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Detection of Moisture and Moisture Related Phenomena from Skylab

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Principal Investigator

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Center for Research, Inc.
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INITIAL INVESTIGATION OF THE VARIATION IN S-194 ANTENNA TEMPERATURE AND S-190A IMAGES WITH SOIL MOISTURE CONTENT

Introduction

On June 5, 1973 Skylab 2 obtained S-190A and S-194 sensor data for a pre-selected test site in Texas (Fig. 1). Supporting ground truth data were collected by a field crew on the ground and by the AAFE aircraft. This test site was selected to evaluate the ability of various sensors to detect soil moisture variation. In this initial report information has been partially gathered regarding soil textures, soil moisture content, S-194 antenna temperatures, precipitation distributions and radar echoes.

SOIL MOISTURE AND TEXTURE INFORMATION FROM S-190A

Some soil textures have been analyzed to obtain an indication of the variation in moisture holding ability of each soil type. For an initial study, selected soil textures in Scurry, Fisher, Mitchell, and Nolan Counties were analyzed. The area of interest is distinctly visible in the red-infrared region, Frame 32, on the S-190A photographs (Fig. 2). It cannot be seen on most of the other S190M bands. Previous soil surveys showed that the area in figure 2 falls across the intersection of the four previously listed counties (Fig. 3). No soil survey information was available for Nolan County. From this information a base map was prepared and appropriate sample sites were selected (Fig. 4). Samples were collected during subsequent field trips in August and September, 1973. Upon completion of the field work, the samples were analyzed for grain size in the laboratory.

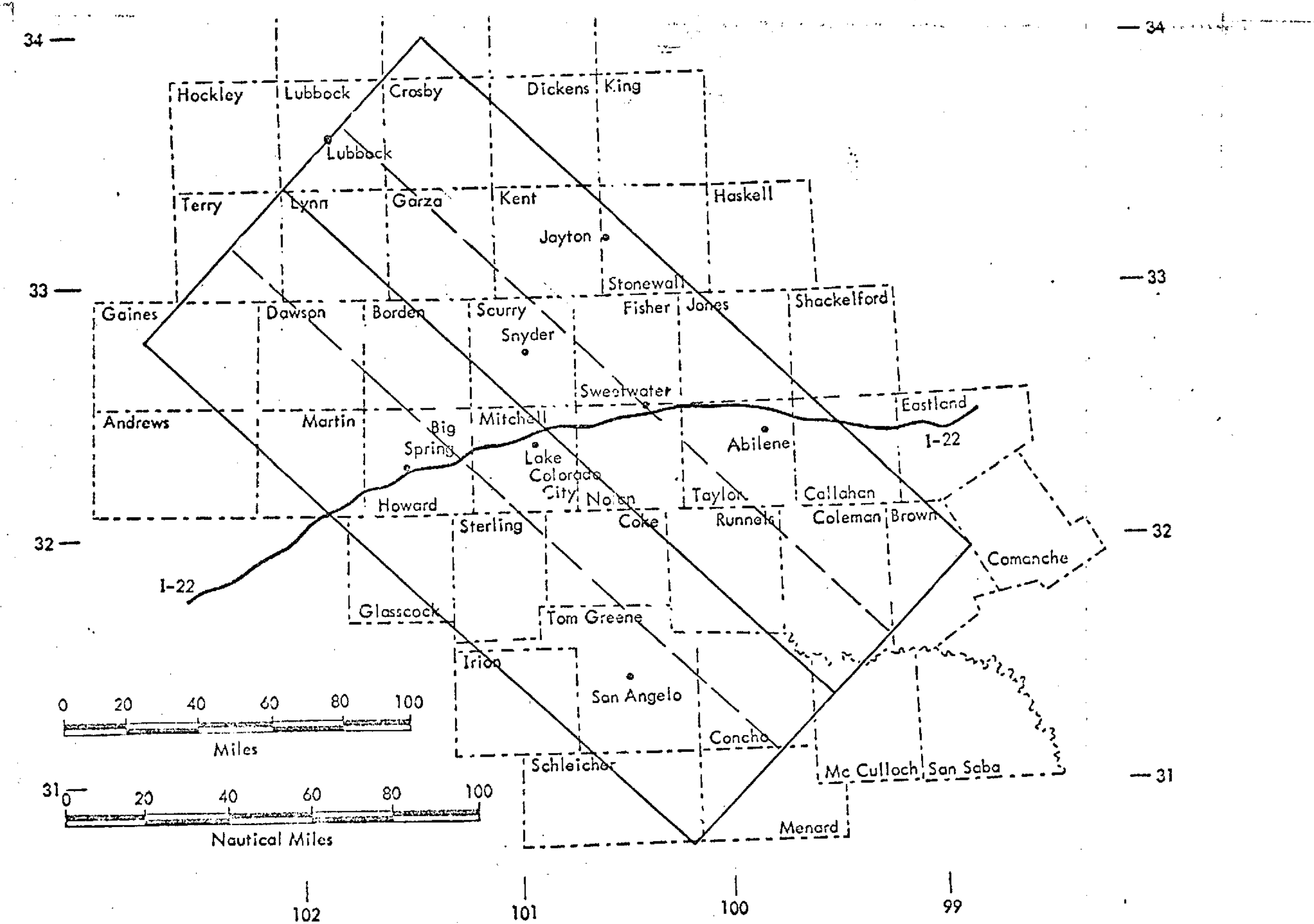

Fig.1. Texas test site location, June 5, 1973.

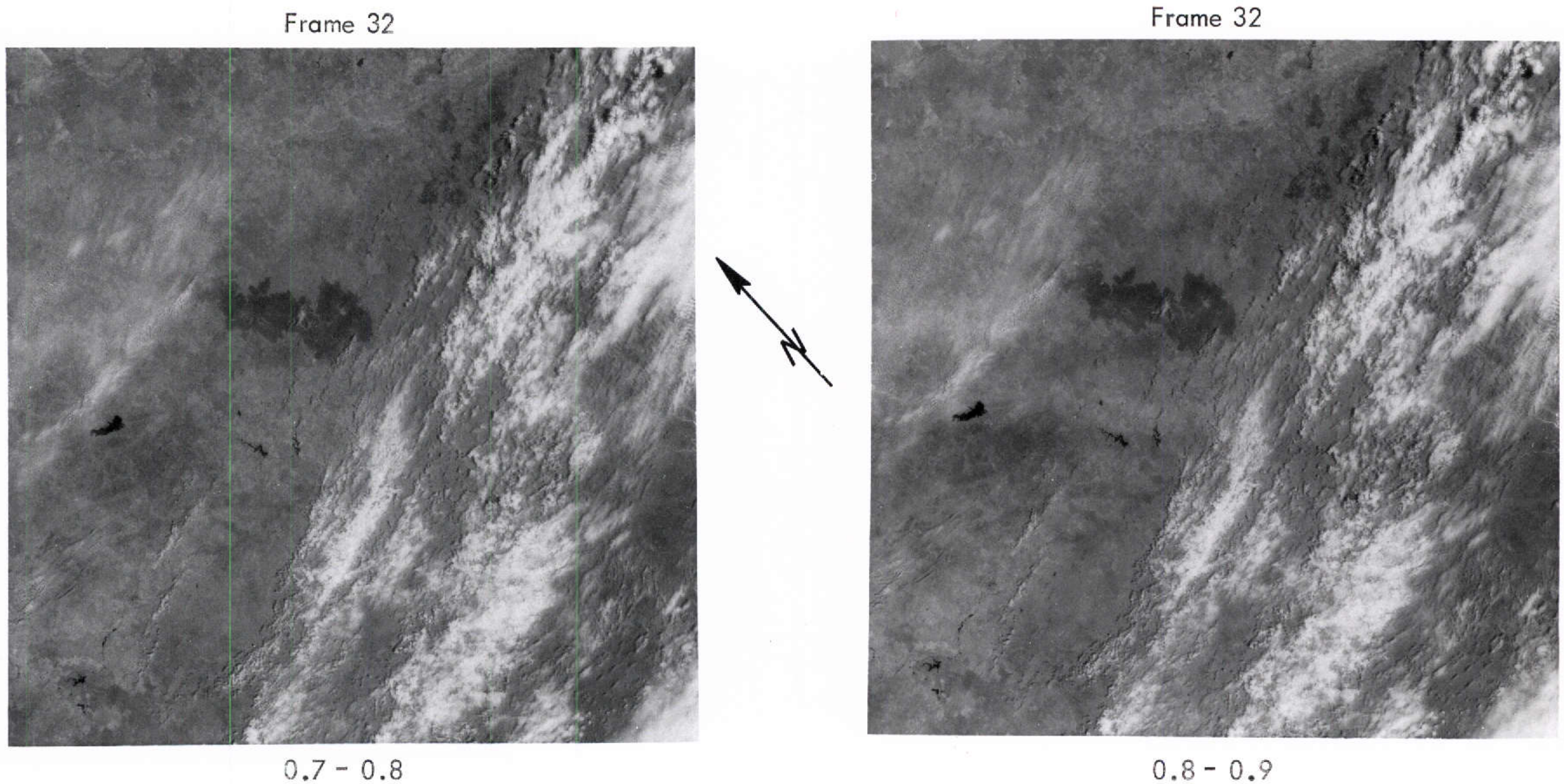

Figure 2. Red/Infrared frames from Skylab 2 190A showing the marked variation between Abilene clay loam(dark area in center) and the surrounding fine sandy loams.

Soils of Fisher, Mitchell and Scurry Co.

(Based On Available USDA County Surveys)

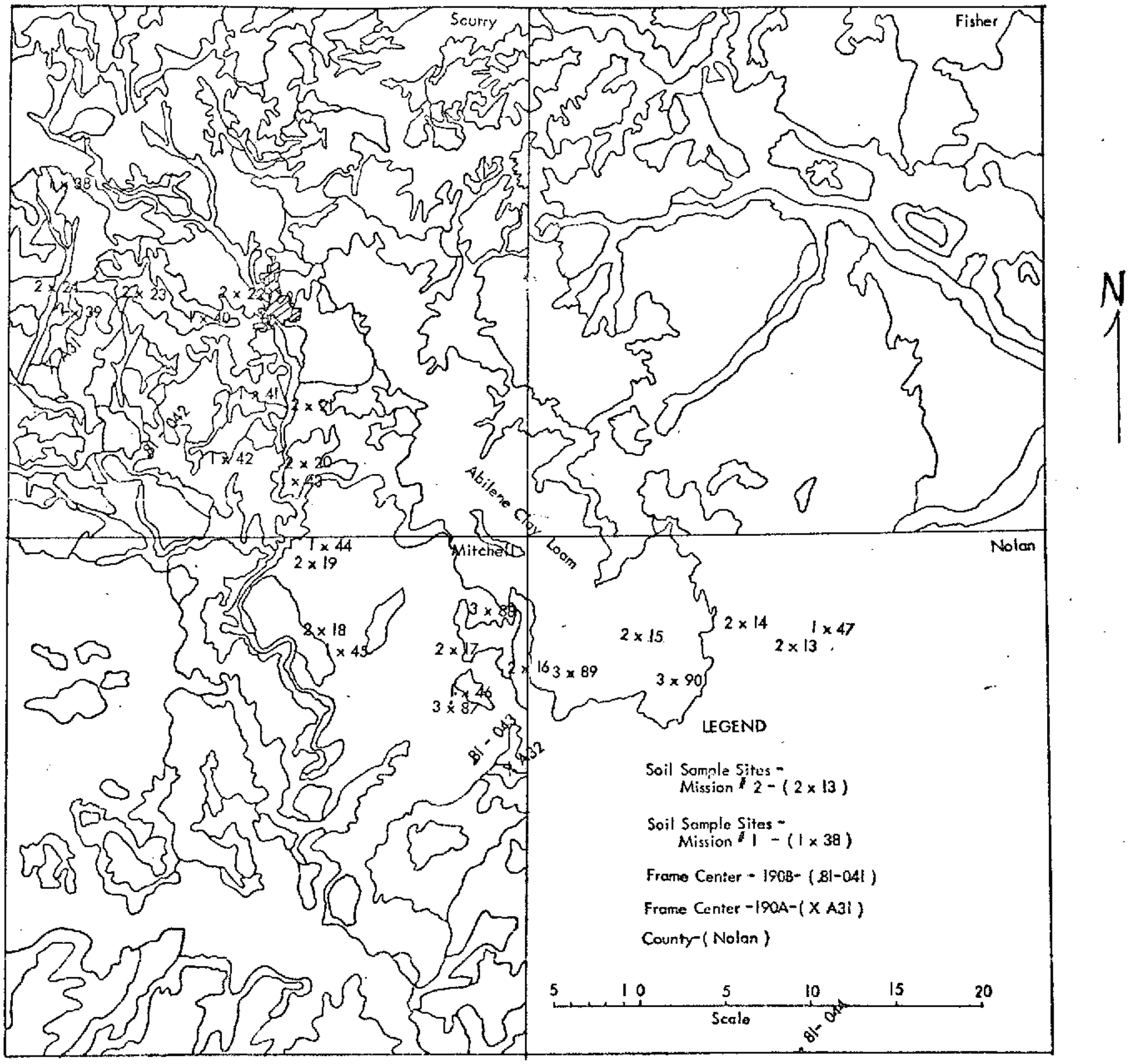

Figure 3. Soils map of Fisher, Mitchell and Scurry Co., Texas.

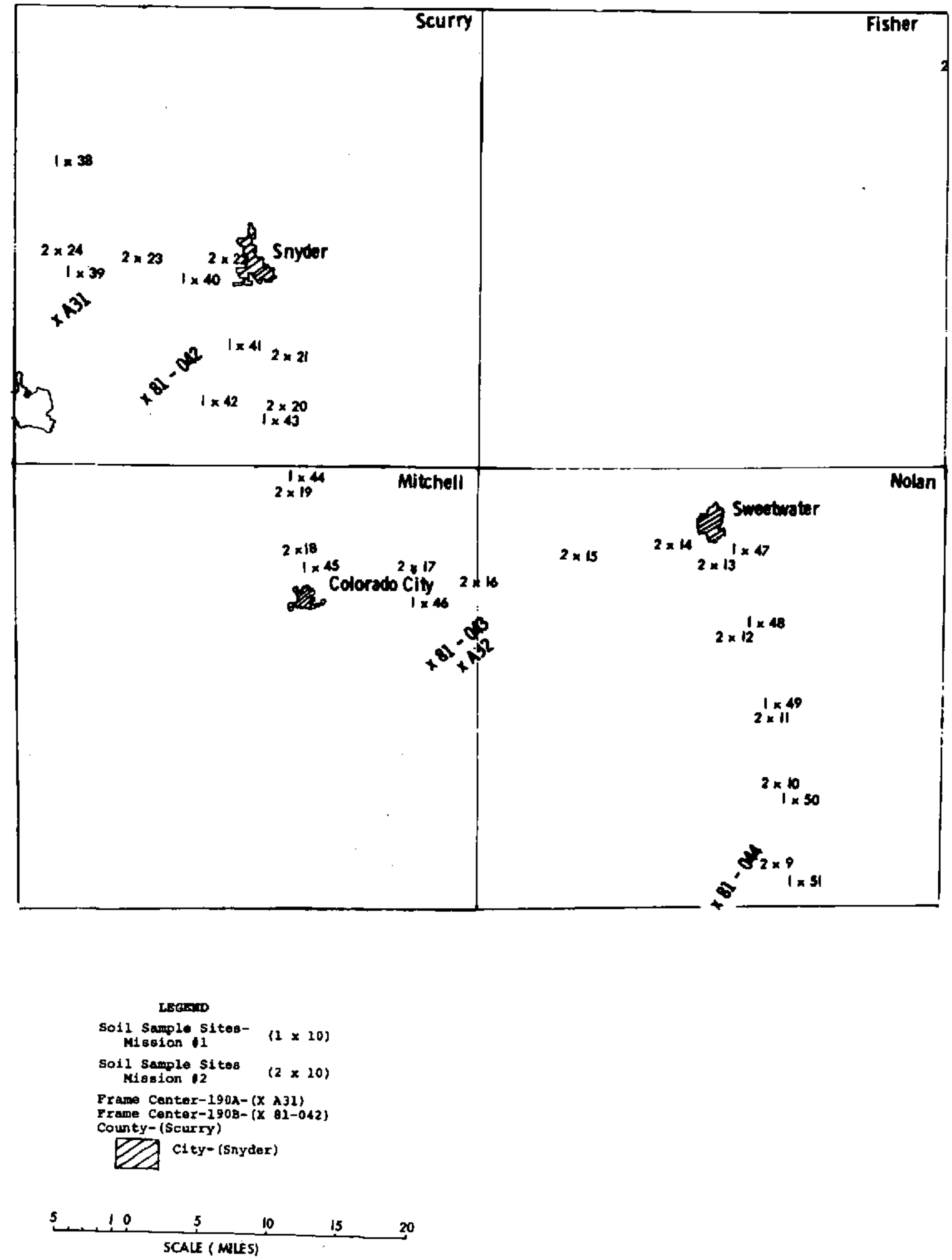

Figure 4. Location base map for pertinent counties in Texas test site.

