Hail Genesis Areas In and Near Northeastern Colorado

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Prepared for the Crop-Hail Insurance Actuarial Association
Report of Research Supported by Nation Science Foundation, Grant NSF G 17964
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Colorado State University

Department of Atmospheric Science

Paper No. 21

COLORADO STATE UNIVERSITY

FORT COLLINS, COLORADO

DEPARTMENT OF CIVIL ENGINEERING

1 October 1961

Mr. Philip S. Brown, Manager
Crop-Hail Insurance Actuarial Association
Room 700, 209 West Jackson Blvd.
Chicago 6, Illinois

Dear Mr. Brown:

I am pleased to transmit herewith the report "Hail Genesis Areas In and Near Northeastern Colorado," a report of research conducted during the summer of 1961 supported by the National Science Foundation and the Crop Hail Insurance Actuarial Association.

As you are aware, the majority of the support for this research work came from the National Science Foundation. Thanks to the assistance given to us by the Crop Hail Insurance Actuarial Association, it has been possible to examine some of the problems of specific interest to your association--this year Hail Genesis Areas. In the interest of presenting a report that would be more readable and not out of context, I have chosen to combine the report to you with other information obtained under National Science Foundation sponsorship. By so doing I hope it will be possible for you to have a better idea of the total program that was conducted in the summer of 1961.

The problems associated with hail formation, its damage, and the potentialities for its control continue to be of interest to us at Colorado State University. I hope we can continue to work together in the future on this problem of mutual interest.

Sincerely yours,

Richard A. Schleusener

Richard A. Schleusener
Associate Research Engineer

Atmospheric Science Technical Paper

Number 21

HAIL GENESIS AREAS IN AND NEAR NORTHEASTERN COLORADO

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INTRODUCTION

Colorado State University has been involved in studies of hail in and near northeastern Colorado since 1959. This region suffers more frequent hail falls than any other region in the United States (1)*. Summertime thunderstorms that develop in this area commonly produce hail damage in eastern Colorado and western Nebraska and Kansas as the storms move progressively further to the east.

Because of the frequent occurrence of hailstorms, this is an excellent area for studying the origin, genesis, and motion of such storms. Hailstorms originating in this region frequently move further to the east and produce damaging storms in Nebraska and Kansas.

Funding for these research studies has come primarily from the National Science Foundation. In 1961 the Crop-Hail Insurance Actuarial Association provided some financial assistance to these studies for a review of the data being collected with regard to the specific interests of the hail insurance industry. This is a report of the research work conducted in this connection.

OBJECTIVES

The objectives of this study were as follows:

1. To determine hailstorm genesis areas.
2. To determine the subsequent track of hailstorms following their formation.
3. To pay particular attention to the genesis areas and subsequent track of those hailstorms that moved into western Kansas.

* Number in parenthesis refers to appended references.

PROCEDURE

Surface Data

Data for this study were obtained from a network of observing stations in northeastern Colorado north of Township 2N and east of Range 59W. Details of the network and a summary of data are presented elsewhere (2,3).

Radar Data

Radar equipment for the project was furnished by Atmospherics Incorporated of Fresno, California. The various components were mounted in a 24-foot house trailer completely equipped for living in the field. The system was mobile and employed 3.2-cm radar operating on a frequency of 9375 megacycles. Peak power output was 60-100 KW. Selective ranges of 4-10-20-80-200 nautical miles were available with the 80 mile range used most commonly.

Included in the system were two independently operating indicators with 7" PPI presentation. One indicator was used for general storm tracking plus still photographs of precipitation echoes. The second indicator was used exclusively for 16 mm time-lapse motion pictures of precipitation area movement, sizes, and vertical development.

Supplemental equipment included plastic overlays for assistance in storm plotting from the indicators, 16 mm movie and $2\frac{1}{4}$ x $2\frac{1}{4}$ still camera equipment for echo recording, field map plotting facilities, and a tape recording unit for voice recording and subsequent read-out of information.

The system was located one mile southeast of New Raymer, Colorado. Elevation of the radar site was approximately 4800 feet above sea level. This location provided an excellent radar view of the study area. Thunderstorms were identified from as far west as the Continental Divide to as far east as the maximum 200 nautical mile range (230.4 statute miles).

The radar antenna was oriented on the North Star for azimuth bearings. Subsequent checks of hail damage on the ground and field reports of thunderstorm locations indicated a position accuracy within one mile at a distance of one hundred miles. The system also employed a tilt indicator which gave the vertical angle of the antenna. The antenna was kept on the horizontal plane during normal scanning operation but could be tilted through a maximum of 35° during measurements of the elevations of the tops of precipitation echoes and studies of growth rates.

Operation of the system was on a 24-hour alert basis. Only two failures of the system occurred during the summer program. Both of these resulted from lightning strikes to ground within 200 yards of the trailer. Maintenance problems were rare and at no time was the radar inoperative for more than 12 consecutive hours. About 400 hours of "on the air" time were logged during the three months program from 15 May to 15 August 1961. Photographs of the complete installation and interior components are shown in Figures 1 and 2.

During the operation of the radar set, sufficient information was recorded to reconstruct the location and areal extent of precipitation echoes at the end of the days operation. Figure 3 shows a sample of the data sheets used. The paths of precipitation echoes shown in the appendix were constructed from data of the type shown in Figure 3.

Photography

Still photographs were taken periodically (Figure 4). After 1 July 1961, 16 mm time-lapse photographic equipment was installed for taking time-lapse pictures of the radar scope.

Meteorological Data

Meteorological data from the U. S. Weather Bureau facsimile network was available from the Colorado State University facsimile facility. Teletype data were made available from the U. S. Weather Bureau at Stapleton Field in Denver.

A summary of the radar operations from 15 May to 15 August 1961 is given in Table 1.

PATHS OF RADAR ECHOES

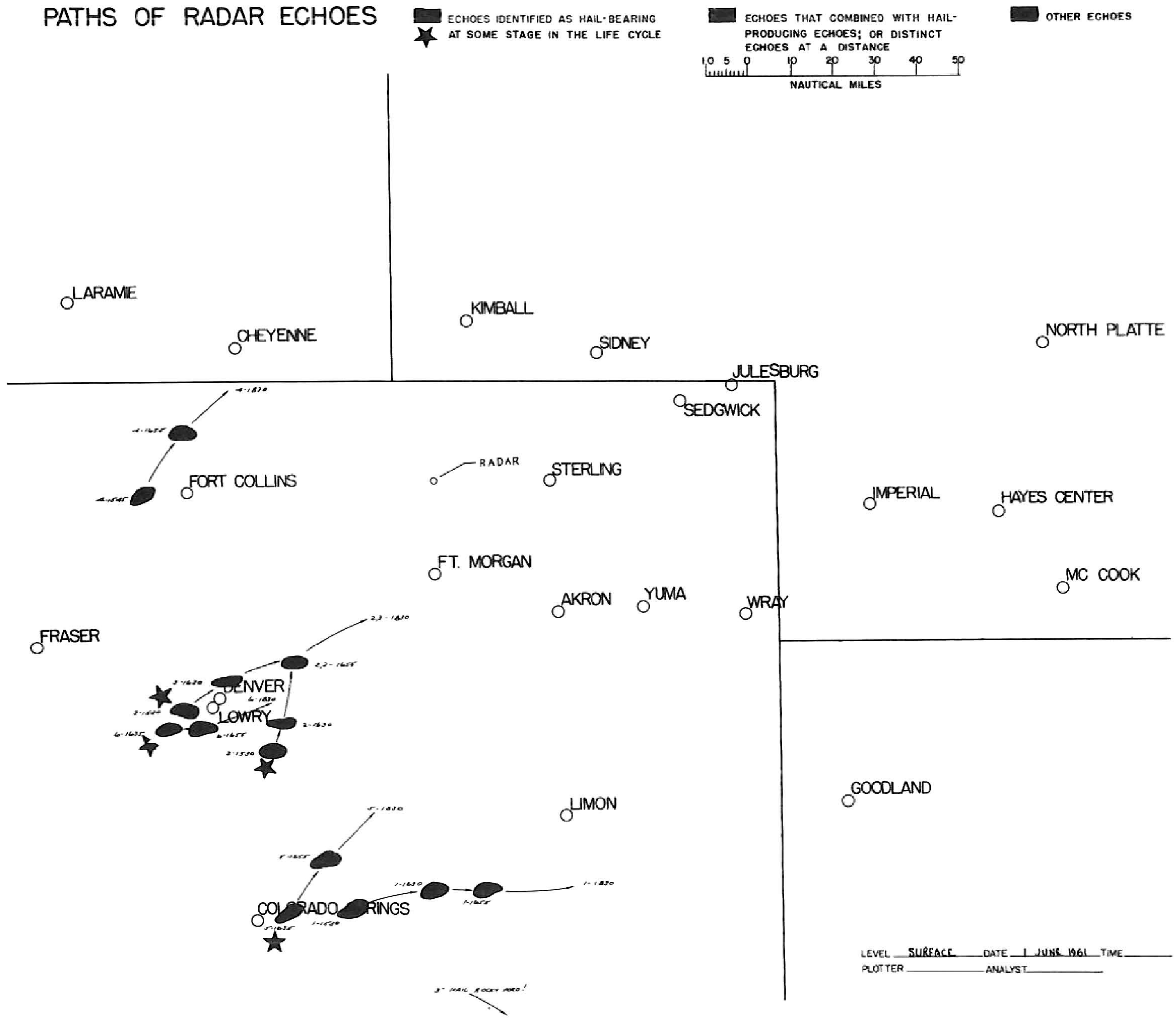


Fig. 1. Radar Trailer Located at New Raymer, Colorado

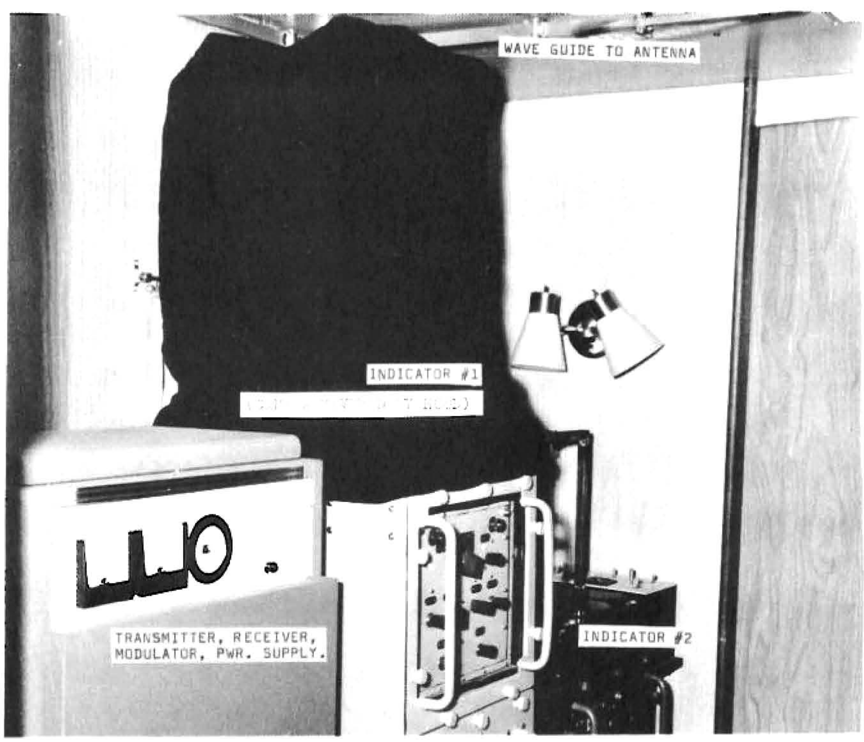
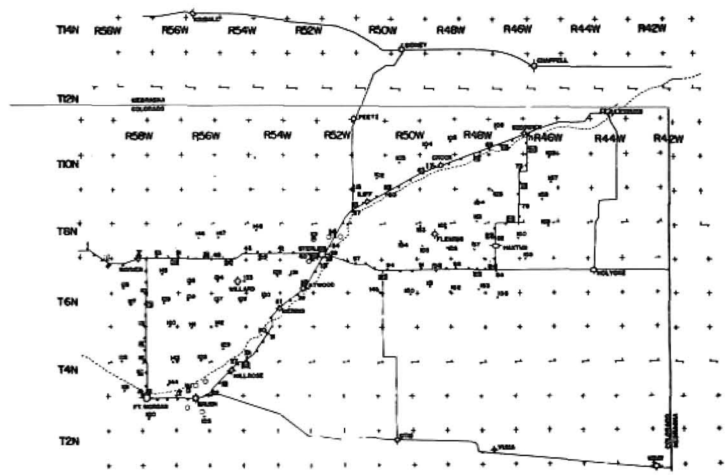


Fig. 2. Radar Equipment

THUNDERSTORM AND HAIL RESEARCH - WEATHER RADAR FIELD STATION
STORM GENESIS AND FIRST ECHO DATA

ECHO NUMBER	TIME (MST)	AZIMUTH (DEGREES)	RANGE (NAUT. MI.)	SPEED (MI./HR.)	DIRECTION (DEGREES)	-REMARKS-
1	1100	0°(4°)	20			
1	1245	Area				66°/12 - 114°/9 - 147°/20 - 135°/10 143°/5 - 90°/7
2	1245	LINE				25°/40 to 62°/42 8 mile wide
2	1400	LINE				50°/52 to 78°/40 to 100/47 5 mi wide
3	1245	0°(180°)	27			
3	1400	0°(158°)	33			
4	1245	0°(145°)	38			
4	1400	0°(150°)	41			
5	1305	0°(188°)	59			
5	1400	0°(177°)	65			
6	1320	0°(7°)	28			
6	1400	0°(3°)	26			
7	1330	0°(21°)	37			
7	1400	0°(12°)	40			
8	1350	0°(170°)	14			
1	1400	2 echoes (SPLIT)				95°/10 & 126°/20 10 mi dia.
1	1430	2 echoes				125°/20 & 151°/32 small
2	1430	Line				88°/60 to 110°/53 7 mi wide

DATE: 8 JULY 1961 SIGNED: T. J. Henderson



THUNDERSTORM AND HAIL RESEARCH - WEATHER RADAR FIELD STATION
PHOTOGRAPHIC DATA

RADAR PHOTOS TIME	RADAR PHOTOS -SUBJECT-	RADAR ~~MISC.~~ PHOTOS TIME	RADAR ~~MISC.~~ PHOTOS -SUBJECT-
1300	TIME LAPSE - TRI X NEG SCOPE	1300	(1) B&W STILL - f 5.6 2 SWEEPS 80 MI RANGE
1600	STOP - 53-100 FT	1400	(2) SAME AS (1) LINE FORMING E
1421	TIME LAPSE - OUTSIDE KODACHROME.	1450	(3) SAME AS (1) MANY SMALL ECHOS.
1636	STOP -	1510	(4) SAME AS (1)
		1600	(5) SAME AS (1) ECHOS MOSTLY SE 40-60 MI.
		1630	(6) SAME AS (1) ECHOS FAR W.
		1700	(7) SAME AS (1)

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THUNDERSTORM AND HAIL RESEARCH - WEATHER RADAR FIELD STATION
VERTICAL DATA OF PRECIPITATION ECHOS

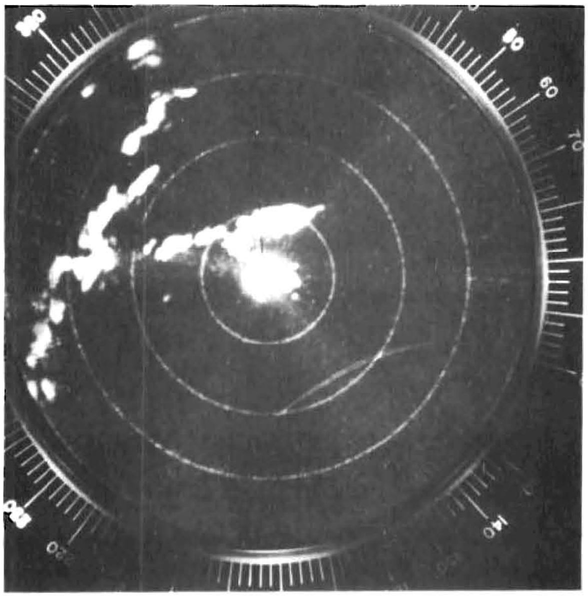
		BASE OF ECHO			TOP OF ECHO		
ECHO NUMBER	TIME (MST)	ANTENNA ANGLE (DEGREES)	RANGE (NAUT. MI.)	ELEVATION ABOVE RADAR (FT)	ANTENNA ANGLE (DEGREES)	RANGE (NAUT. MI.)	ELEVATION ABOVE RADAR (FT.)
3	1250	-4°(181°)	26		+11°(181°)	30 (34.5)	35,000
3	1340	-4°(161°)	30		+12°(164°)	31 (35.7)	40,000
1	1410	-4°(110°)	12		+24°(113°)	15 (17.3)	39,000
1	1430	-4°(122°)	10		+21°(121°)	12 (13.8)	27,000
1	1500	-5°(154°)	18		+15°(155°)	20 (23.0)	31,400
1	1535	-5°(171°)	36		+9°(168°)	37 (42.6)	36,200
1	1620	-4°(158°)	52		+5°(160°)	52 (59.9)	29,600

REMARKS: 1400: ECHO E. STRONG - LTG. IC-CG 1435 HARD E WIND. 1445: LOW CLOUDS DEVELOPING E. & BLOWING W. 1540: E. WIND STILL STRONG - TEMP DROPPED 10° IN 30 MIN. 1630: HARD COLD E. WIND CONTINUES!

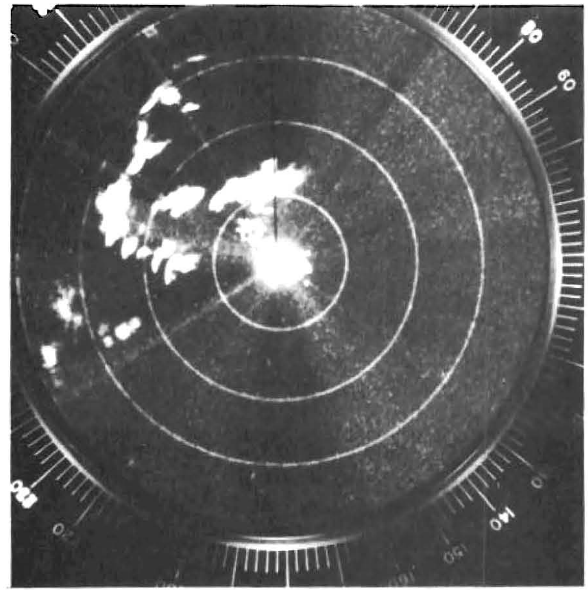
DATE: 8 JULY 1961 SIGNED: T. J. Henderson

Fig. 3. Daily data sheets for 8 July 1961.

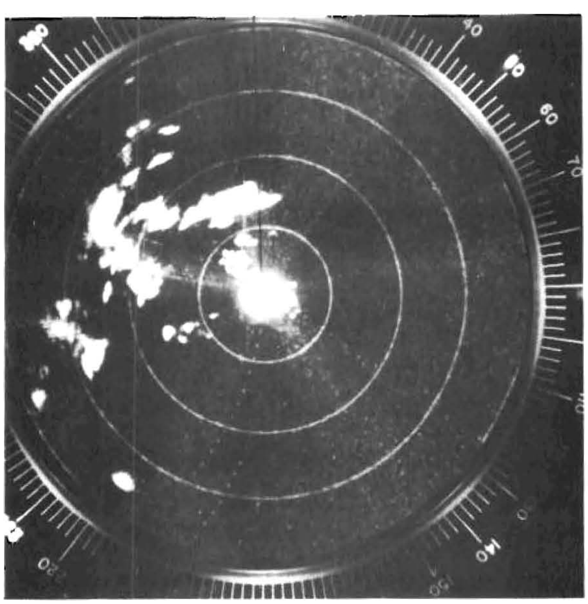
Fig. 4. Photographs of 3 cm radar indicator. Range: 80 n.m. (20 n.m. range marks, antenna elevation 0 deg.) Thunderstorms of 2 June 1961. Hail damage covered wide area and produced sections of 100 per cent loss to crops.



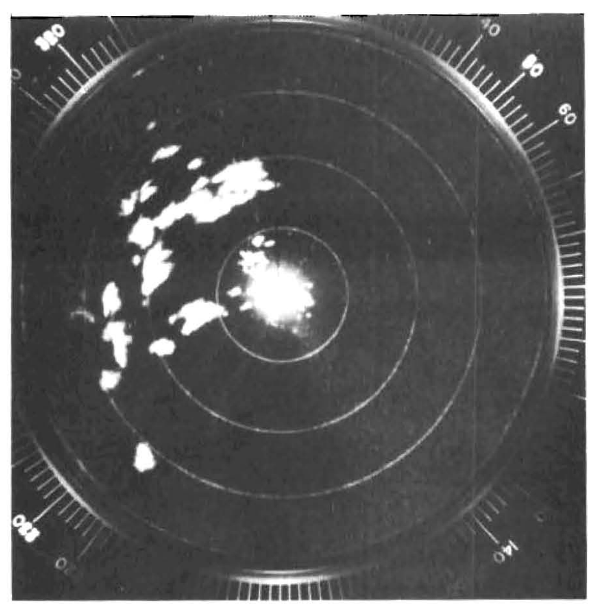
A. 1130: Two lines of intense echos tending to merge at some common point often result in severe hail damage to crops.



B. 1200: Notice how intense echos 25 miles NNW of radar have started to move <u>NW</u> toward N end of main squall line.

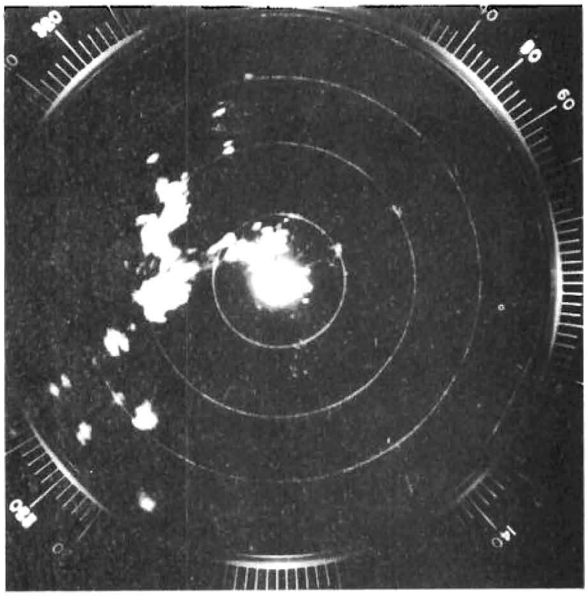


C. 1215: Squall line has not "formed up" completely but is remaining almost stationary while echos NNW of radar continue to move NW.

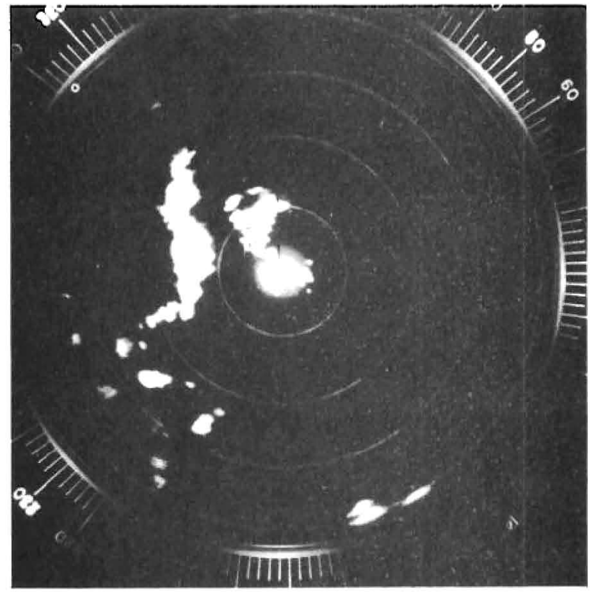


D. 1230: Intense echo originally NW of radar has now merged with N end of squall line about 35 miles NNW. Echo SW moving N toward squall line.

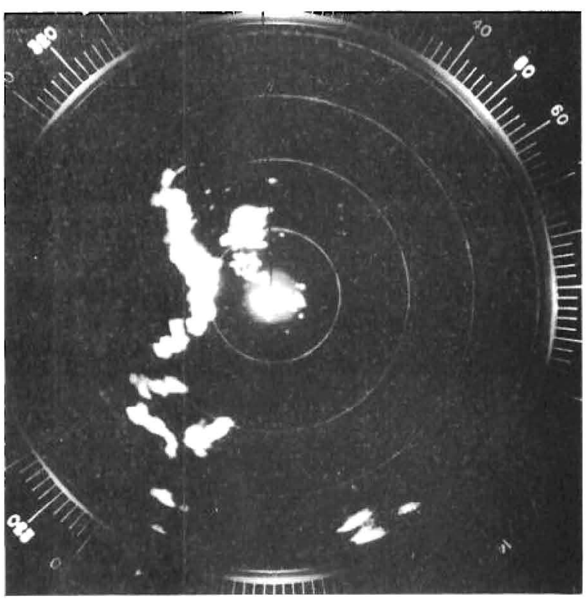
Fig. 4. (cont'd) Photographs of radar scope



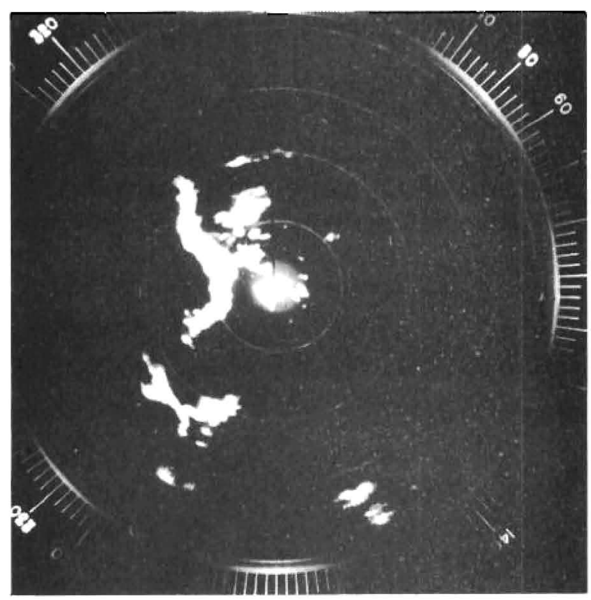
E. 1300: Intense squall area is now well formed and starting to move E. Notice new echo forming ahead of line about 10 miles NW of radar.



F. 1325: Squall line continues to move E while new echo in previous photo is moving NW toward intense portion of line. Notice new echos 150°-160°, about 80 miles.

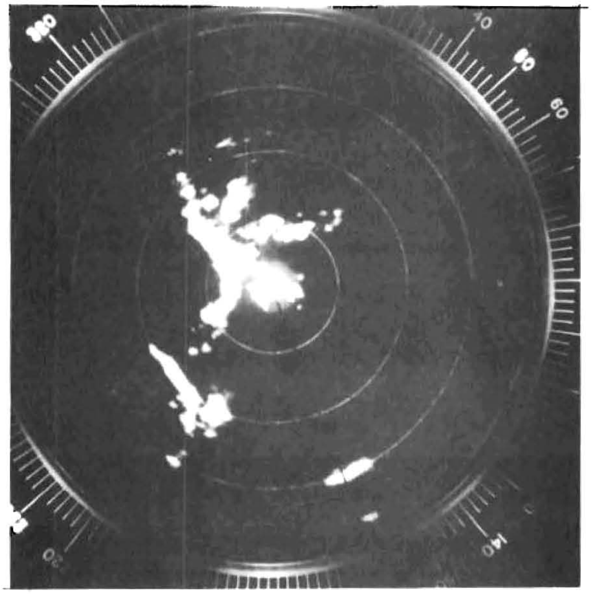


G. 1345: Echo NNW of radar is moving toward N end of squall line and new echo forming 12 miles NW radar. Echo development ahead of squall line is common in most cases of thunderstorm activity.

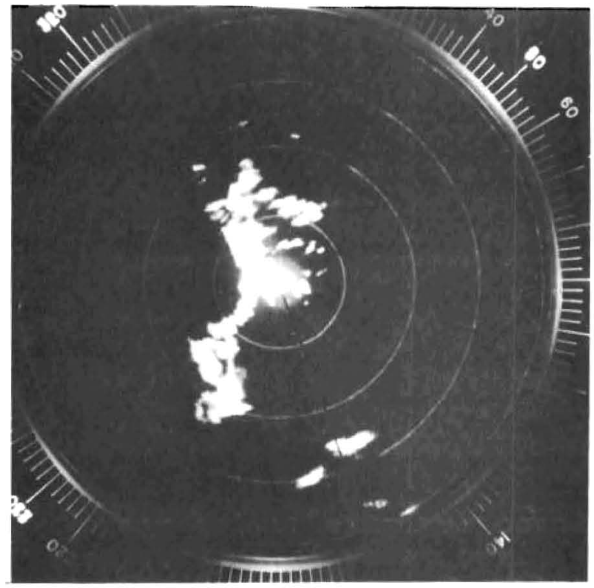


H. 1400: Echo NW radar is now merging with squall line. Echos 160°/70 miles moving <u>NW toward squall line area</u>. Giant cells in squall line appear to act like vacuum cleaners.

Fig. 4. (concluded)



I. 1415: Precipitation area now very intense and producing severe hail immediately west of radar. Notice echo 160°/ 60 miles is still being drawn toward main storm area.



J. 1420: All echos in main storm area now in solid line and continue to move east. Echos SSE of radar continue to be drawn toward intense portion of squall line.

K. Normal stand of wheat in northeast Colorado during the 1961 season. Dorene Walker - New Raymer, Colorado.

L. Dorene Walker examines complete destruction of wheat near Buckingham, Colorado. Hail storm of 2 June 1961 swept across 50 miles of wheat country.

