RADAR CLIMATOLOGY OF HAIL STORMS IN AND NEAR NORTHEASTERN COLORADO 15 MAY - 31 JULY 1962 WITH COMPARATIVE DATA FOR 1961

by

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Prepared for the Crop-Hail Insurance Actuarial Association

Report of Research Supported by
National Science Foundation
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Civil Engineering Section
Colorado State University
Fort Collins, Colorado

November 1962

CER62RAS79

APPENDIX

Daily maps of the position and track of individual precipitation echoes during the period 15 May - 31 July 1962.

"Starred" positions indicate locations of hail on the ground as determined from various sources (cooperative observers, hail indicators, newspaper clippings, on-the-site inspection, crop-hail reports, etc.)

Precipitation echoes identified as hail-bearing at some time during their life time are shown in black. Echoes not identified as hail-bearing at some time during their life time are uncolored.

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ABSTRACT

Data are presented on the origin and track of hail producing precipitation cells during the period 15 May - 1 August 1961.

The data from 1962 tend to confirm the preliminary results from 1961 which indicated a general change in storm movement from the west or southwest in May and June to a direction of movement from the northwest in July.

A scattering of hail risks perpendicular to these directions would appear to be advantageous.

These data provide a substantial beginning in determining the climatology of hailstorms in the High Plains region. With confirming data from years of less intense hail activity, application can be made to problems of insurance premium rating.

The data in this report are being used in development of plans for attempts at beneficial modification of hailstorms.

CONTENTS

TABLES

FIGURES

RADAR CLIMATOLOGY OF HAILSTORMS IN AND NEAR NORTHEASTERN COLORADO 15 MAY - 31 JULY 1962 WITH COMPARATIVE DATA FOR 1961

INTRODUCTION

The High Plains Region of eastern Colorado and Wyoming, and western Nebraska, suffers from frequent damaging hailstorms. Since there is little information available on the climatology of these hailstorms, a study of the radar climatology of hailstorms was undertaken by Colorado State University in 1961 and was continued in 1962.

These studies of the climatology of hailstorms are an integral part of the hail studies of Colorado State University, which are directed toward ultimate beneficial modification of hailstorms. Most of the support for these studies has been provided by the National Science Foundation. The Crop-Hail Association has provided some financial support for those phases of the study of most interest to the Association, namely

(1) Determination of areas of hailstorm genesis;
and (2) Determination of the subsequent track of hailstorms following their formation.

RADAR SYSTEMS, DATA, AND METHODS

Three radar systems were available on the project during the 1962 season. These were the CPS-9 system at Lowry Air Force Base near Denver, the vertical scanning system modified by Colorado State University and located near New Raymer, Colorado, and the weather radar system of Atmospherics Incorporated also located near New Raymer.

The data used to compile the information in this report were obtained primarily from the weather radar system furnished and operated by Atmospherics Incorporated. This was 3cm equipment operating on a frequency of 9375 megacycles with a peak power output of about 60 kw. A maximum range of 200 nautical miles was available with a choice of ranges of 4-10-20-80-200 nautical miles.

The system was located about one mile southeast of New Raymer at an elevation of about 4800 feet above sea level. The site provided an excellent radar view of the project study area. Precipitation echoes were tracked and hail paths identified from as far west as the Rocky Mountains to as far east as the maximum 200 nautical mile range.

This radar system included two indicators with 7" PPI presentation. The first indicator was used for general storm tracking plus black and white photographs of the more interesting precipitation periods. Time-lapse photos were made of precipitation cells on the second indicator by taking one time exposure of the indicator each revolution of the antenna (approximately one exposure each 12 seconds).

The radar system employs a tilt indicator which gives the vertical angle of the antenna. The antenna was kept on an angle of about $+1^{o}$ for most of the general scanning but was occasionally elevated through a maximum of $+35^{o}$ during measurements of the elevations of precipitation echo tops and studies of growth rates.