The samples were separated by the standard sieve process, each of the size categories ($\frac{1}{4}\phi$)[1] were weighed and percentages of each grain size class were calculated. Histograms for each sample site (3 x 87 to 3 x 90, see Fig. 3) were then plotted (Fig.'s 5A-5D).

In figures 5A-5D it can be seen that there is less fine material present in the Cobb-Miles fine sandy loam (site 3 x 87 and 3 x 88) than in the Abilene clay loam (site 3 x 89 and 3 x 90). The texture gives some indication of the moisture holding ability of each soil type, the soils having a greater percentage of small size grains can be expected to have a greater moisture capacity. It can be observed in figure 5 that the fraction greater than 4.75 ϕ has been grouped together. This was necessary since samples smaller than this grain diameter require more sophisticated techniques of separation and will be undertaken at a later date.

Each size class percentage was plotted as part of a cumulative curve (Fig. 6). For purposes of this study, figure 6 serves to indicate that there is a separation of soils texturally, and this can be readily seen by cumulative probability plots on the same scale.

Measurements of soil moisture content across the Abilene clay loam showed substantial increases of moisture content (Figure 7). Since the precipitation amounts were relatively even over this area during the previous several days it is apparent that the clay loam soil holds more moisture than the surrounding fine sandy loam. Therefore, the reason this area is so well defined may be related to soil moisture content, soil texture or a combination of the two.

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1. ϕ (PHI) = a grain size measurement based upon calculated $-\log_2$ of the grain size diameter in millimeters.

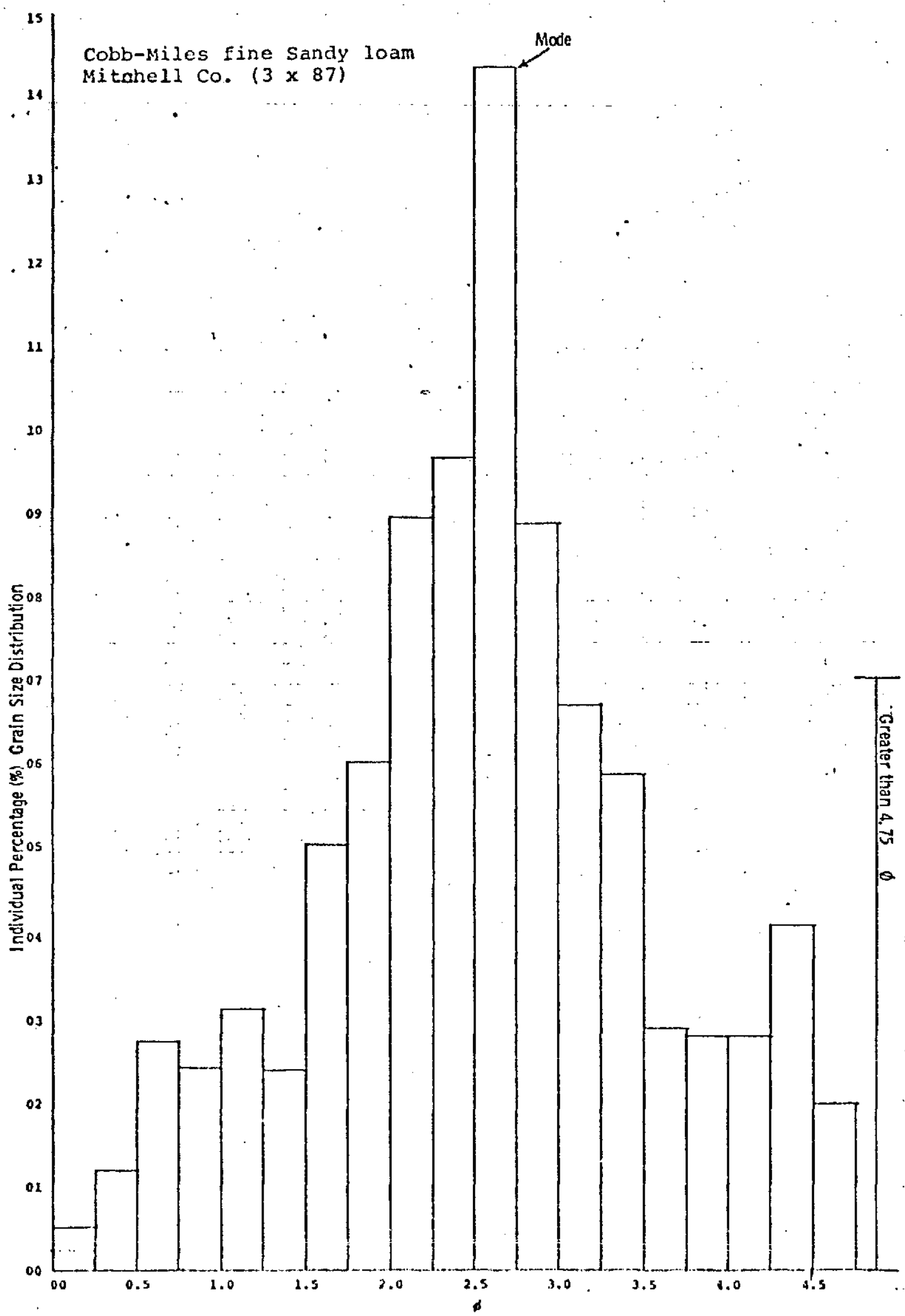

Fig. 5A. Texture analysis.

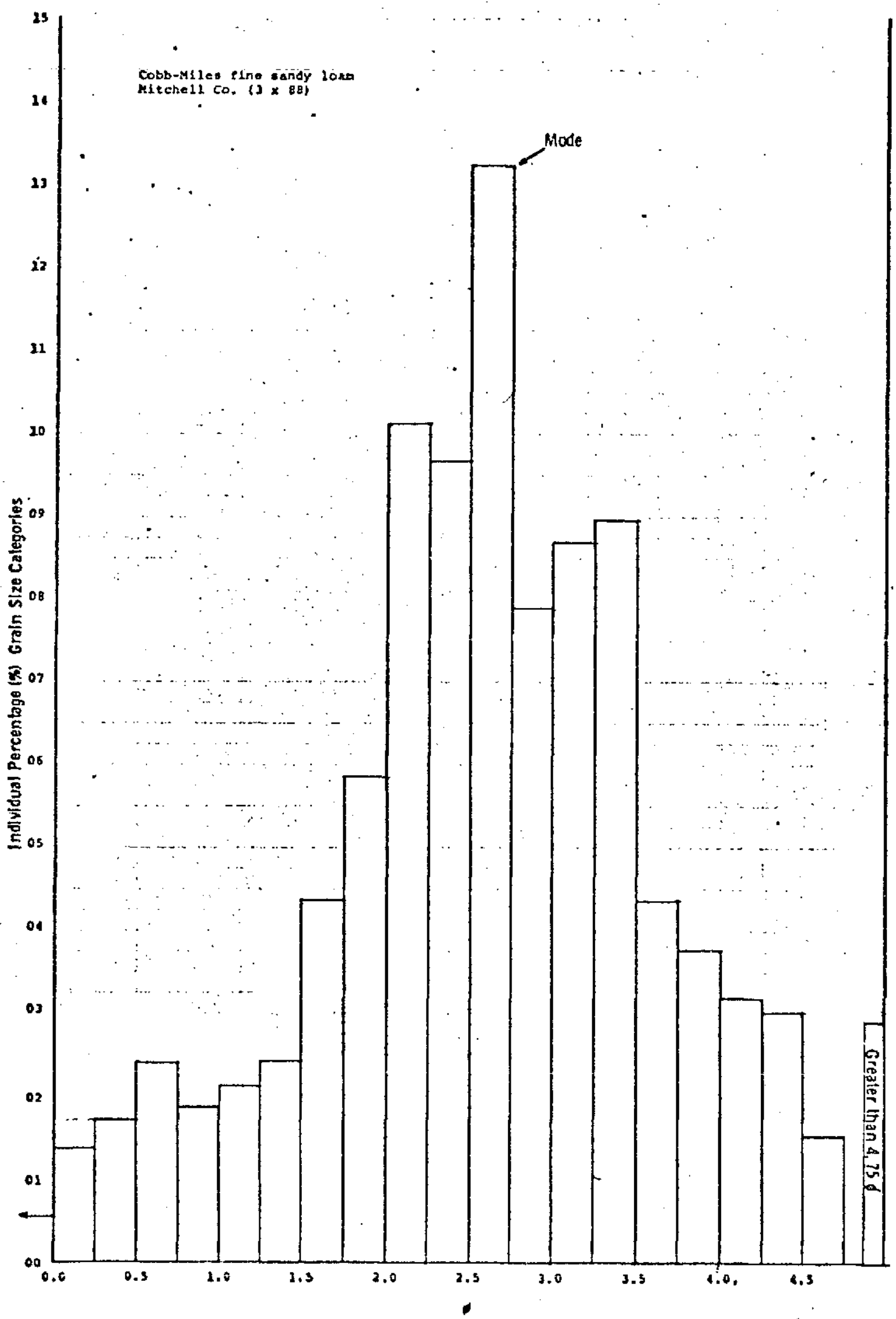

Fig. 5B. Texture analysis.

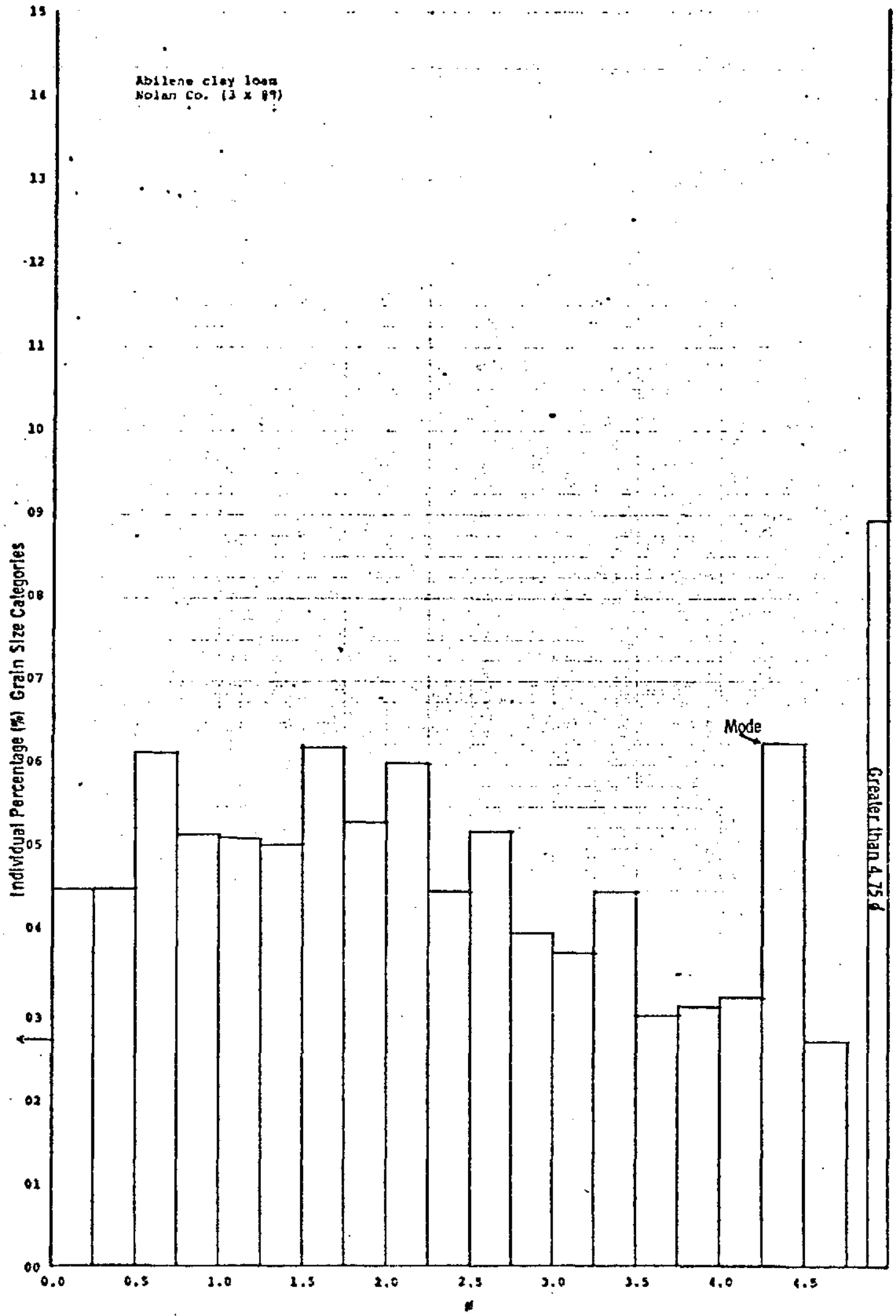

Fig. 5C. Texture analysis.

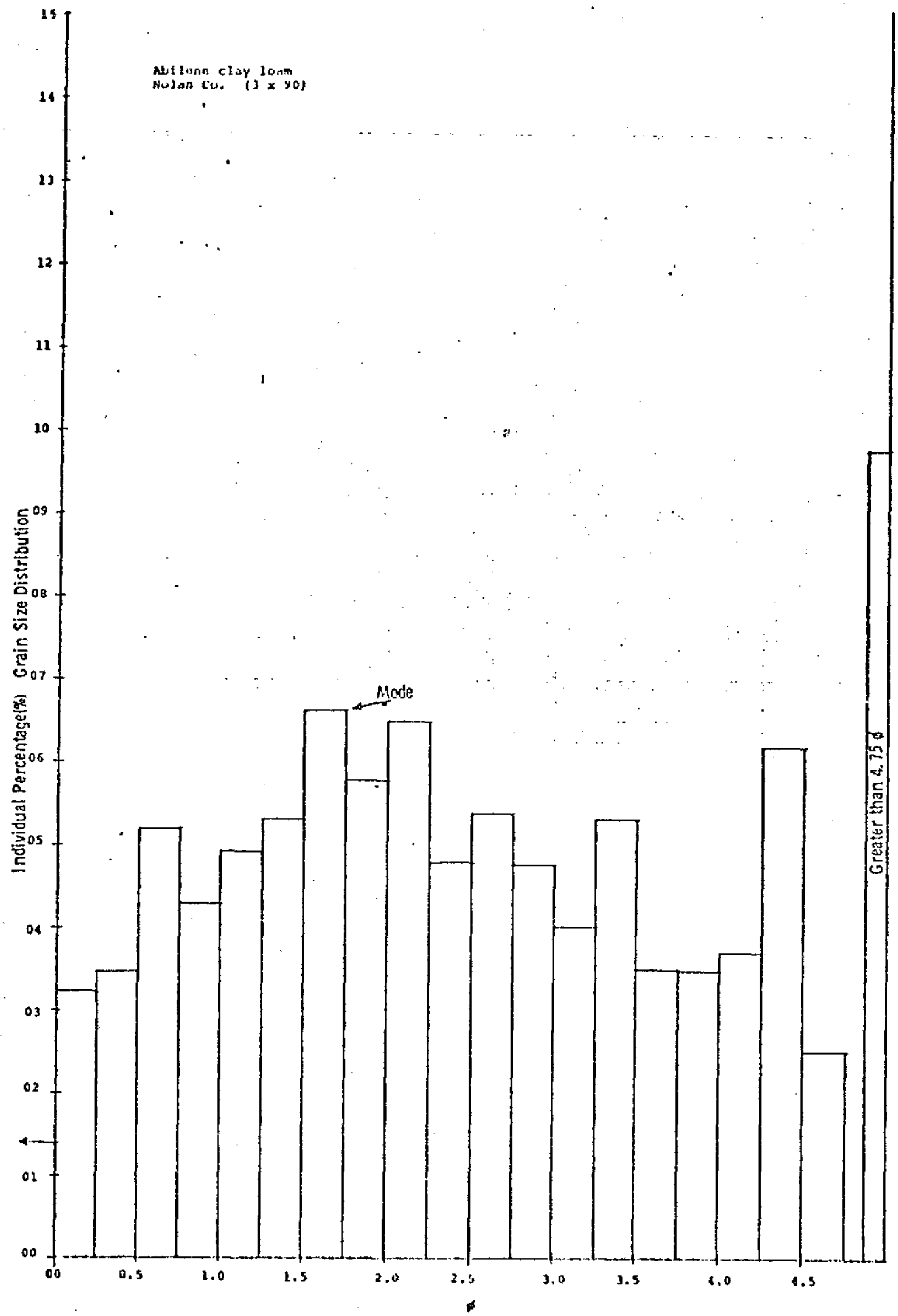

Fig. 5D. Texture analysis.