TABLE I: SUMMARY OF RADAR OPERATIONS (15 May 1961 - 15 August 1961)

DATE	TIME-MST ON	TIME-MST OFF	NUMBER OF ECHOS CATALOGED	RADAR SCOPE PHOTOGRAPHY: NUMBER	STILLS TIME-MST FIRST	STILLS TIME-MST LAST	TIME LAPSE TIME-MST BEGIN	TIME LAPSE TIME-MST END	FEET
5/15	1400	1830	13		NONE			NONE	
5/16	1310	1915	21		NONE			NONE	
5/18	1720	0045	6	5	1925	2115		NONE	
5/19	1400	1500	1		NONE			NONE	
5/21	1305	2015	5		NONE			NONE	
5/24	0955	1830	13		NONE			NONE	
5/28	1440	1930	8	7	1735	1930		NONE	
5/29	1610	2245	8		NONE			NONE	
5/30	1420	1930	11		NONE			NONE	
5/31	1030	1850	12	8	1715	1830		NONE	
6/1	1530	1655	6		NONE			NONE	
6/2	1100	2045	10	11	1130	1430		NONE	
6/3	1240	2230	5	6	1645	1920		NONE	
6/4	1330	1810	14		NONE			NONE	
6/5	1155	1845	19	3	1635	1715		NONE	
6/6	1240	1730	20		NONE			NONE	
6/8	1445	2100	11	1	1605	1605		NONE	
6/11	1720	1905	5		NONE			NONE	
6/12	1525	2240	13		NONE			NONE	
6/13	1330	1900	10		NONE			NONE	
6/14	1150	1915	11		NONE			NONE	
6/19	1500	1845	10		NONE			NONE	
6/23	1500	2120	9		NONE			NONE	
6/24	1145	1745	19		NONE			NONE	
6/25	1215	2100	10		NONE			NONE	
6/26	1345	1800	10		NONE			NONE	
6/27	1200	1830	7		NONE			NONE	
6/28	1345	2000	6		NONE			NONE	
6/30	1730	0015	8		NONE		1830	2330	72
7/1	1130	1930	11		NONE		1250	1930	95
7/5	1435	1930	10		NONE			NONE	
7/6	1500	1900	10		NONE			NONE	
7/7	1400	2300	23	14	1510	2320	1500	1800	53
7/8	1100	1930	11	7	1300	1700	1300	1600	47
7/10	1130	1830	11		NONE		1330	1820	75
7/11	1330	1900	13	8	1415	1900	1550	1900	71
7/14A	0030	0600	4	4	0045	0145	0030	0545	93
7/14P	1130	1800	11	5	1345	1700	1330	1745	60
7/19	0700	1900	11		NONE		1430	1814	37
7/20	1345	1830	18	9	1445	1900		NONE	
7/21	1000	1630	6		NONE		1300	1600	60
7/25	1315	2200	19		NONE		1400	1903	37
7/28	1140	2400	22	11	1630	2400	1450	2200	100
7/29	1300	2115	7		NONE			NONE	
7/30	1140	0200	16		NONE		1350	2145	110
8/1	0930	1800	21		NONE		1130	1730	90
8/7	1300	2000	10	7	1500	1900	1430	2000	90
8/9	1330	1730	7		NONE			NONE	
8/10	1500	1800	5		NONE			NONE	
8/12	1330	1600	16	5	1345	1540	1340	1556	45
TOTALS			563	111					1135

Determination of "Hailers" and "Non-Hailers"

Within the region of radar coverage, a determination was made as to whether a particular precipitation echo was or was not a damaging hailstorm.

Echoes that passed through the Colorado State University hail recording network were classified as hail producers if hail reports were received from the CSU hail reporting network. To determine whether an echo was a "Hailer" when it was outside of the network, a plot of precipitation echoes was compared with a similar plot of insurance claims for a particular date. If it was determined that the precipitation echo was the only one in the region, that echo was classified as a hail-producing echo.

In addition to the insurance claims and the regular reports from the CSU hail reporting network, local information was utilized for classifying echoes as hailers or non-hailers. Examples of this included local newspaper reports and word-of-mouth reports that were obtained from CSU field personnel in the area.

RESULTS

Number of Occurrences of Hail

Table 2 summarizes the occurrence of hail events during the summer of 1961. The maximum number of days with hail occurred during the first half of June, while the first half of July gave the greatest number of echoes that were identified as hail producers at some stage in their life cycle.

Origin of Hailstorms

The location of first precipitation echoes, and their subsequent movement, are shown in the Appendix for each date for which radar data were obtained. Summaries of these data are given in Tables 3 and 4.

TABLE 2

THUNDERSTORM DAYS AND HAIL WITHIN RANGE
OF THE RADAR AT NEW RAYMER, COLORADO

PERIOD	STORM DAYS WITH HAIL	STORM DAYS WITHOUT HAIL	TOTAL	TOTAL ECHOES CATALOGED	NUMBER OF ECHOES WHICH LED TO PRODUCTION OF OR ACTUALLY PRODUCED HAIL ON THE GROUND
15-31 May	10	2	12	98	35
1-15 June	13	0	13	124	51
16-30 June	7	2	9	79	28
1-15 July	8	4	12	104	53
16-31 July	9	2	11	99	37
1-15 August	4	5	9	59	8
TOTAL	51	15	66	563	212

TABLE 3

ORIGIN AND MOVEMENT OF ECHOES IDENTIFIED AS
PRODUCING HAIL ON THE GROUND
15 MAY THROUGH 15 AUGUST 1961

ECHOES MOVED TO	NUMBER OF ECHOES ORIGINATING IN			
	COLORADO	KANSAS	NEBRASKA	WYOMING
COLORADO	74	0	14	11
KANSAS	10	7	6	0
NEBRASKA	15	0	10	10
WYOMING	3	0	0	6

TABLE 4

ORIGIN AND MOVEMENT OF ECHOES NOT IDENTIFIED AS PRODUCING HAIL ON THE GROUND 15 MAY THROUGH 15 AUGUST 1961

ECHOES MOVED TO	NUMBER OF ECHOES ORIGINATING IN			
	COLORADO	KANSAS	NEBRASKA	WYOMING
COLORADO	241	1	10	14
KANSAS	4	7	0	0
NEBRASKA	9	0	17	13
WYOMING	10	0	0	25

Table 3 shows that more echoes that produced hail at the ground in Kansas came from Colorado than from any of the other states of Nebraska or Wyoming. For echoes not identified as hail producers in Kansas, most echoes originated in Kansas (Table 4).

Figures 5 through 10 show the location of origin of echoes identified as hail-bearing, and their subsequent track for each half-month period from 15 May to 15 August 1961. Examination of the figures shows that during late spring, echoes tend to move from west to east. Later in the summer the most common direction of movement is from the northwest quadrant.

The Effect of Terrain and Low-level Wind on Hail Genesis

New echoes that developed within a 75-nautical mile radius of the radar during the first two hours of operation each day were examined in a study of the effects of terrain and low-level wind flow. From data obtained within the hail network and from examination of crop-hail insurance claims these echoes were categorized as hailers or non-hailers. Echoes that were first reported as lines, or groups of cells, or cells that developed in close proximity to an earlier cell, were not included in this analysis, since these echoes were moving through the area and not forming in the field of observation.

To examine possible effects of terrain and low-level wind on the genesis of these echoes, a "Genesis point" was determined arbitrarily 10 miles up-motion from the first echo. At this "Genesis point" and at four additional points located in the cardinal directions on a 20 mile radius from the "Genesis point", a topographic lift factor was computed. This factor is a measure of the amount of low-level lift produced by topographic effects. Details of the procedure for computing this topographic lift factor are given elsewhere (3).

A comparison was made of this lift parameter at the "Genesis point" with the average of the four surrounding points.

Results of this study are shown in Table 5. A positive difference indicates that the topographic lift factor was higher over the area where the echo first developed than for an average of the surrounding points.

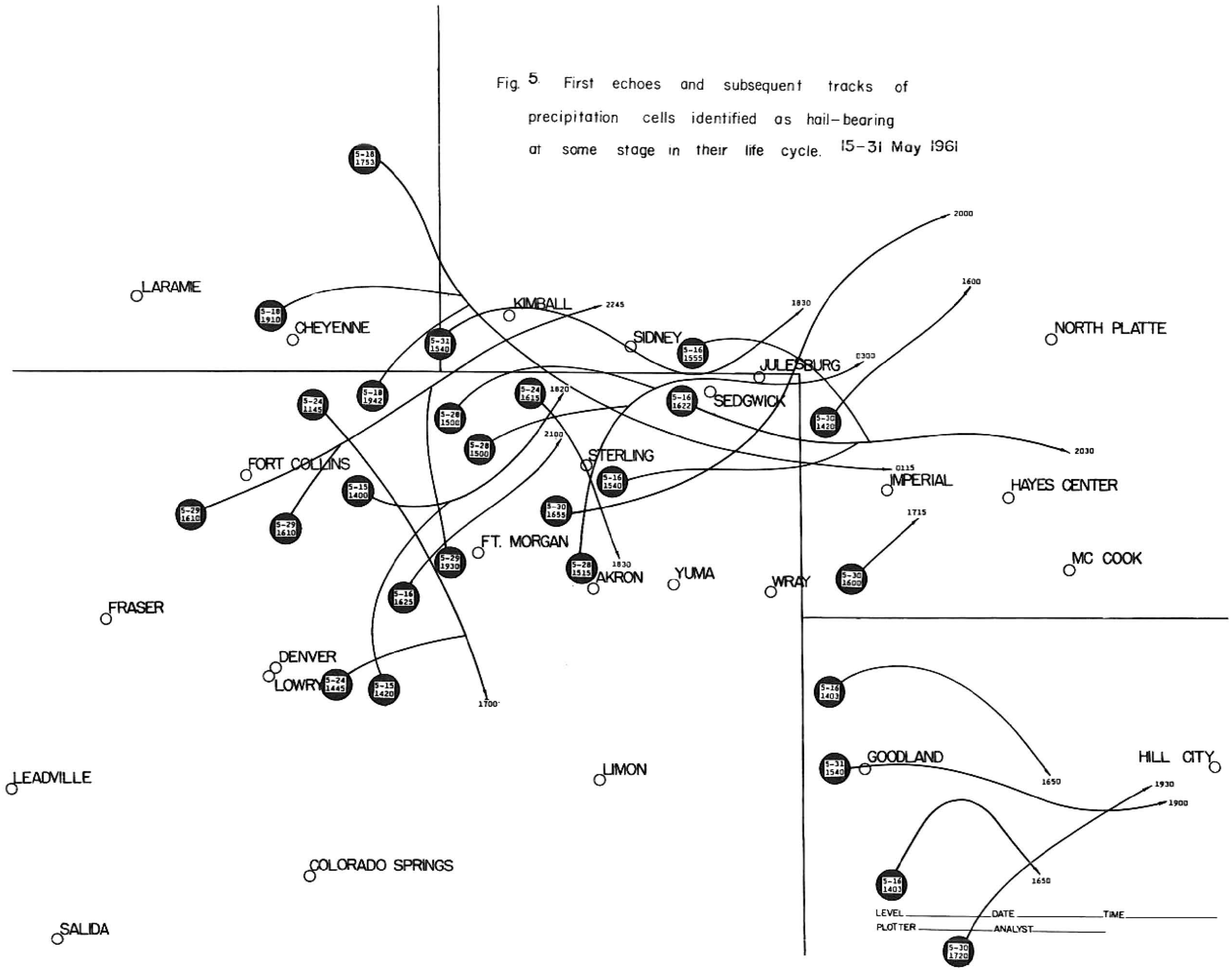


Fig. 5. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 15-31 May 1961

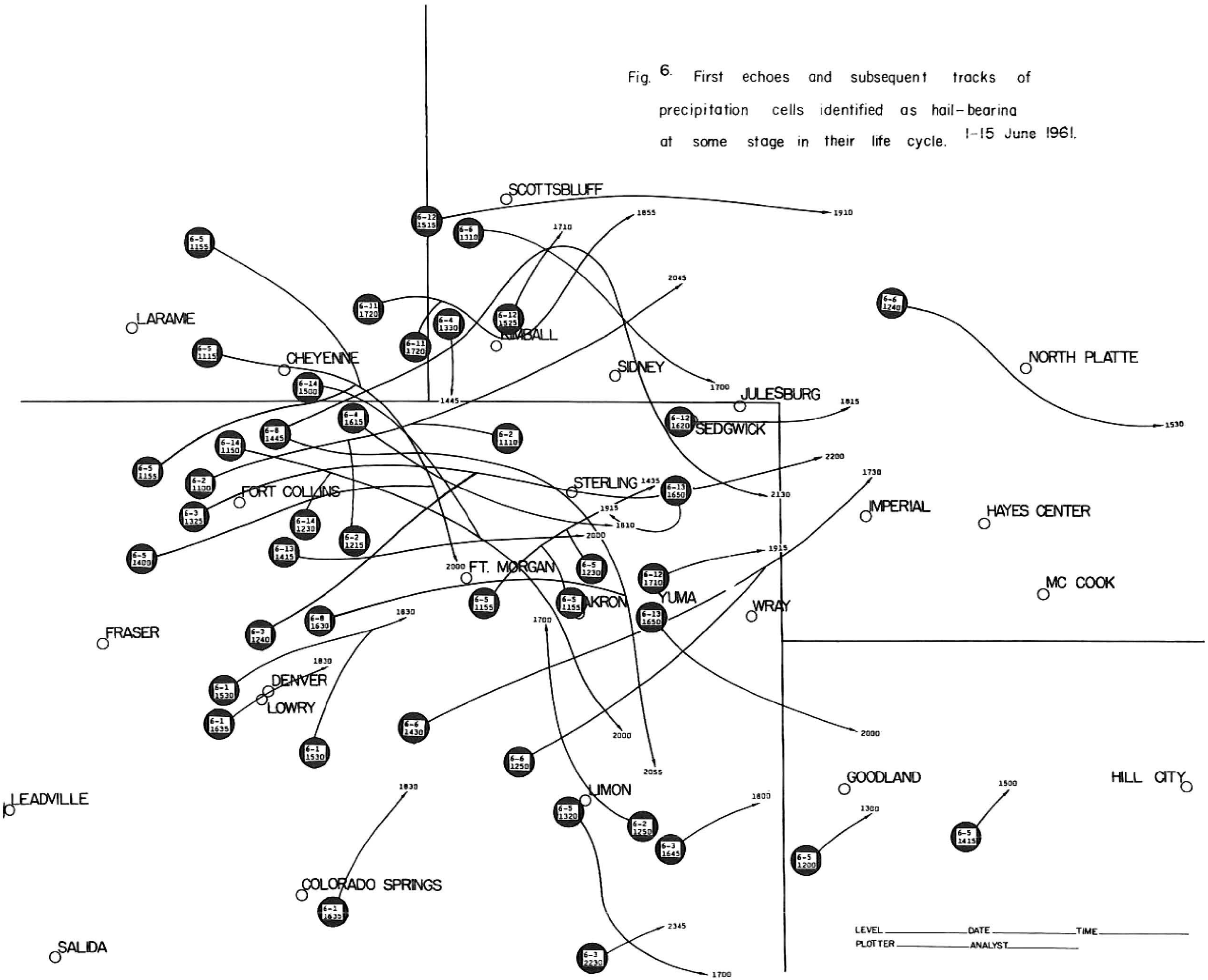


Fig. 6. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 1-15 June 1961.

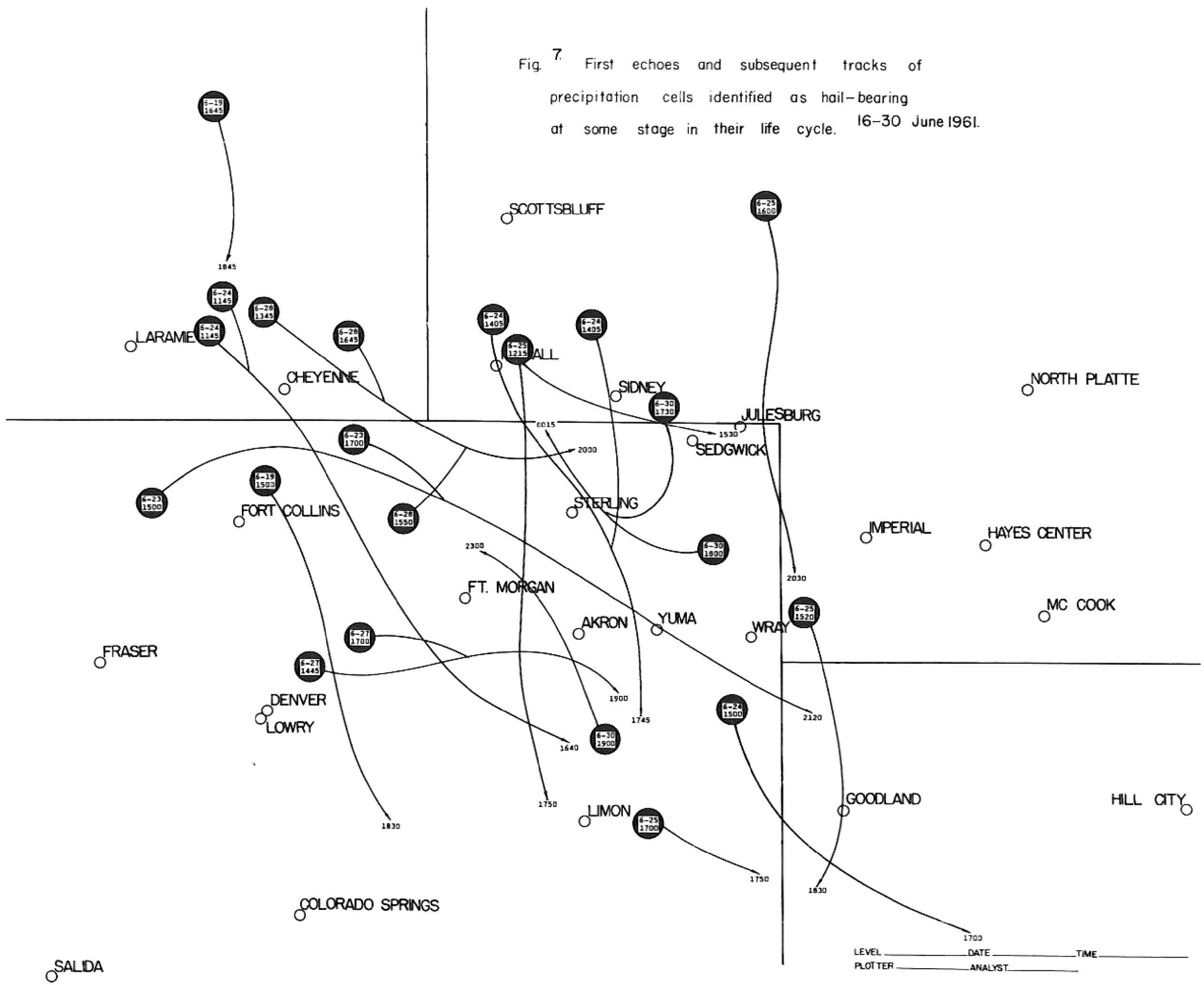


Fig. 7 First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 16–30 June 1961.

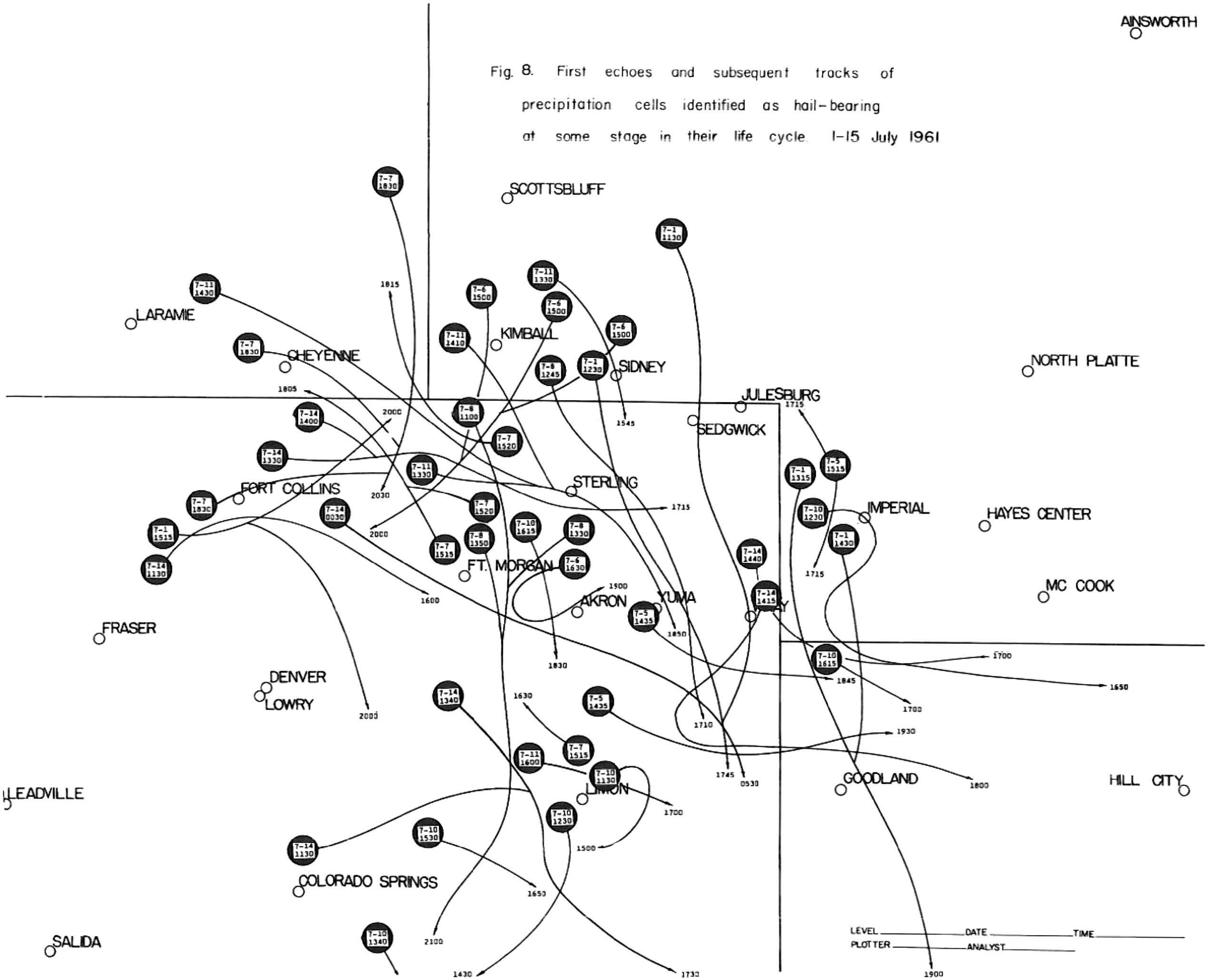


Fig. 8. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 1-15 July 1961

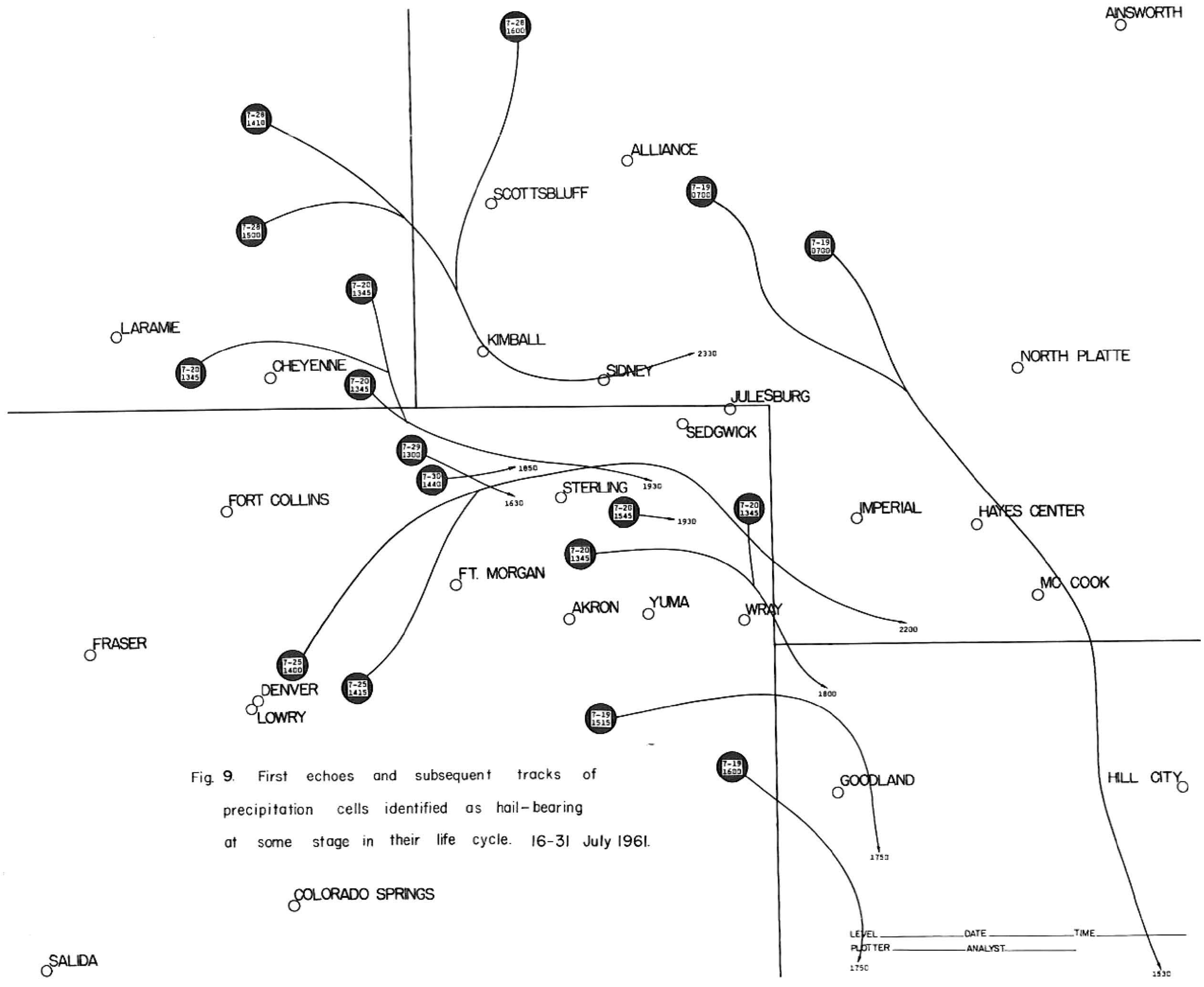


Fig. 9. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 16-31 July 1961.

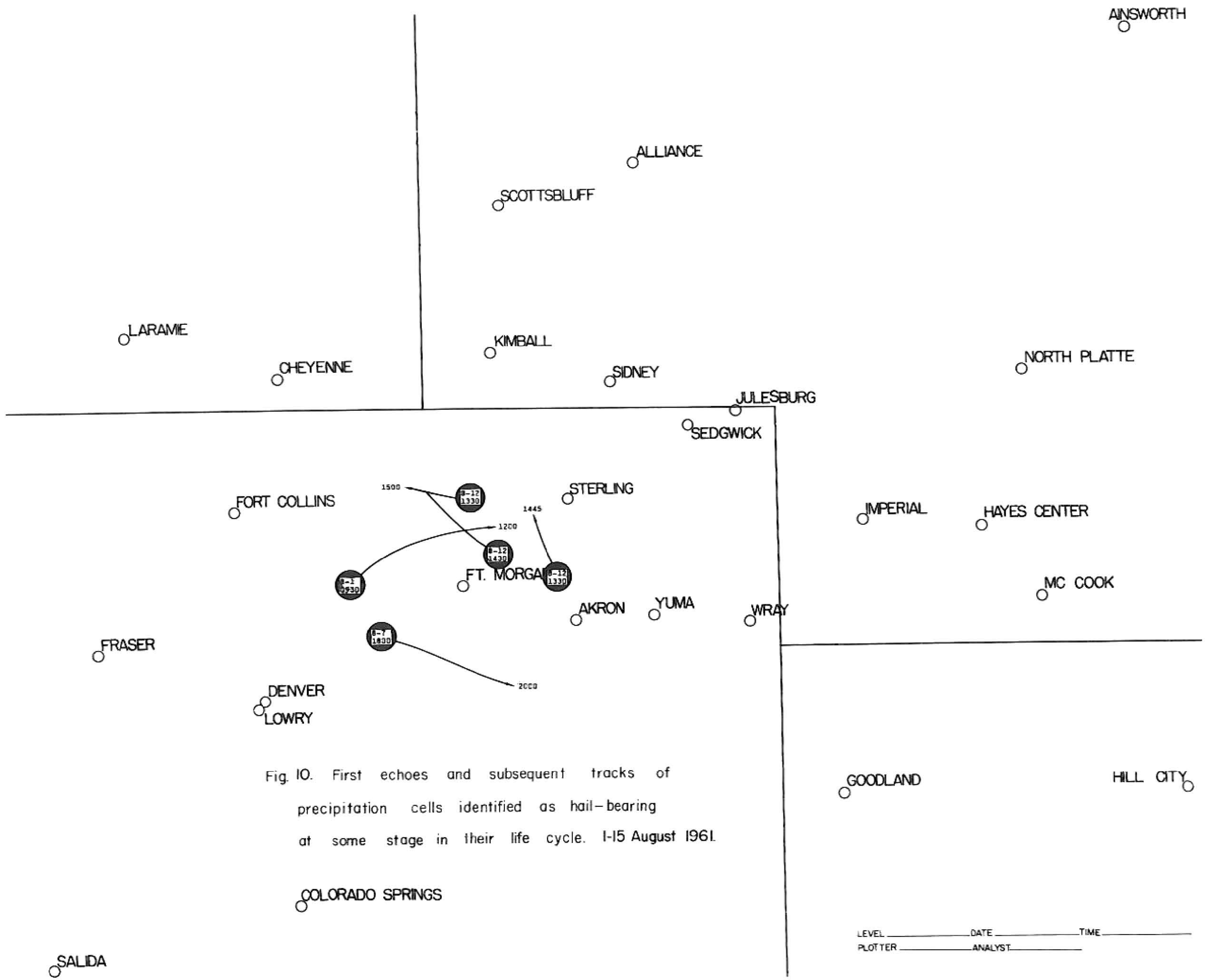


Fig. 10. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 1-15 August 1961.

Table 5 shows a significant difference occurs only for echoes originating below 5,000 ft msl. The results of Table 5 indicate that the irregularities of terrain in regions above 5,000 ft msl probably are sufficiently large to preclude use of the "Topographic lift parameter" for prediction of regions of first development of hail-producing echoes. Below 5,000 ft msl it appears that some success might be attained by use of the "Topographic lift parameter" for this purpose. However, the sample is small, and the need for further testing of this parameter is indicated.

TABLE 5

DIFFERENCE IN TOPOGRAPHIC LIFT PARAMETER, FT PER HOUR, (GENESIS POINT MINUS AVERAGE OF FOUR SURROUNDING POINTS).

ELEVATION CLASS	NUMBER OF CASES		CHI SQUARE	
	Positive	Negative	Value	Probability
I All echoes	50	44	.37	.56
II Below 7000 ft msl	35	29	.56	.47
III Below 5000 ft msl	11	3	4.6	.035*

IMPLICATIONS TO HAIL INSURANCE INDUSTRY

The data included in this report have direct application to problems of the hail insurance industry. The paths of damaging hail, Figures 5 - 10, indicate a change in direction of damaging hail paths from early to the late season. It would seem judicious to scatter the insurance risk in such a matter as to be perpendicular to the most common hail paths. For example, if the primary period for hail hazard is in late spring, it appears from Figure 5 that the most common hail path direction is from west to east, and it would be desirable to scatter the hail insurance risk from north to south, so as to be perpendicular to the most frequent hail damage path. On the other hand, if the most common period of hazard is during the late summer season, the most frequent hail path is from the northwest and it would appear wise to scatter the hail risk from the northeast to southwest to be perpendicular to this path.

