of occurrence of the second tornado, the devasting Lubbock storm. During this period all small echoes to the southwest of the major echo converged to the nearly stationary major one. It has been known that echo convergence and even echo collision take place at the time of tornado occurrences, a similar phenomenon in this case might be described by saying that the "Lubbock storm echo swallowed all small echoes to the southwest."

After 11:00 pm some of the echo motions began to show signs of rotation. So seen in the midnight picture, there are two definite circulations about 50 miles in diameter. A third one with a smaller diameter is also seen in the picture. At this time, however, the transition from the initial appearance of the Lubbock tornado echo to this circulation is not clear.

A radar thin line which appears along the line of large refractive index gradient is clearly visible in these radar pictures taken between 7:00 pm and midnight. Its location corresponds to the line of small cummuli in the ATS-III pictures. Due to their relatively shallow depth, thin lines can be seen only within about 50 miles from the radar station.

As has been pointed out by Fujita (1965) and Browning (1964), a hook echo can be effectively seen only when it is near to a radar operated at low elevation angles. If we



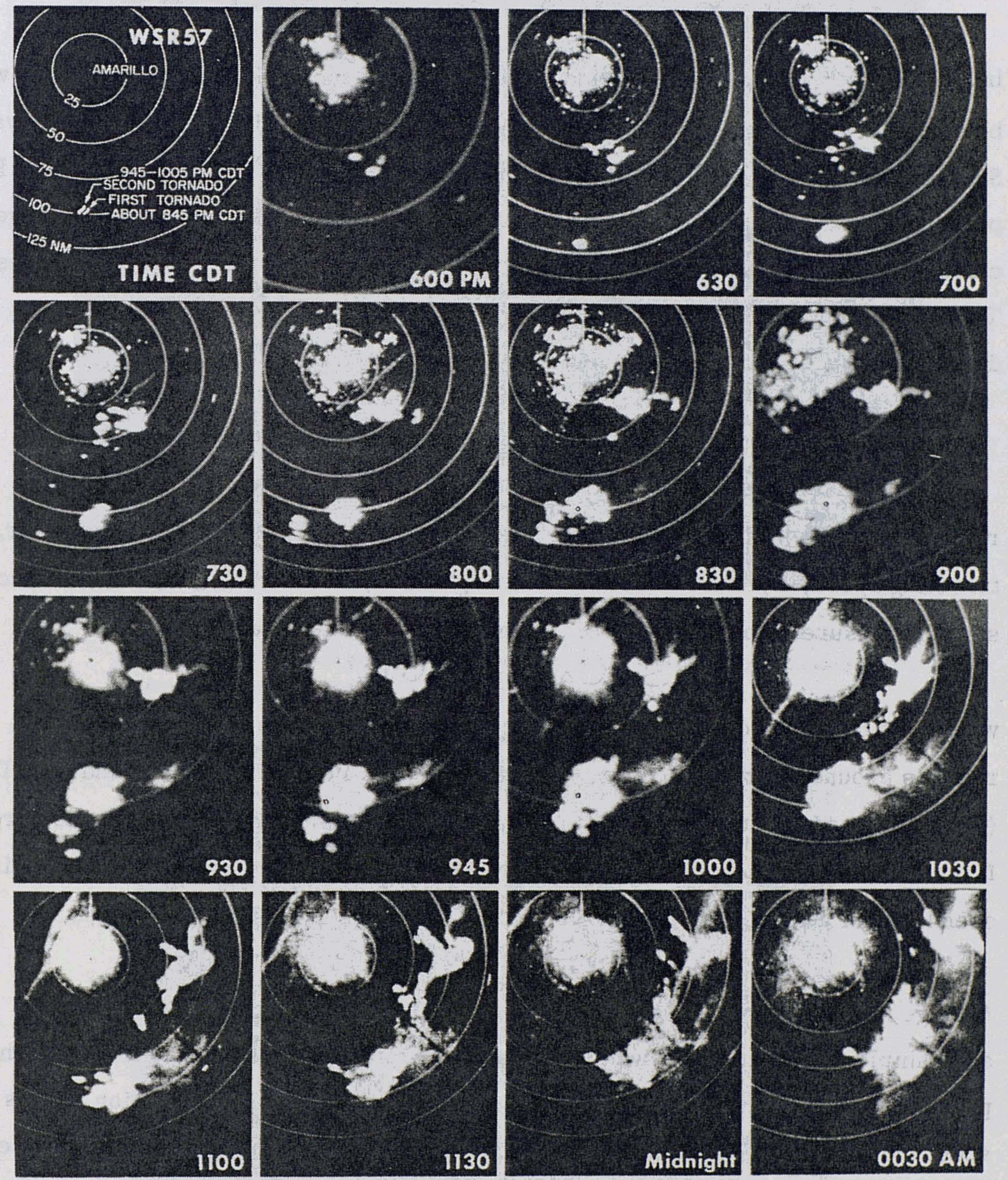


Fig. 9. WSR-57 scope pictures taken by Amarillo Weather Bureau. Small circles in 8:30 and 9:00 pm pictures indicate locations of first tornado and in 9:45 and 10:00 pm pictures that of second tornado. Note that the echo pattern began showing large vortex motion one hour after dissipation of second tornado.