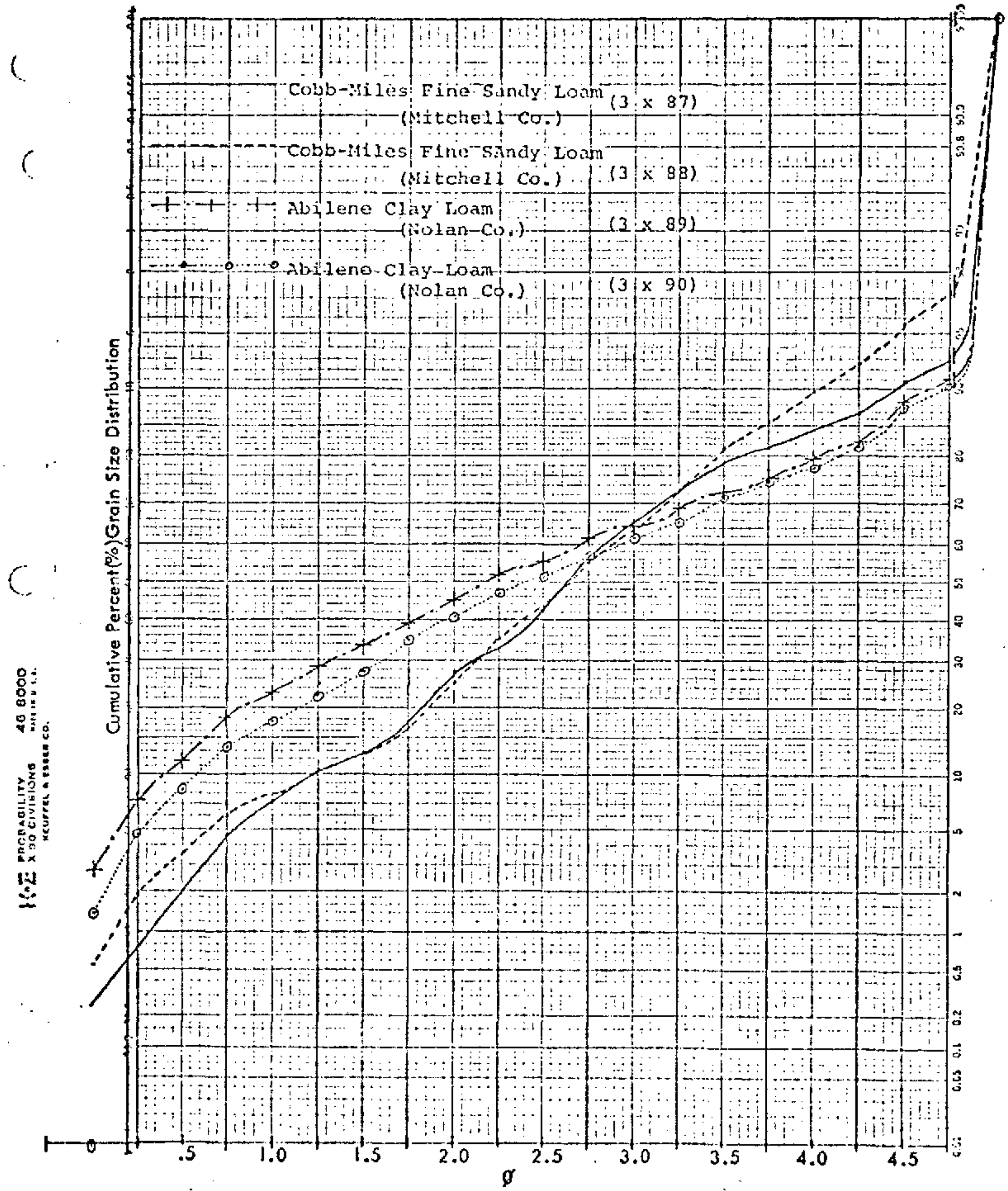

Fig. 6. Texture analysis--Cumulative curve.

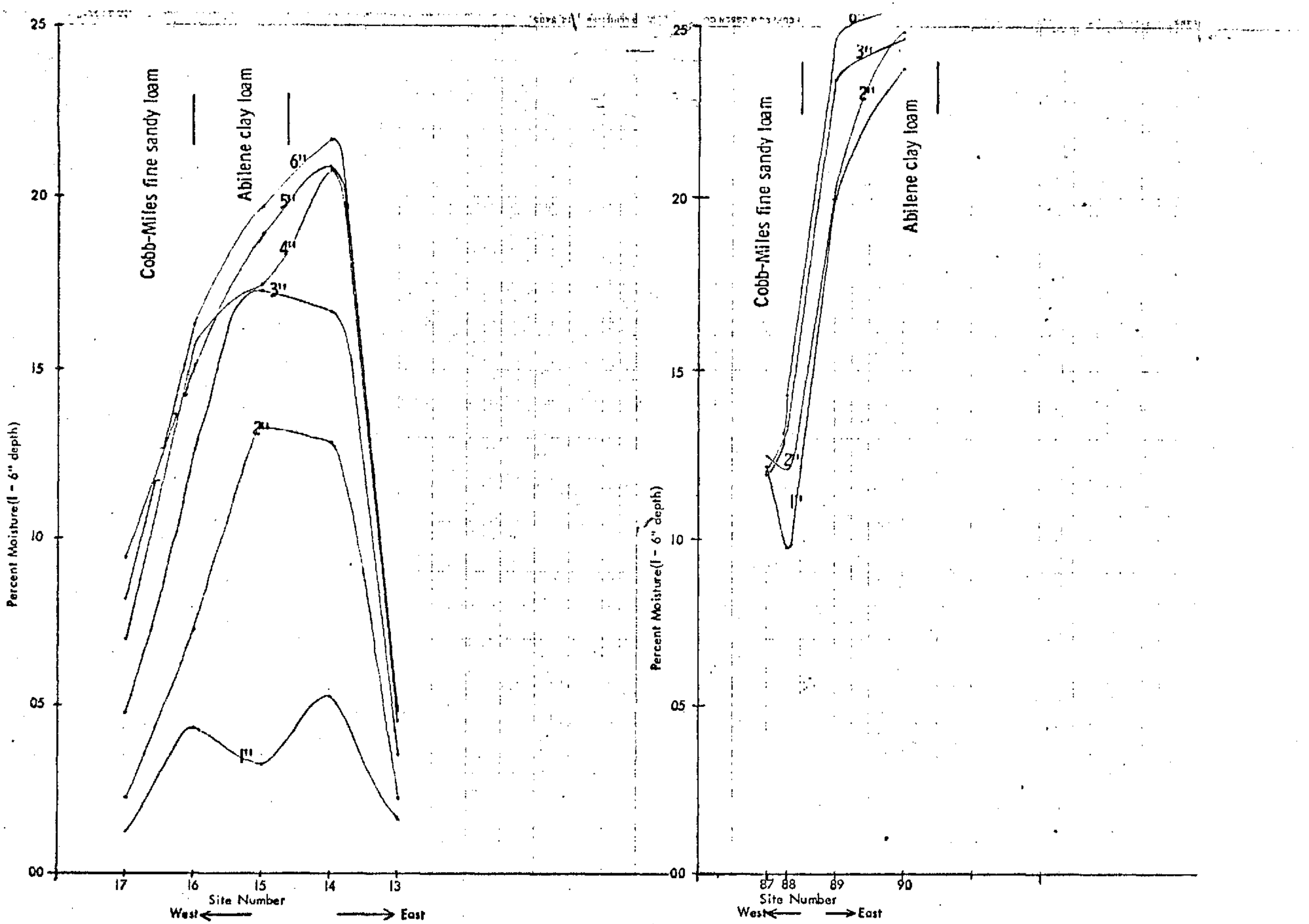

Fig. 7. Soil moisture variations across the Abilene clay loam.

It may be worth noting that the boundary of the Abilene clay loam was so distinct that its distribution in Nolan County is shown in Figure 3 as extracted from the SI90A photograph (Figure 2). The sharpness of the boundary as seen from Skylab allowed a detailed comparison with the boundary from previous detailed ground work in Fisher, Mitchell and Scurry counties. The good agreement allowed the boundary of this soil type to be located with considerable confidence in Nolan County.

S-194 ANTENNA TEMPERATURE

In order to obtain an inital insight into the changing antenna temperatures over the test site, a general map was produced (Fig. 8). As the Antenna Temperatures measured by the S194 sensor are for circular areas 60 miles in diameter with a given latitude and longitude as the center of the circle, a 30 nautical mile radius was selected for initial study so that a 50% overlap of temperature values would occur along the test track. This produced 7 temperature values. As can be observed from figure 8, these temperatures gradually decrease in value until the bottom of the test site is reached where a slight increase in temperature occurs.

Looking at this temperature distribution in more detail, variations of the average S-194 Antenna Temperature (TAC) were examined. First, every other latitude and longitude coordinate point where S-194 observations were available as extracted from the data tabulations were used for the length of the test site. This resulted in 26 points each separated by 7 miles giving a total distance of 175 miles. By selecting every other given coordinate point, six Antenna Temperature values could be assigned to each selected point. These six values were averaged for each point. The average Antenna Temperature value for each point was then plotted on a graph (Fig. 9).

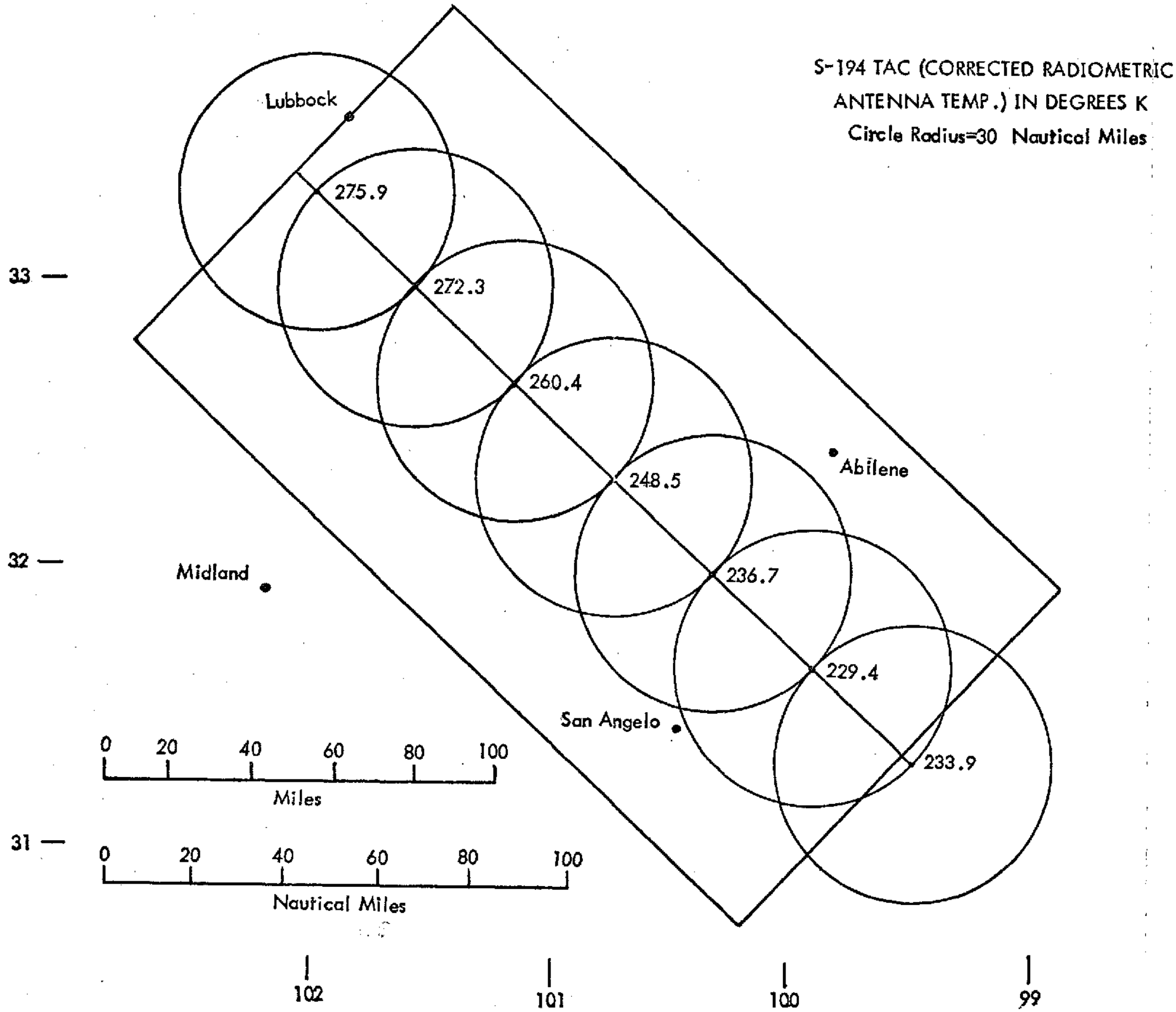

Fig. 8. General variation of S-194 Antenna Temperature in Degrees K.

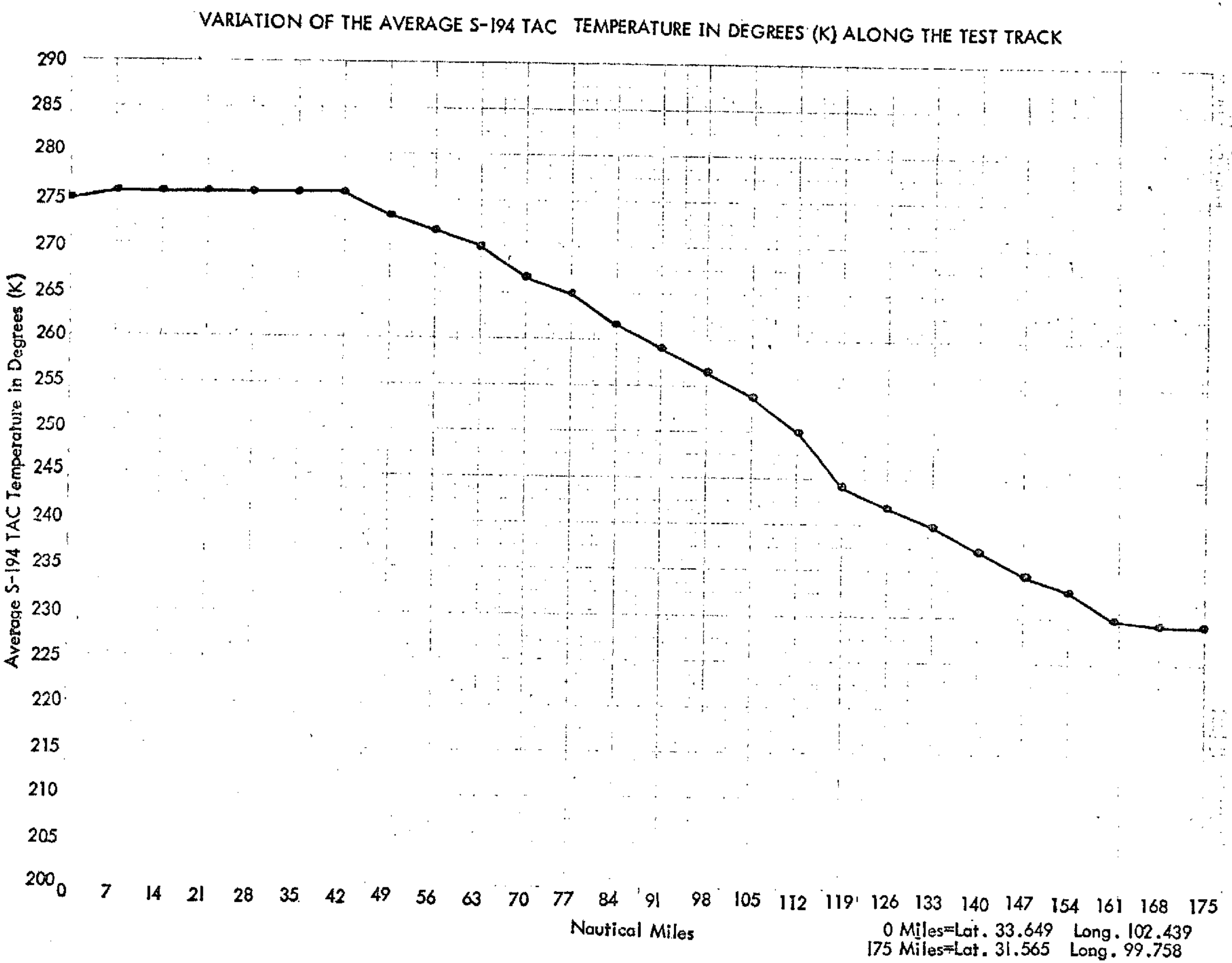

Fig. 9. Variation of the average S-194 antenna temperature in Degrees K.

Figure 9 reveals in more detail than figure 8 the changing S-194 Antenna Temperatures. A temperature plateau may be observed for the first 42 miles, then a gradual drop in temperature continues along the test track until a minimum level is reached at the 168 nautical mile point.

SOIL MOISTURE MEASUREMENTS

Soil samples were taken from 66 locations in the test area on June 5 and June 6, 1973. The distance between sites was approximately four statute miles. Six samples, one for each inch in depth down to six inches, were taken from each site location. These samples were dried and weighed in the laboratory, then the percentage of moisture in the soil was calculated by weight. This information was then plotted on three graphs (Fig's 10, 11, & 12) showing the variation of the average soil moisture for the 1-3 inch, 4-6 inch, and 1-6 inch layer at 7 mile intervals along the test track.