From the first year's operation of the radar, it appears that radar data could be of immediate operational use to the hail insurance industry. For example, it would be possible to give an immediate indication of the hailstorm damage paths at the end of each day. Such information could be used as protection against false damage claims, and could also be used in the scheduling and timing of adjusters' visits.

RECOMMENDATIONS FOR FURTHER STUDY

In this investigation, as in any scienfitic investigation, more questions appeared than there were answers obtained. Some of the more pertinent items for which further study would be desirable include the following: In relating hail risk to crop-hail insurance rates, it is probable that one year's data is not a representative sample of a longer period. Several years' data would appear to be a minimum for obtaining a representative sample that might be used in connection with hail insurance rating.

There is a need for linking physical measurements of hailstorm intensity with crop damage. For example, it was found that in 1961 almost three times as much total depth of ice fell as fell in 1960, despite the fact that spectacular storms with large hail stones were rather rare in 1961. It would be desirable to undertake studies to provide a link between crop damage to various crops and physical measurements of hail such as the number of stones per unit area, the size of stones, the impact energy of hailstorms, and other measurements that could be obtained through a combination of radar studies and the operation of a surface network. Such studies would have value both for a basic understanding of the mechanism that produces crop damage and also could provide a means of protection against fraudulent hail damage claims.

A further advantage of relative physical measurements of hail intensity to crop damage would be to develop suitable simple instrumentation and procedures to prevent insuring of crops after damage has occurred. In addition, such instrumentation could permit adjusters to differentiate between wind and hail damage.

REFERENCES

1. Climate and Man, Yearbook of Agriculture, U. S. Department of Agriculture, 1941, p. 730.

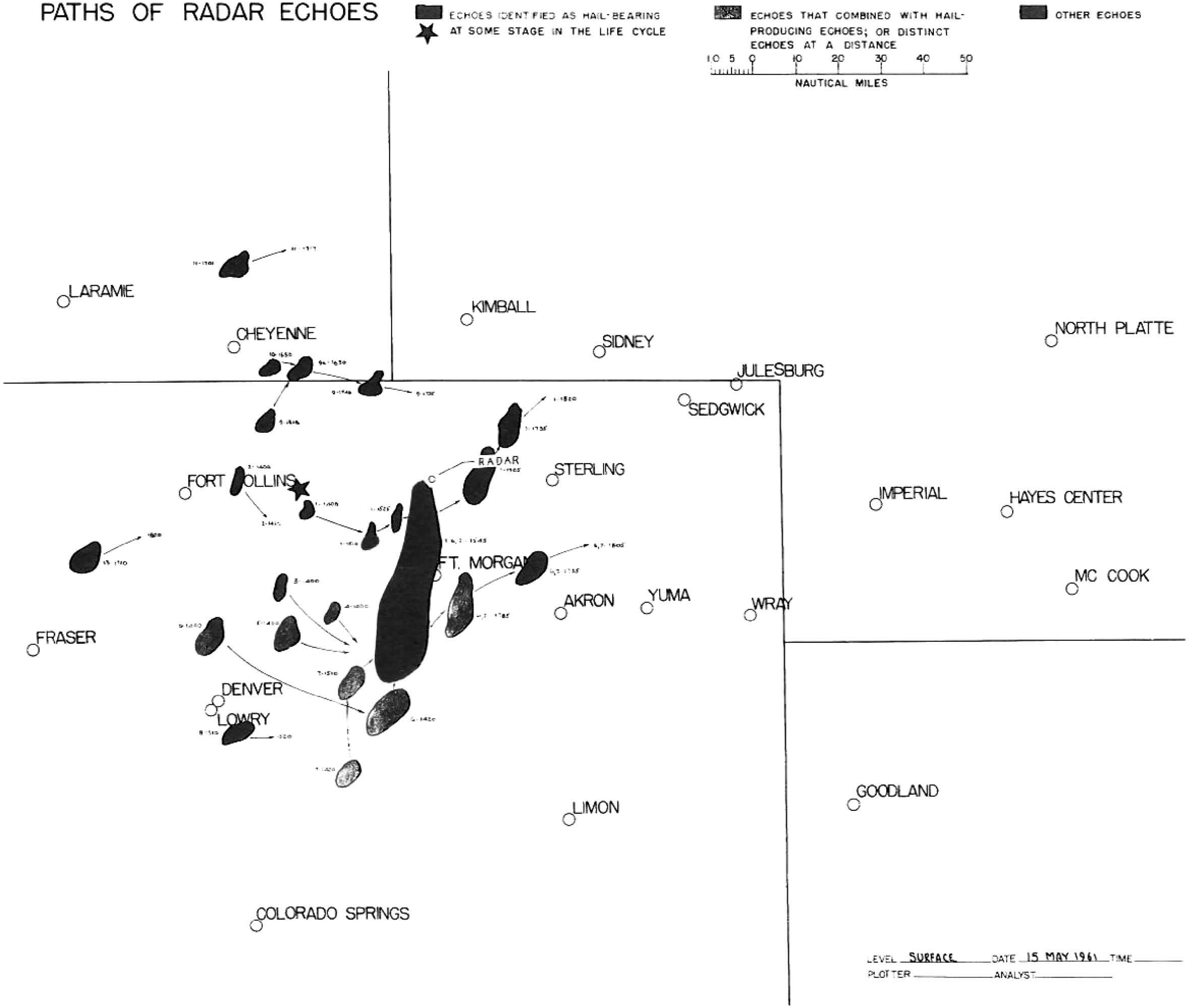
2. Schleusener, Richard A., The 1959 hail suppression effort in Colorado and evidence of its effectiveness. Scheduled for publication in Nubila IV (3), 1961.

3. Schleusener, Richard A., and Lewis O. Grant, Characteristics of Hailstorms in the Colorado State University Network, 1960-61. Ninth Weather Radar Conference, October, 1961.

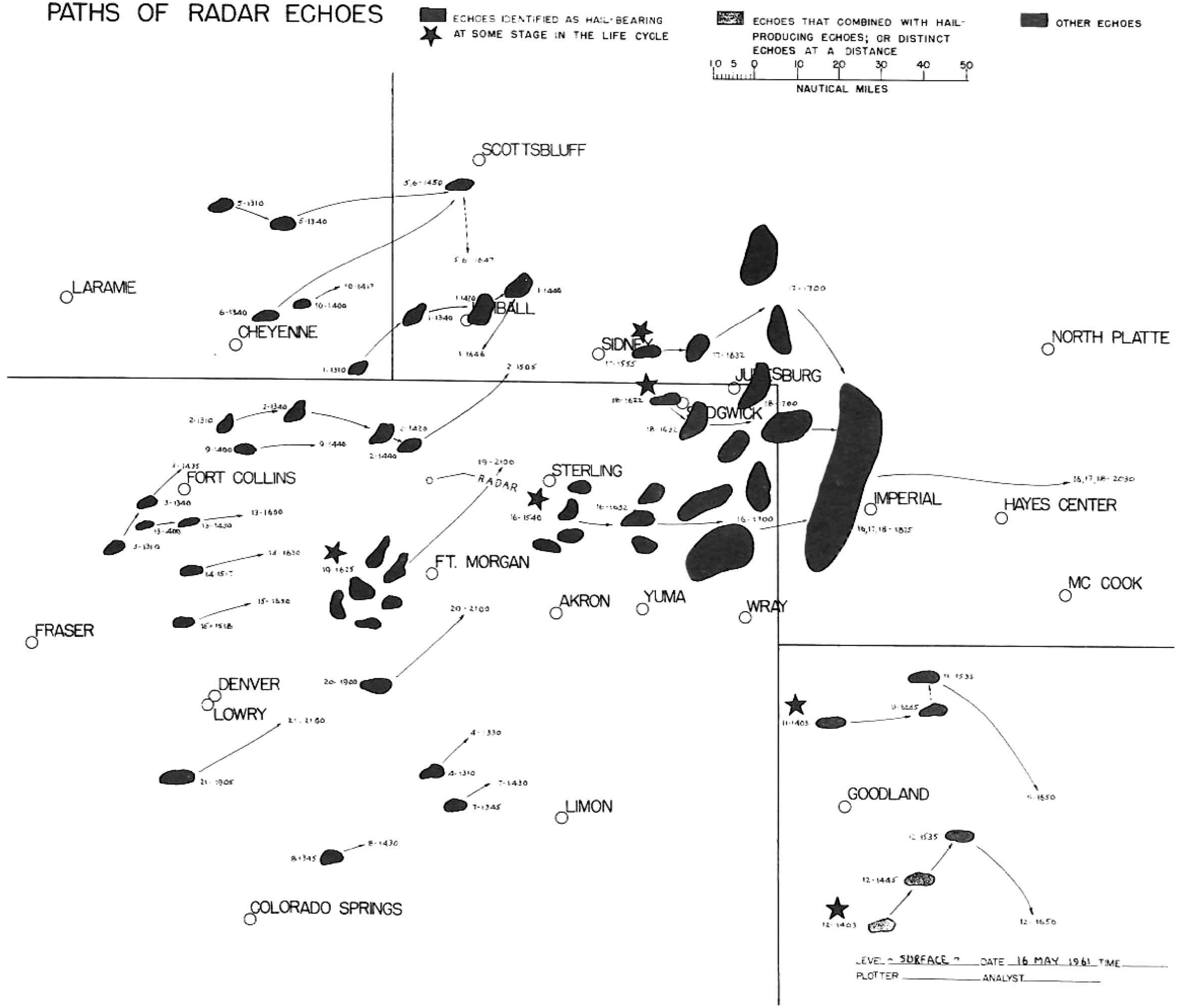
APPENDIX

Daily Plots of Precipitation Echoes.

PATHS OF RADAR ECHOES



PATHS OF RADAR ECHOES



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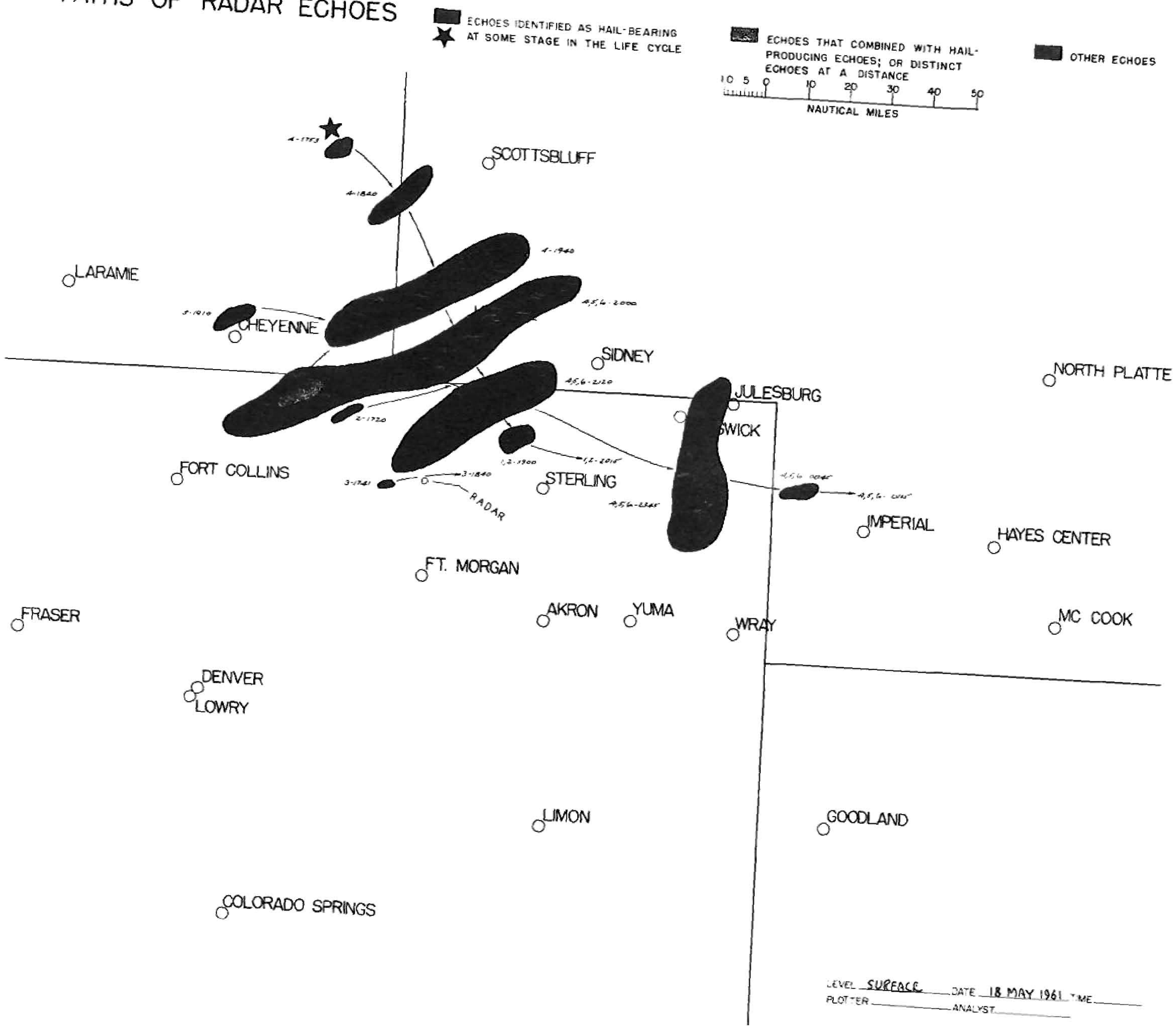
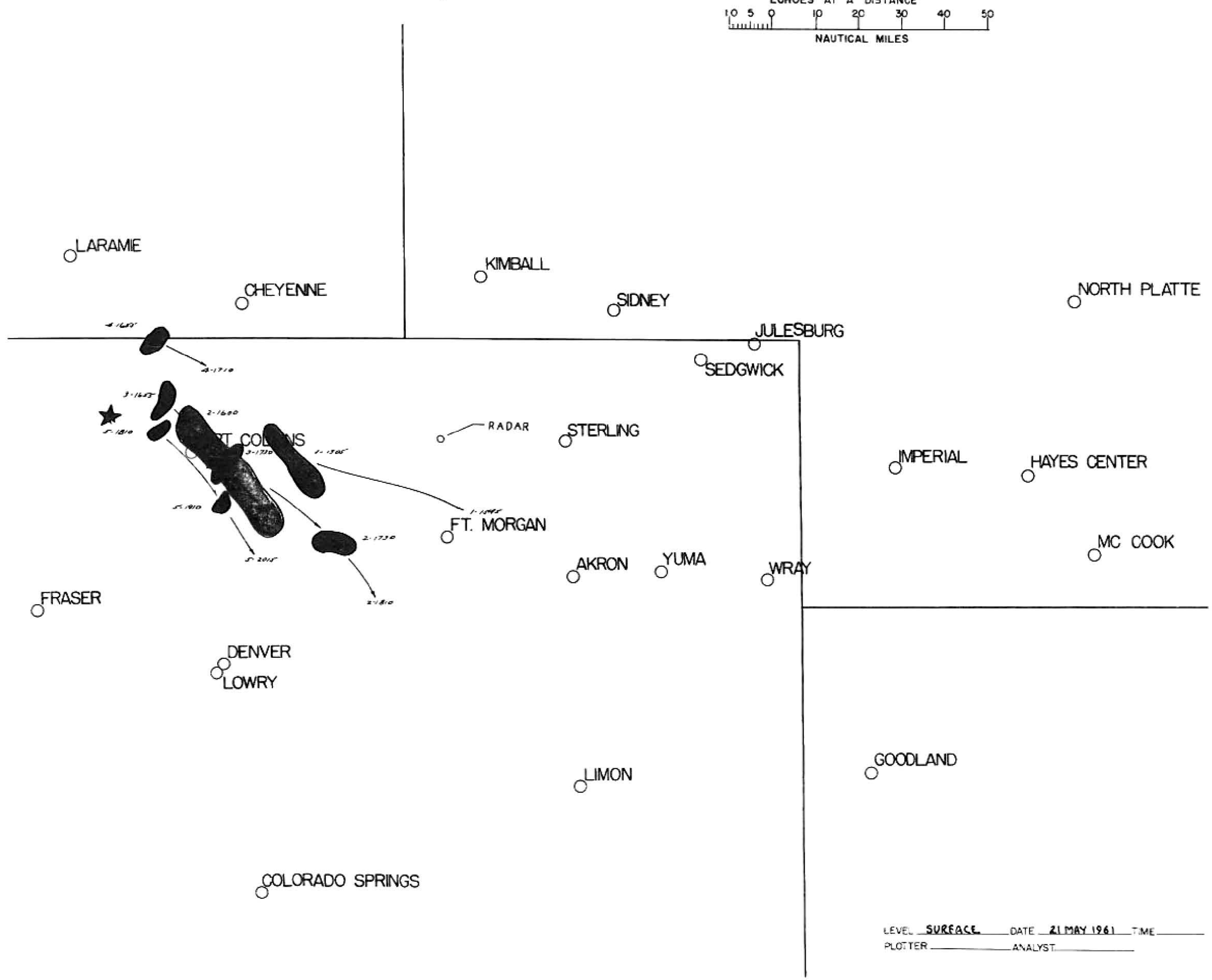


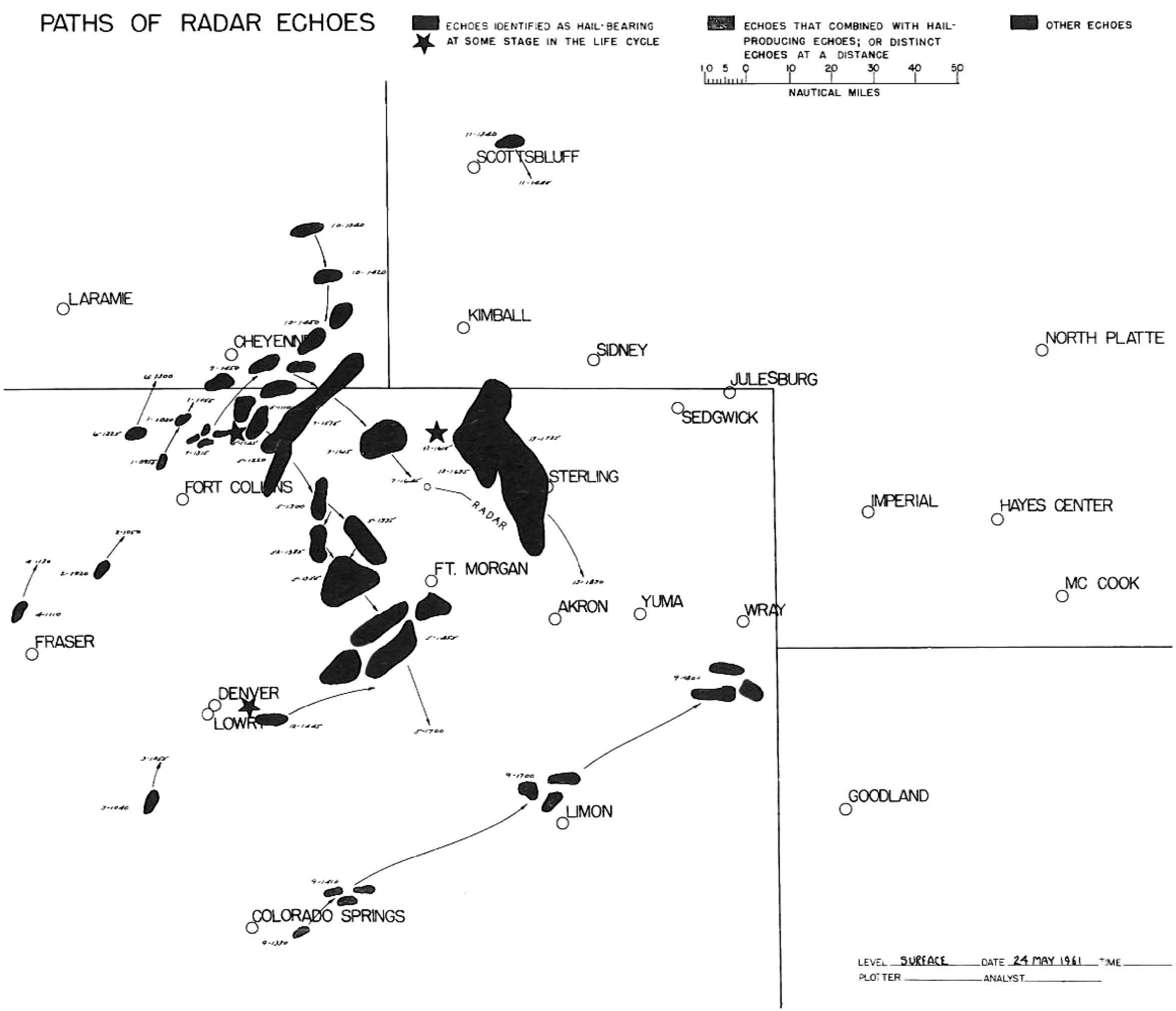
PATHS OF RADAR ECHOES

ECHOES IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THE LIFE CYCLE

ECHOES THAT COMBINED WITH HAIL-PRODUCING ECHOES; OR DISTINCT ECHOES AT A DISTANCE

OTHER ECHOES

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PATHS OF RADAR ECHOES

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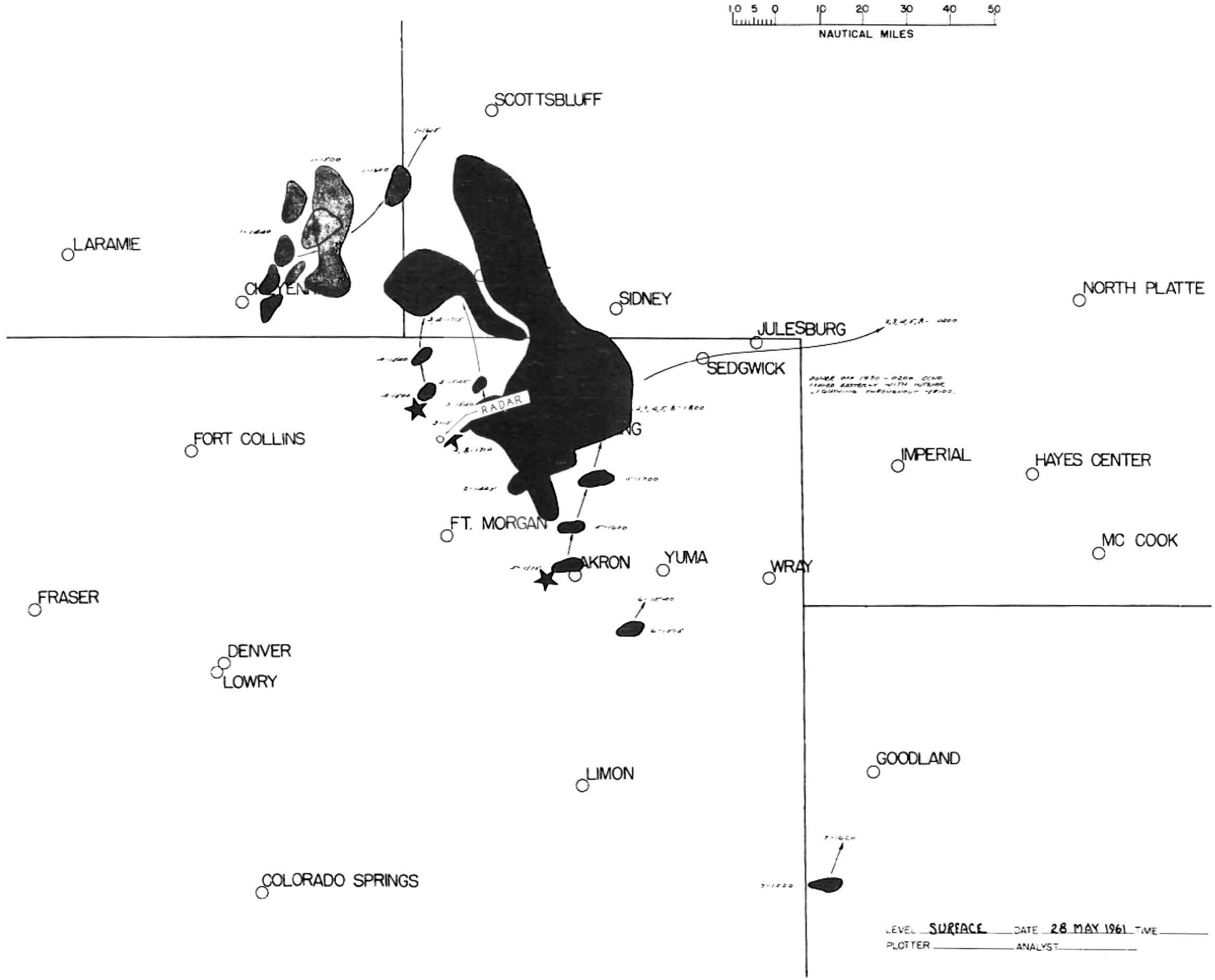

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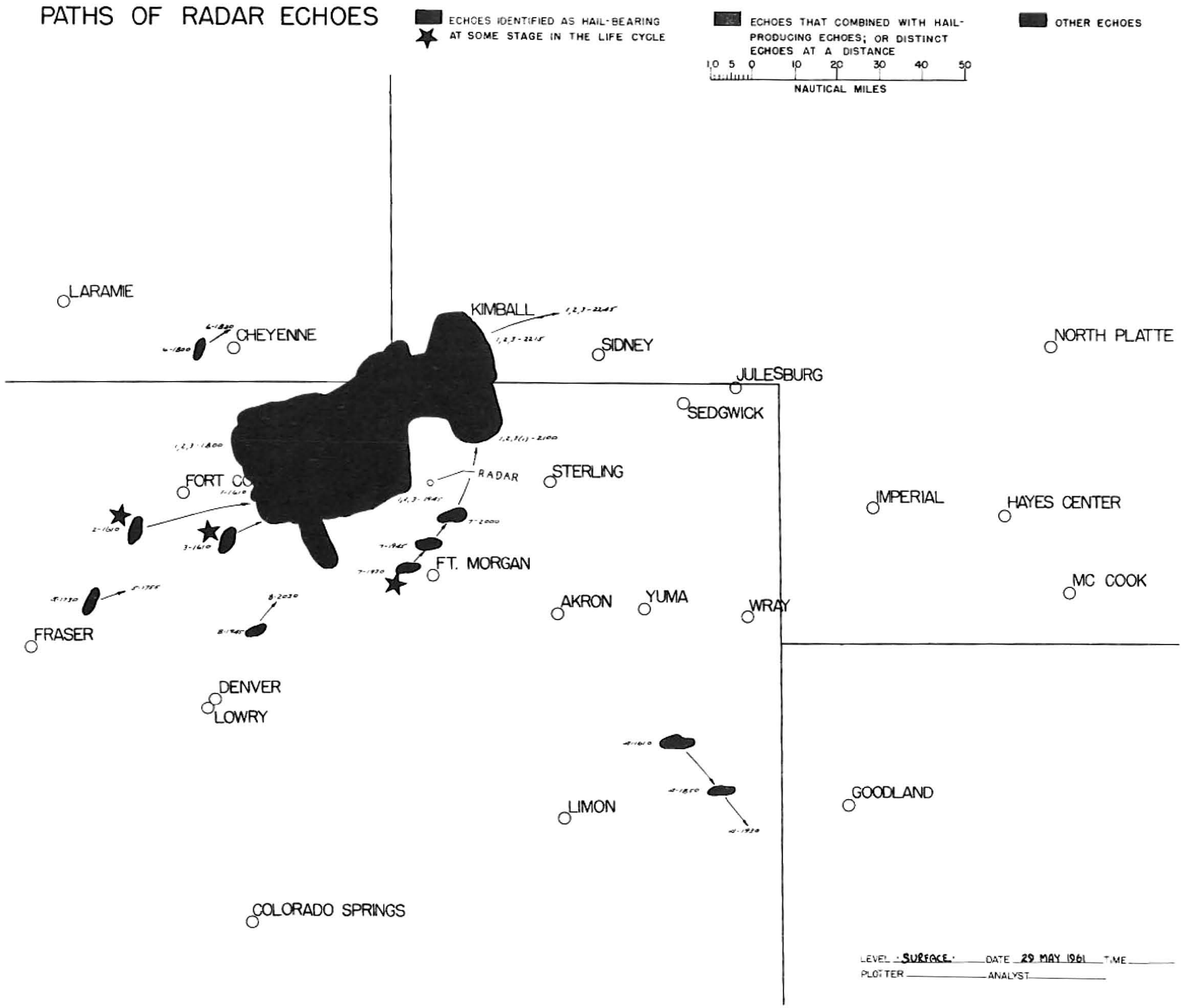