Supplemental equipment included an illuminated clock and digital display which was positioned around the PPI scope of the second indicator. This display allowed film documentation of various data including time, date, antenna angle, and other information considered pertinent. Other facilities provided by Atmospheric Incorporated at this radar location included a tape recorder unit for voice recording and subsequent read-out of the information, field map plotting facilities, a K-100 16 mm movie camera, 2-1/4 x 2-1/4 still camera equipment for echo recording, and plastic overlays for assistance in plotting storms as they appeared on the radar indicators.

Operation of the equipment was on a 24-hour alert basis. The system proved reliable. Only one failure occurred during the summer. This single failure was caused by nearby lightning strikes. Off-the-air time amounted to only about four hours out of the 500 hours (approximately) of on-the-air time that were logged during the summer program. Photographs of the installation are shown in Figures 1 and 2.

FIGURE 1. View looking easterly from radar site at New Raymer, Colorado. Giant ice crystal cap of thunderstorm is nearly 50,000 feet high. Trailer houses 3cm radar equipment with 200 mile range and is used for tracking precipitation echoes and identifying hail areas.

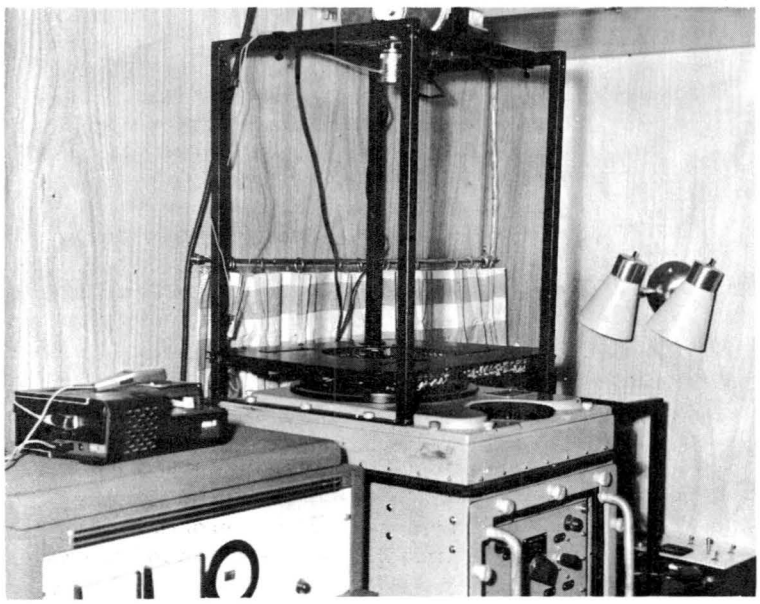


FIGURE 2. View of radar equipment inside trailer. Unit on left houses transmitter, modulator, receiver, and power supplies. Unit in center is PPI indicator with digital display unit for documenting certain data within the field of the time lapse camera. Unit on right is second PPI indicator used for routine viewing and still photographs.

Figure 3 shows a sample of the data sheets used in recording data. Sufficient information was recorded to reconstruct the location and areal extent of precipitation echoes at the end of each day's operation. The sizes, locations, and paths of precipitation echoes shown in the appendix were constructed from data of the type shown in Figure 3, plus information taken from plastic overlays. Of particular interest are the radar scope photographs appearing in Figure 4 which shows a typical sequence taken during the severe hailstorm of 13 July 1962. Similar sequences of still photographs are available for most of the operational days during the 1962 program.

Figure 5 shows damage from this storm in the vicinity of Snyder, Colorado.