Figures 10, 11, and 12 indicate that for most of the test site the 1-3 inch layer has the least amount of moisture, 2.5%-20.0% of the total weight, and the 4-6 inch layer the largest amount of moisture, 7%-22% of the total weight. All three graphs show the drier soils to be at the beginning of the test track and the more moist soils near the end of the test track.

It should be noted that for these soil moisture averages only the three soil sample sites nearest the selected latitude and longitude coordinates were used. Since rainfall amounts change rapidly over short distances, using so few data points resulted in wide fluctuations of moisture values along the test track. If figures 10, 11, & 12 are compared to figure 9, a general trend can be seen. When the S-194 Antenna Temperature is high the soil moisture content is low and the lower the antenna temperature the higher the soil moisture content. A more detailed correlation will be presented

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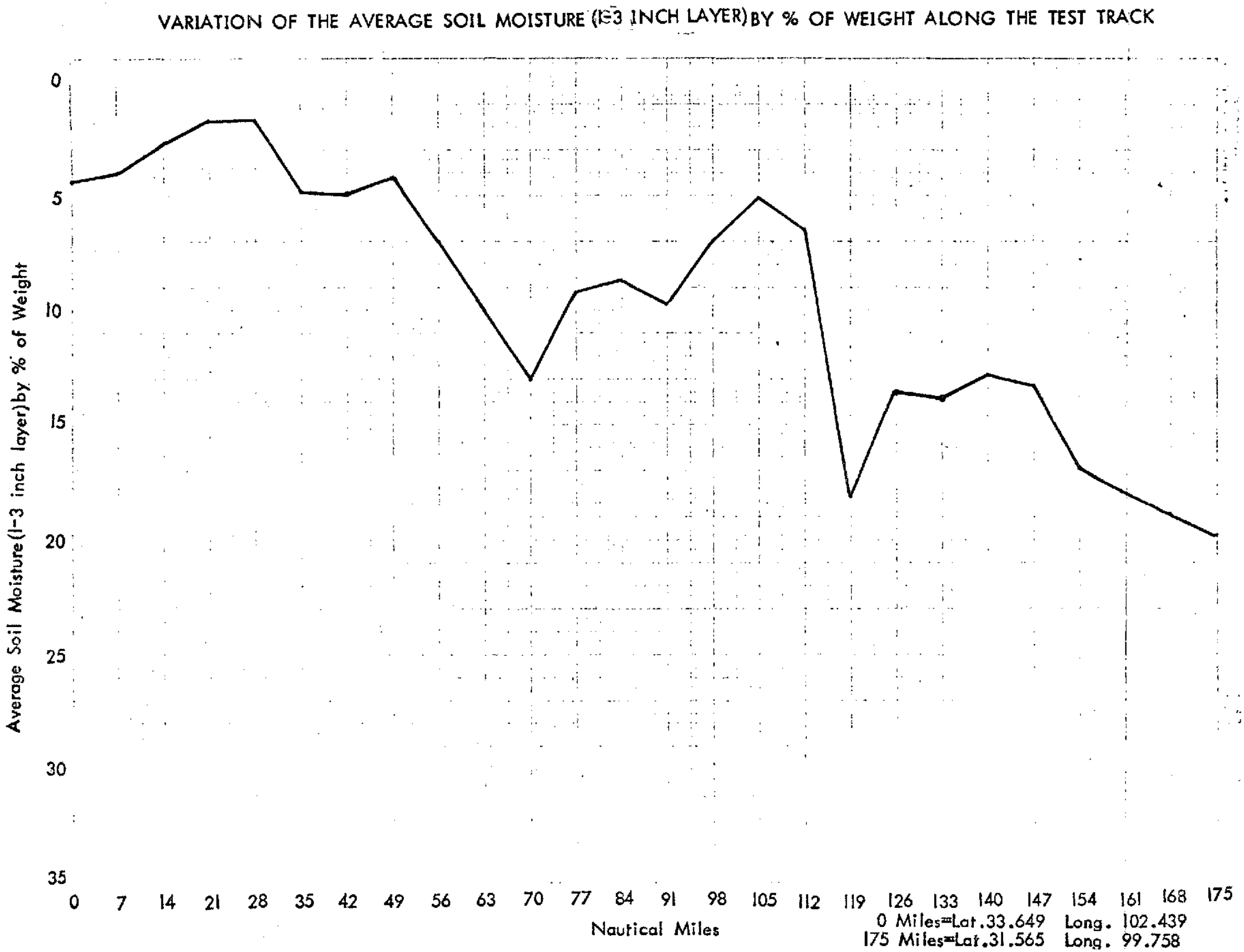

Fig. 10. Variation of the average soil moisture (1-3 inch layer) by % of weight.

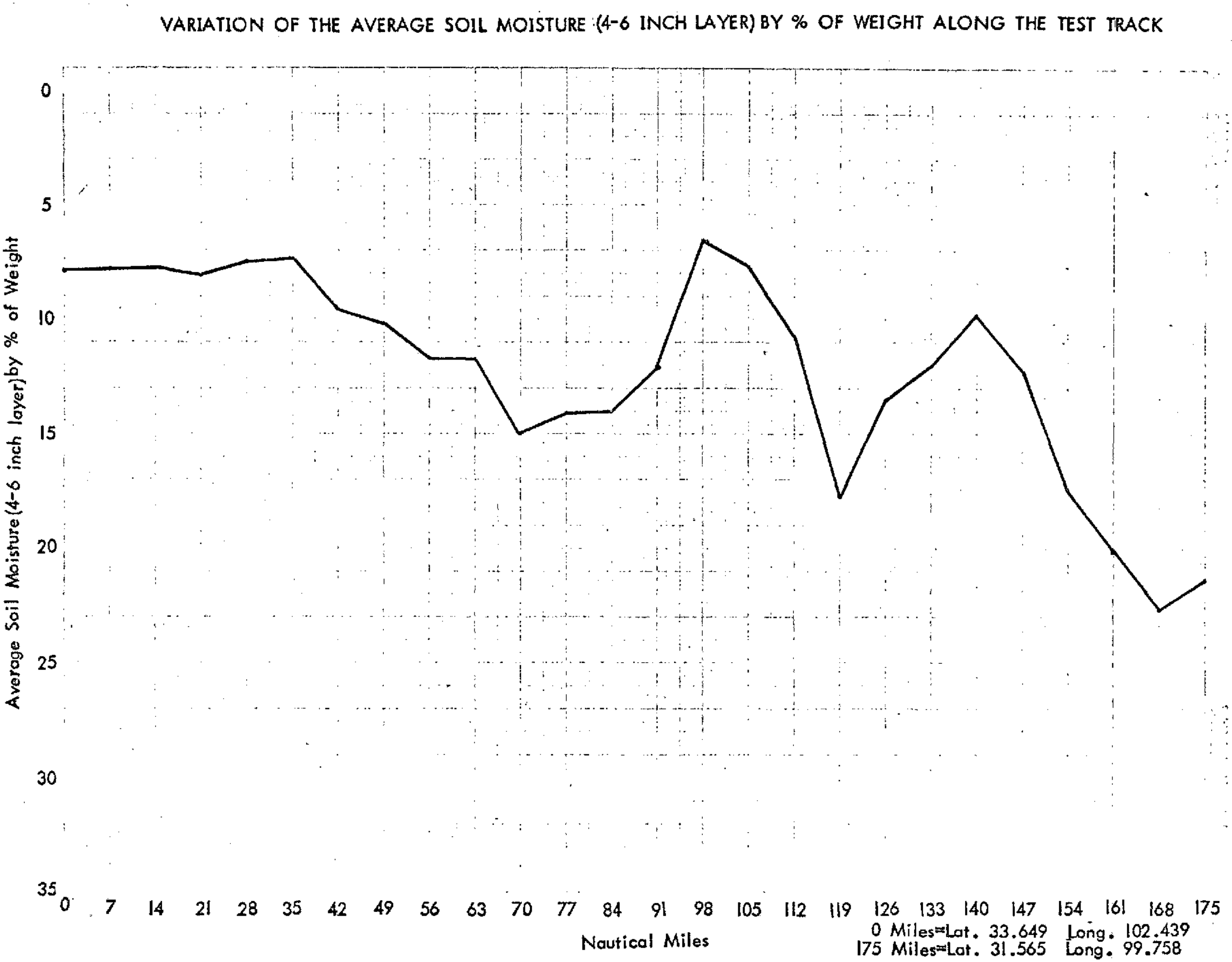

Fig. 11. Variation of the average soil moisture (4-6 inch layer) by % of weight.

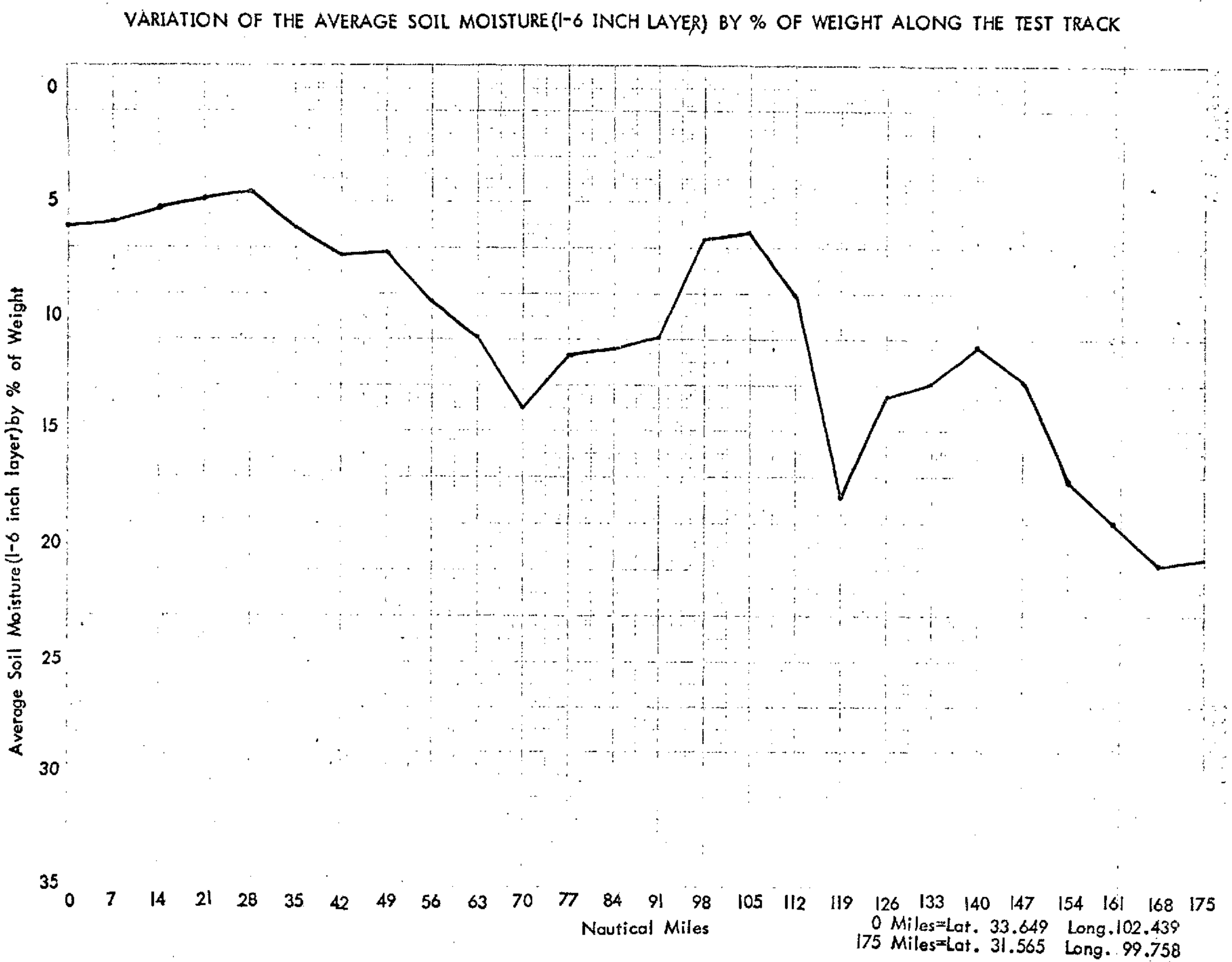

Fig. 12. Variation of the average soil moisture (1-6 inch layer) by % of weight.

later in this report. The comparison of these figures served as a first rough estimate. For a more precise comparison all the soil moisture sites within a 30 mile radius of the center of the S194 data circle must be averaged so that a direct comparison can be made.

PRECIPITATION DISTRIBUTION

Total precipitation amounts were obtained from 41 rain gauge sites for the period of June 1-5, 1973. These sites are not equally distributed throughout the test site, however, they occur frequently enough to obtain a general idea of the precipitation distribution that developed prior to the Skylab 2 overflight.

An isoline map was made (Fig. 13) showing the general precipitation distribution. Due to summer type convectional thunderstorms that generally produce heavy localized rainfall, significant variation of precipitation may be observed. Rainfall amounts vary less than ½ inch in the top portion of the test site to some local maximums of more than three inches. The general trend shows an increase in precipitation while moving from NW to SE along the test track. This pattern is consistent with the soil moisture graphs previously discussed.

RADAR ECHOES

Radar film from Midland, Texas was obtained covering the dates from May 31, 1973 to June 5, 1973. All radar echoes indicated on the film were plotted on base maps (Fig.'s 14A-14D). Each echo represents the maximum area covered by any given thunderstorm or group of storms. The radar echoes were broken down into four maps so that precipitation patterns may be observed at various intervals prior to the Skylab 2 overflight.

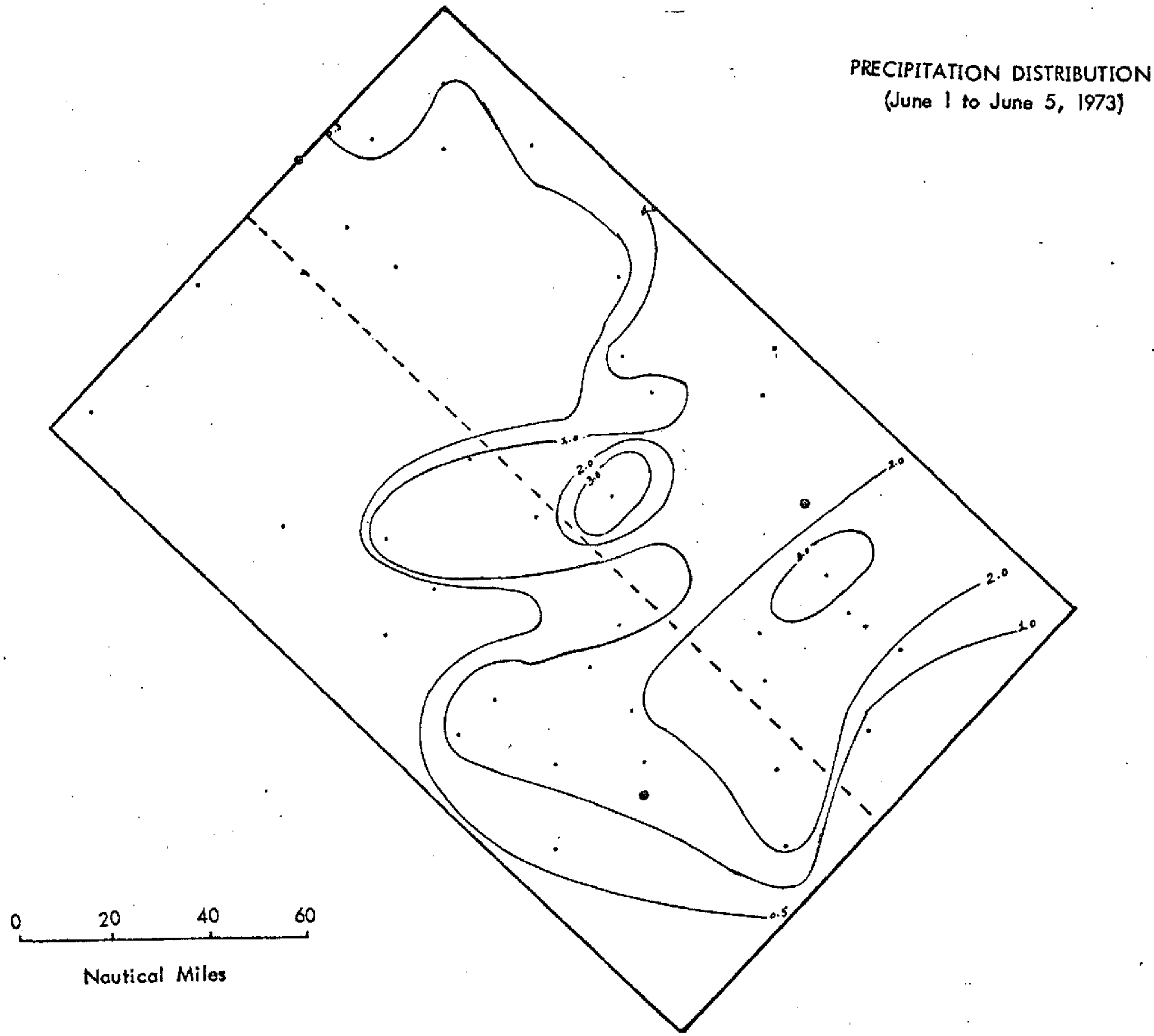

Fig. 13. Precipitation distribution June 1-5, 1973, collected from available rain gauge sites.