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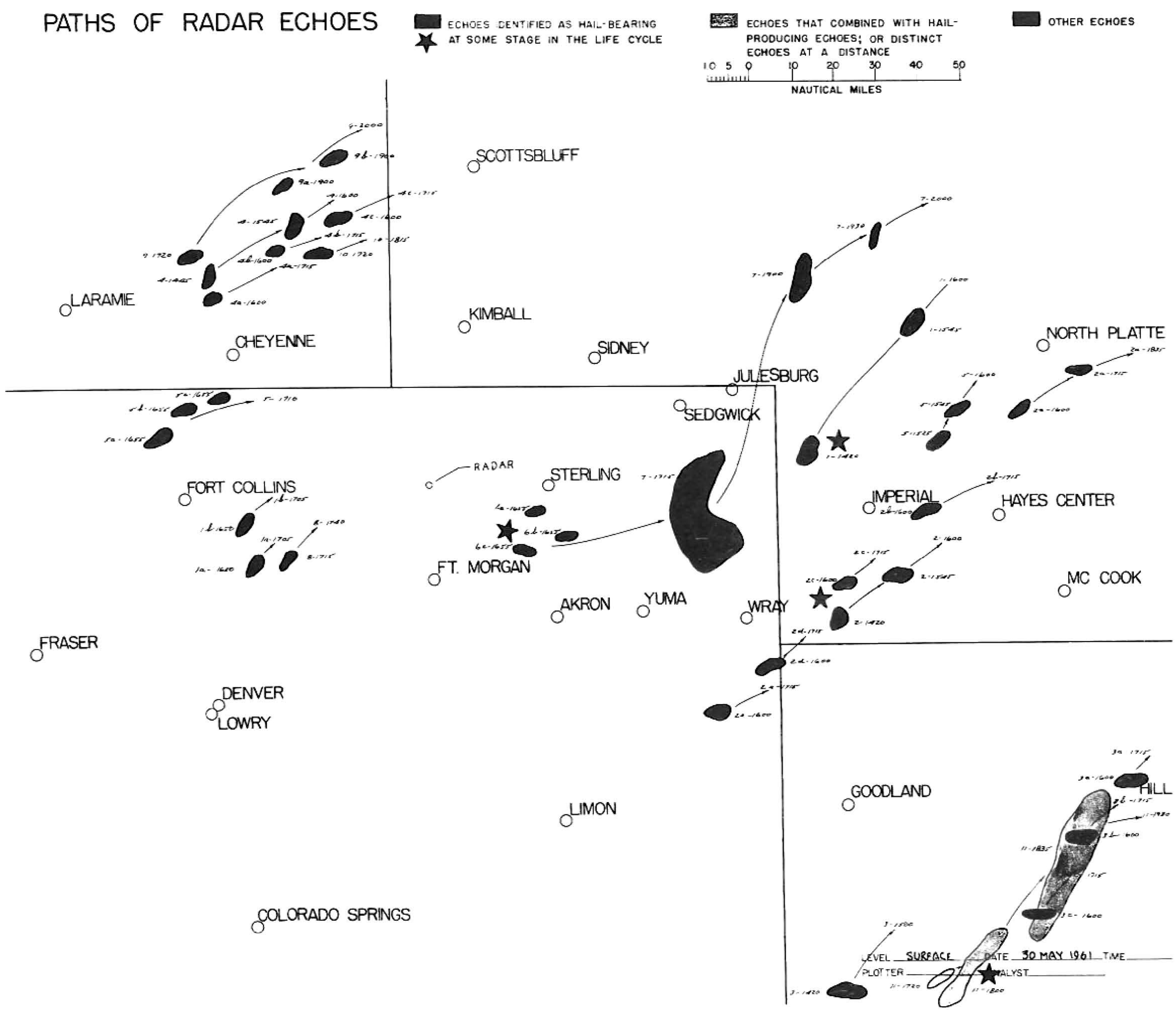

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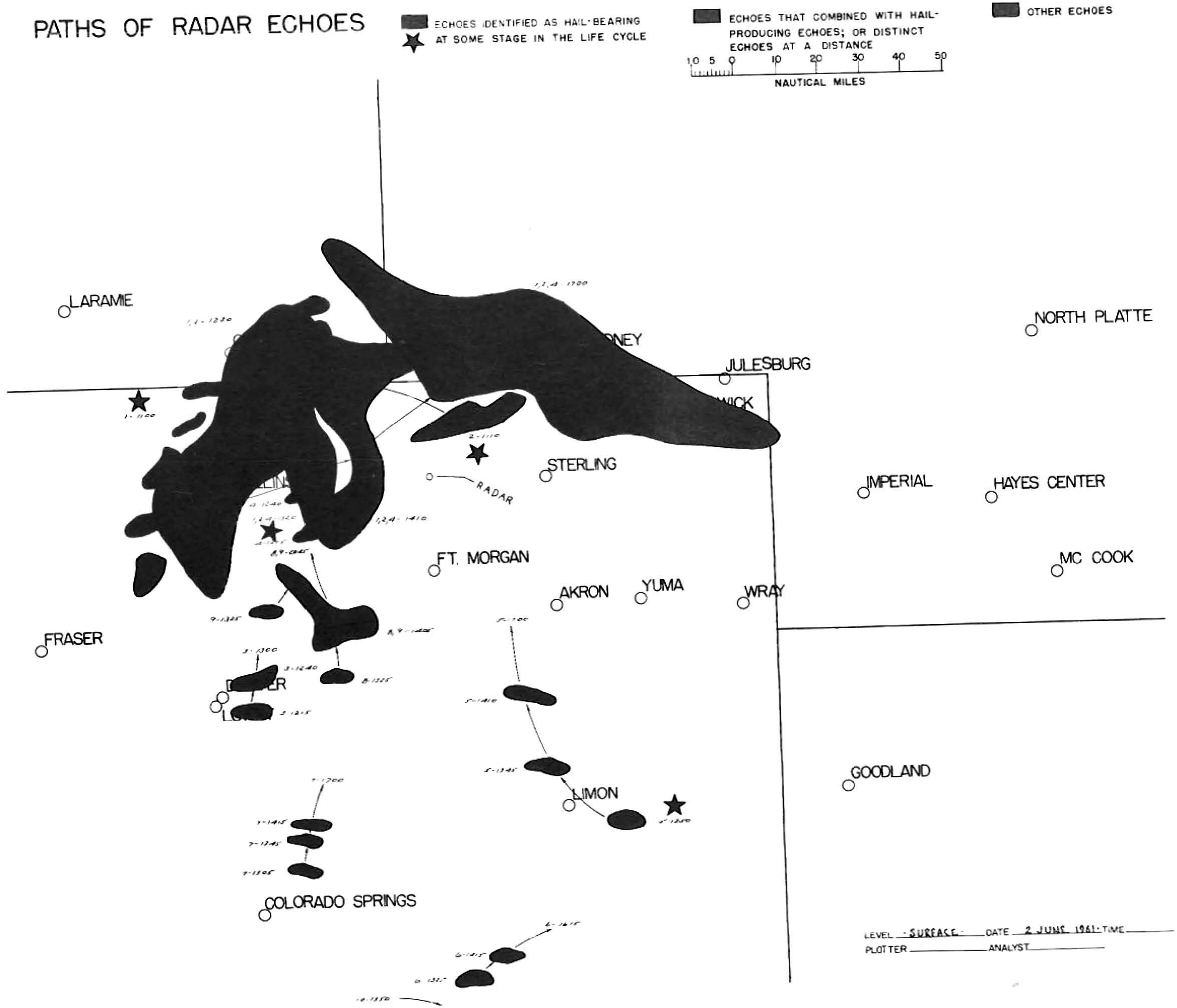

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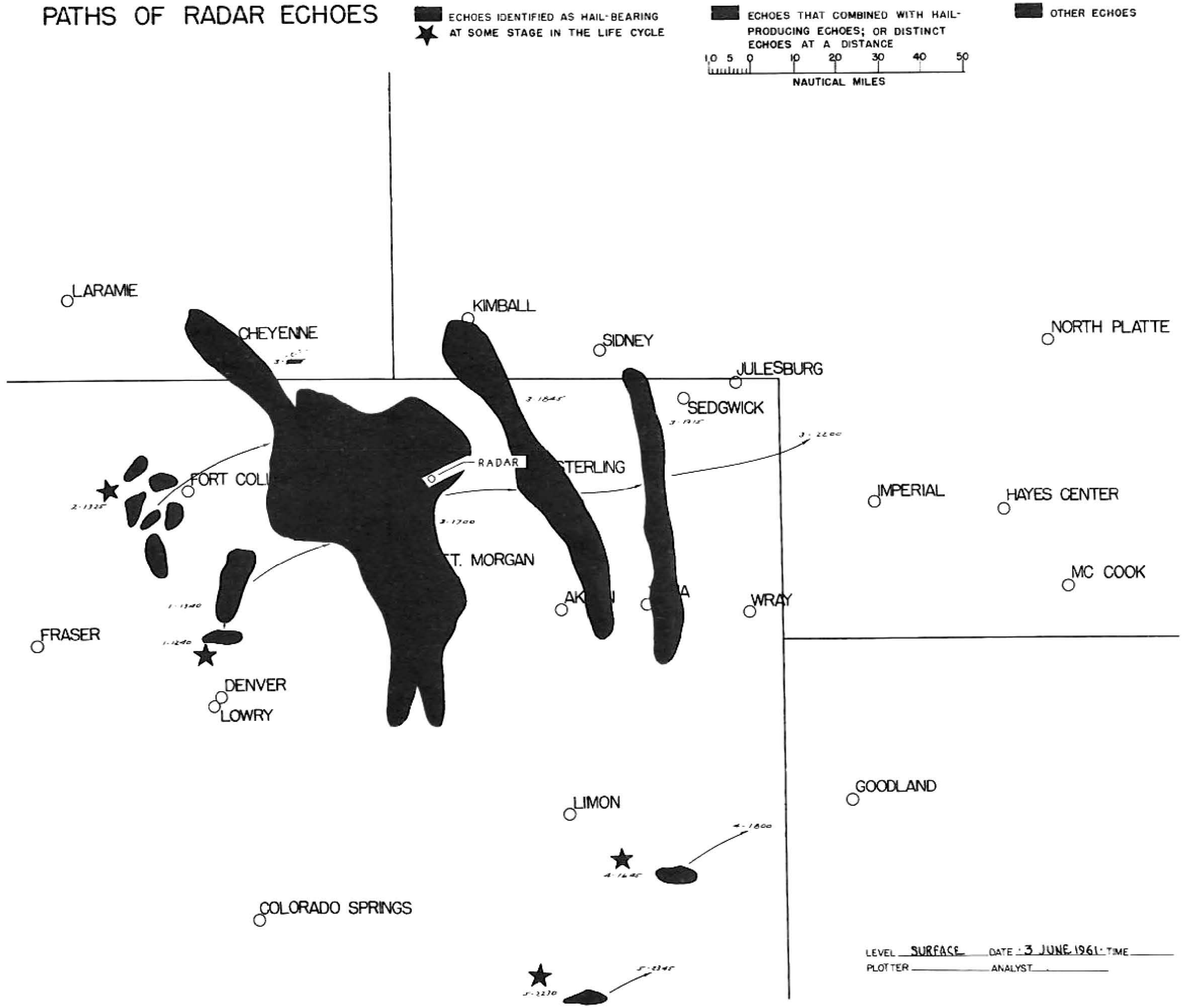

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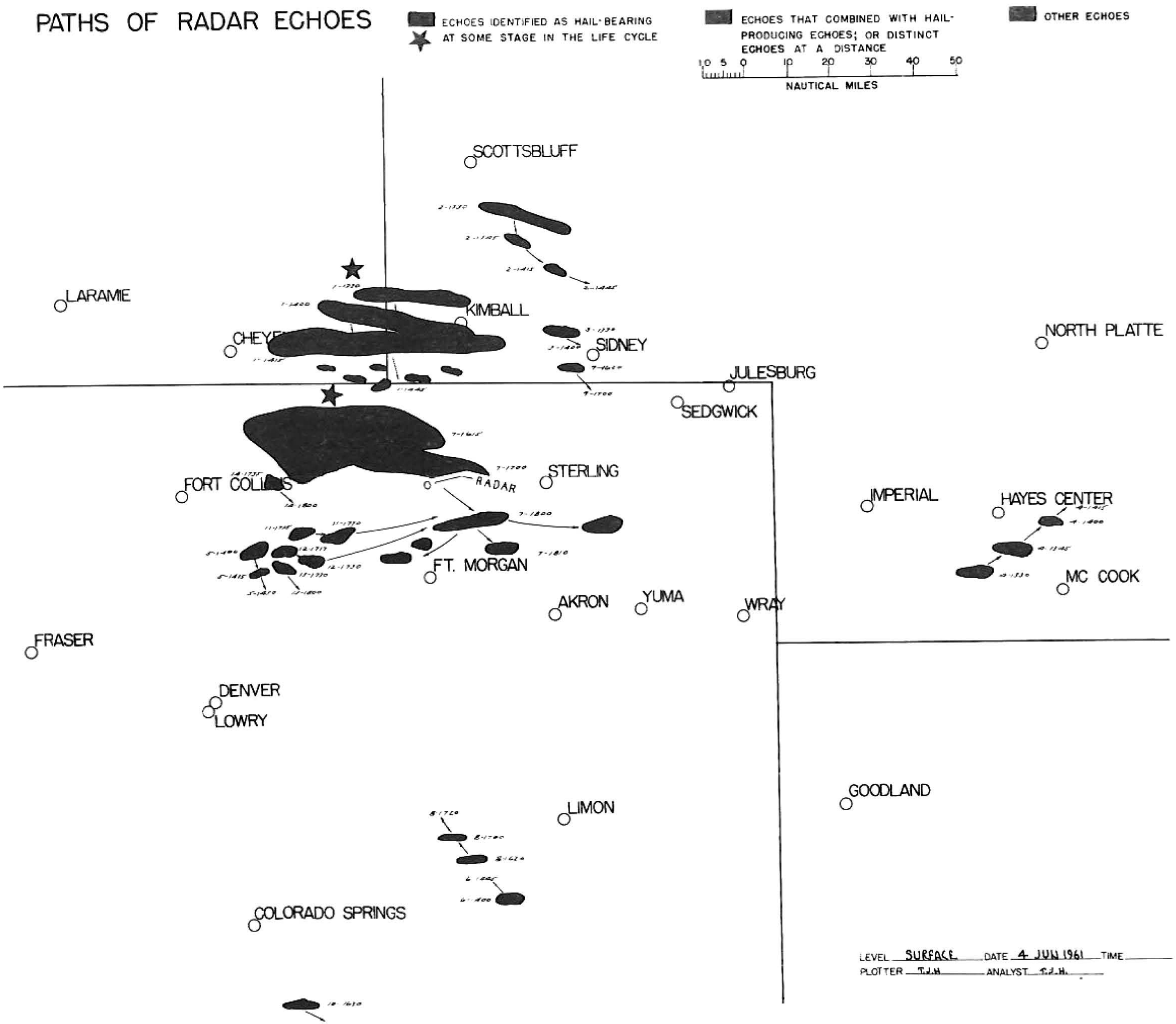

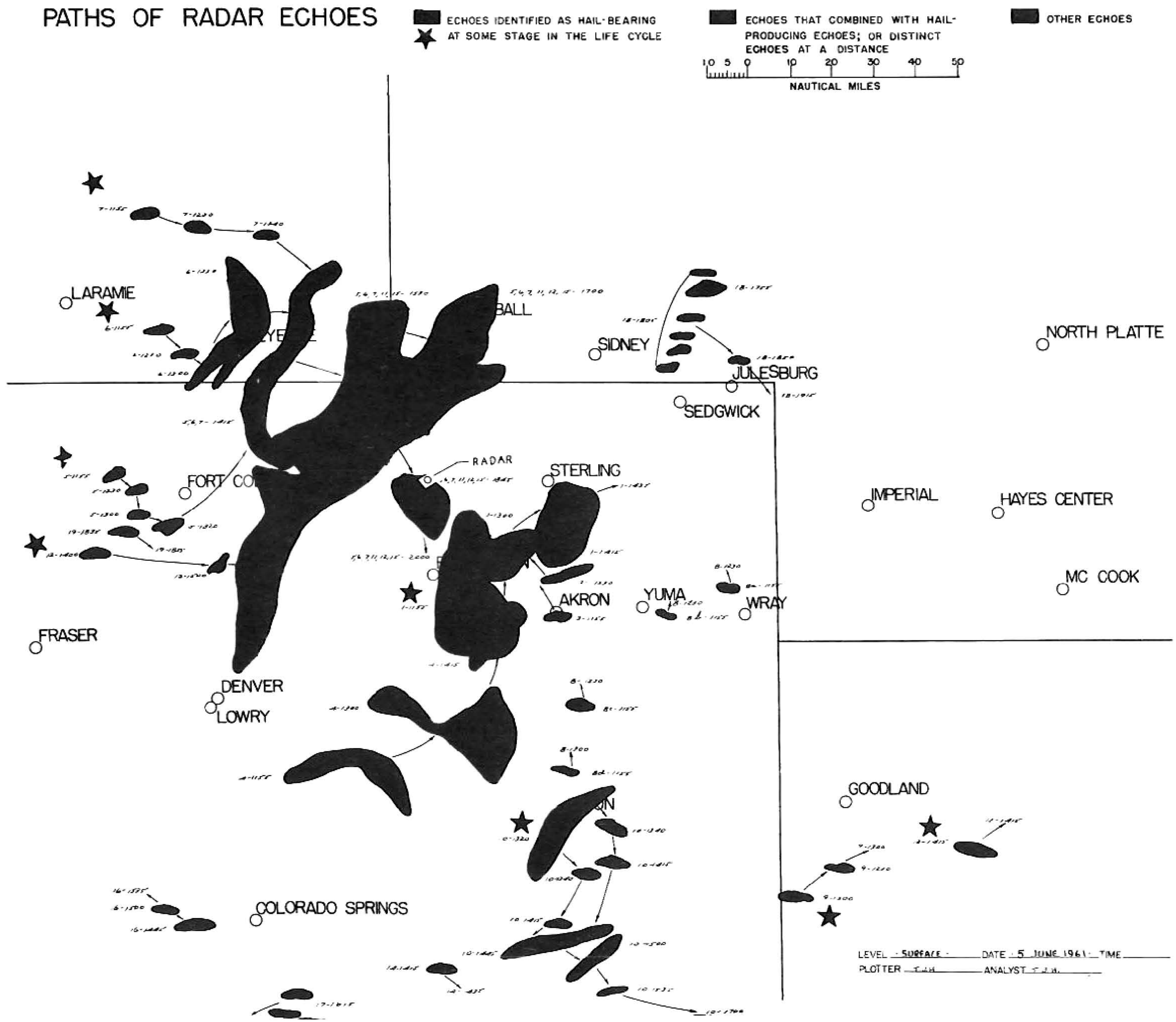
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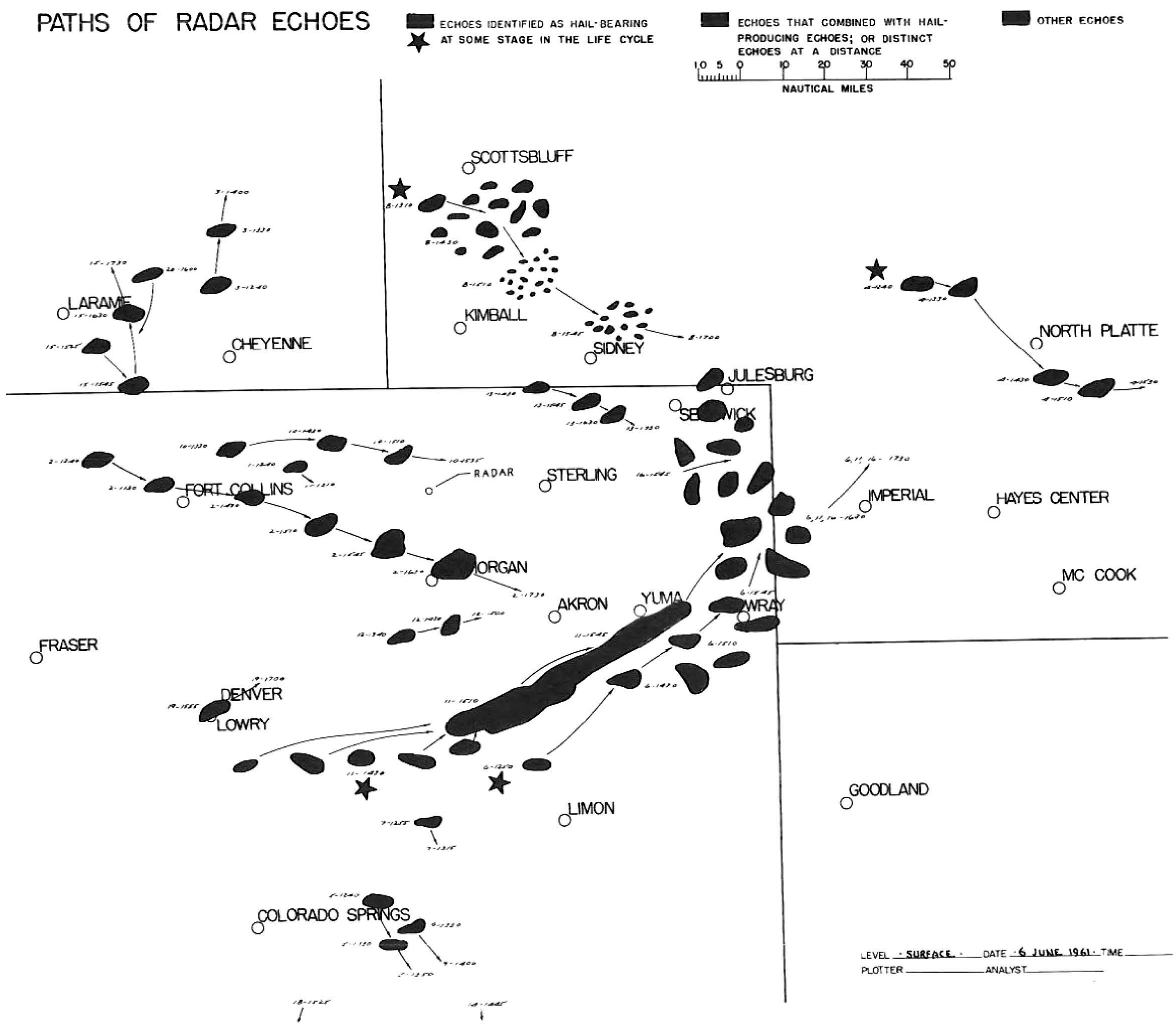
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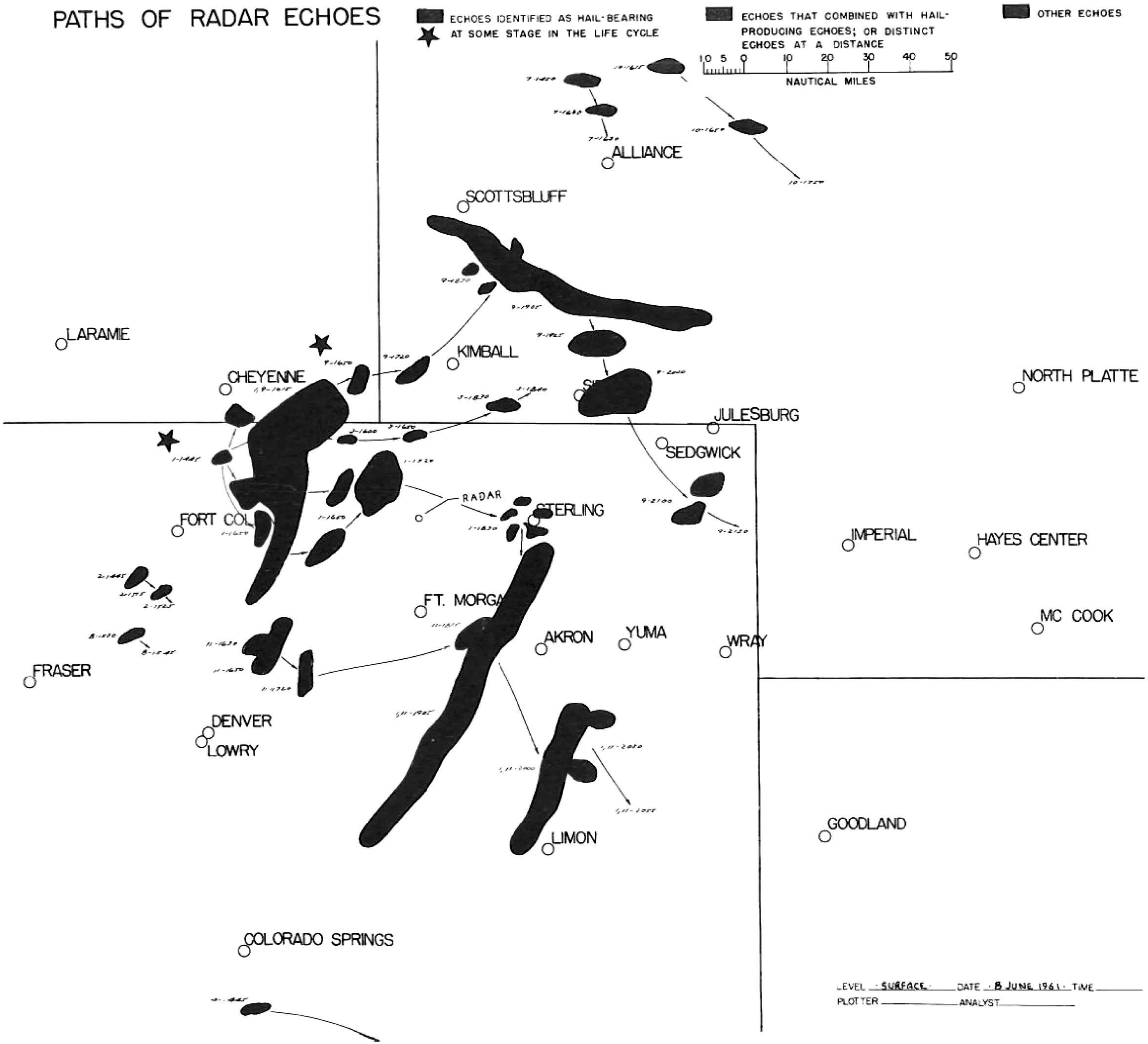

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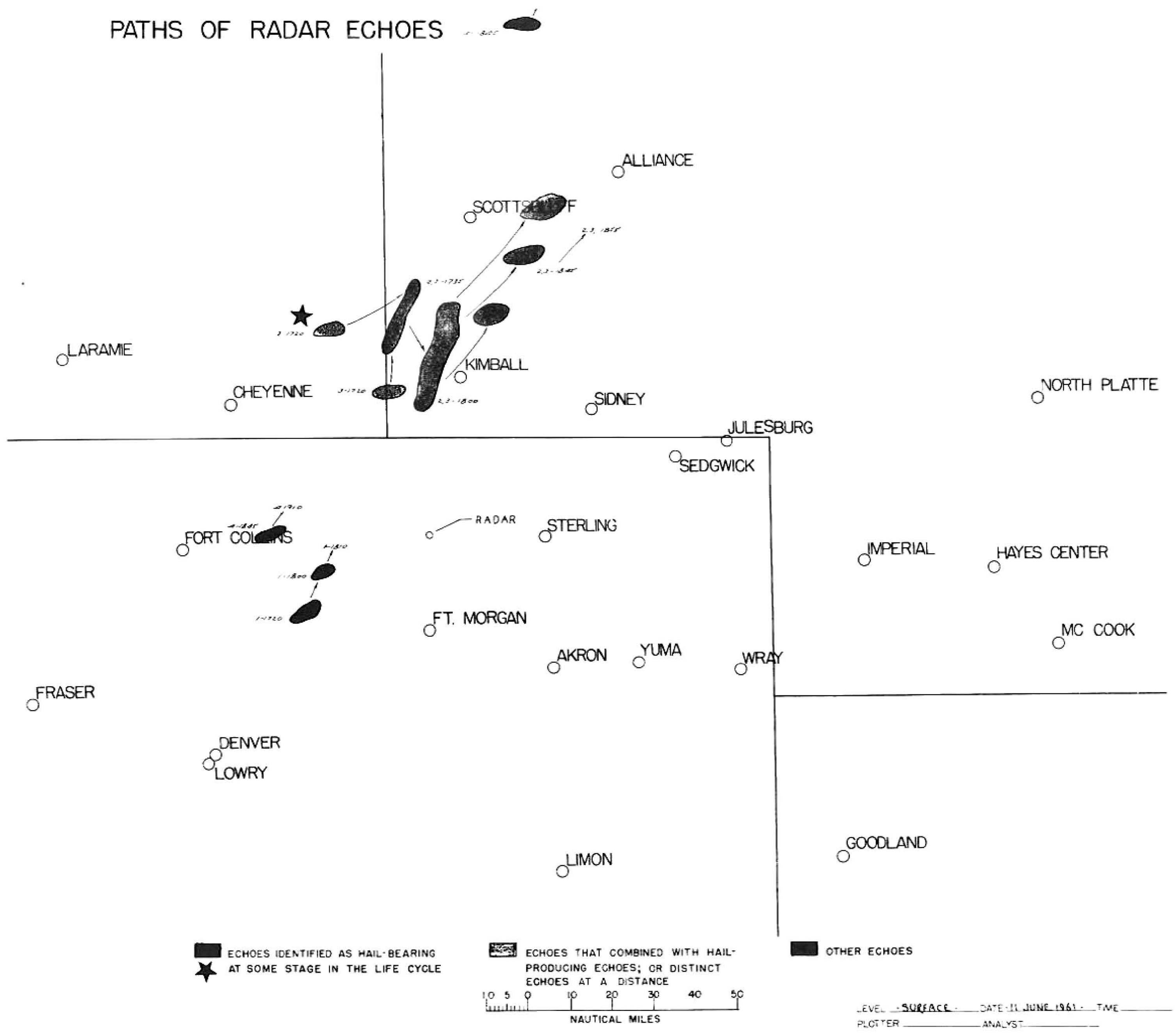