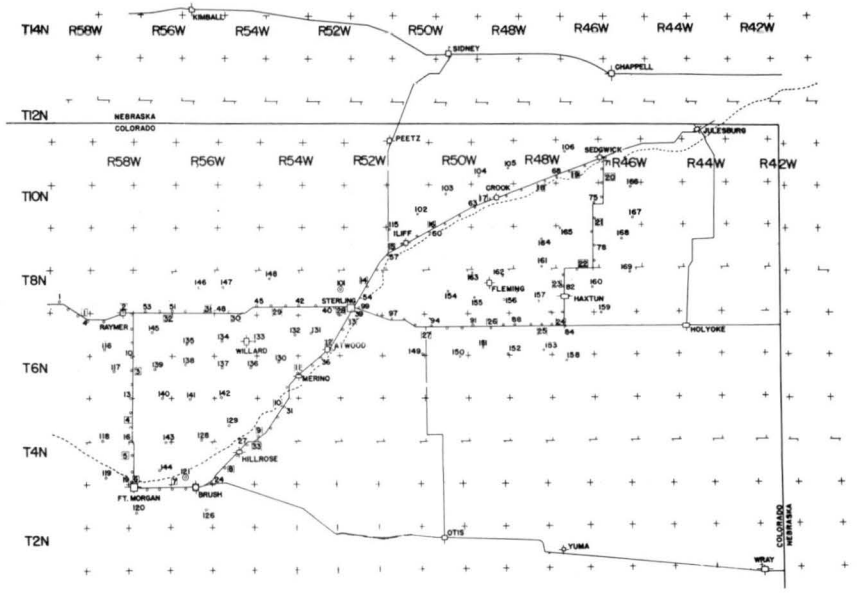
A summary of available data is given in Table 1.

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	1145	292°	50			Strong
1	1220	300°	45			DISPT NE 1300
2	1205	278°	96			DISPT NE 1230
3	1215	264°	85			DISPT NE 1330
4	1235	336°	32			
4	1325	Line				330°/38 - 352°/37
5	1246	333°	53			
5	1325	286°	55			DISPT N at 1400
6	1310	296°	33			
6	1325	Line				301°/32 - 334°/38
7	1300	147°	50			
7	1325	201°	45			
8	1330	358°	73			
8	1400	346°	60			
9	1356	344°	46			
9	1445	352°	45			8 mi diam
10	1350	318°	33			DISPT NE 1425
4	1400	Line				345°/35 - 354°/30 - 30/40
6	1400	336°	35			DISPT 1410

DATE: _____



3

THUNDERSTORM AND HAIL RESEARCH - WEATHER RADAR FIELD STATION

PHOTOGRAPHIC DATA

RADAR PHOTOS TIME	-SUBJECT-	MISC. PHOTOS TIME	-SUBJECT-
1130	T-L b & w - TRIX 80 mi range	1235	(10) b & w outside - Cu N
1648	STOP Rt & LTG	1343	(11) same as 10 - Cu closer
1740	START - RAIN & HAIL E.	1352	(12) same as 11
1850	STOP - LINES BROKEN E	1325	(1-3) 3 section plot - Cu N
1503	(9) line N now split 2 areas W 1 area S - strong	1340	(4) scope - 80 mi. - 1 sweep 2 lines NNW area 40 SSW
1535	(10) line W area SE line NNE	1410	(5-6) outside giant Cu - echo #4
1605	(11) outside - ice crystal cap	1415	(7) scope - strong 35 N 30 SSW 50-60 W
1605	(12) scope - line W area E area NNE	1412	(8) large area S area 30-40 N 3 areas W

DATE 13 JULY 1962

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 NAUTICAL MILES	GAIN SETTING	ANTENNA ANGLE (DEGREES)	RANGE (NAUT. MI.)	ELEVATION ABOVE RADAR (FT.)
1	1145	-2° (293°)	49	(30)	+8° (294°)	50	44,000
1	1215	-2° (301°)	51	(66)	+8° (300°)	40	35,000
4	1235	-2° (336°)	30	(42)	+9 (325°)	27	26,500
4	1246	-2° (333°)	27	(32)	+15 (331°)	27	43,000
4	1310	-2° (325°)	30	(28)	+17 (330°)	30	54,000
4	1330	-2° (342°)	29	(32)	+16 (343°)	30	50,500
4	1400	-2° (358°)	32	(30)	+14 (354°)	32	48,000
4	1510	-2° (17°)	35	(37)	+12 (18°)	39	51,000
14	1510	-2° (287°)	33	(30)	+15° (282°)	33	53,000

REMARKS: _____

DATE: _____

RESULTS

Summary of radar climatology

Table 2 gives a summary of the radar climatology of hailstorms within range of the radar at New Raymer, Colorado for 1961 and 1962. A comparison of the data from Table 2 shows that 1962 was a year of more hail than 1961, both in terms of a greater number of total echoes, and a greater number of echoes which were known to have produced hail at the ground.