intend to use PPI radars for tornado warning based upon hook-echo detection, it will be necessary to operate a radar station within 50 miles of cities in tornado alleys. Successful detection of hook echoes by the Lubbock Weather Bureau and Reese AFB personnel lead to immediate tornado warnings. It should also be noted that large circulation echoes such as seen in the midnight picture did not produce tornadoes. Tornado-producing hook echoes usually have an eye of no more than 3 miles in diameter, around which a hook encircles.

## Estimated Windspeeds from Suction Swaths

The traveling speed of suction spots as they move around a tornado core represents the rotational speed of the storm. For a tornado with core diameter, D, traveling speed, U, and funnel rotational speed, V, the distance, S, between suction swaths measured along the path of the tornado center is given by

$$S = U\Delta t = \pi D U V^{-1}$$

where $\Delta t$ is the time required for a specific suction spot to make one complete rotation around the tornado core. Fujita (1967) and Fujita, Bradbury, and Van Thullenor (1970) reported that there were 3 to 5 suction spots moving around a tornado core. If the number of evenly distributed suction spots around the core is n, the rotational speed, V, of a funnel can be expressed by

$$V = \frac{\pi D U}{n S}\ .$$

A large number of suction swaths were found in the area of the second tornado, but, for an example, there suction swaths just north of Kent St. are shown along with the path of the tornado center (Fig. 10). The distance between these suction swaths was about 150 meters while the core diameter as determined from the shape of these swaths was 650 meters. Assuming the traveling speed of the tornado to be 21 mph, the rotational speed of the funnel is now given by

$$V = \frac{290}{n}\ \text{mph.}$$

Since the exact number of suction spots is not known, a reasonable rotational speed must be selected between 290 mph and 145 mph because 97 mph, which corresponds