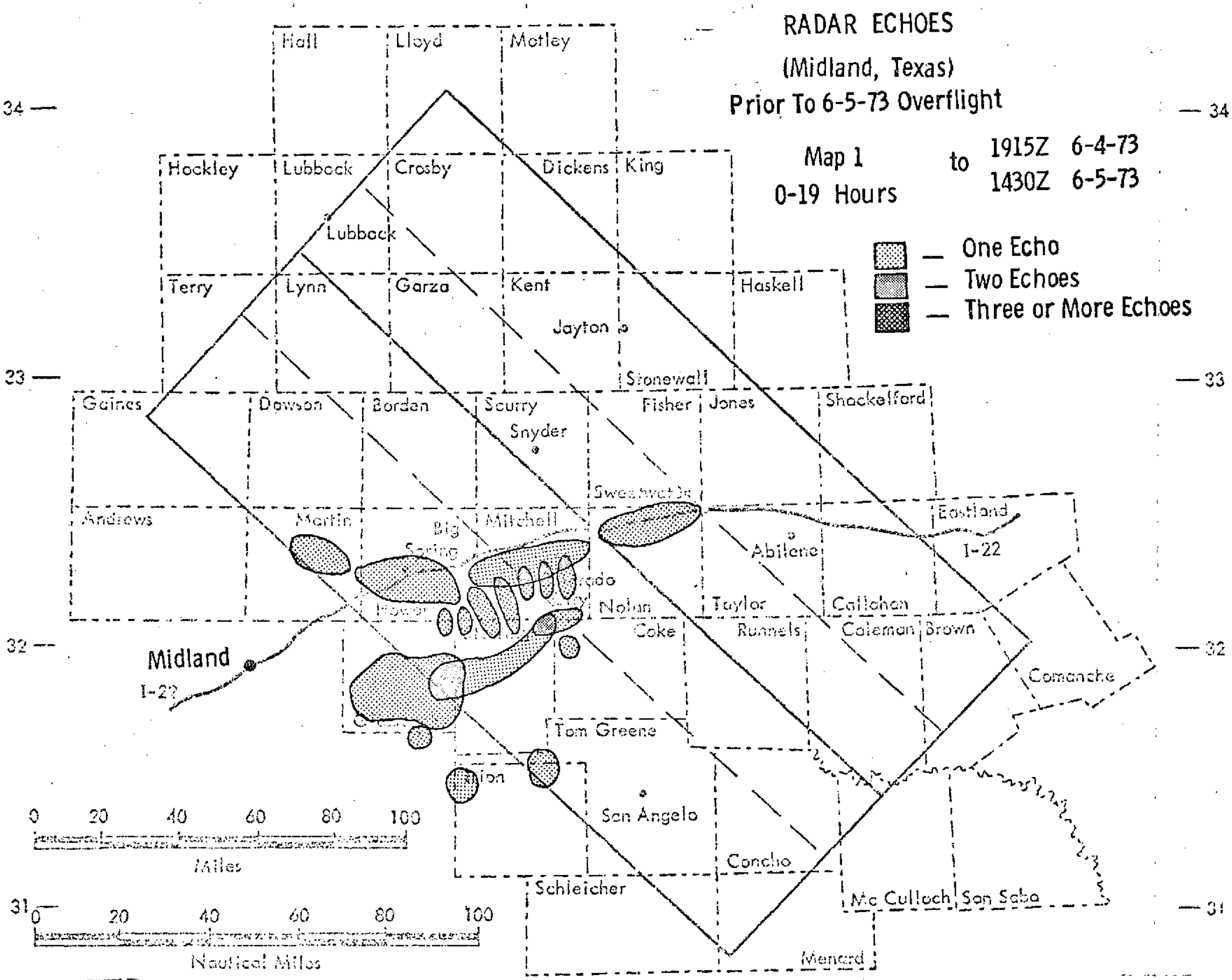

Fig. 14A. Radar Echoes--0-19 hours prior to 6-5-73 overflight.

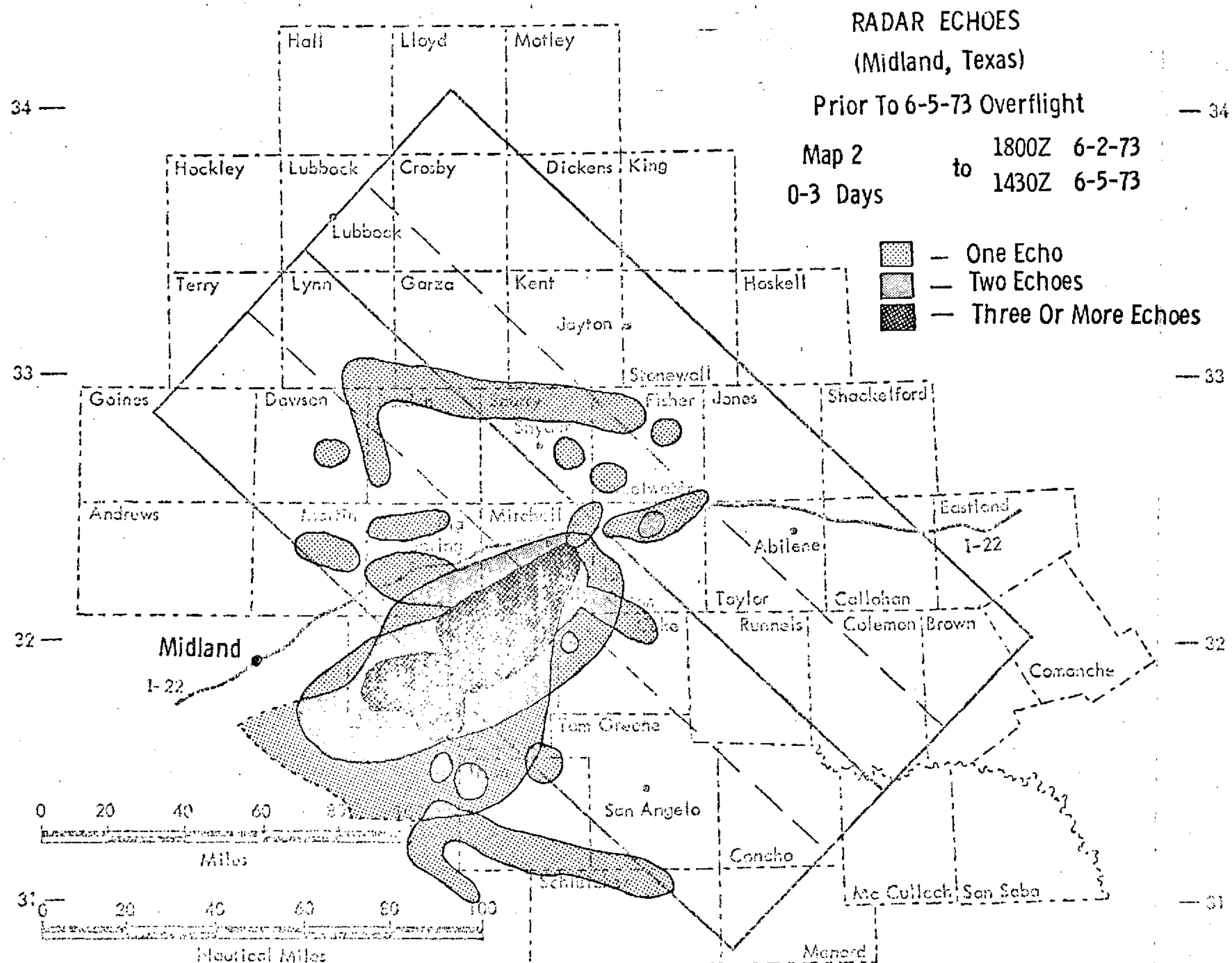

Fig. 14B. Radar Echoes--0-3 days prior to 6-5-73 overflight.

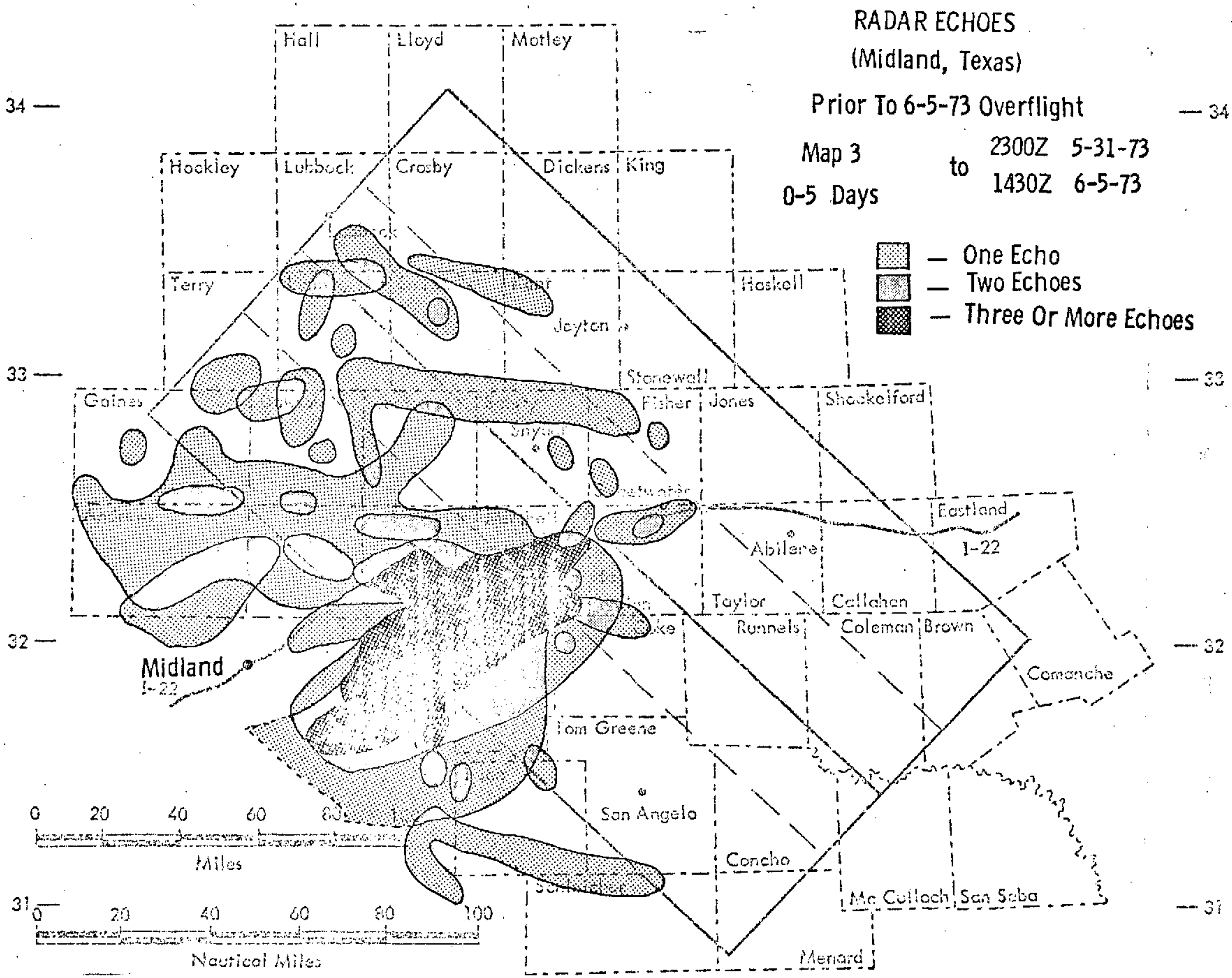

Fig. 14C. Radar Echoes--0-5 days prior to 6-5-73 overflight.

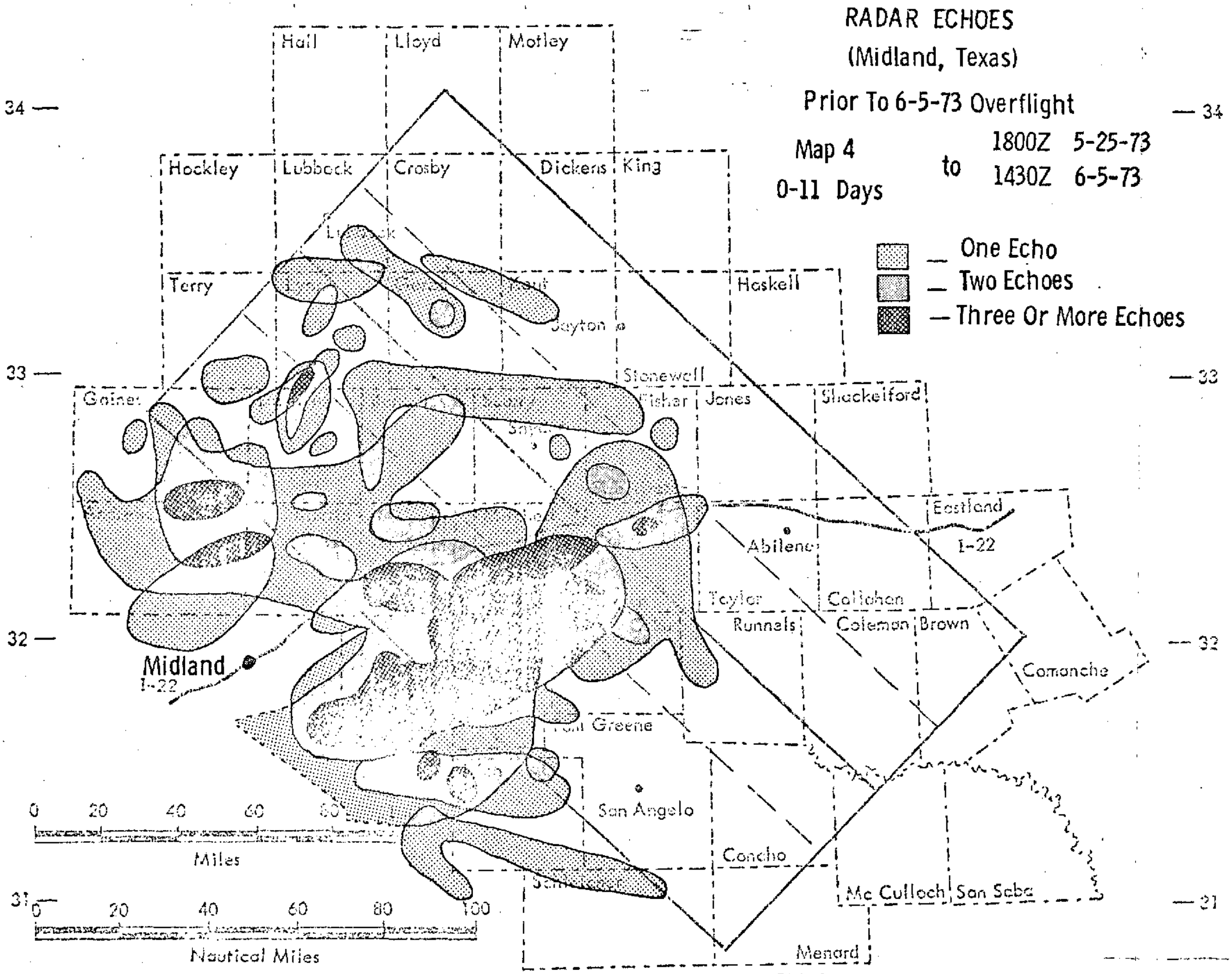

Fig. 14D. Radar Echoes--0-11 days prior to 6-5-73 overflight.

Figure 14A reveals only scattered echo development up to 19 hours prior to overflight. Figure 14B shows considerable echo activity up to 3 days prior to overflight with a maximum occurring in the south-central portion of the test site. Figure 14C extends the echo activity to 5 days prior to overflight. For this time period a large portion of the test site shows at least one echo coverage with a very definite maximum occurring in the south-central area. Figure 14D gives an 11 day coverage. By extending the coverage for this length of time numerous two and three echo areas have developed. It should be noted that the area beyond the outer perimeter of the echoes in the test site is assumed to be beyond the Midland, Texas radar range. With more detailed analysis to be conducted in the future, these echo locations will be compared with soil moisture data obtained from soil sample sites.

These radar echoes may already be compared with the precipitation distribution map shown as figure 13. In comparing the precipitation distribution with figure 14C (same time coverage), that in general, areas of light echo coverage correspond to areas of less than ½ inch precipitation while the maximum area of precipitation in the central portion of the test site corresponds to the area of three or more echoes. The southern 1/3 of the test site should be excluded from this comparison due to lack of radar data. In addition, the comparison is hindered somewhat due to the lack of sufficient rain gauge sites. Echoes occur in many areas where no precipitation measurements were available.