Origin and movement of hail-producing echoes

Table 3 shows the origin and movement of echoes identified as producing hail on the ground. From Table 3 it may be noted that in 1962 more storms moved from south-to-north and fewer moved from north-to-south than in 1961. (Compare data for echoes originating in Nebraska and Wyoming and moving to Colorado and Kansas with data for echoes originating in Colorado and Kansas and moving to Nebraska and Wyoming.)

First echoes and subsequent tracks of cells identified as hail-bearing

Figures 6 through 15 show the first echoes and subsequent tracks of precipitation cells which were identified as hail bearing at some stage in their life cycle by half-month periods from 15 May to 31 July for 1961 and 1962.

15 - 31 May

In comparing the data for 1961 and 1962 from Figures 6 and 7, it may be seen that more cells were identified as hail bearing in 1962 than in 1961. The precipitation cells in 1961 has a more erratic track than in 1962. In 1962, most of the cells moved southwest-to-northeast. In addition, it may be noted that the precipitation cells which were identified as hail bearing listed on both Figure 6 and 7, were identifiable over distances usually in access of 100 miles.

1 - 15 June

Figures 8 and 9 show the first echoes and subsequent tracks of precipitation cells identified as hail bearing for the period 1 - 15 June for 1961 and 1962. In comparing the tracks for this period with the tracks for the preceding 15 day period (figures 6 and 7), we note that during both 1961 and 1962, the tracks of the cells frequently tended to curve in a clock-wise direction. From Figure 9, we note that there are two separate areas that were the genesis areas for most of the cells for the first half of June 1962: in the vicinity of Cheyenne, and between Denver and Fort Morgan. For both 1961 and 1962, the period 1 - 15 June was a period of transition in direction of movement of cells; the direction changing from southwest-to-northeast to northwest-to-southeast.

16 - 30 June

In comparing Figures 10 and 11, which show the tracks of precipitation cells for the period 16 - 30 June, we note a difference in direction of movement between 1961 and 1962. In 1961 the predominant direction of motion was northwest-to-southeast, while in 1962 a majority of the cells moved southwest-to-northeast. We also note a larger number of cells during this period in 1962 than in 1961. A larger fraction of the cells in 1962 showed relatively short tracks of less than 100 miles than in 1961.

1 - 15 July

The primary difference between 1961 and 1962 for the first half of July as shown in Figures 12 and 13 is the difference in direction of movement of the echoes. In 1961 most of the echoes moved northwest-to-southeast. In 1962 the predominant direction of movement was southwest-to-northeast; the same direction as the predominant direction of movement during the preceding month. The first half of July and the first half of June in 1962 were the only periods during which there were fewer echoes which produced hail in 1962 than in 1961. From Figure 13 it may be seen that there were a larger fraction of the echoes with a comparatively short path in 1962 than in 1961.

16 - 31 July

In comparing Figure 14 with Figure 15, we note a greater number of echoes in 1962 than in 1961. During both years the direction of movement was predominantly from west-to-east or northwest-to-southeast. The echoes in 1961 were more widely dispersed than in 1962. During both years, there was a tendancy for long identifiable tracks of individual cells. There was a concentration of echo genesis areas in 1962, in the region northeast of Fort Collins, near the junction of the states of Colorado, Nebraska and Wyoming.

Figures 16 and 17 show the centroid of the echo genesis areas and a quantitative measure of their dispersion for 1961 and 1962. The centroids were determined by assuming that each echo genesis point had a unit mass of one. The measure of dispersion is the smallest circle which can be drawn around the centroid which will include 2/3 of the genesis points. Figures 16 and 17 indicate no definite seasonal changes in either the centroid location or dispersion characteristics. During 1961 the centroids were randomly distributed around the New Raymer radar while in 1962 all of the centroids were west and south of the New Raymer radar site.