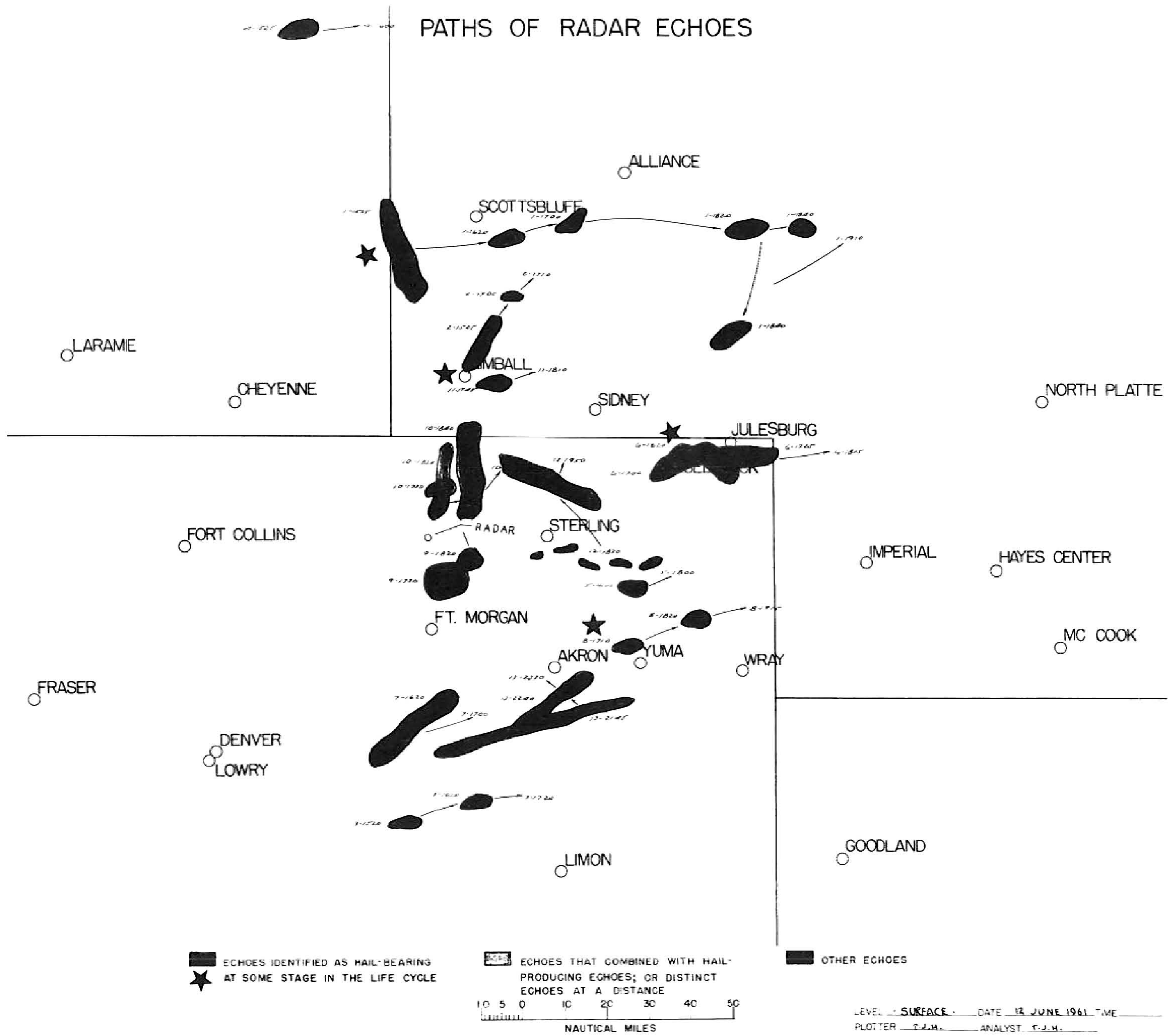
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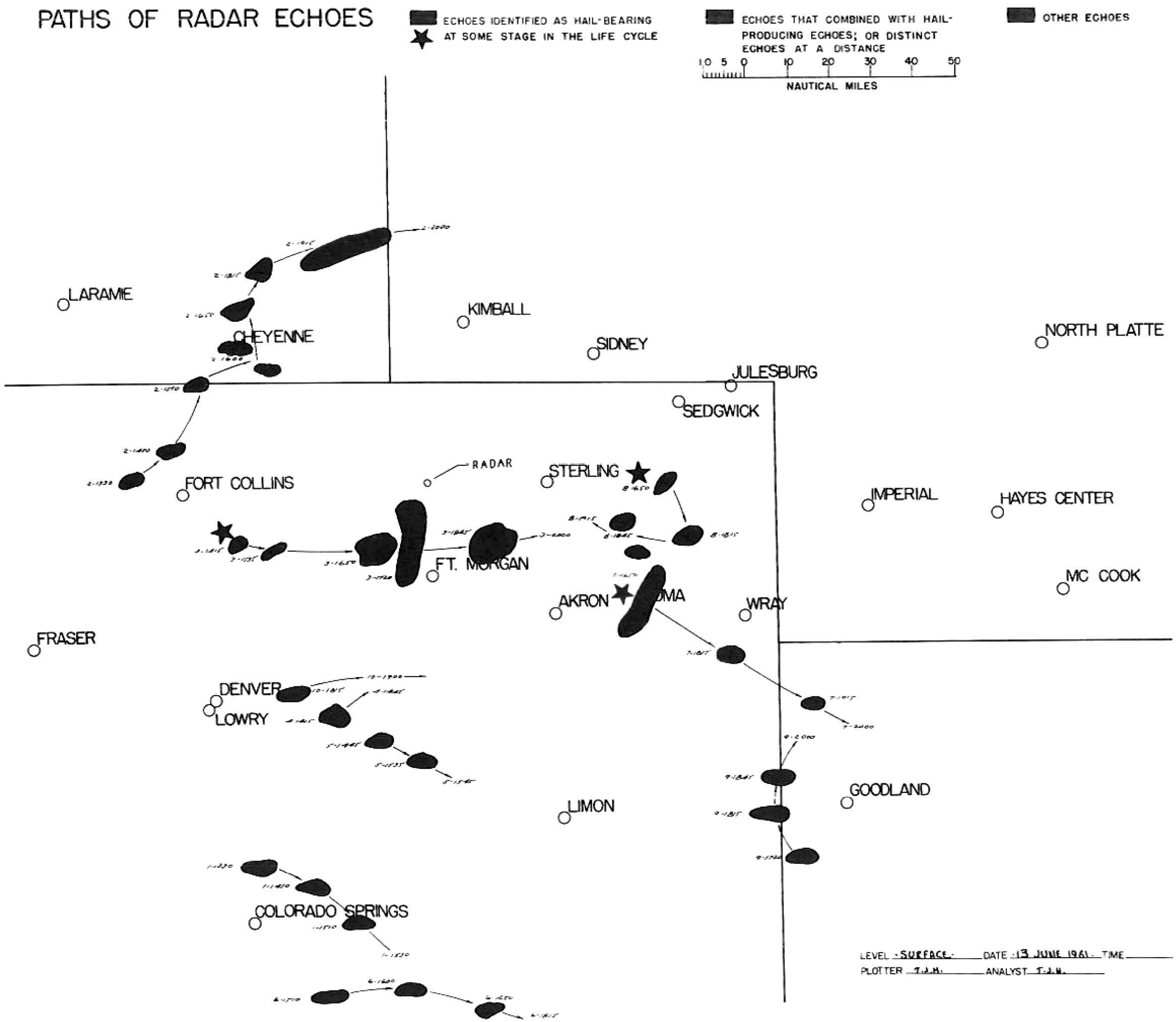
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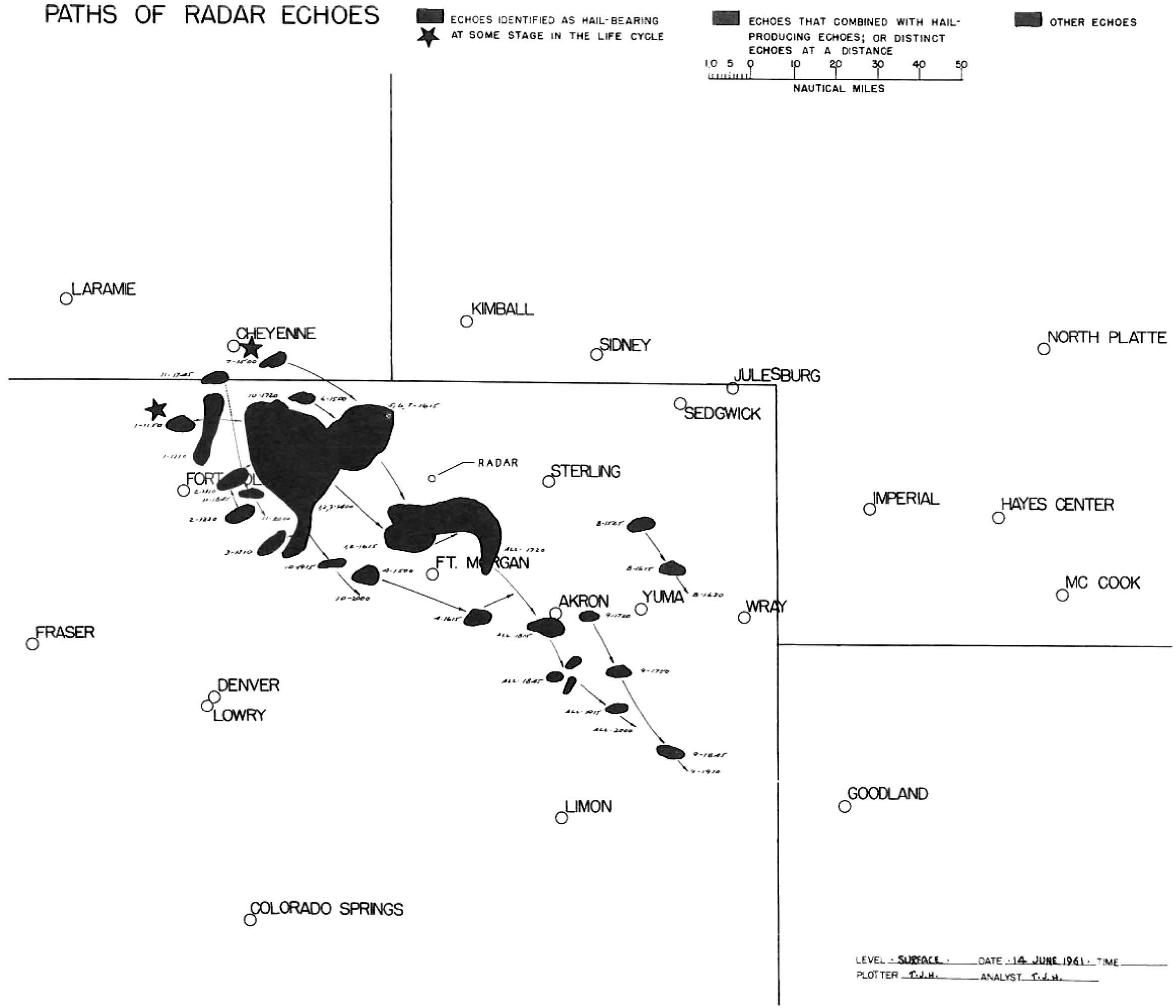

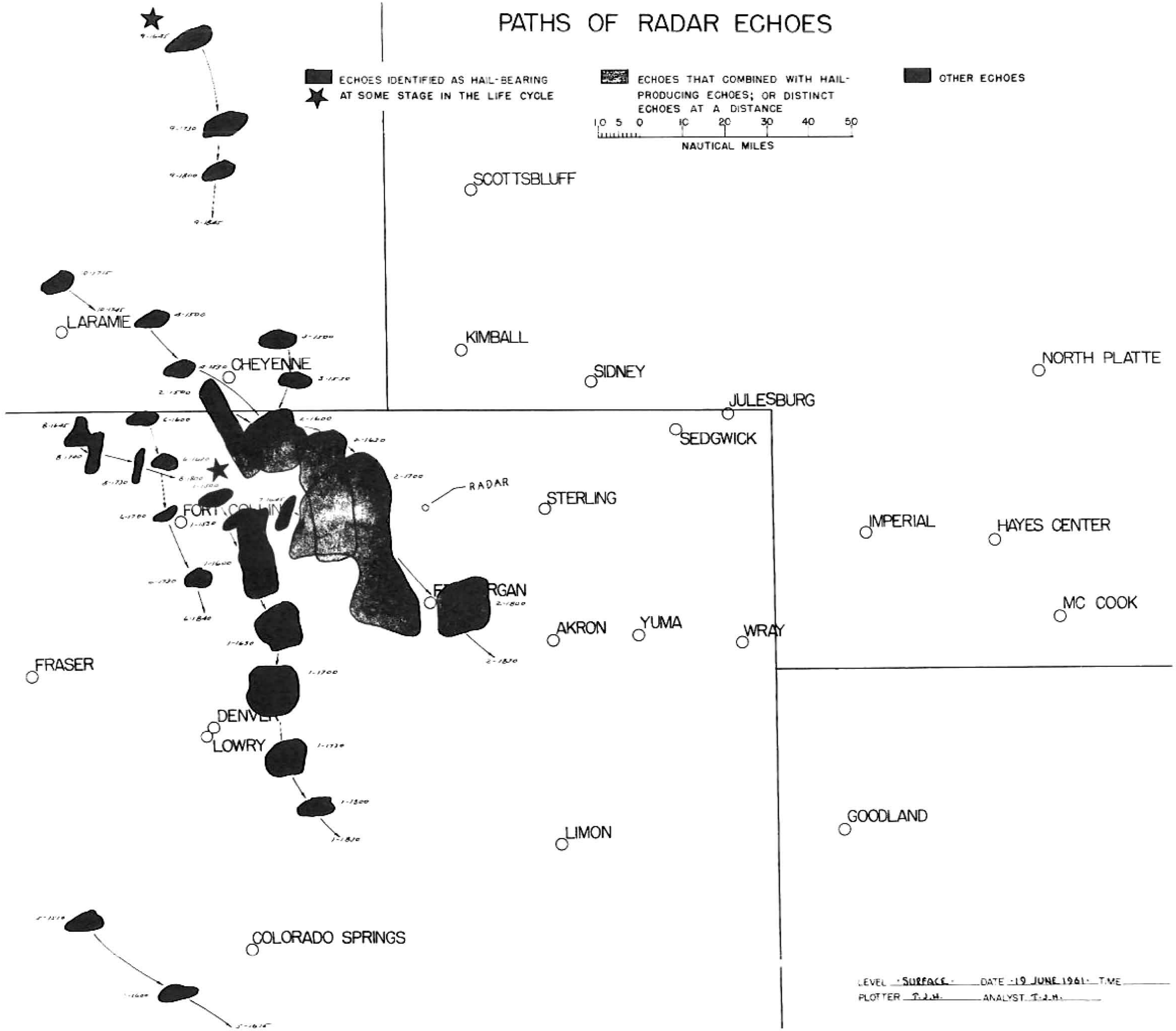
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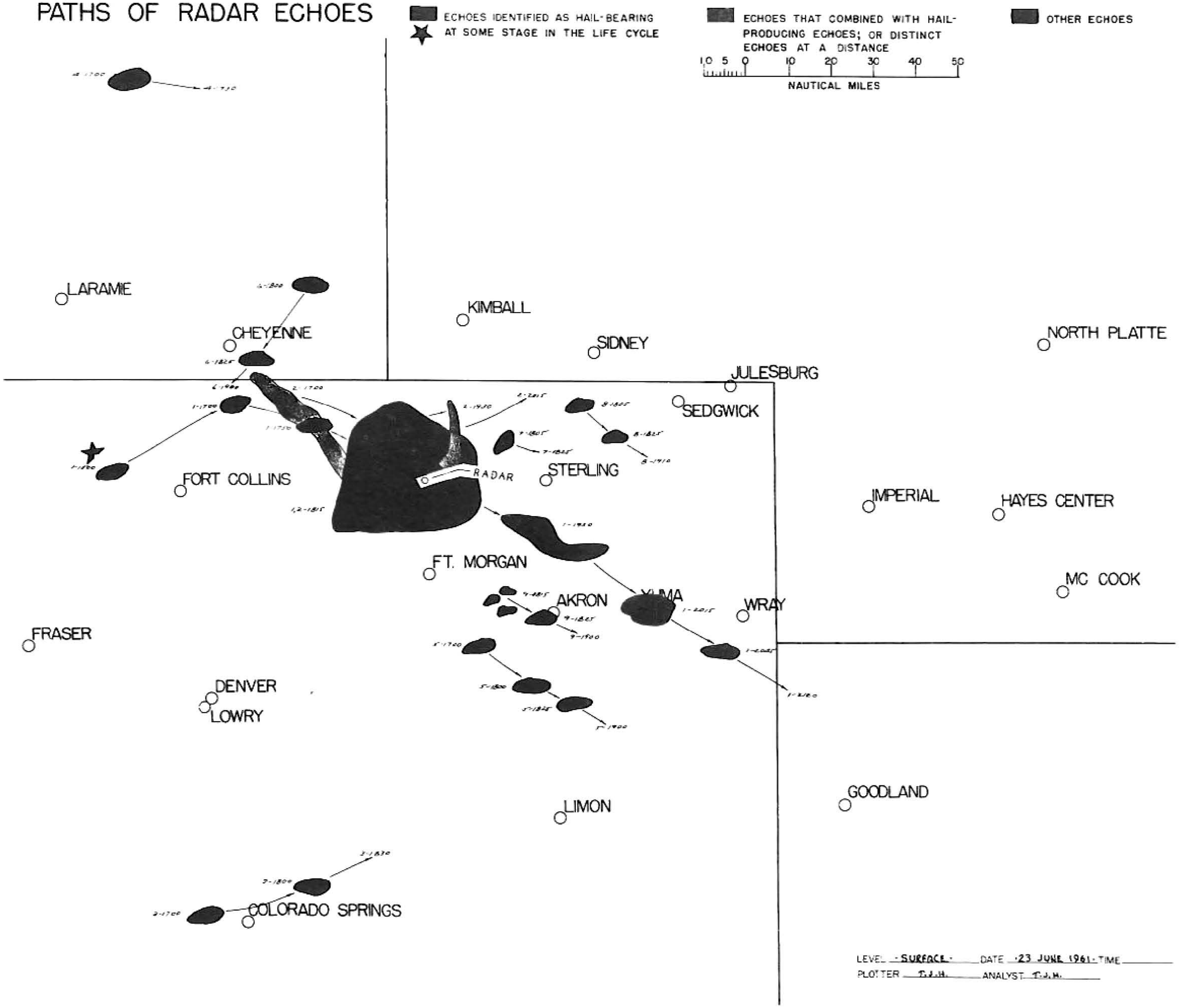

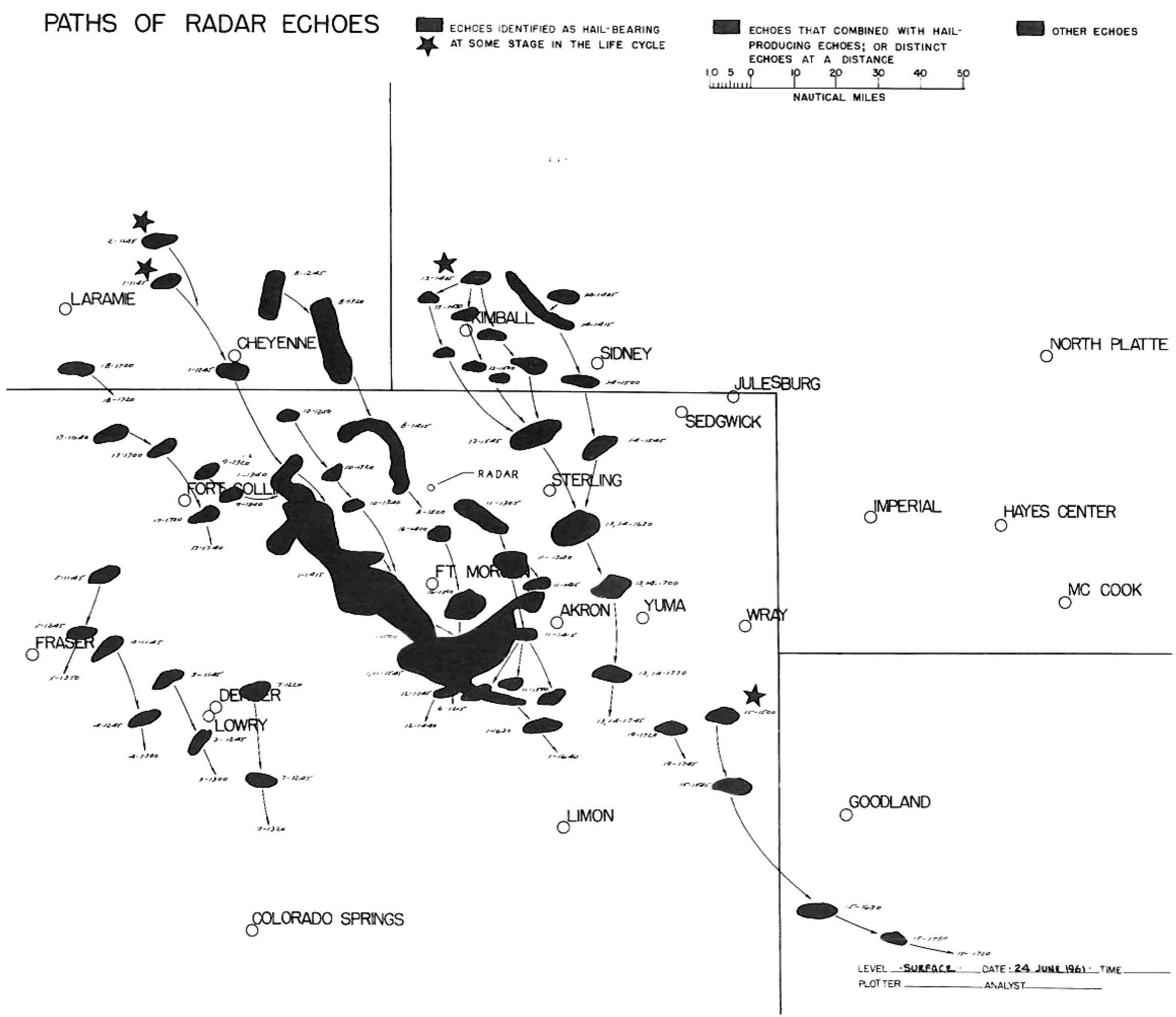
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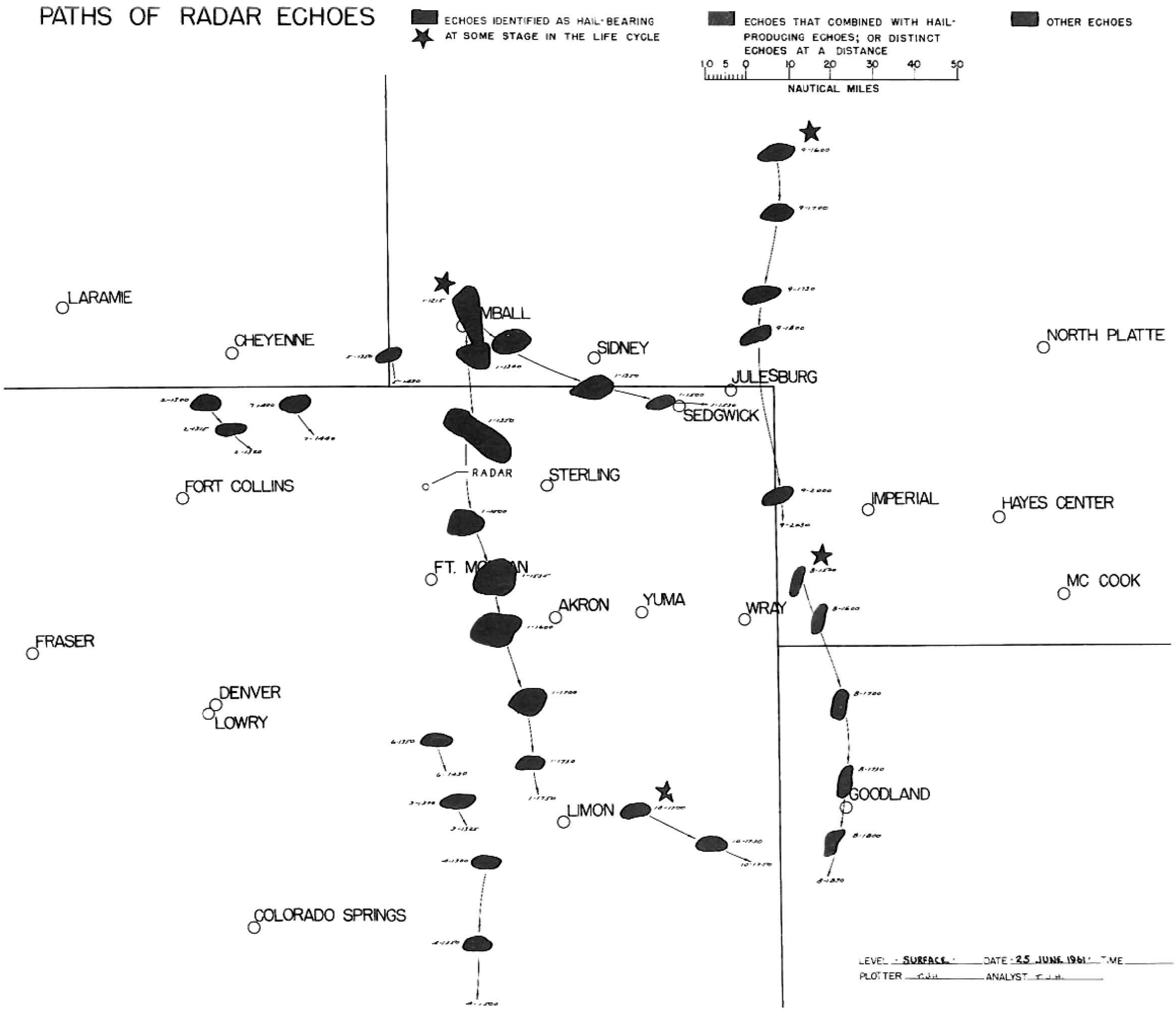