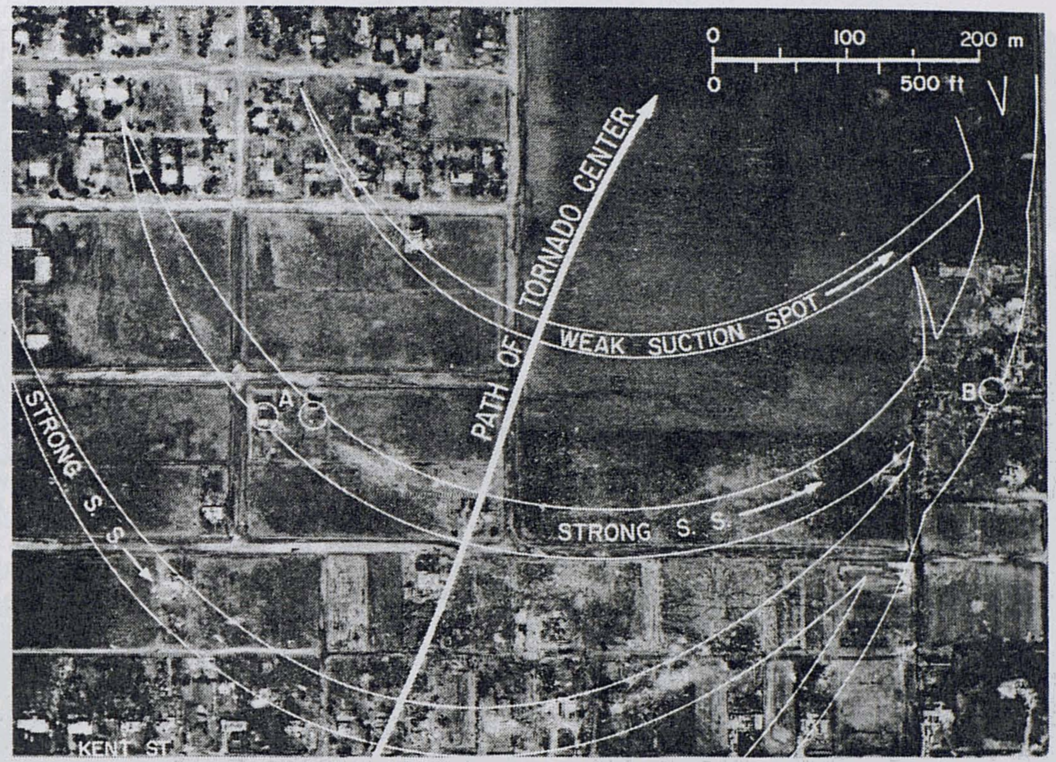


Fig. 10. Pattern of three suction swaths north of Kent St. Destructive damage can be followed within each suction swath in the direction of arrows. Note that the extent of damage is not always related to distance of structures from tornado center. (Picture by NASA)

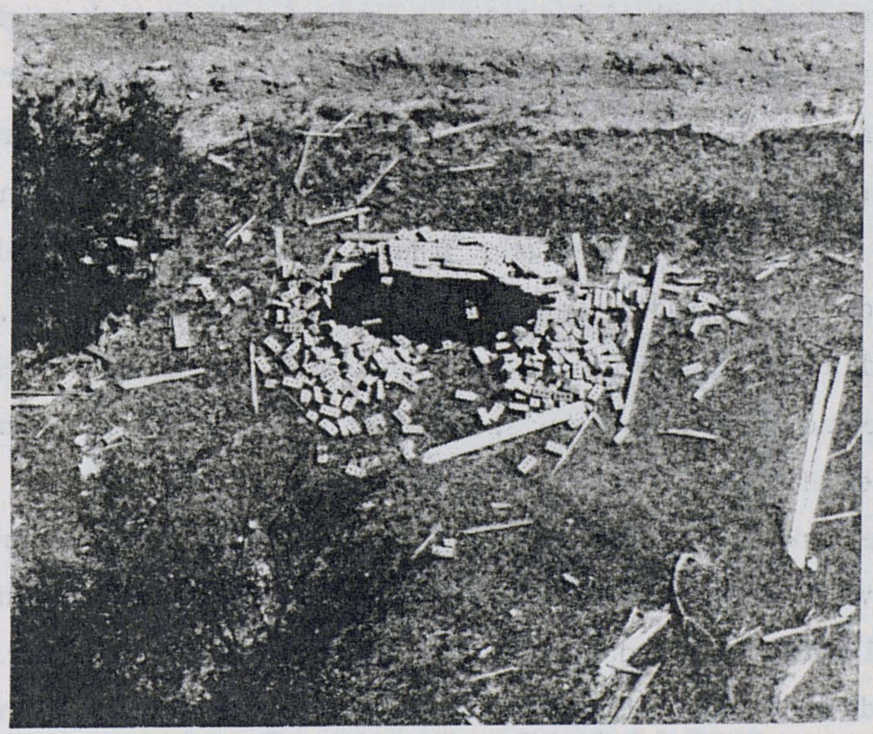

Fig. 11. Pile of bricks located near eastern edge of a suction swath. Picture taken looking south.

to n = 3, seems to be too low to cause such destruction as was observed in the area. At location A, everything from two houses except the concrete foundations were disintegrated and carried some 200 feet into the field. Five persons were killed at this location. At location 13, a large pile of construction bricks was at the eastern edge of a suction swath. A close-up picture of the pile looking south shows that the bricks were blown off from both ends, leaving a wake-flow pattern (Fig. 11).

## Other Suction Spot Damage

There have often been reports of train derailments due to tornado winds. A very good example of the impact of a suction spot is illustrated by the chain of 15 freight cars which were on a railroad siding near Goodpasture, Inc. at the north edge of the town (Fig. 12). The final positions of the cars clearly indicate the path of a strong suction spot which moved from the lower left corner of the grain storage building to a demolished house on the left edge of the picture. Cars I and J were carried as far as 70 meters off the tracks.