Figures 18 and 19 show the initial locations of radar echoes which later produced hail in 1961

TABLE 1. SUMMARY OF PPI RADAR OPERATIONS (15 May - 31 July 1962)

DATE	TIME-MST ON	TIME-MST OFF	NUMBER OF ECHOES CATALOGED	RADAR SCOPE PHOTOGRAPHY: STILLS NUMBER	STILLS TIME-MST FIRST	STILLS TIME-MST LAST	TIME LAPSE TIME-MST BEGIN	TIME LAPSE TIME-MST END	FRAMES
5/15	1255	1730	9		NONE			NONE	
5/20	1645	1800	7		NONE			NONE	
5/21	1215	1640	5	8	1230	1610	1245	1635	2400
5/24	1545	1900	5		NONE			NONE	
5/25	1115	0050	29	14	1935	0050	1115	0050	5940
5/26	1500	2125	11	12	1600	2125	1536	2125	2890
5/27	0825	1620	10	7	1225	1620	0800	1640	4430
5/28	1230	2000	25	13	1405	2000	1345	2020	3210
5/29	1015	1755	20	8	1510	1545	1025	1523	2130
5/31	0900	1520	19	12	1055	1515	0910	1520	3880
6/2	1130	1650	9	6	1300	1650	1155	1650	3600
6/4	1430	1940	13	2	1510	1755	1502	1920	3075
6/5	1515	0320	37	26	1620	0335	1545	0320	5830
6/6	1115	2215	15	14	1235	1715	1233	1724	3670
6/7	1200	1645	13	14	1245	1810	1236	1645	3540
6/11	1300	2315	39	22	1325	2310	1312	1906	3210
6/12	1200	2355	28	17	1410	2315	1428	2350	4580
6/13	1500	2130	13	18	1505	2030	1500	2130	1100
6/14	1325	1645	4		NONE		1335	1558	1835
6/15	1310	1820	15	5	1545	1800	1445	1815	2520
6/16	1215	2100	21	6	1450	1715	1600	1642	500
6/19	0100	0210	3		NONE			NONE	
6/20	1430	2050	22		NONE			NONE	
6/21	1415	2315	14		NONE		1501	1816	2340
6/22	1145	1600	5		NONE			NONE	
6/23	1200	1900	37	12	1516	1805	1241	1900	4475
6/24	1310	1830	21	10	1540	1815	1617	1815	1415
6/25	1300	1930	3		NONE			NONE	
6/28	1715	1815	6		NONE			NONE	
6/29	1330	1930	26	11	1530	1725	1400	1930	3310
6/30	1300	1940	36	10	1425	1915	1320	1940	4050
7/5	1330	1620	5	3	1420	1515	1415	1610	1380
7/7	1455	1950	14		NONE		1508	1950	3455
7/8	1145	1625	8		NONE		1433	1540	805
7/9	1450	1635	7		NONE			NONE	
7/11	1440	2050	20		NONE		1605	1930	2460
7/12	1330	2000	30	15	1525	1945	1430	1945	3780
7/13	1145	1905	19	19	1235	1850	1150	1850	4415
7/15	1915	2045	3		NONE			NONE	
7/16	1330	1945	17	7	1325	1535	1341	1600	1550
7/17	1700	2030	15	11	1735	2010	1703	2010	2245
7/18	1315	1730	7	5	1410	1715	1405	1725	995
7/19	1245	1715	3		NONE		1315	1715	1440
7/24	1500	1630	4		NONE		1518	1618	720
7/25	1350	1830	19		NONE			NONE	
7/26	1445	1700	5		NONE			NONE	
7/27	1145	1700	12	2	1530	1535	1230	1702	3180
7/28	1500	1940	10		NONE			NONE	
7/30	1330	1700	12		NONE		1400	1710	2125
7/31	1119	2000	22	20	1355	1915	1320	1800	3200
TOTALS			752	329					105,680 (2642 ft)

TABLE 1. (cont'd) SUMMARY OF PPI RADAR OPERATIONS (15 May - 31 July 1961)

DATE	TIME-MST ON	TIME-MST OFF	NUMBER OF ECHOES CATALOGED	RADAR SCOPE PHOTOGRAPHY: STILLS 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	13	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
TOTALS			504	99					910