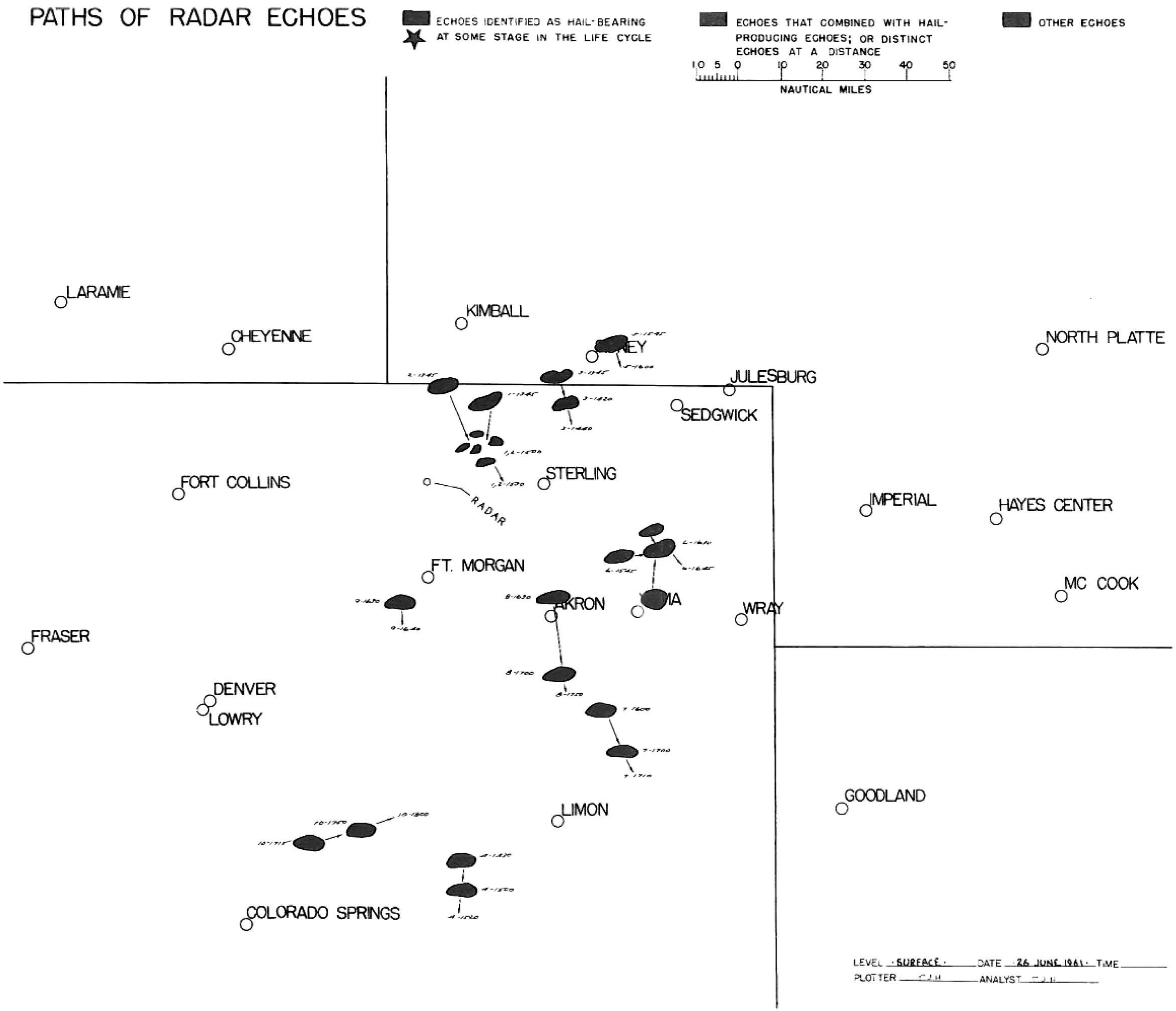

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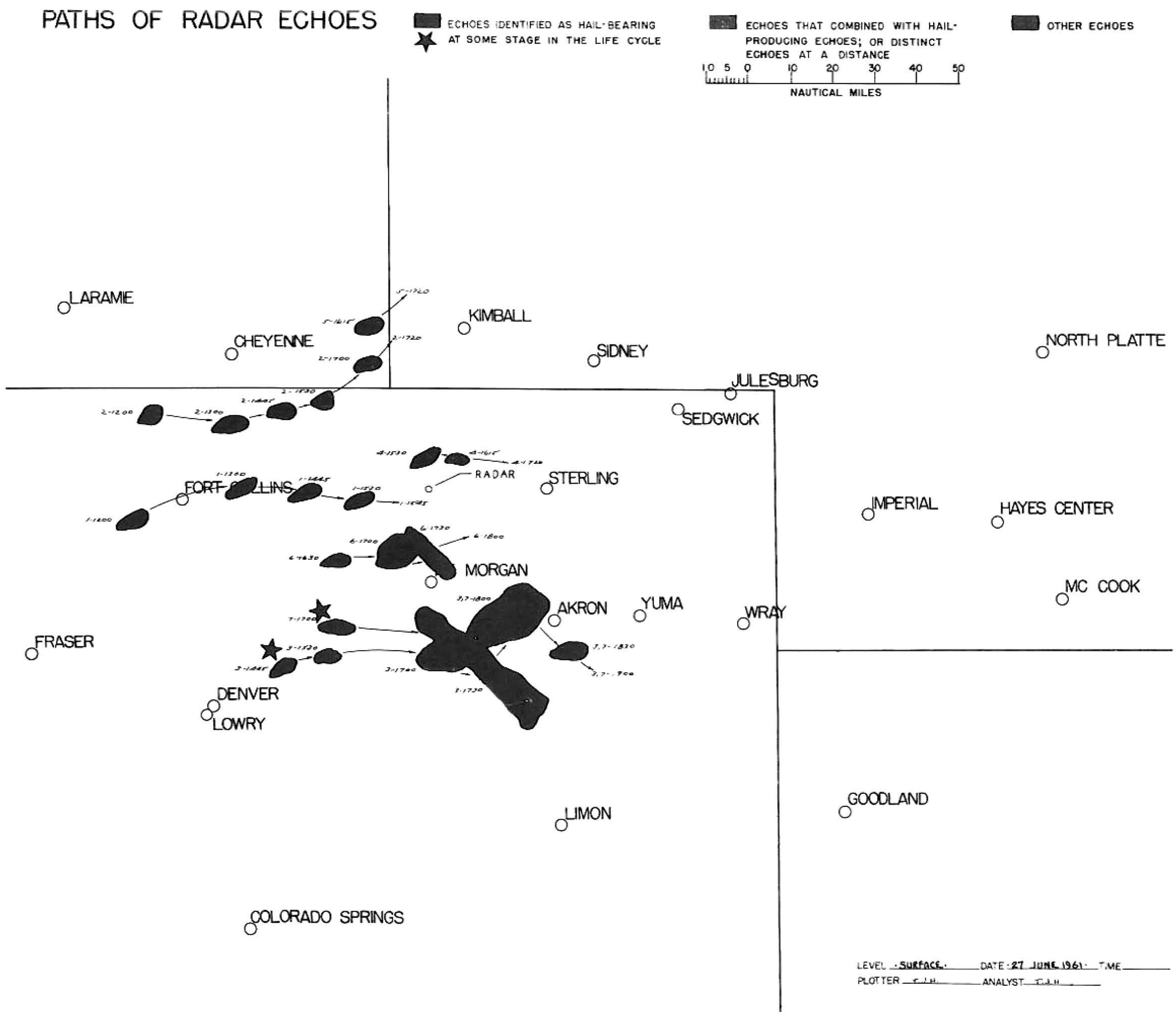
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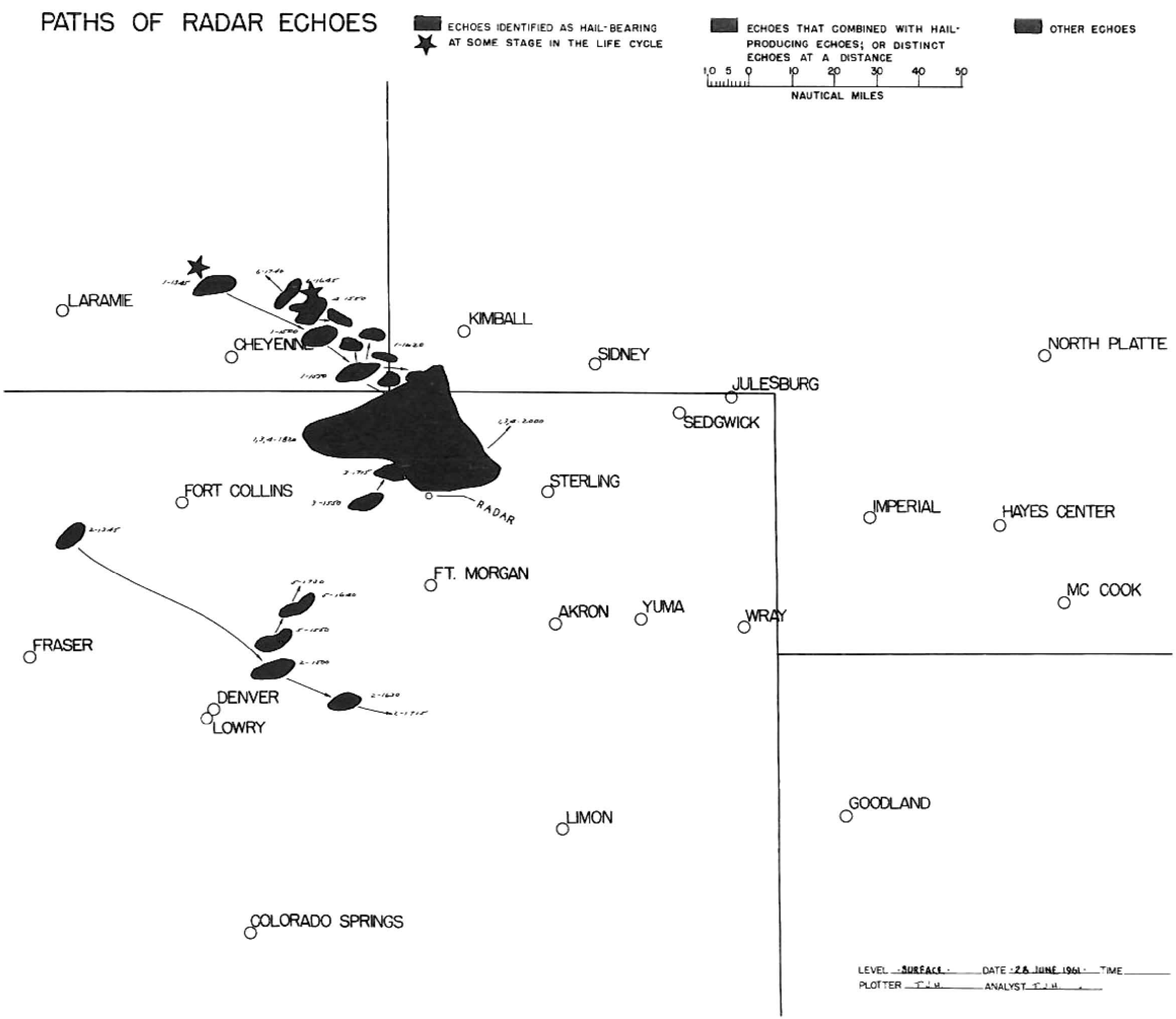
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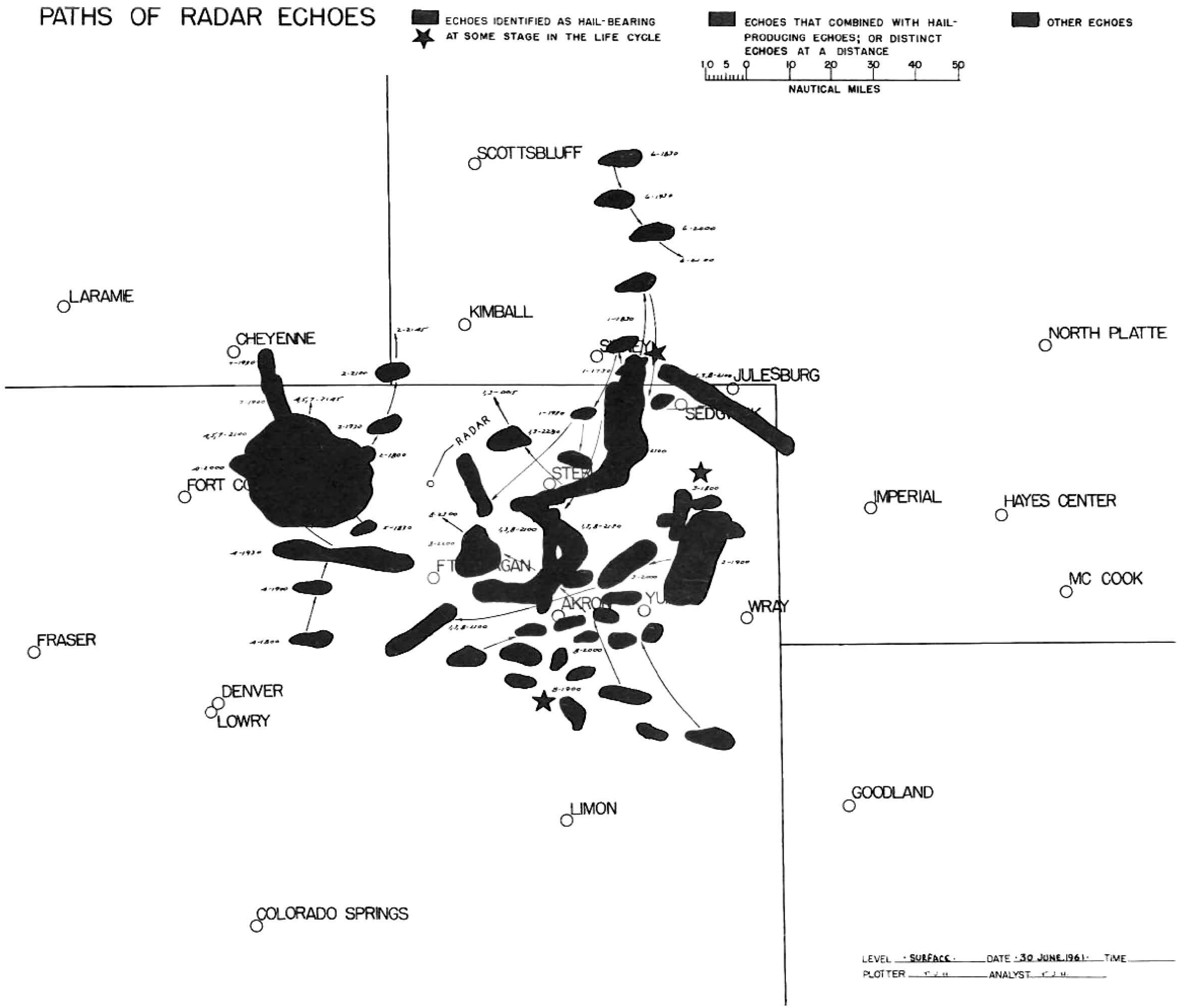
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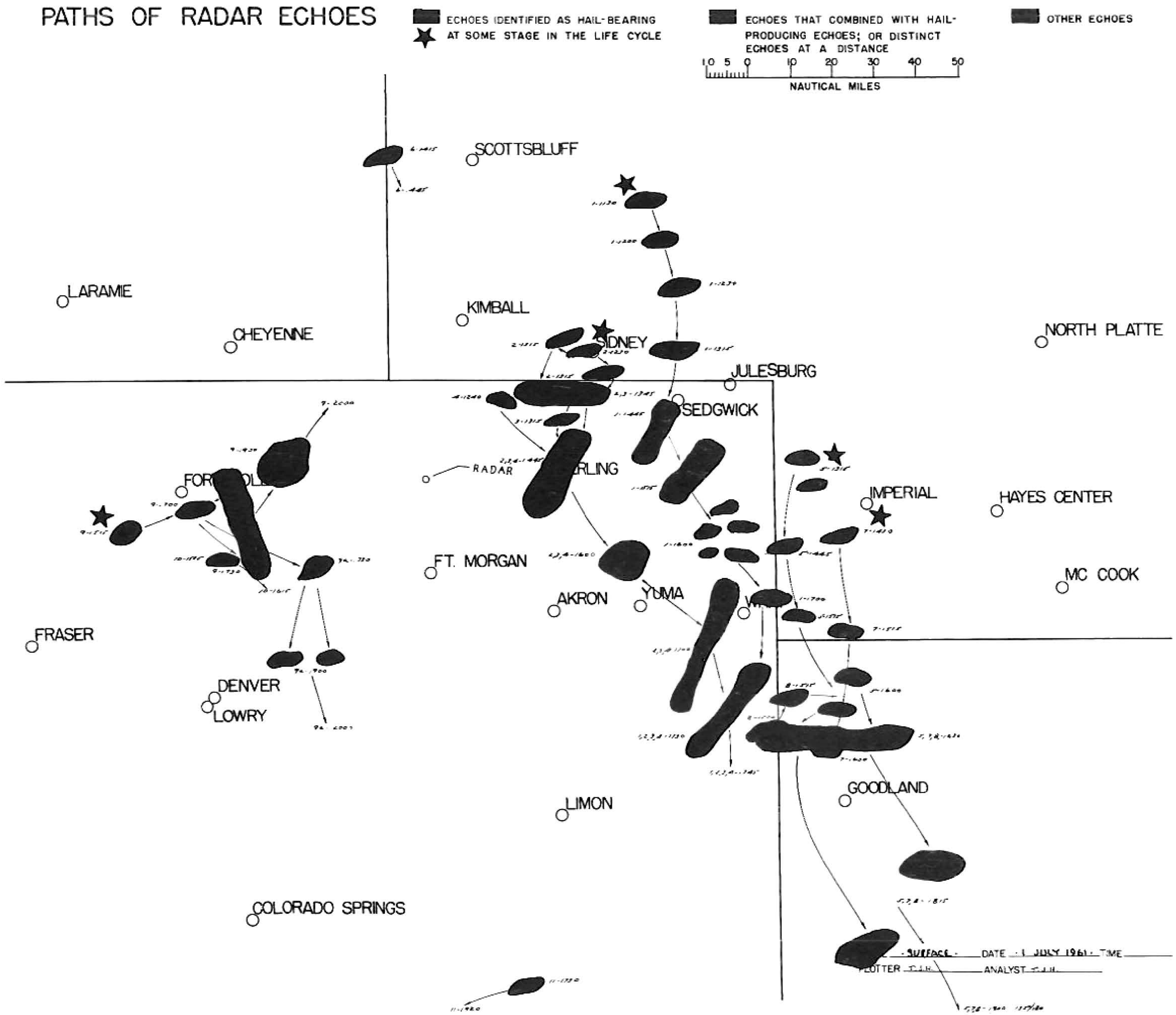
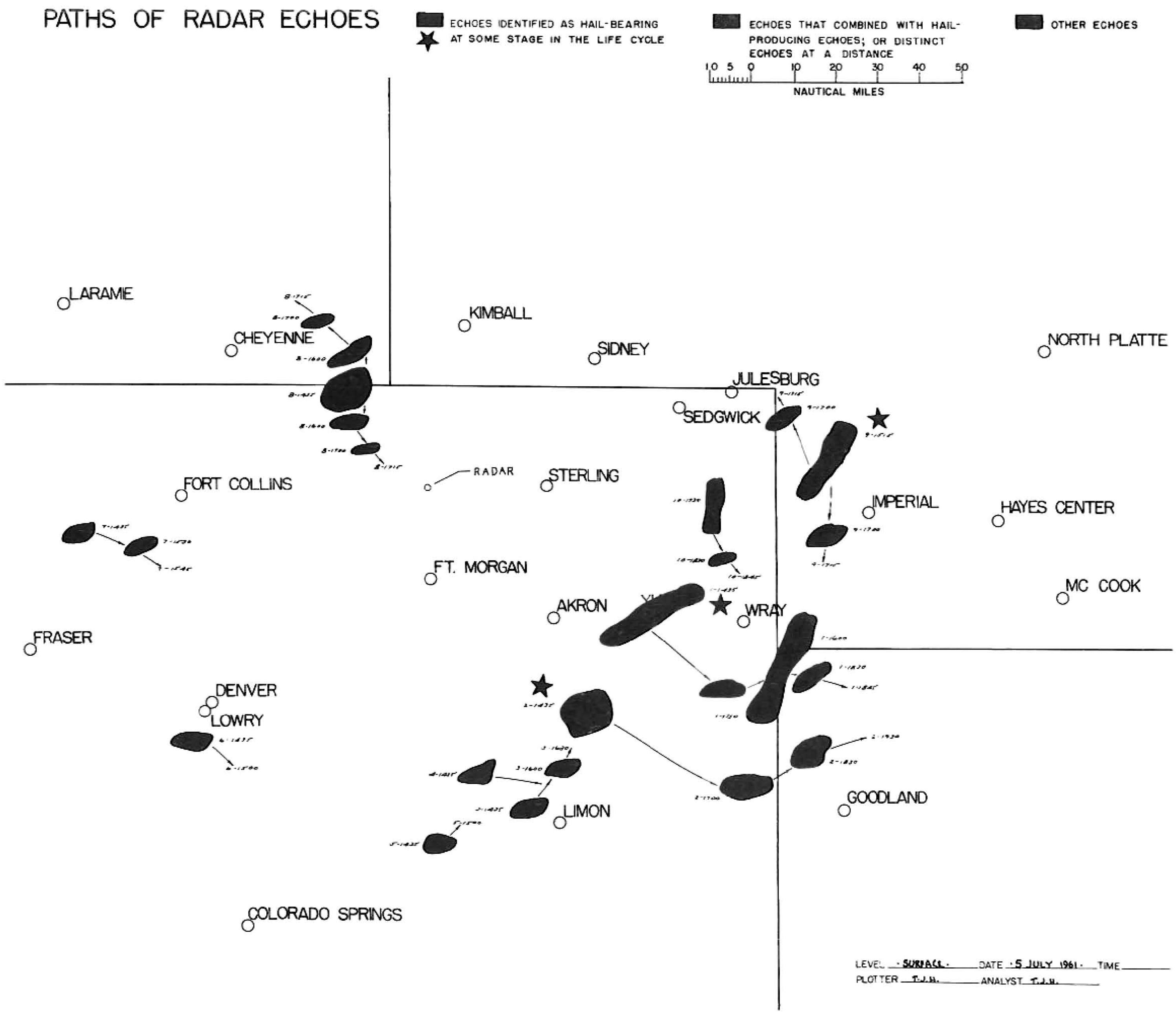
PATHS OF RADAR ECHOES

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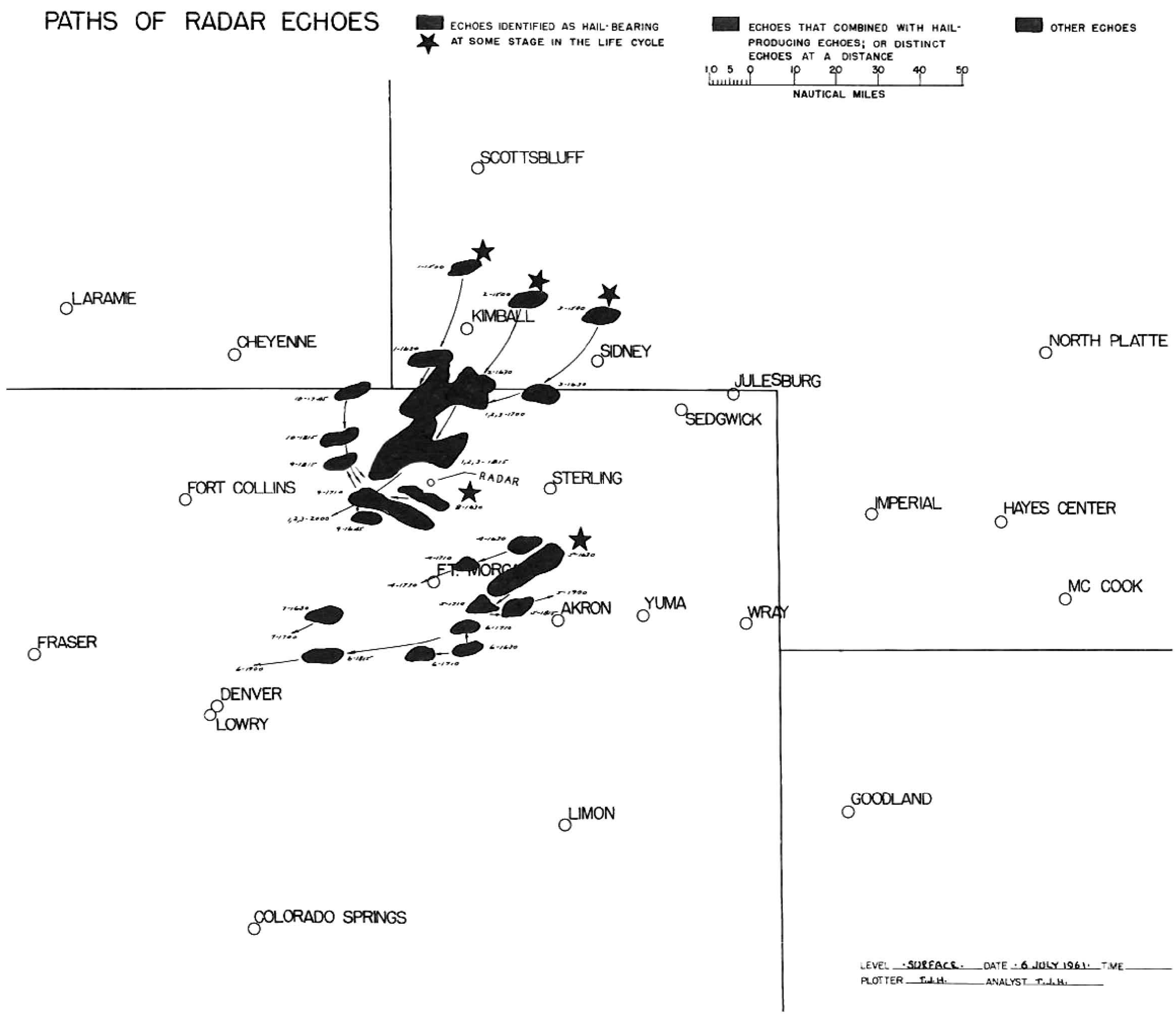

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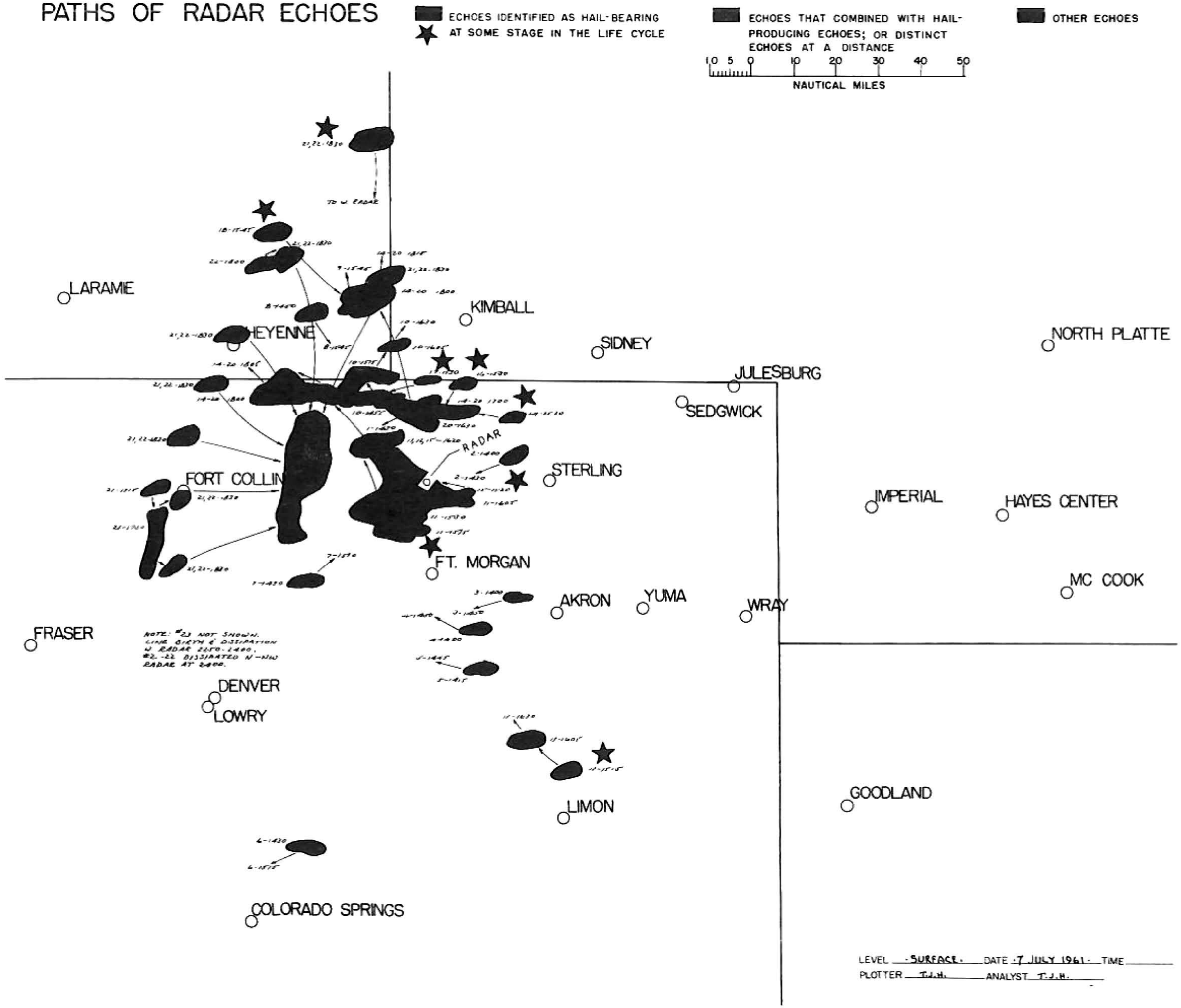
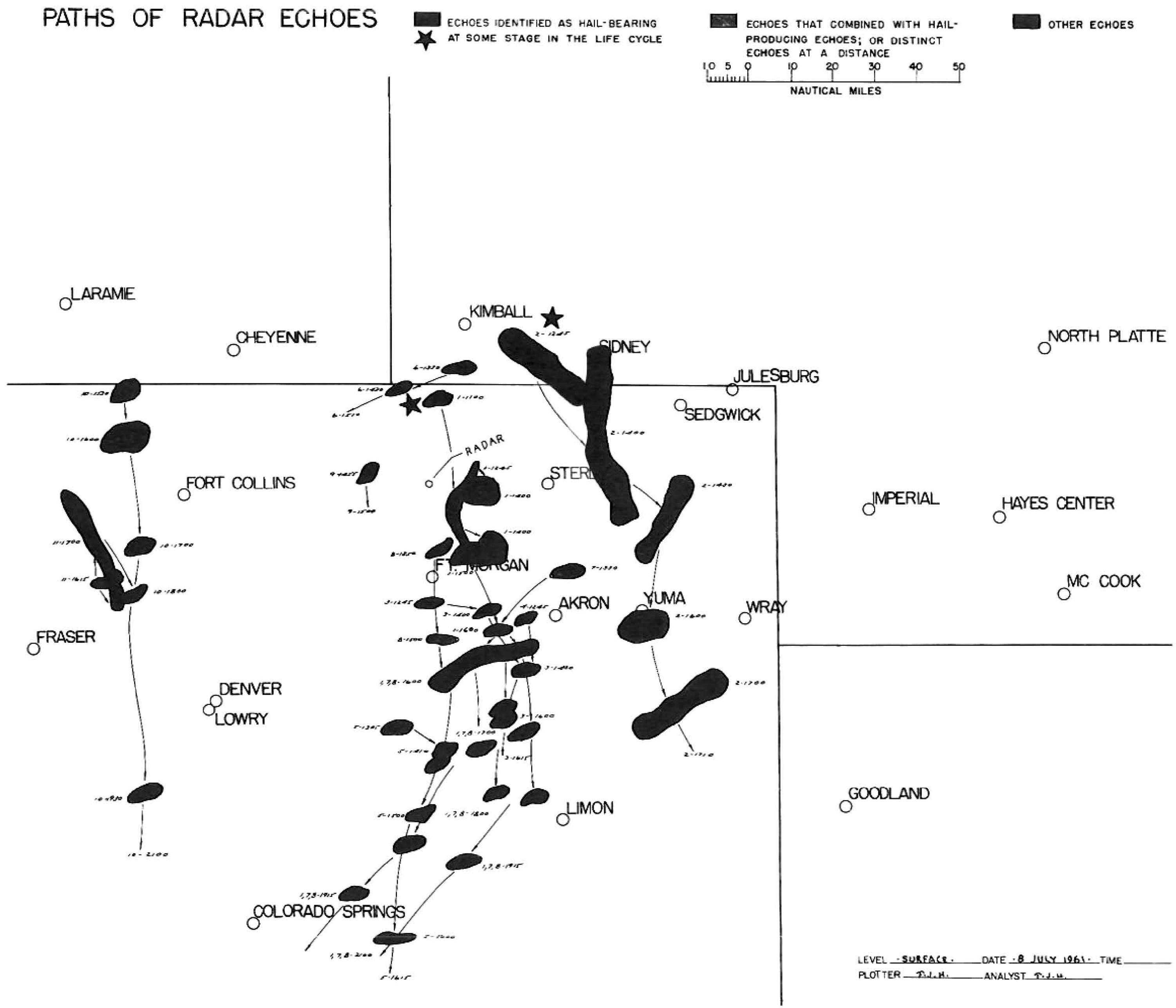
PATHS OF RADAR ECHOES

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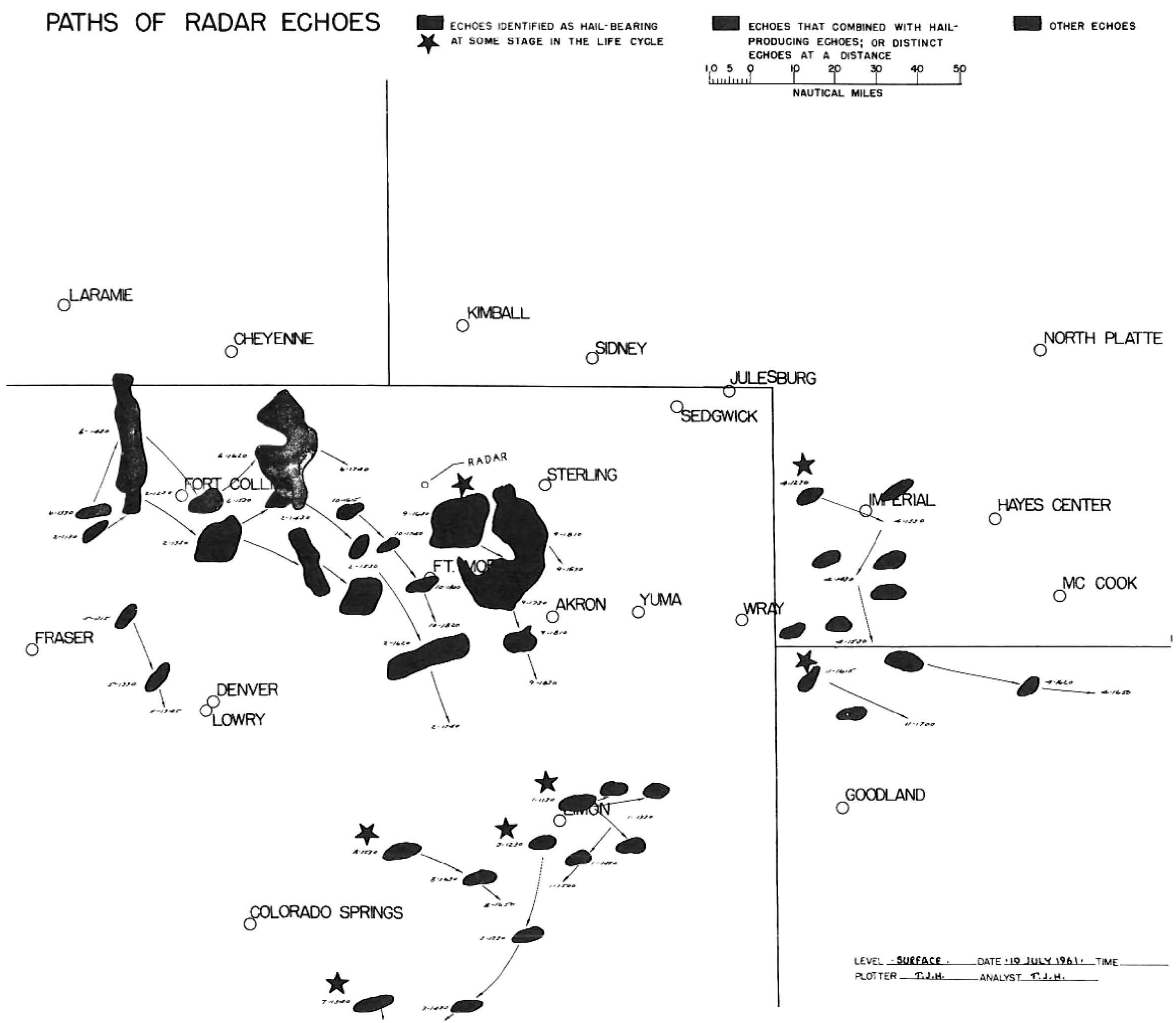
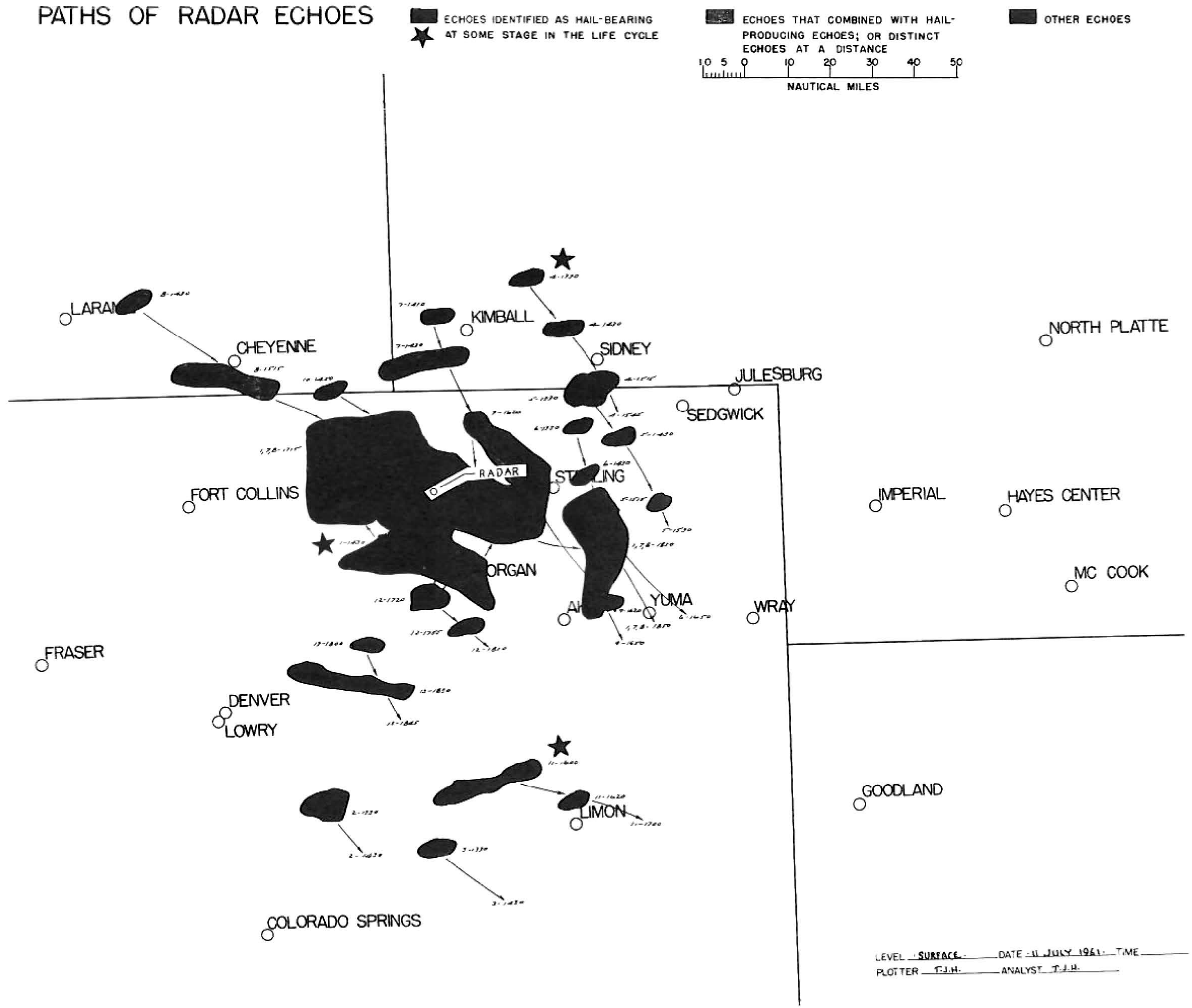
WRAY
MC COOK
FRASER
DENVER
LOWRY
LIMON
GOODLAND
COLORADO SPRINGS
LEVEL -SURFACE- DATE -8 JULY 1961- TIME
PLOTTER T.J.H. ANALYST T.J.H.