From a spot north of this train an empty fertilizer tank weighing 16 tons traveled somehow to a spot 890 meters away (Fig. 13). There were evidences that the tank moved on the ground 190 m from its impact point to final resting point. A close examination of aerial photographs failed to find more than one impact point along the expected path of the tank. It is likely that the tank was airborne for a distance of 700 meters, crossing over US 87, a four-lane highway.

Within one block of the location where a woman died after being swept out of her house and wrapped in flying sheet metal, a tree was found standing "dressed-up" with pieces of sheet metal (Fig. 14).

The Goodpasture, Inc. grain elevator is located on the southwest edge of a suction swath. Five of the circular tops to the clindrical grain bins were lifted and collapsed against the median superstructure between the bins (Fig. 15). These tops were made of 10-inch thick concrete. Beginning at the bottom of the picture it shows that the first bin was empty, the second was 95% full with grain visible in the picture, the third top was not lifted, and the fourth through sixth were empty and were lifted.



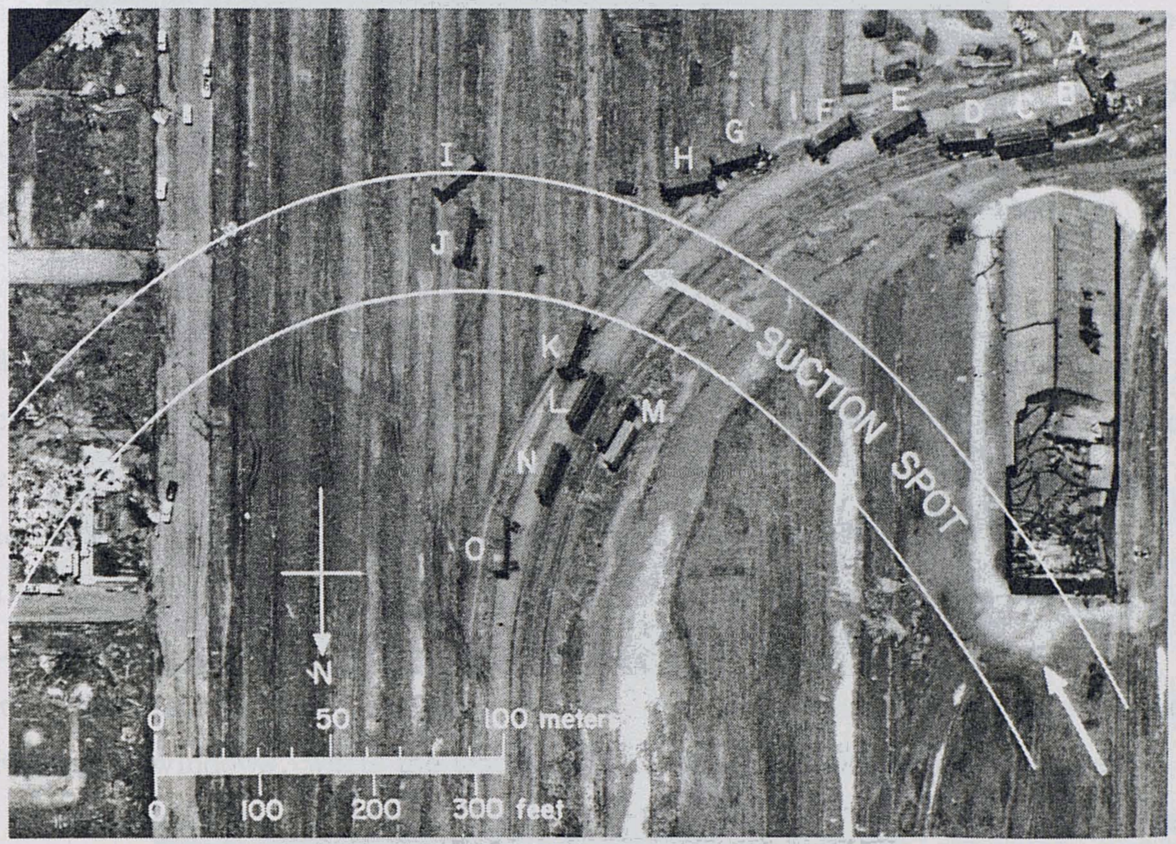


Fig. 12. Final position of 15 freight cars as related to the path of a suction spot. (Picture by NASA)

Fig. 13. A 16-ton empty fertilizer tank believed to have been airborne through a distance of 700 meters and then rolled 190 meters to its final resting position. (Picture and information supplied by Dr. J. A. Shanahan, Bechtel Corporation, San Francisco)

Fig. 14. A tree "dressed-up" with strip of sheet metal. Note that the upper part of tree was debarked.