TABLE 2. THUNDERSTORM DAYS AND DAYS WITH HAIL WITHIN RANGE OF THE PPI RADAR AT NEW RAYMER, COLORADO

1962

PERIOD	STORM DAYS WITH HAIL	STORM DAYS WITHOUT HAIL	TOTAL	TOTAL ECHOES CATALOGED	NUMBER OF ECHOES WHICH WHICH WERE KNOWN TO HAVE PRODUCED HAIL ON THE GROUND
15 - 31 May	11	6	17	140	34
1 - 15 June	9	6	15	186	37
16 - 30 June	10	4	14	194	55
1 - 15 July	11	4	15	106	28
16 - 31 July	11	3	14	126	29
TOTAL	52	23	75	752	183

1961

15 - 31 May	10	2	12	98	26
1 - 15 June	13	0	13	124	42
16 - 30 June	7	2	9	79	21
1 - 15 July	8	4	12	104	43
16 - 31 July	9	2	11	99	17
TOTAL	47	10	57	504	149

TABLE 3. ORIGIN AND MOVEMENT OF ECHOES IDENTIFIED AS PRODUCING HAIL ON THE GROUND

ECHOES ORIGINATED IN	COLORADO		KANSAS		NEBRASKA		WYOMING	
	1961	1962	1961	1962	1961	1962	1961	1962
COLORADO	56	67	12	5	21	52	3	8
KANSAS	0	0	7	1	0	3	0	0
NEBRASKA	12	1	6	1	11	19	0	0
WYOMING	13	7	0	0	7	14	1	5

	1961	1962
TOTAL ECHOES IDENTIFIED AS PRODUCING HAIL ON THE GROUND	149	183

and 1962. Two facts may be noted from comparison of these figures: (1) In 1962 there were more echoes which produced hail; and (2) A larger fraction of the echoes developed closer to the Rocky Mountains in 1962 than in 1961.

Frequency of first echoes within grids of 200,000 feet on a side

Figure 20 shows the frequency of occurrence (within grid squares of 200,000 feet on a side) of first echoes that later produced hail. From this figure a general tendency can be noted for a greater number of first echoes west of the radar site than east of the radar site. In addition, the grids containing higher numbers of first echoes frequently coincide with areas of marked change in elevation (see figure 21).

CONCLUSIONS AND SUMMARY

This report gives information on the radar climatology of hailstorms in the High Plains in and near northeastern Colorado. The location and tracks of precipitation cells which produced hail are given by half-month periods from 15 May - 1 August for both 1961 and 1962. The data from 1962 tend to confirm the preliminary results of 1961 which indicated a general change in direction of storm movement from the west or southwest in May and June to a direction of movement from the northwest in July (figures 6 - 15).

A scattering of insurance risks perpendicular to these directions would appear to be advantageous to insurance companies insuring against hail damage.

The centroids of echo genesis in 1962 were displaced toward the west from the 1961 locations (figures 16 and 17).

The frequency of occurrence of initial locations of radar echoes which later produced hail is higher in the areas of rapid change of elevation of terrain than in flat terrain (figures 18 - 20).

Daily plots of the dimensions and movement of individual precipitation cells are given in the appendix.

These data provide a substantial beginning of developing factual knowledge concerning the climatology of hailstorms and information on their physical characteristics. Since hail damage was unusually heavy during both 1961 and 1962,* it is not possible to determine whether the common features of 1961 and 1962 would also apply to years of less intense hail activity.

With the addition of data from another season or two, a firm base of knowledge of the climatology of hailstorms and their physical characteristics would be available as a basis for application to problems of premium rating.