CORRELATION OF S-194 ANTENNA TEMPERATURE AND SOIL MOISTURE

For this correlation more precise calculations were made in order to determine the ability of the S194 sensor to detect soil moisture content. In obtaining the average S-194 antenna temperature, latitude and longitude coordinates were used so that only

3.5 nautical miles separate each point. This allowed three TAC temperature values to be assigned to each coordinate. These three values were averaged for each point with the resulting values assigned to each appropriate coordinate point. The resulting graph (Fig. 15) is merely a refinement of figure 9.

In order to compare the soil moisture content with the S194 data all soil sample sites within a 30 nautical mile radius of each selected latitude and longitude coordinate were used. This ranged from 12 to 22 soil sample sites per coordinate. The distance separating coordinate points was reduced to 3.5 nautical miles (Fig. 16). A comparison of figures 15 and 16 shows a more definite correlation between S-194 Antenna Temperature and soil moisture than did figures 8 and 11.

For a more precise correlation of S-194 Antenna Temperature with soil moisture, correlation coefficients (r) were obtained for varying soil layers 0-6 inches in depth. Table 1 indicates that the 0-2 inch soil layer produces the highest correlation coefficient, $r = 0.988$, with the 0-1 inch layer, $r = 0.985$, and 1-2 inch layer, $r = 0.987$, also resulting in very high correlation. This indicates that the S194 sensor is able to respond to soil moisture variation very effectively.

In order to see visually how close each value of real data comes to the regression line, correlations between the S-194 Antenna Temperature and each soil layer shown in Table 1 have been plotted on Scattergrams (Fig's 17A-17J). For these diagrams, x coordinate values represent the Antenna Temperature and y coordinate values are the changes in soil moisture content. In the scattergrams, (x's) show the real data plots while (*'s) show the regression plots. The closer the real data points are to the regression plots the higher the correlation coefficient (r). Figure 17F shows the lowest correlation coefficient, $r = 0.88$, and therefore more of the real data plots occur farther

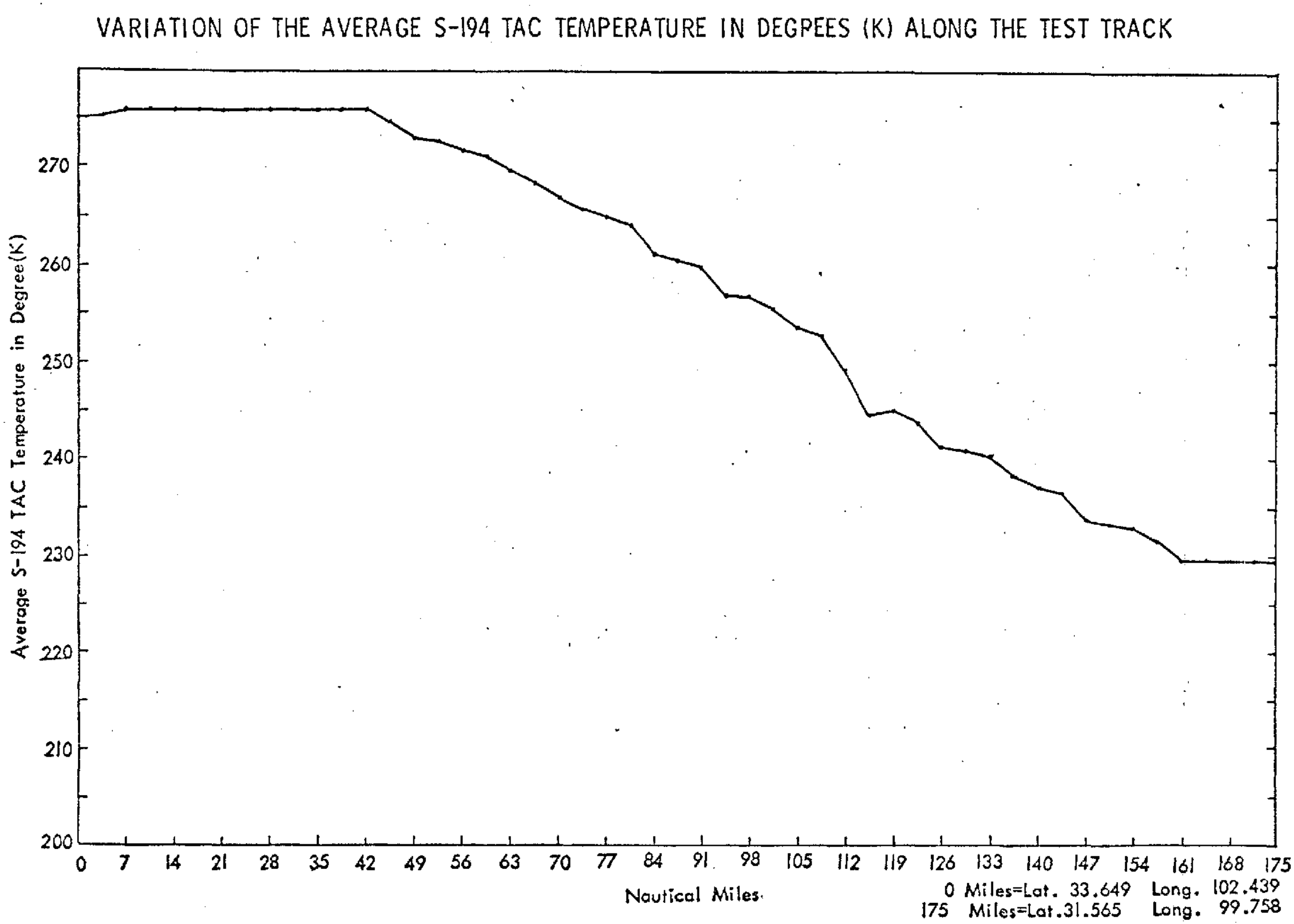

Fig. 15. Detailed variation of the S-194 Antenna Temperature in Degrees K.

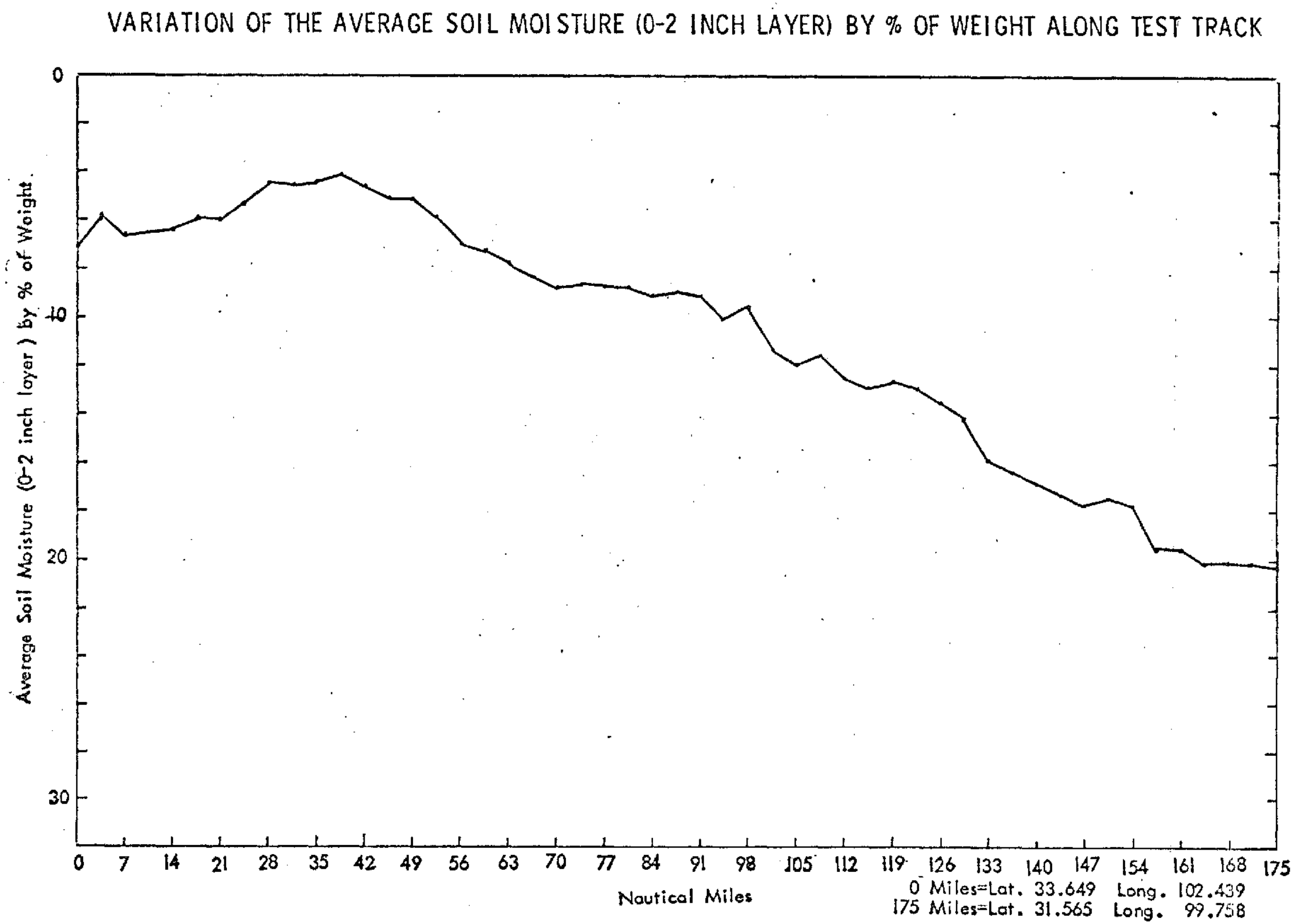

Fig. 16. Detailed variation of the soil moisture 0-2 inch layer by percent of weight

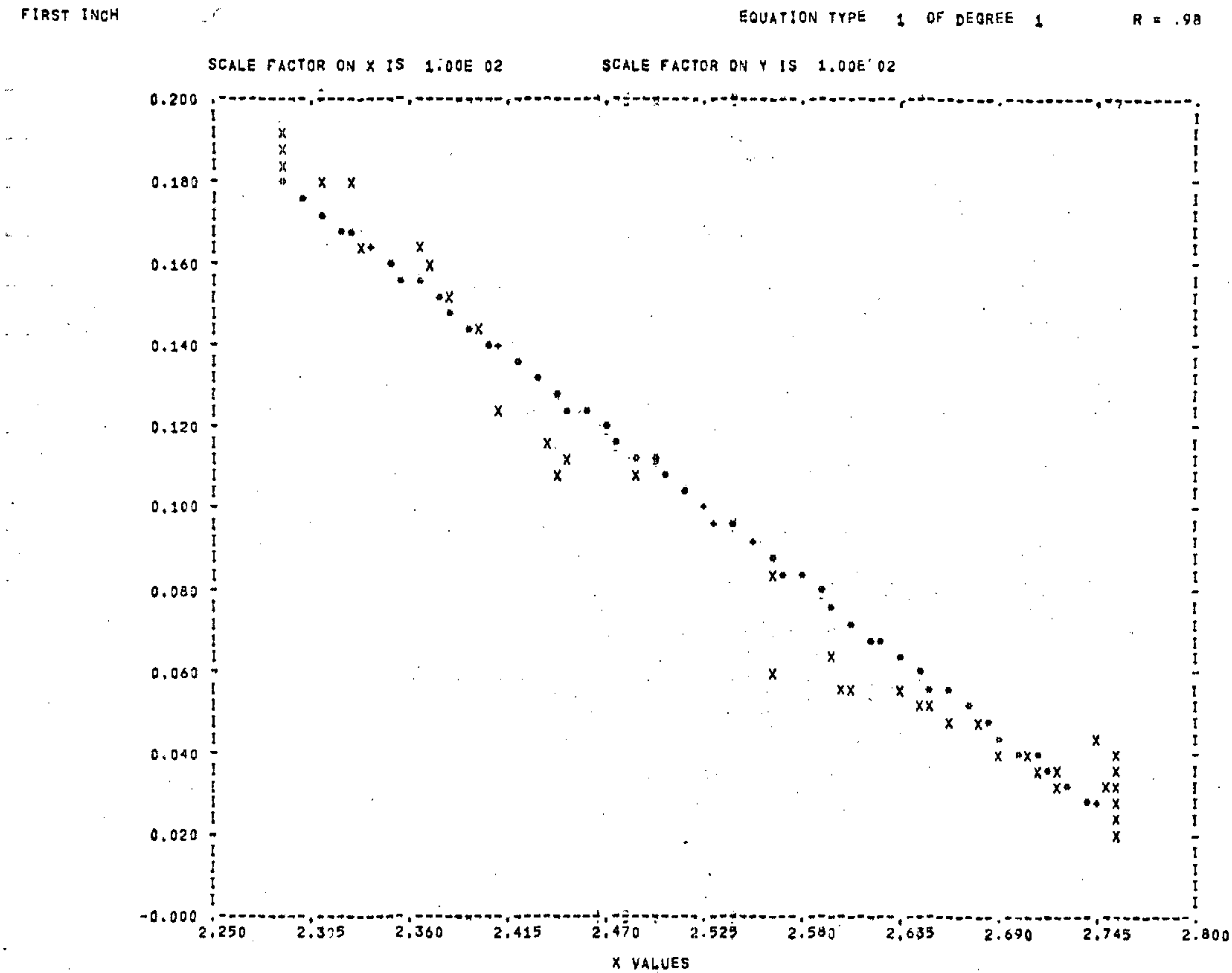

Fig. 17A. Correlation Scattergram---Antenna temperature vs. soil moisture 0-1 inch in depth.

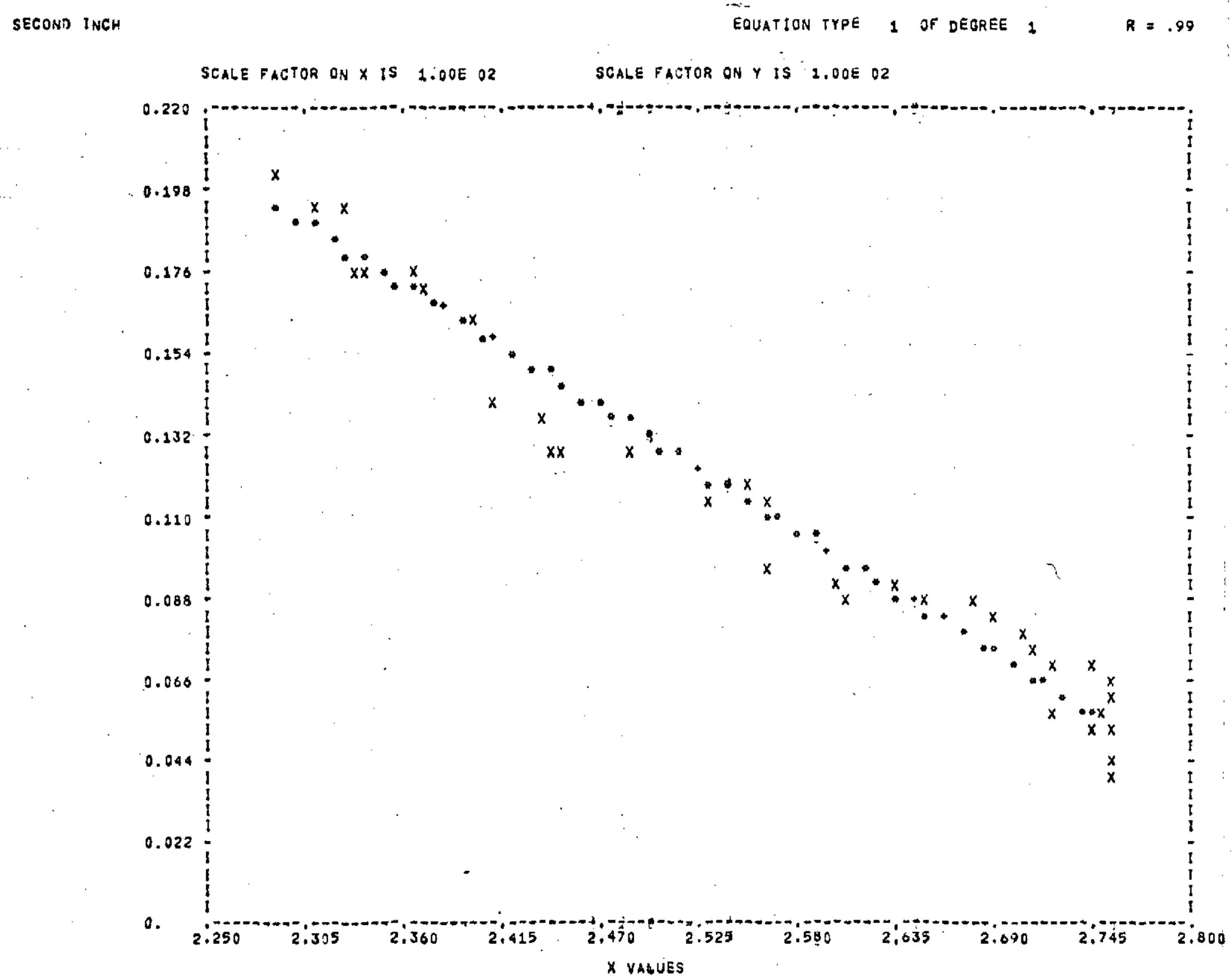

Fig. 17B. Correlation Scattergram---Antenna temperature vs. soil moisture 1-2 inches in depth.