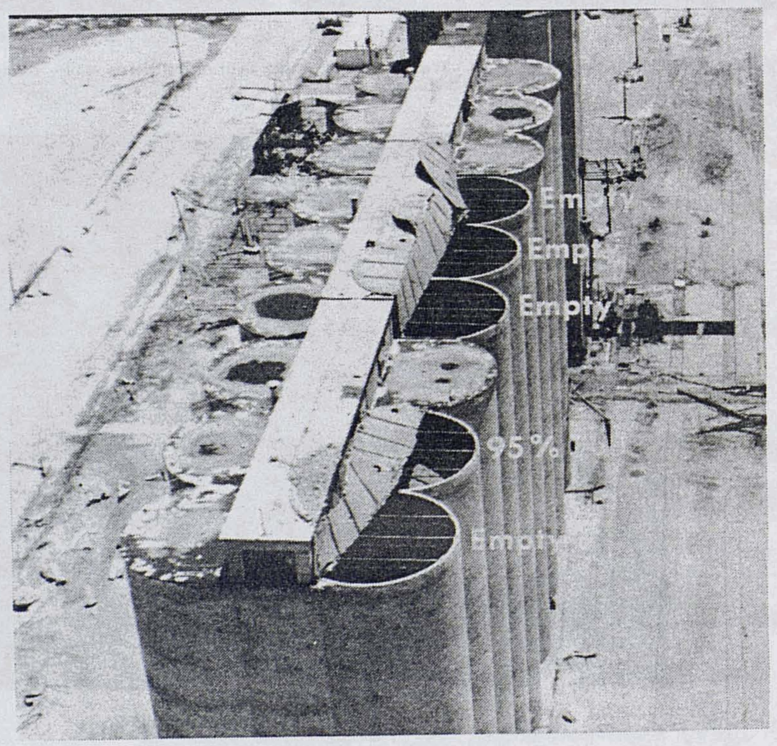


Fig. 15. Lifted tops of grain storage bins at Goodpasture, Inc. Tops were made of 10-inch thick concrete and had a diameter of 33 feet. Note that the second one was 95% filled with grain while others damaged ones were empty.



If the lifting was the result of the expansion of in-storage air, the one which was 95% full should not have behaved like the empty ones. A closer examination and engineering analysis of these elevator storage bins are highly recommended.

## A Wooden Shack in Tornado

A small wooden shack in a direct path of the second tornado was found to be practically undamaged because it was standing between suction swaths. A panoramic picture from southwest through northeast shows, from left to right, three buildings with increasing structural strength; a wooden shack, a frame house, and a block church (Fig. 16). After the passage of the tornado, the damage to these three structures was exactly opposite to what would be expected from constructural strength. The block church was 90% destroyed, the frame house had damage to the roof and broken windows, while the wooden shack that could have been destroyed easily by 100 mph winds was nearly free of visible damage. The mystery is how the wind, pressure, and rate of pressure change which accompanied the very destructive second Lubbock tornado failed to damage a wooden shack located at the bottom of the boundary layer of the atmosphere as the tornado moved right over it. This evidence along with several others observed during the survey of the entire damage area suggest that the full effects of the wind forces and pressure drop are inside the suction spots with horizontal dimensions at least one order of magnitude smaller than those of the parent tornado core.

Due to the small size and fast traveling speed of suction spots, the rate of change in pressure must be at least 10 times greater than what had been previously computed from pressure profiles of tornadoes and their traveling speed.

## Conclusions and Recommendations

Although the present findings by the author will require some revisions in light of further research on the Lubbock tornadoes, a list of tentative conclusions will be of value to those who are interested in violent tornadoes.