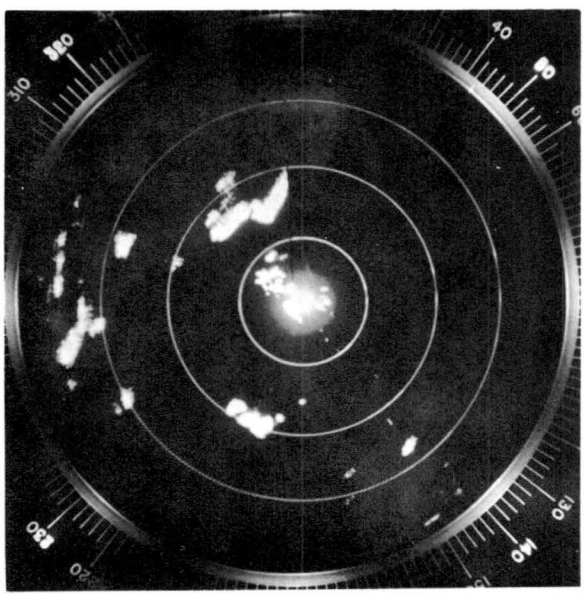
The data in this report are being used in making plans for attempts at beneficial modification of hailstorms.

* Mr. Lymon Andrews, Southern District Manager of Great Western Sugar Company in Denver advises that hail damage to beets in 1961 was much above normal, and that 1962 was much more than 1961.

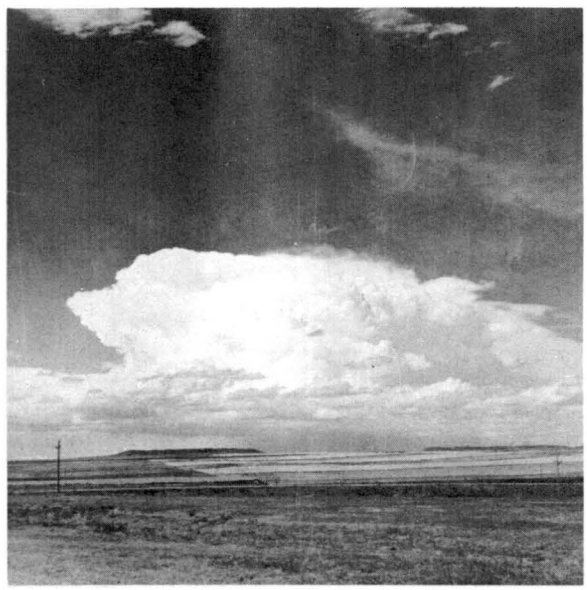
FIG. 4. Photographs of 3cm radar indicator. Range: 80 n.m. (20 n.m. range marks - antenna elevation +1°) Thunderstorm of 13 July 1962 was one of season's worst. Hail damage was extensive over very wide areas with the sections around Snyder, Colorado receiving the most intensive pounding.

A. 1252: View looking NNW from radar location at New Raymer toward large developing cumulus about 40 miles away. Notice great masses of water droplet type cloud and smaller unstable types nearer radar, and closer to the ground.

B. 1325: View looking north from radar site. Development in previous photo has now moved to this more northerly position and still contains great masses of water in liquid state. Echo tops were near 50,000 feet msl at this time.

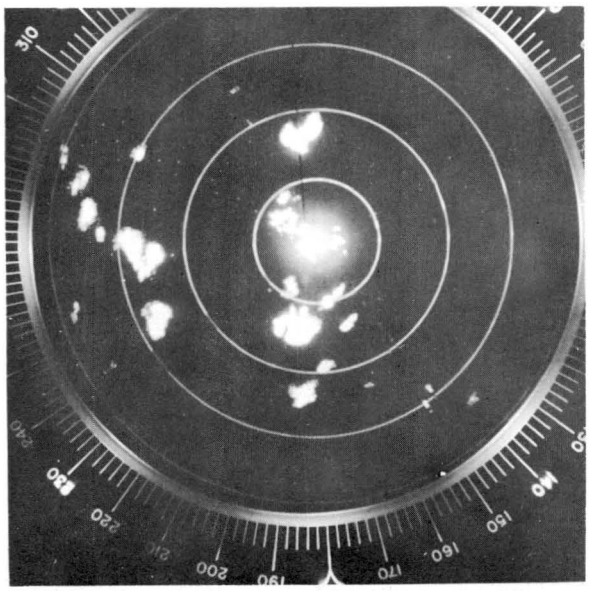


C. 1340: Strong echoes 30-40 miles north to northwest are from cumulus development in previous photos. General movement is toward southeast. Directions change in subsequent photos.