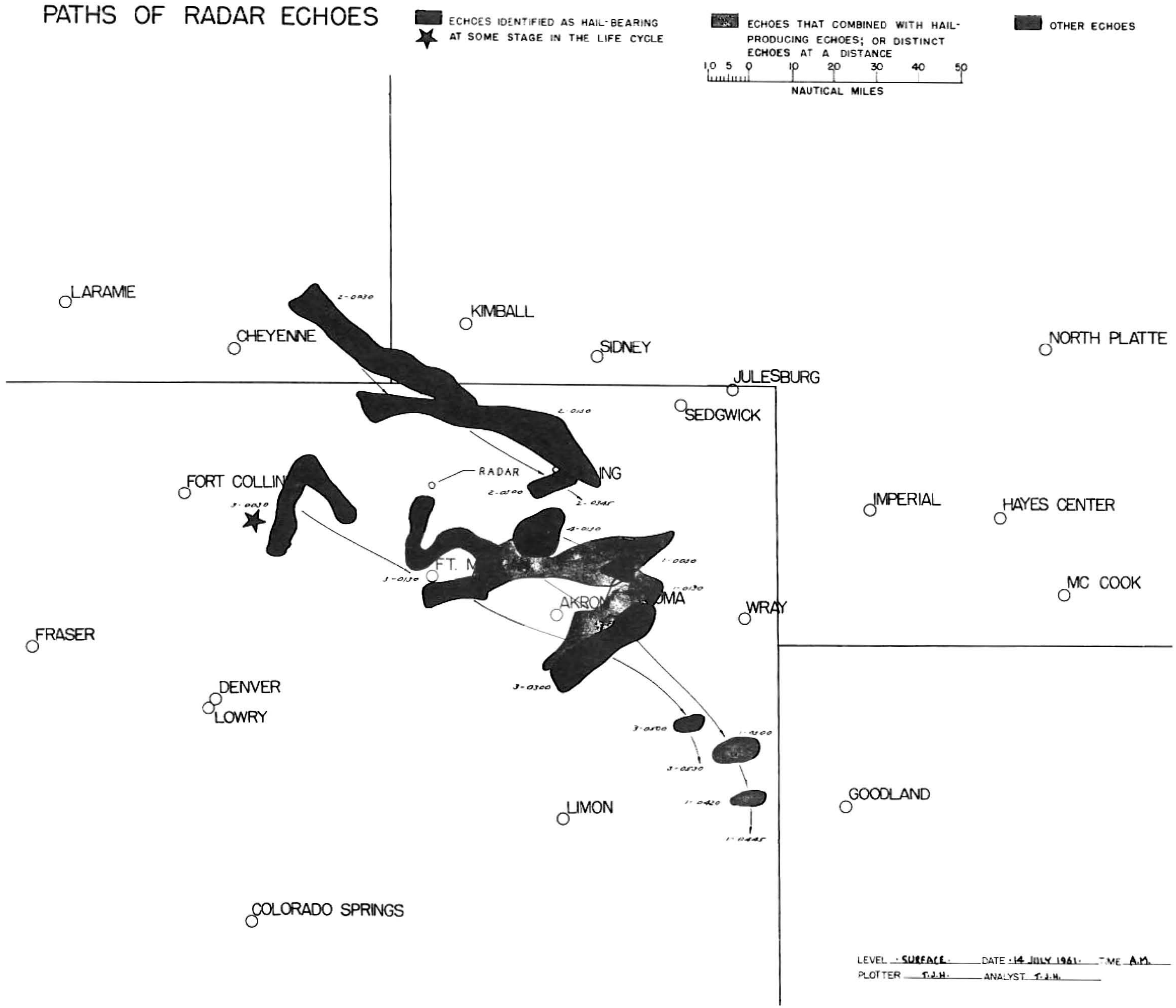

PATHS OF RADAR ECHOES
ECHOES IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THE LIFE CYCLE
ECHOES THAT COMBINED WITH HAIL-PRODUCING ECHOES; OR DISTINCT ECHOES AT A DISTANCE
OTHER ECHOES
10 5 0 10 20 30 40 50
NAUTICAL MILES
LARAMIE
CHEYENNE
KIMBALL
SIDNEY
NORTH PLATTE
JULESBURG
SEDGWICK
RADAR
STERLING
FORT COLLINS
IMPERIAL
HAYES CENTER
FT. MORGAN
AKRON
YUMA
WRAY
MC COOK
FRASER
DENVER
LOWRY
GOODLAND
LIMON
COLORADO SPRINGS
LEVEL SURFACE DATE 19 JULY 1961 TIME
PLOTTER T.J.H. ANALYST T.J.H.

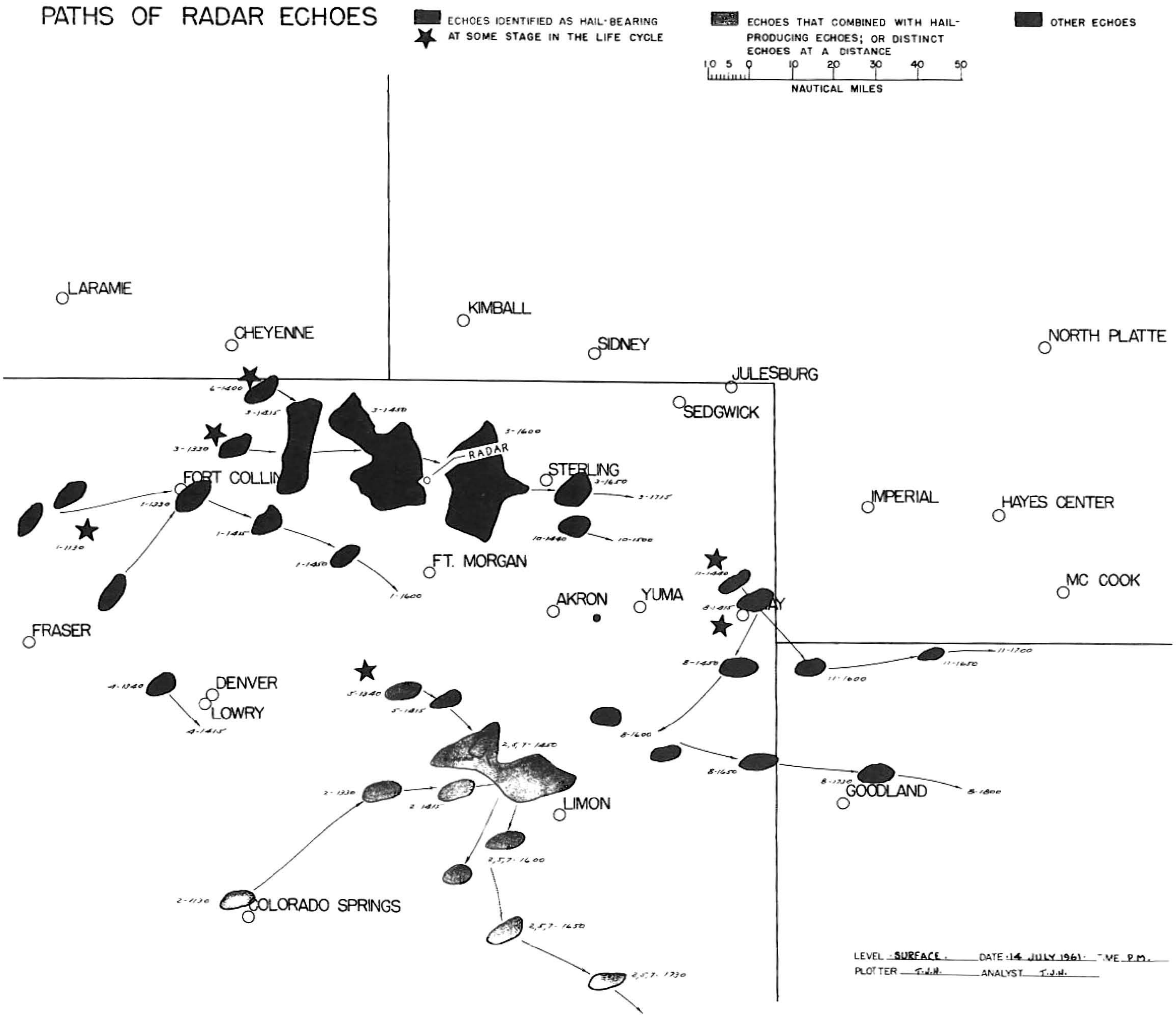
PATHS OF RADAR ECHOES



LEVEL SURFACE DATE 11 JULY 1961 TIME ______
PLOTTER T.J.H. ANALYST T.J.H.

PATHS OF RADAR ECHOES




PATHS OF RADAR ECHOES
ECHOES IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THE LIFE CYCLE
ECHOES THAT COMBINED WITH HAIL-PRODUCING ECHOES; OR DISTINCT ECHOES AT A DISTANCE
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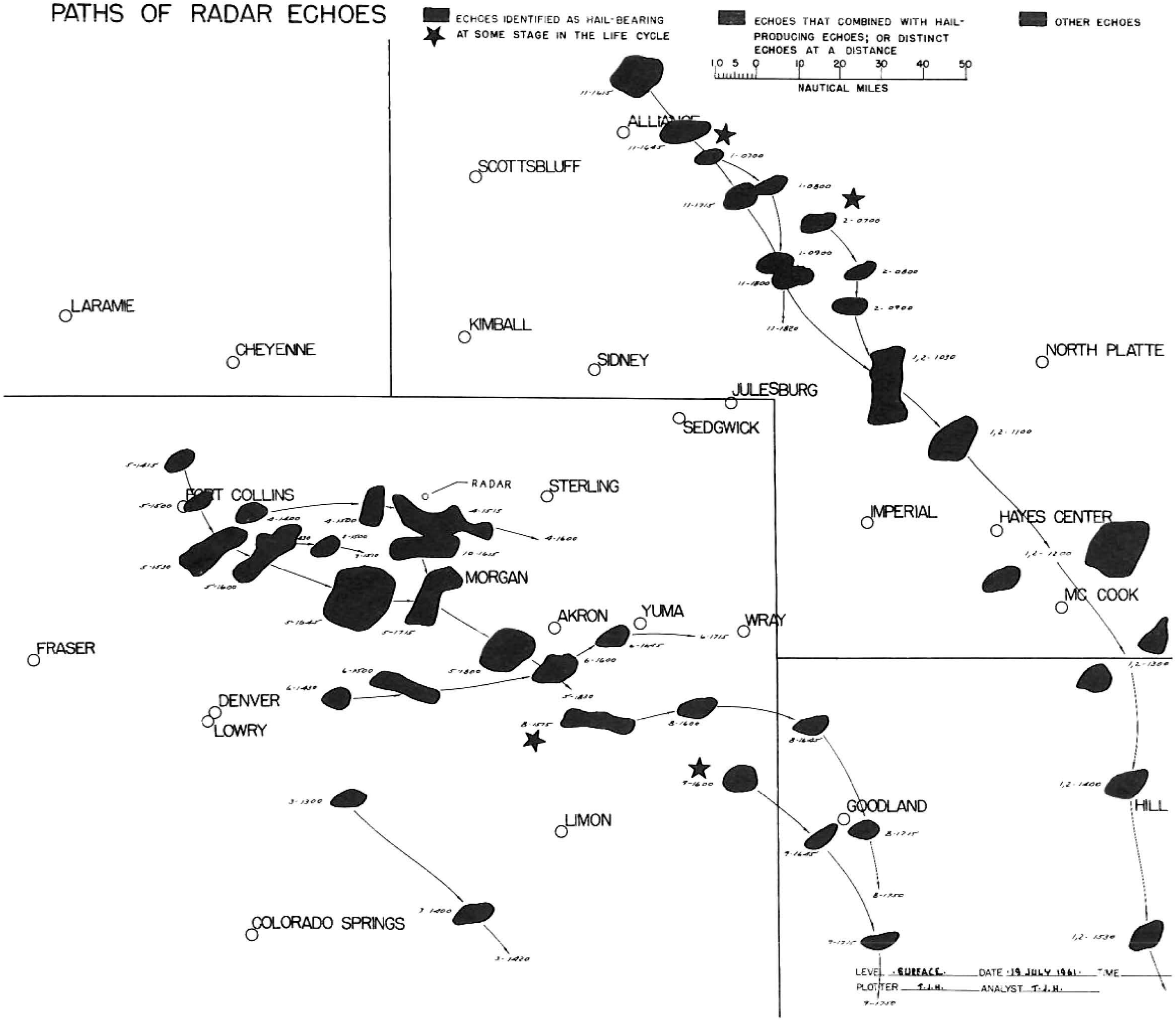
10 5 0 10 20 30 40 50
NAUTICAL MILES
LARAMIE
CHEYENNE
KIMBALL
SIDNEY
NORTH PLATTE
JULESBURG
SEDGWICK
RADAR
STERLING
FORT COLLINS
IMPERIAL
HAYES CENTER
FT. MORGAN
AKRON
YUMA
MC COOK
FRASER
DENVER
LOWRY
LIMON
GOODLAND
COLORADO SPRINGS
LEVEL SURFACE DATE 14 JULY 1961 TIME P.M.
PLOTTER T.J.H. ANALYST T.J.H.

PATHS OF RADAR ECHOES

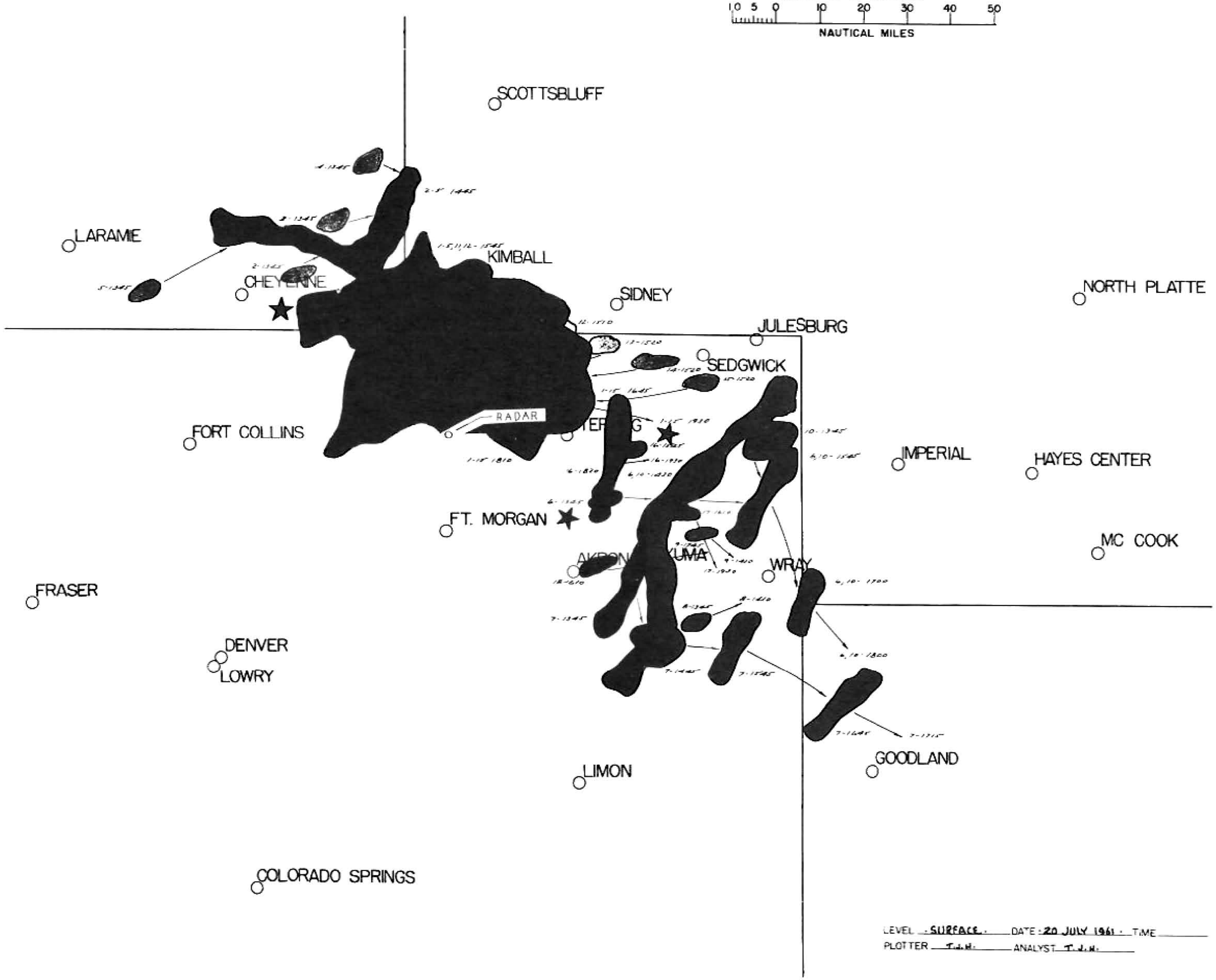


PATHS OF RADAR ECHOES

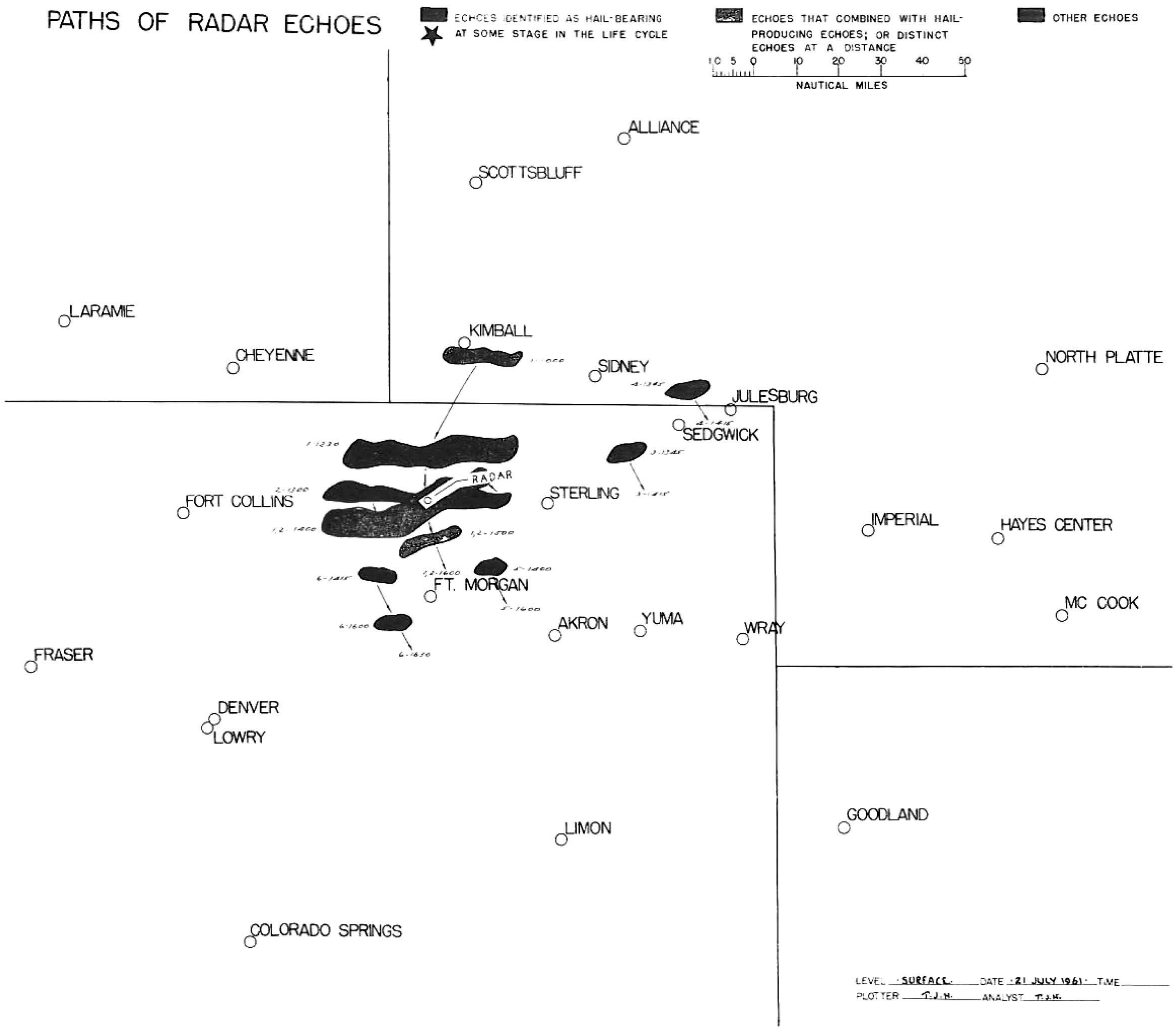
ECHOES IDENTIFIED AS HAIL-BEARING
AT SOME STAGE IN THE LIFE CYCLE

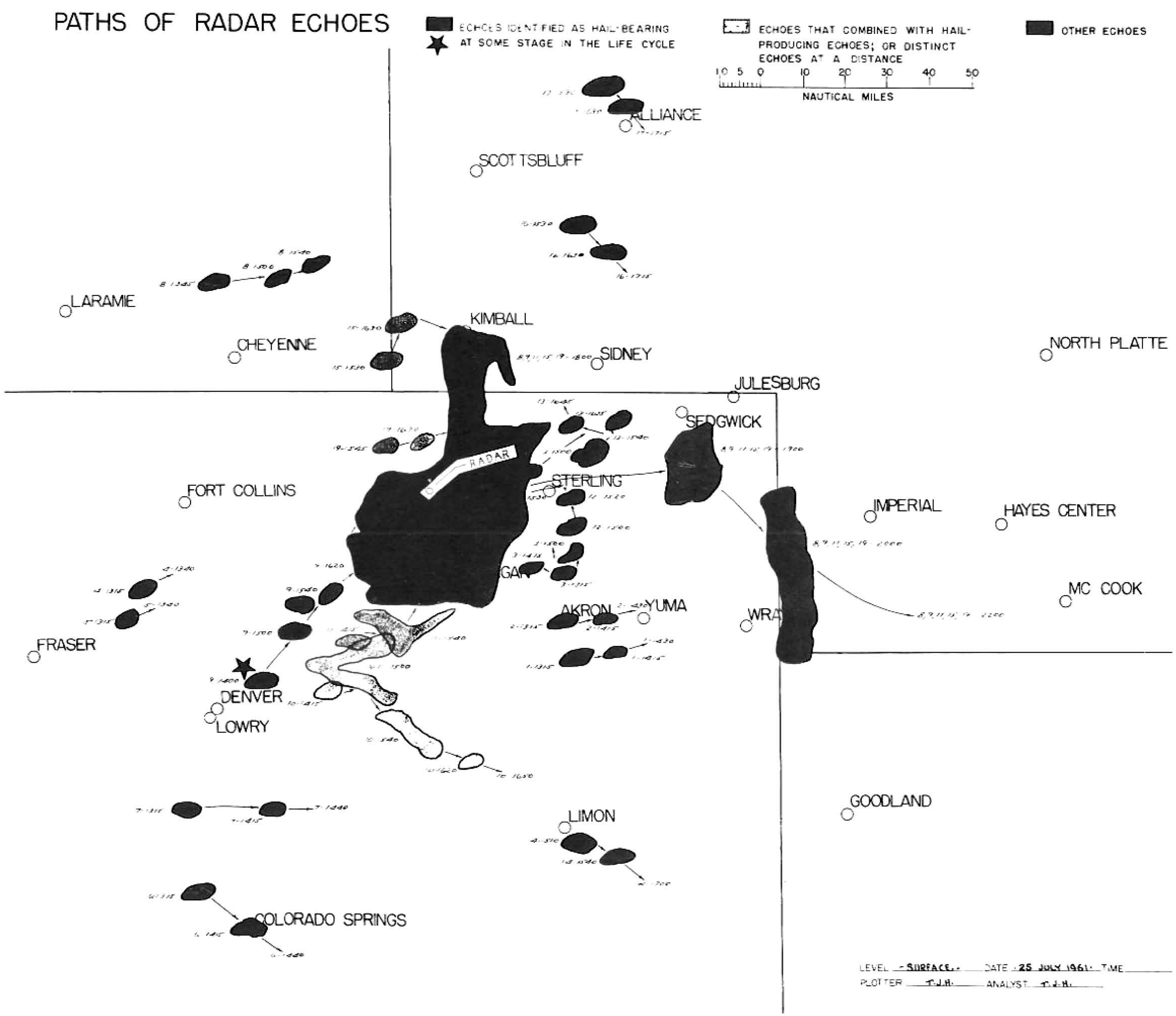
ECHOES THAT COMBINED WITH HAIL-PRODUCING ECHOES; OR DISTINCT ECHOES AT A DISTANCE

OTHER ECHOES



LEVEL SURFACE DATE 20 JULY 1961 TIME
PLOTTER T.J.H. ANALYST T.J.H.


PATHS OF RADAR ECHOES
ECHOES IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THE LIFE CYCLE
ECHOES THAT COMBINED WITH HAIL-PRODUCING ECHOES; OR DISTINCT ECHOES AT A DISTANCE
OTHER ECHOES
10 5 0 10 20 30 40 50
NAUTICAL MILES
ALLIANCE
SCOTTSBLUFF
LARAMIE
CHEYENNE
KIMBALL
SIDNEY
NORTH PLATTE
JULESBURG
SEDGWICK
RADAR
STERLING
FORT COLLINS
IMPERIAL
HAYES CENTER
FT. MORGAN
MC COOK
AKRON
YUMA
WRAY
FRASER
DENVER
LOWRY
GOODLAND
LIMON
COLORADO SPRINGS
LEVEL SURFACE DATE 21 JULY 1961 TIME
PLOTTER T.J.H. ANALYST T.J.H.