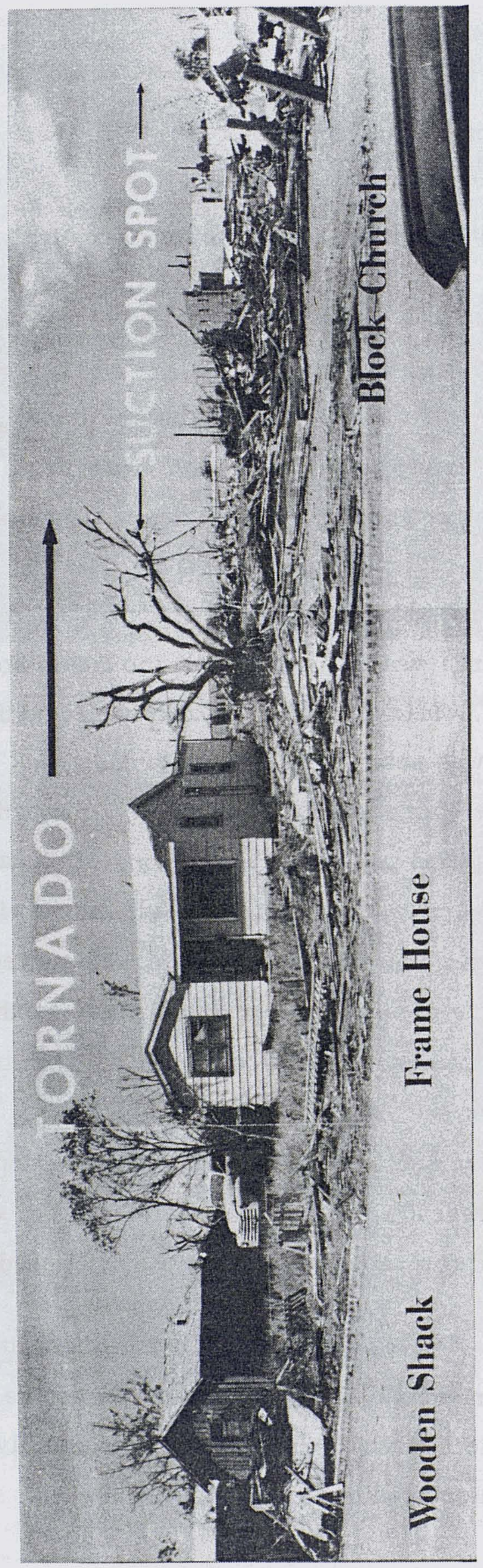


Fig. 16. Three structures with varying construction strengths which were located beneath the path of the second Lubbock tornado, a giant storm, with a core diameter of 0.5 miles.



(1) The devastating Lubbock tornado was preceded by a weak tornado acting as a forerunner. A relatively large area should be included in the "Tornado Warning" issued by the Weather Bureau because destructive storms may occur anywhere in the vicinity. This recommendation was made by McCrabb (1970).

(2) The Lubbock tornado cloud developed just behind a northwestward advancing moist front with little temperature difference across the front. Upper level conditions were not adequate to support the formation of a tornado outbreak such as the Palm Sunday 1965 storms.

(3) The specially enlarged ATS-III pictures by NASA were useful in determining the features and location of the advancing moisture front as well as the localized intense convective systems in their early stages. For continuous day-and-night storm watch coverage, an infrared camera system is highly desirable.

(4) The weather radars at Reese AFB and Lubbock Weather Bureau detected the tornado-bearing hook echoes. A complete analysis of the WSR-57 radar pictures from Amarillo is likely to establish the mechanisms for the development and growth of the mesocyclones forming immediately after the dissipation of the second Lubbock tornado.

(5) The majority of deaths and fatal injuries due to the tornado occurred along the suction swaths inside the second tornado. However, a wooden shack located between two distinct suction swaths escaped damage when the tornado moved over it.

(6) A suction spot will be accompanied by an excessive rate of pressure change because of its small size and fast traveling speed. The rate is likely to be

one order of magnitude larger than that computed from the pressure profile and movement of the tornado as a whole.

(7) A survey of the structural damage over the entire affected area should be made in an attempt to estimate the effect of wind, pressure, and rate of pressure change. This effort should be combined with the meteorological aspects and fine structure of the tornadoes.



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