THIRD INCH

EQUATION TYPE 1 OF DEGREE 1 R = .95

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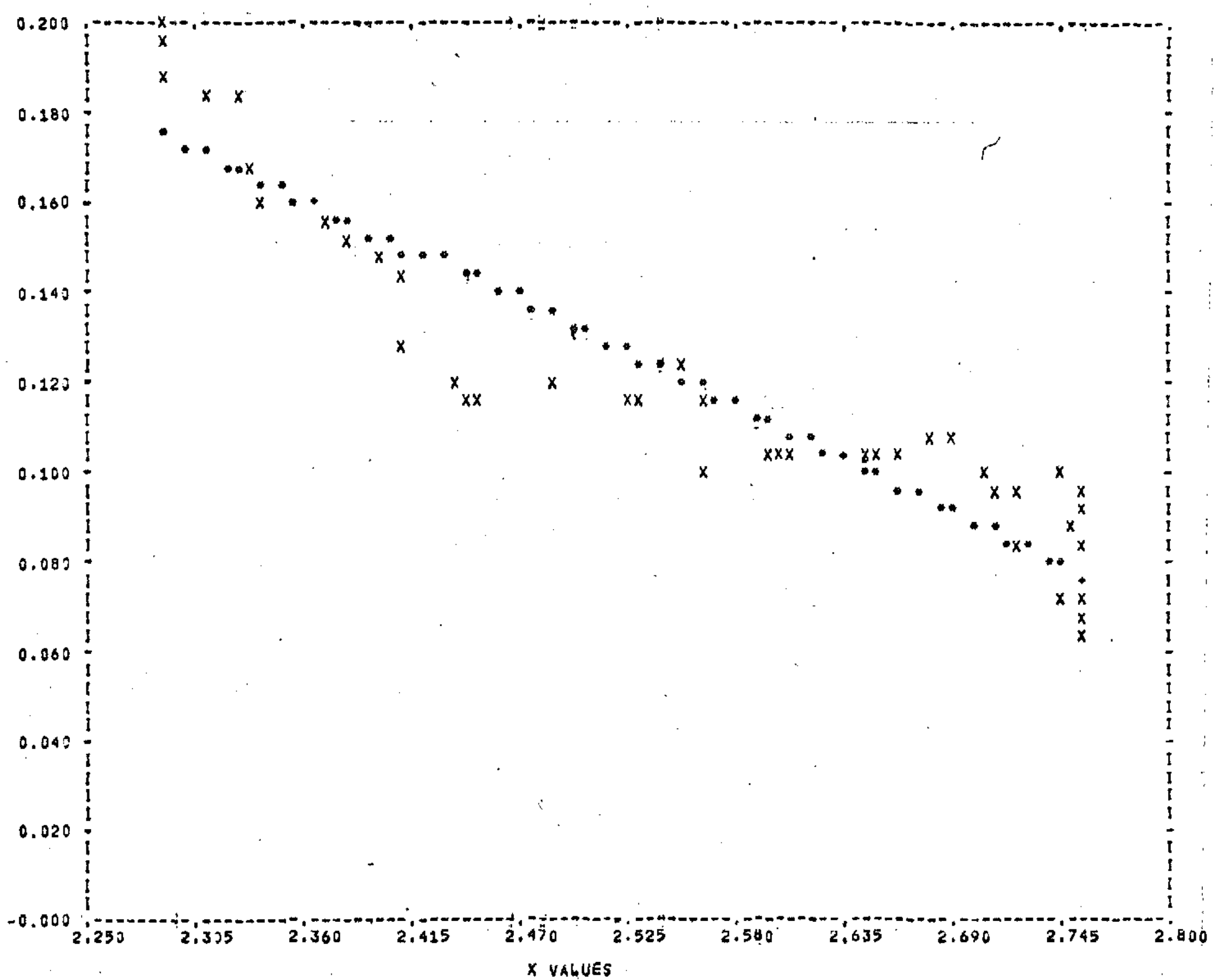

Fig. 17C. Correlation Scattergram---Antenna temperature vs. soil moisture 2-3 inches in depth.

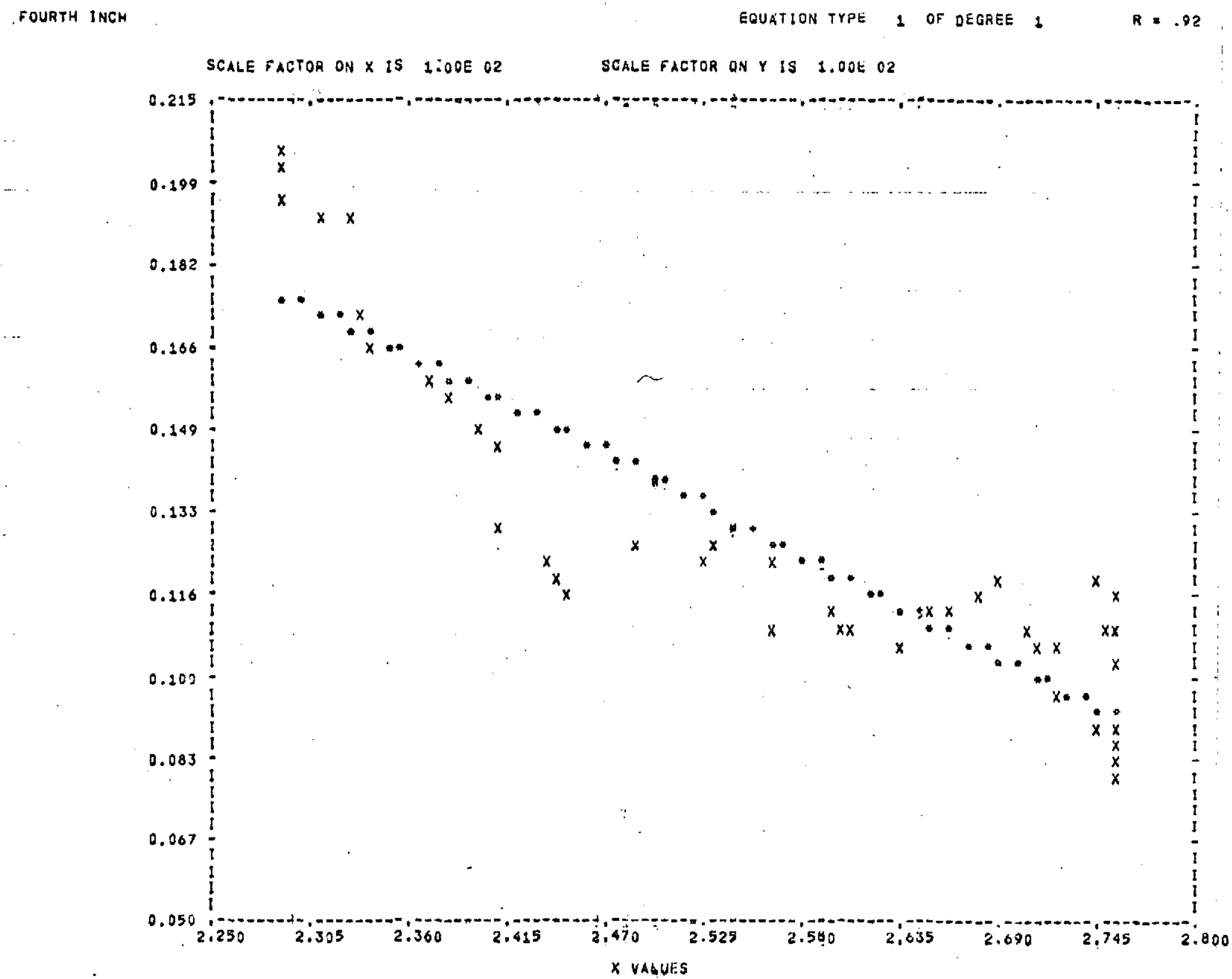

Fig. 17D. Correlation Scattergram---Antenna temperature vs. soil moisture 3-4 inches in depth.

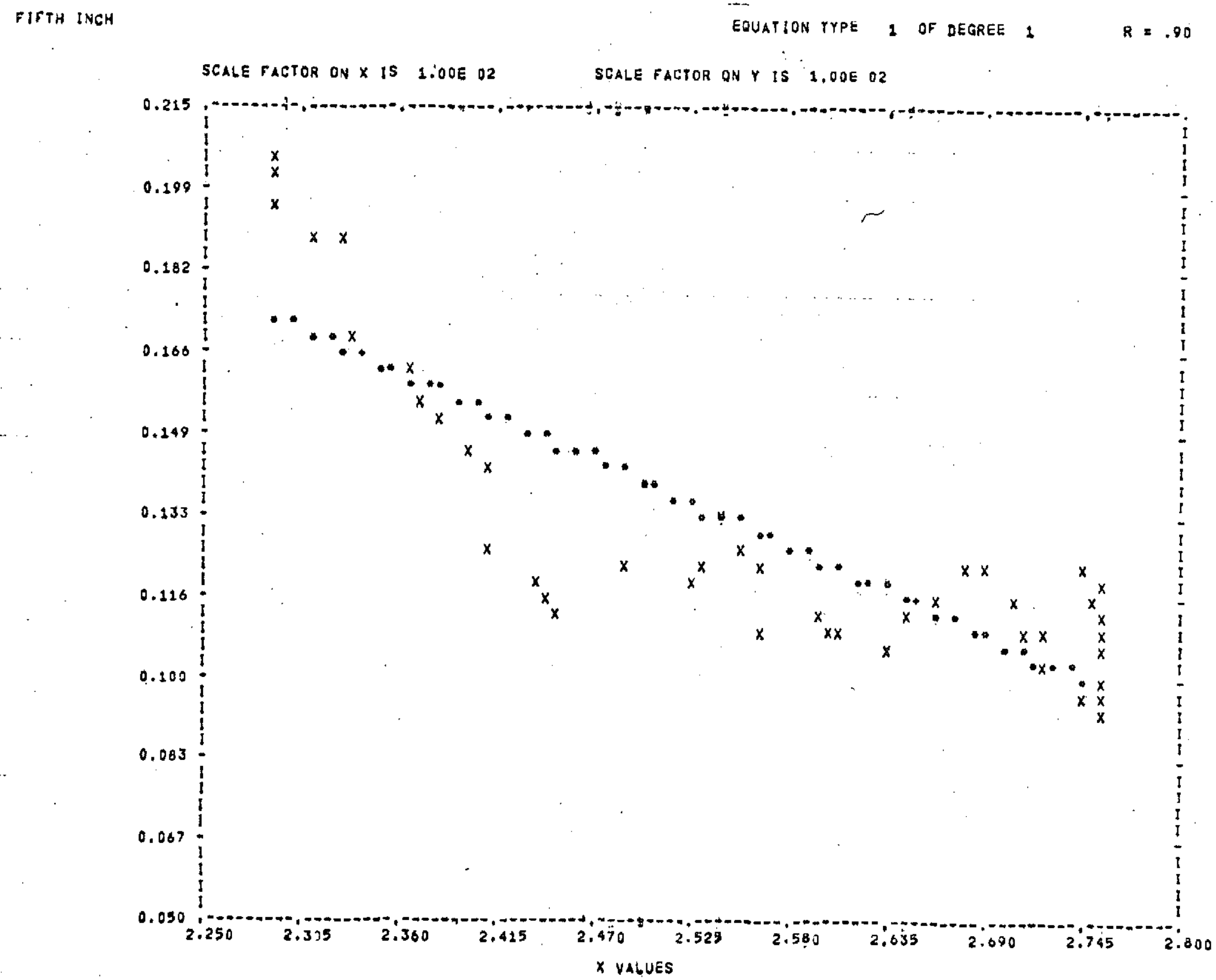

Fig. 17E. Correlation Scattergram---Antenna temperature vs. soil moisture 4-5 inches in depth.

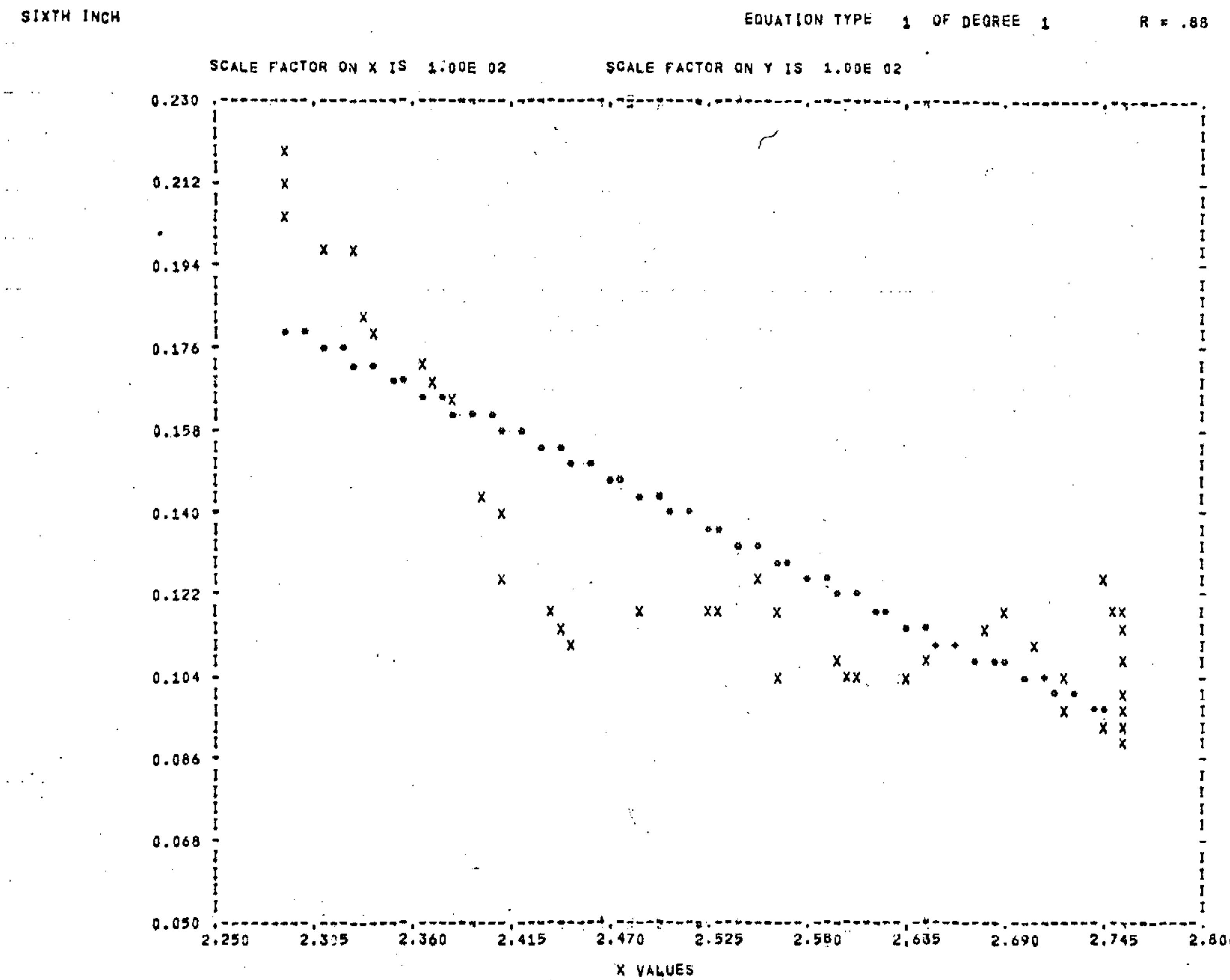

Fig. 17F. Correlation Scattergram---Antenna temperature vs. soil moisture 5-6 inches in depth.