PATHS OF RADAR ECHOES
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ECHOES THAT COMBINED WITH HAIL-PRODUCING ECHOES; OR DISTINCT ECHOES AT A DISTANCE
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ALLIANCE
SCOTTSBLUFF
LARAMIE
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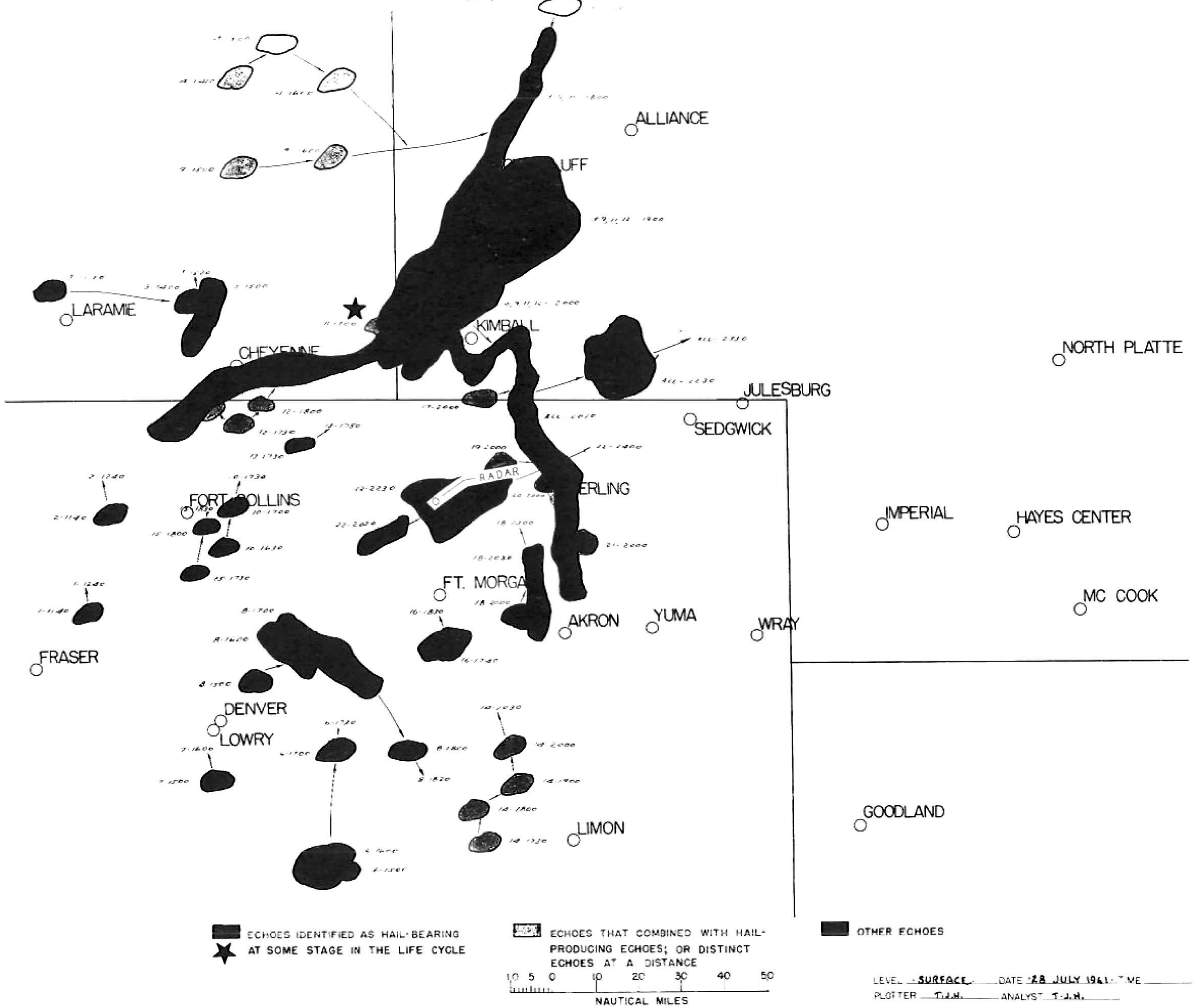
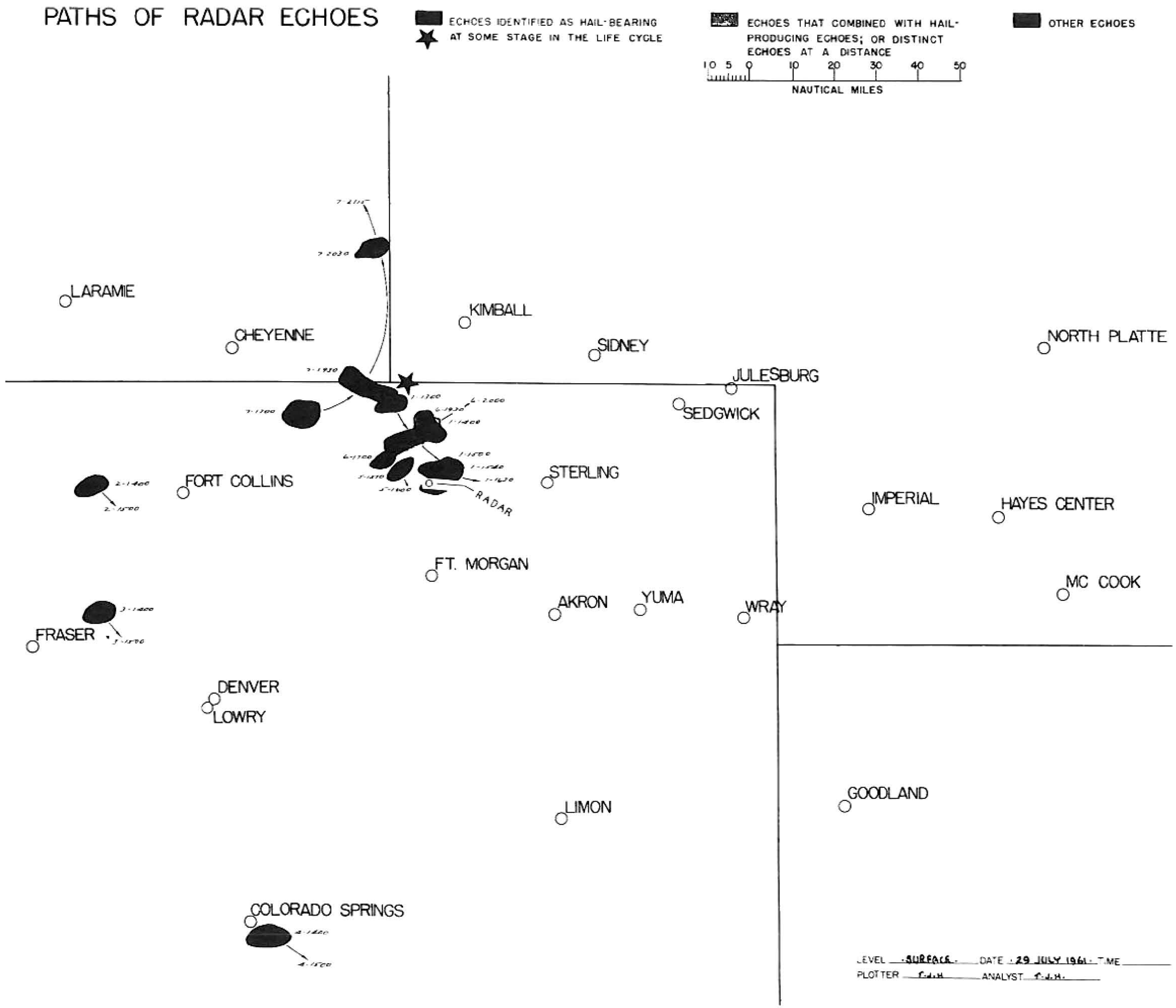
KIMBALL
SIDNEY
NORTH PLATTE
JULESBURG
SEDGWICK
RADAR
STERLING
FORT COLLINS
IMPERIAL
HAYES CENTER
MC COOK
AKRON
YUMA
WRAY
FRASER
DENVER
LOWRY
LIMON
GOODLAND
COLORADO SPRINGS
LEVEL SURFACE DATE 25 JULY 1961 TIME
PLOTTER T.J.H. ANALYST T.J.H.

PATHS OF RADAR ECHOES

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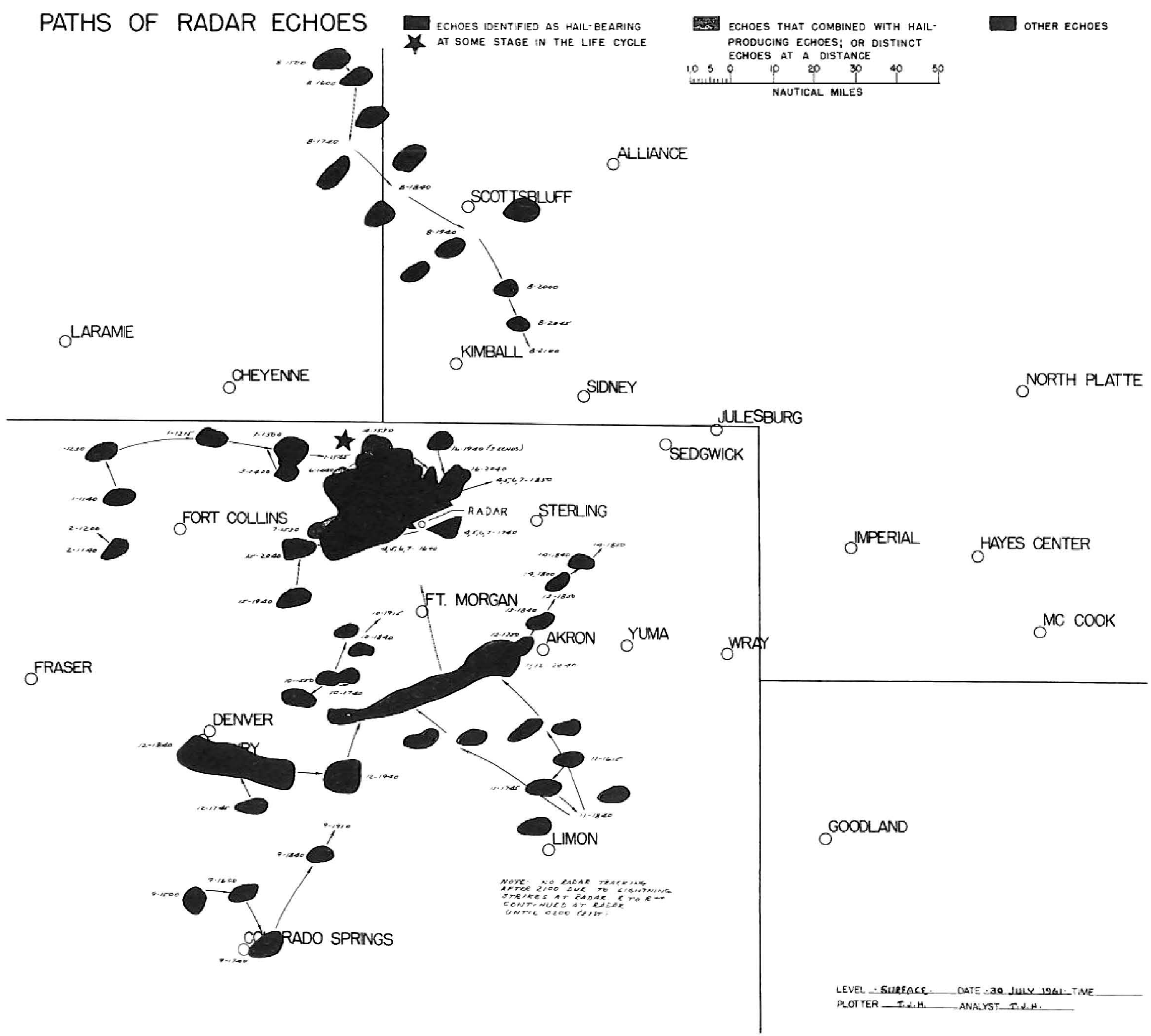
HAYES CENTER
FT. MORGAN
MC COOK
AKRON
YUMA
WRAY
FRASER
DENVER
LOWRY
GOODLAND
LIMON
COLORADO SPRINGS
LEVEL SURFACE DATE 29 JULY 1961 TIME
PLOTTER
ANALYST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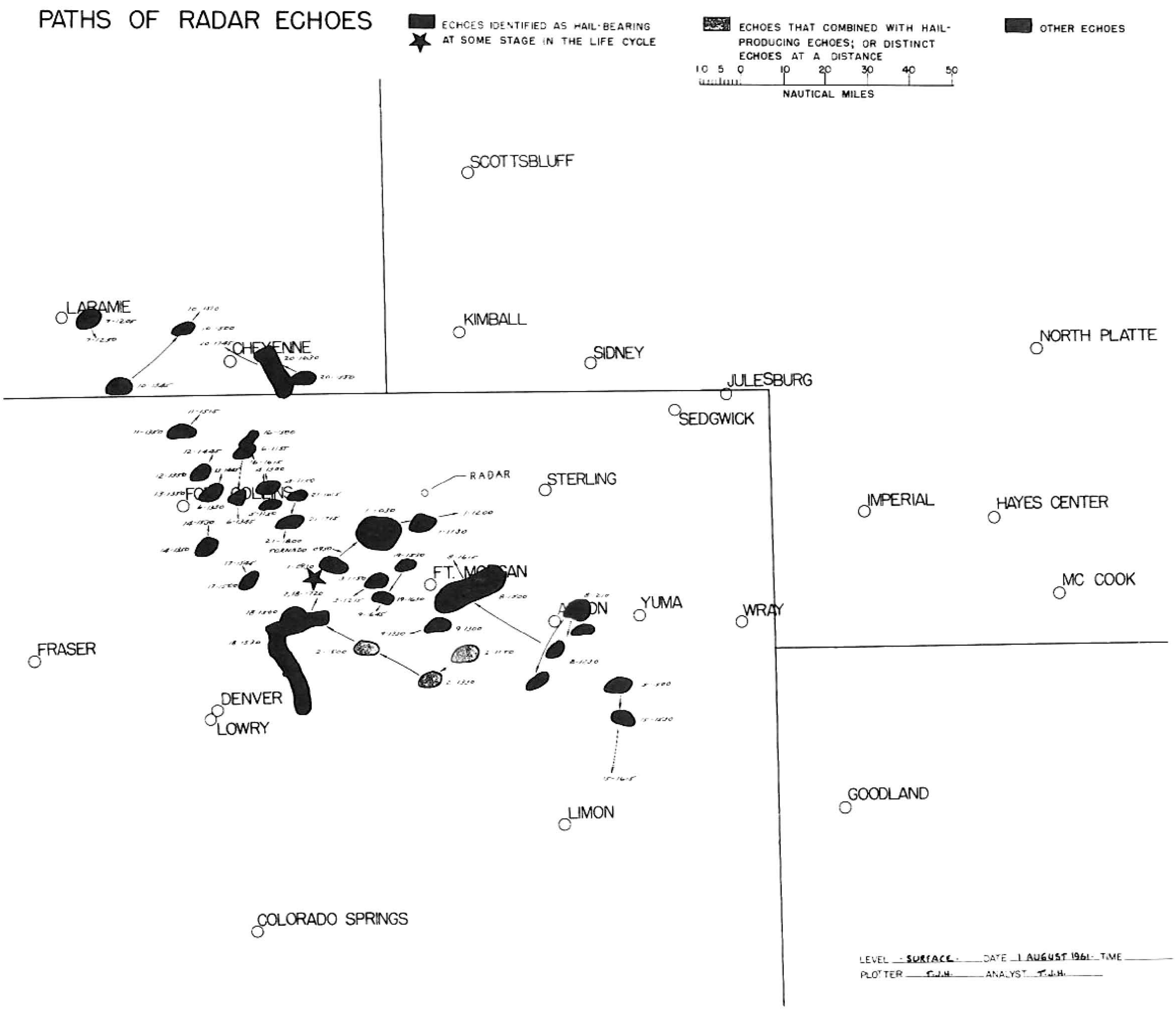
LEVEL SURFACE DATE 30 JULY 1961 TIME
PLOTTER T.J.H. ANALYST T.J.H.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FT. MORGAN
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YUMA
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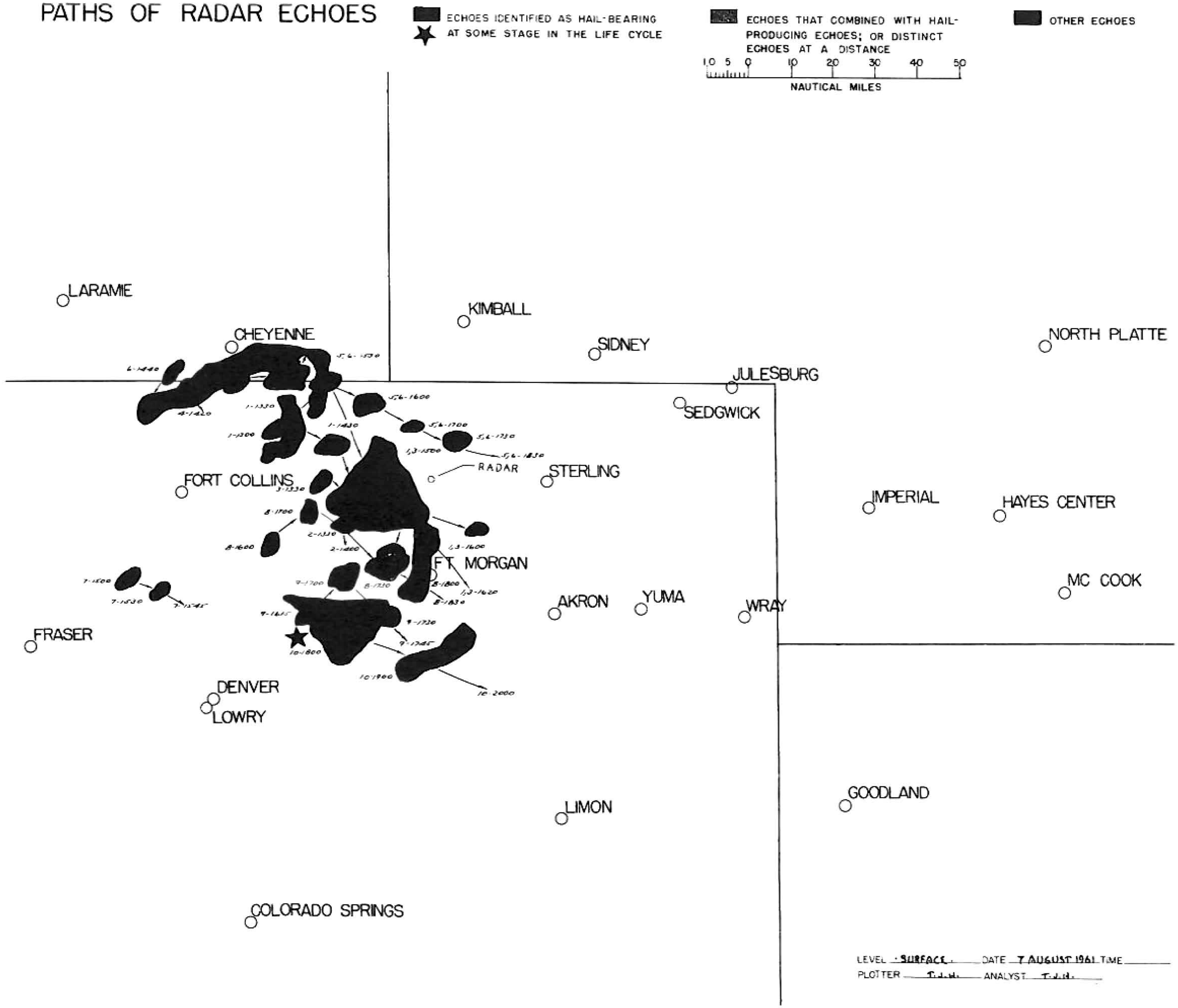
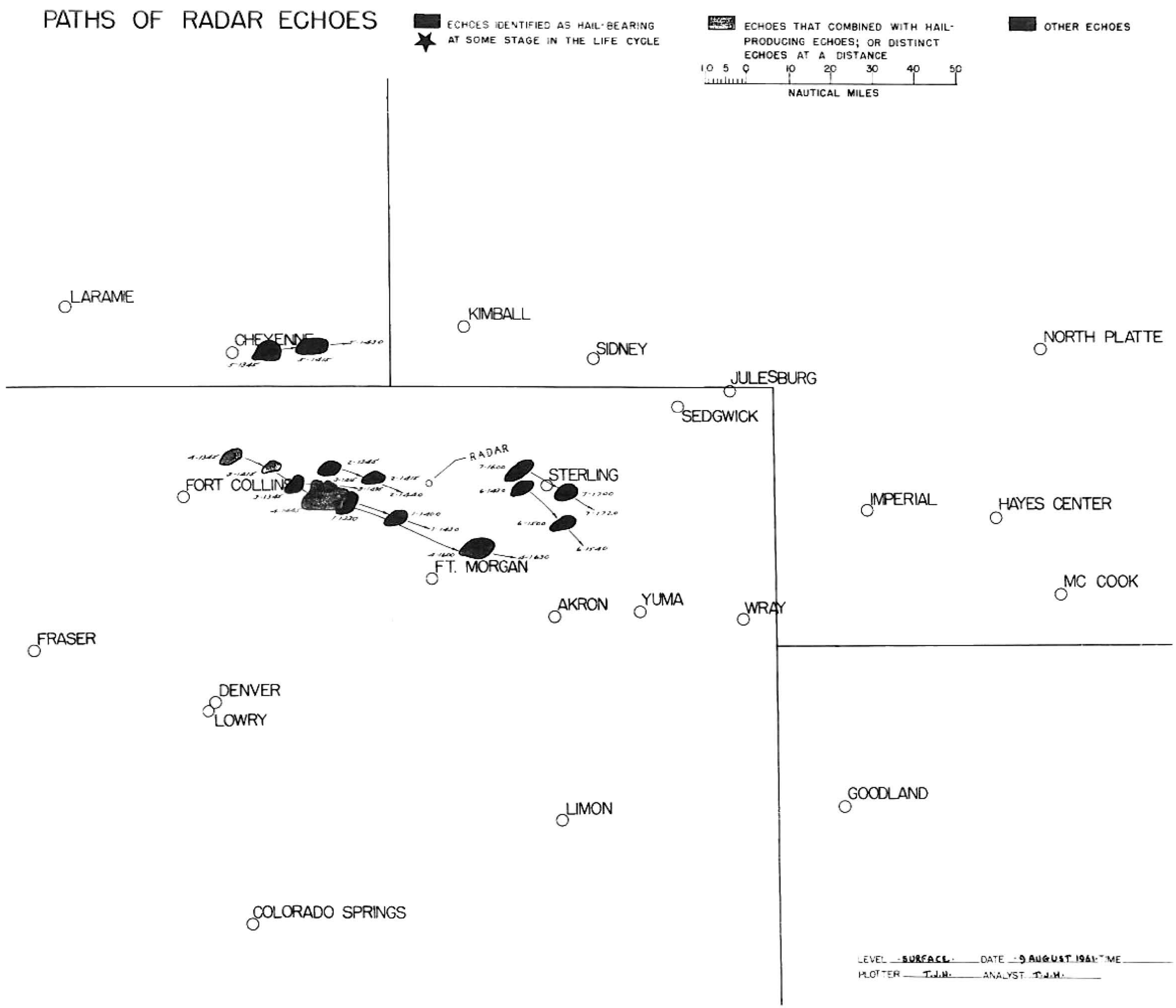
LIMON
COLORADO SPRINGS
LEVEL SURFACE DATE 1 AUGUST 1961 TIME
PLOTTER T.J.H. ANALYST T.J.H.

PATHS OF RADAR ECHOES



LEVEL SURFACE DATE 7 AUGUST 1961 TIME

PLOTTER T.J.H. ANALYST T.J.H.


PATHS OF RADAR ECHOES
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WRAY
FRASER
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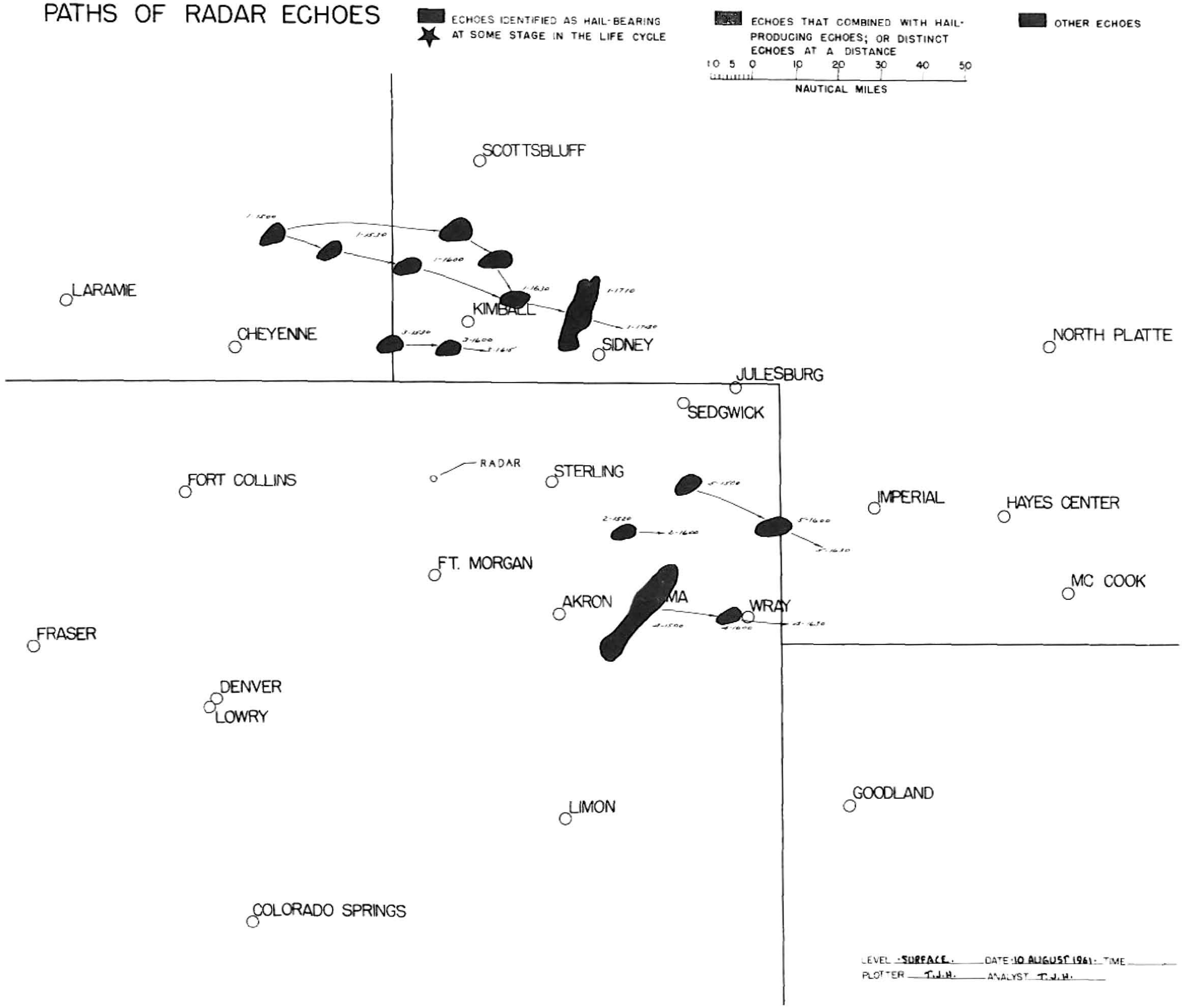
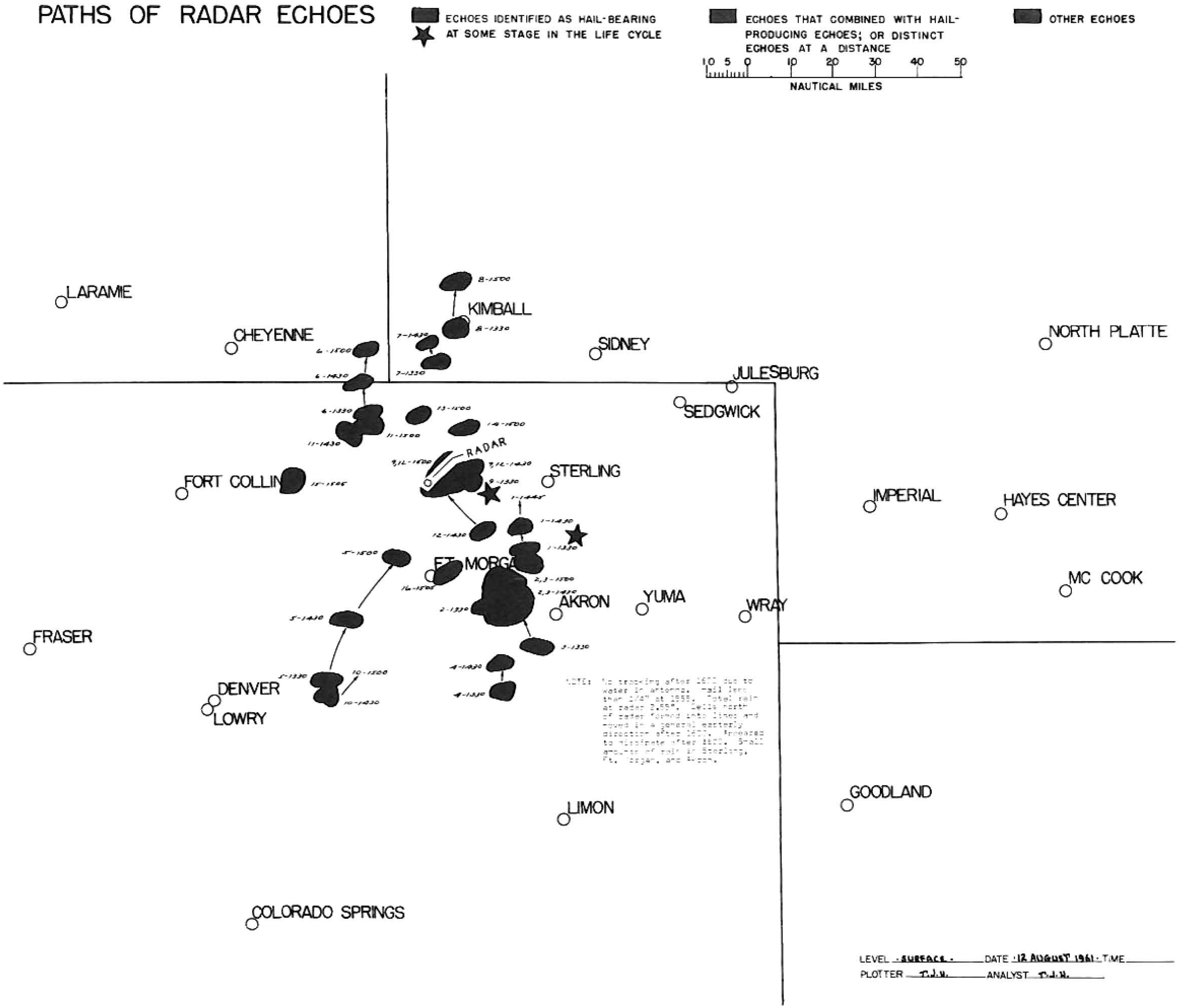
LIMON
COLORADO SPRINGS
LEVEL SURFACE DATE 9 AUGUST 1961 TIME
PLOTTER T.J.H. ANALYST T.J.H.

PATHS OF RADAR ECHOES



PATHS OF RADAR ECHOES



PATHS OF RADAR ECHOES