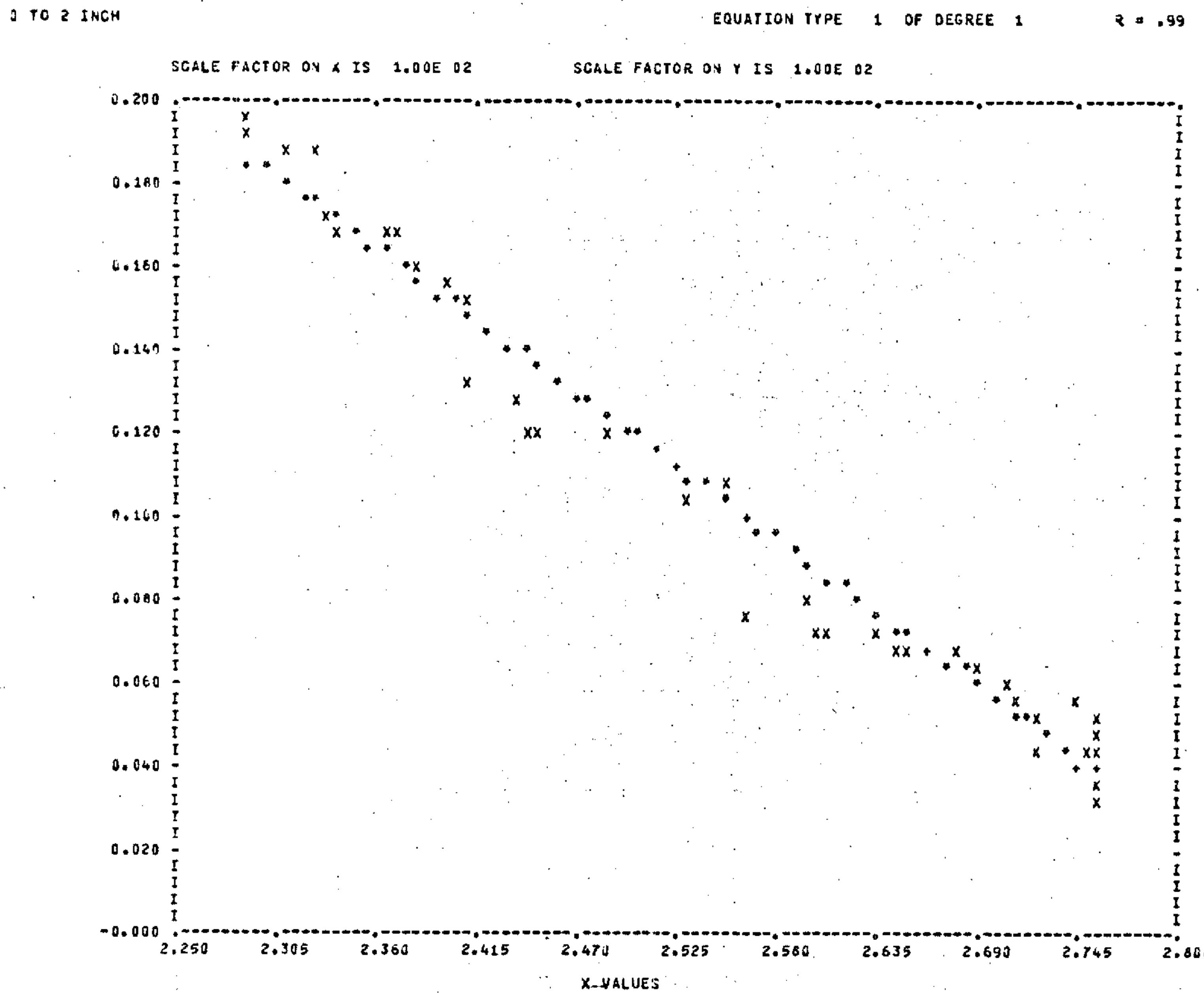

Fig. 17G. Correlation Scattergram---Antenna temperature vs. soil moisture 0-2 inches in depth.

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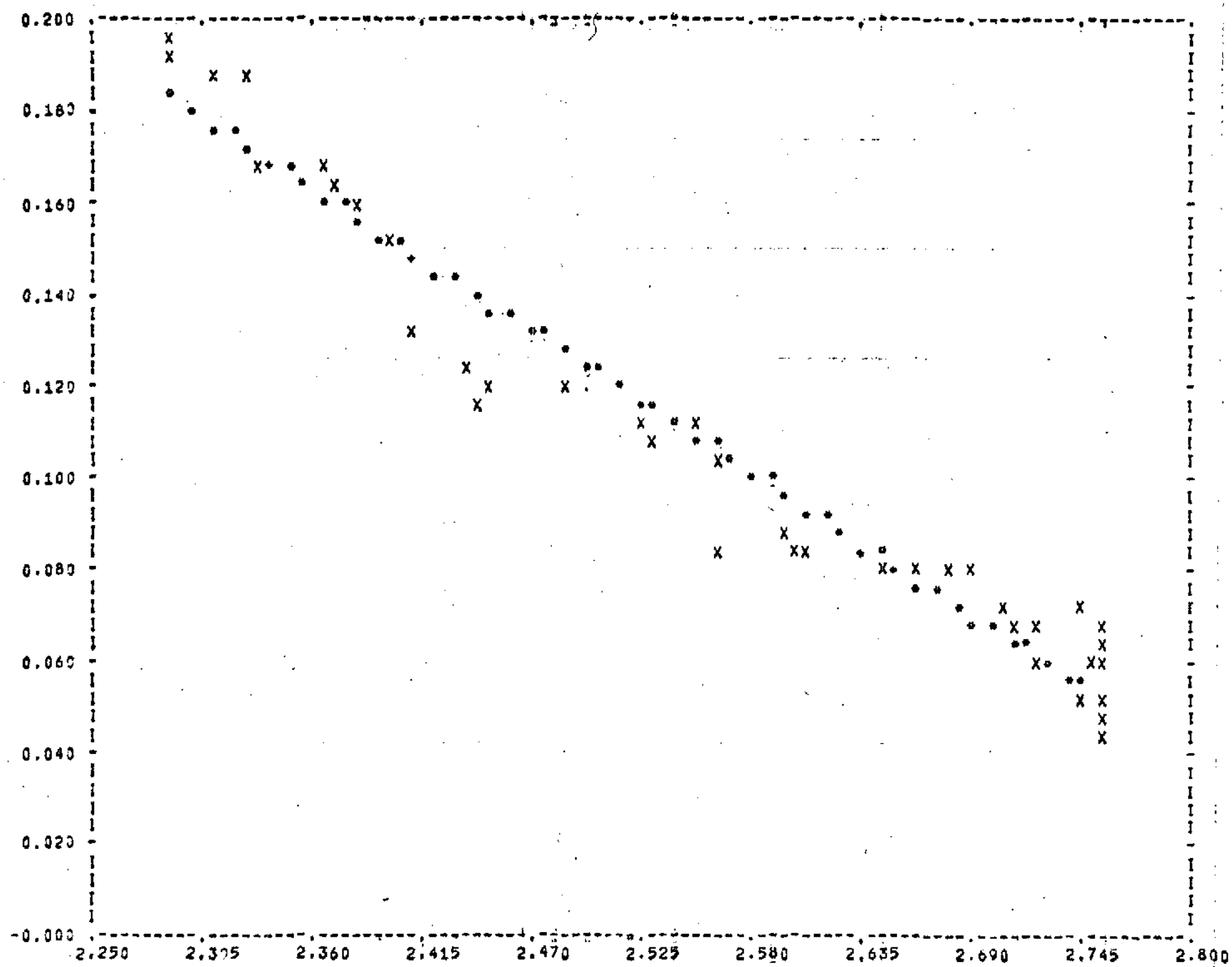

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Fig. 17H. Correlation Scattergram---Antenna temperature vs. soil moisture 0-3 inches in depth.

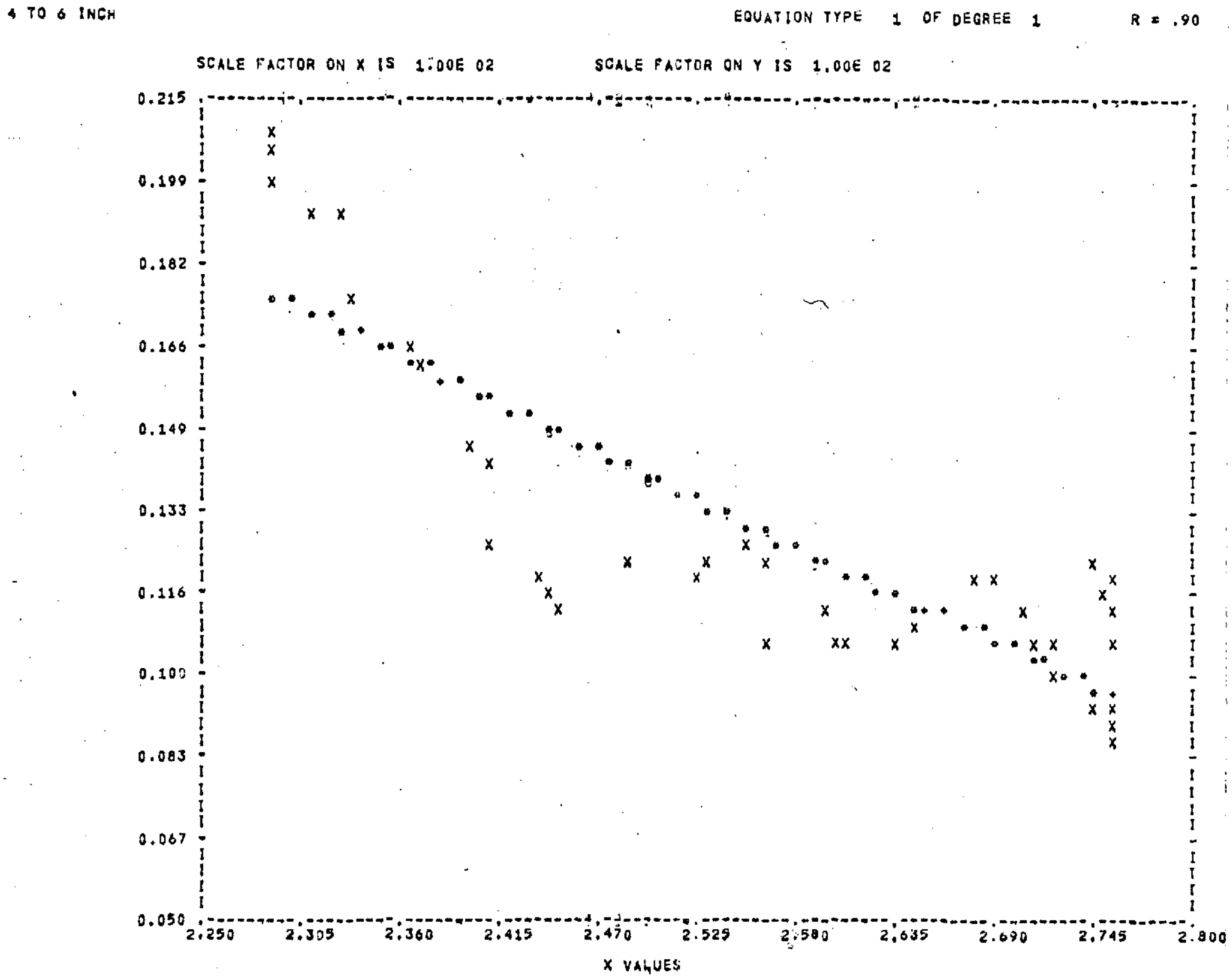

Fig. 17I. Correlation Scattergram---Antenna temperature vs. soil moisture 4-6 inches in depth.

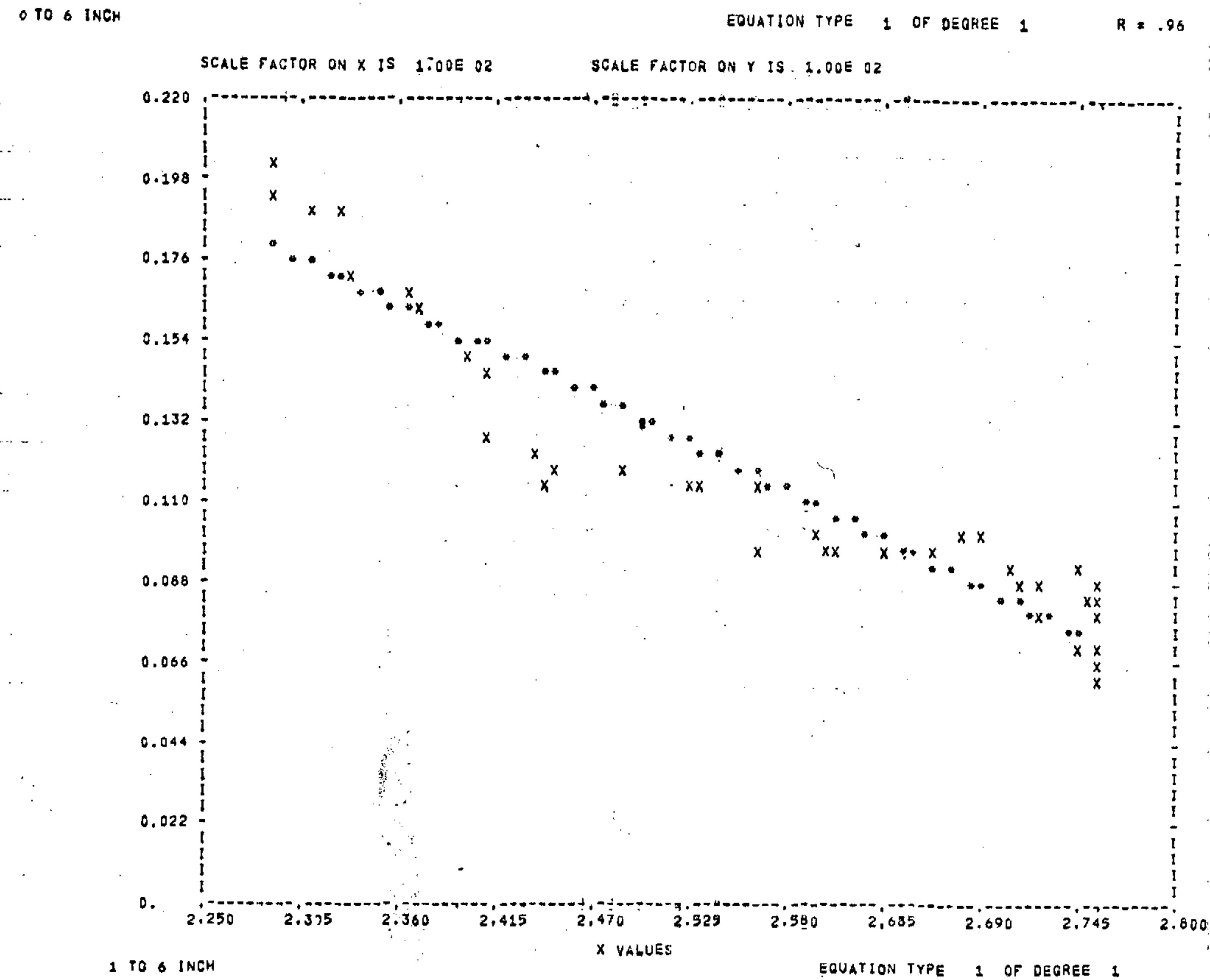

Fig. 17J. Correlation Scattergram---Antenna temperature vs. soil moisture 0-6 inches in depth.

CORRELATION BETWEEN SOIL MOISTURE AND S-194 ANTENNA TEMPERATURE

Soil Moisture Layer	Correlation Coefficient	Regression Equation
0-1 inch	0.985	SM=94.78-0.3351AT
1-2 inch	0.987	SM=87.99-0.2995AT
2-3 inch	0.947	SM=65.59-0.2095AT
3-4 inch	0.925	SM=59.26-0.1814AT
4-5 inch	0.897	SM=53.65-0.1588AT
5-6 inch	0.884	SM=61.00-0.1871AT
0-2 inch	0.988	SM=91.30-0.3170AT
0-3 inch	0.981	SM=82.80-0.2814AT
3-6 inch	0.903	SM=57.97-0.1758AT
0-6 inch	0.960	SM=72.09-0.2357AT

Sample Size=50
SM=Soil Moisture
AT=Antenna Temperature

Table 1. Correlation between soil moisture and S-194 Antenna Temperature.

away from the regression line than occurs in figure 17G where the correlation coefficient is the highest, r = .99. The correlation coefficient value, rounded to the nearest hundredth, is located in the upper right hand corner of each figure.

These correlations not only show the ability of the S194 sensor to respond to large scale soil moisture variations, but also provide information on the effective depth of response. The correlations are lower for the 5-6 inch soil layer. The antenna temperature correlates best with the soil moisture content from the surface to two inches within the soil. Since this correlation is quite good the S194 sensor should provide considerable information on the soil moisture content near the surface of the earth.

SUMMARY OF SIGNIFICANT RESULTS

This is a preliminary report on the ability to detect soil moisture variation from two different sensors on board Skylab. Initial investigations of S190A and S194 Skylab data and ground truth data has indicated the following significant results:

1. There was a decrease in S-194 Antenna Temperature from NW to SE across the Texas test site.
2. Soil moisture increases were measured from NW to SE across the test site.
3. There was a general increase in precipitation distribution and radar echoes from NW to SE across the site for the few days prior to measurements. This was consistent with the soil moisture measurements and gives more complete coverage of the site.
4. There are distinct variations in soil textures over the test site. This affects the moisture holding capacity of the soils and must be considered.

5. Strong correlation coefficients were obtained between S-194 antenna temperature and soil moisture content. As the antenna temperature decreases soil moisture increases.

6. The S-194 antenna temperature correlated best with soil moisture content in the upper two inches of the soil. A correlation coefficient of .988 was obtained.

7. S190A photographs in the red-infrared region were shown to be useful for identification of Abilene clay loam and for determining the distribution of this soil type in a county having no soil survey information.