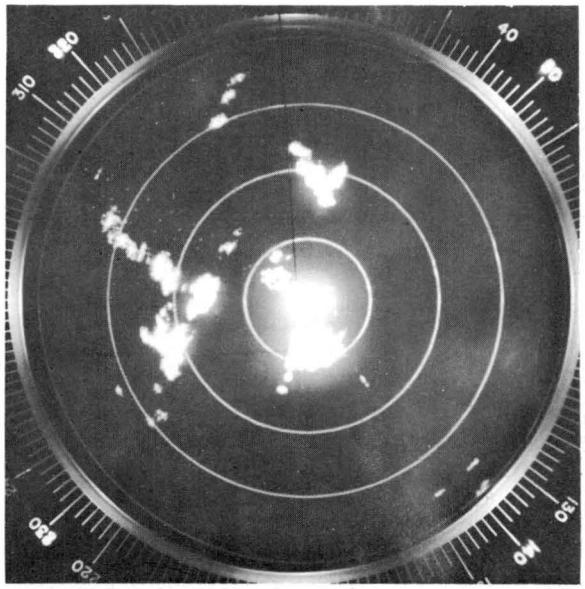


D. 1410: Again looking northerly from radar site. This cumulus development is still producing tops to about 50,000 feet msl. True north is about center of photo.

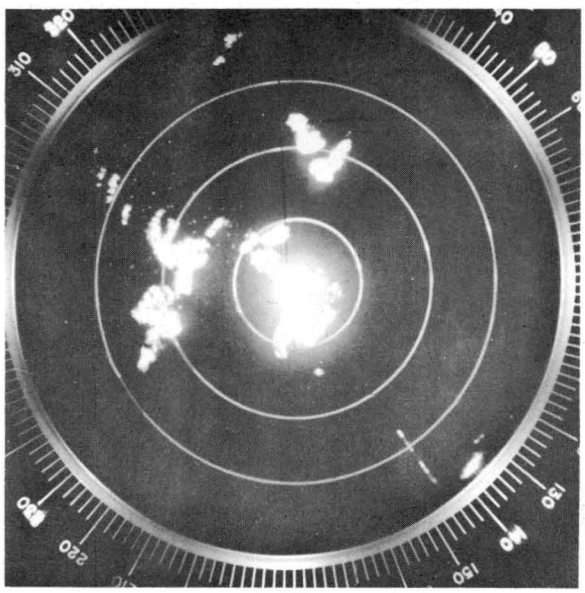
FIG. 4. (cont'd) Photos of radar scope - 13 July 1962



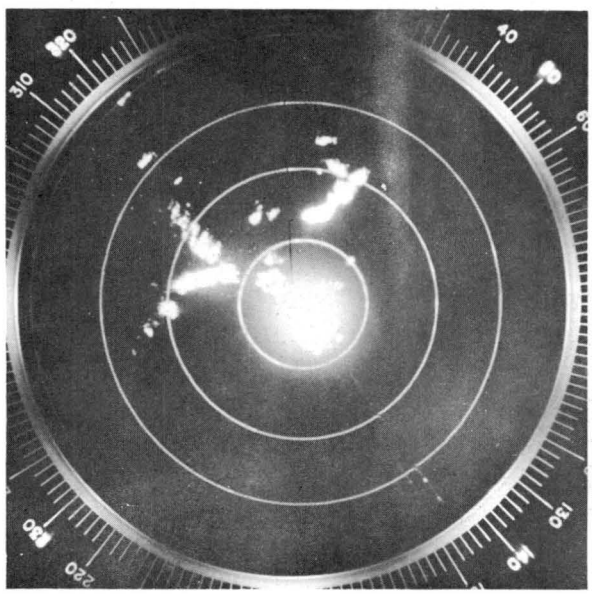
E. 1415: More strong echoes now developing in areas west and south. Notice strong echo about 30 miles south of radar. Movement is toward northeast and in next hour this cell is to produce extreme hail damage along a 35 mile path.



F. 1450: Echo 10-20 miles south still remains intense. Hail falling from this cell at this time is $\frac{3}{4}$" diameter and in tremendous quantities. Severe wind accompanied hail fall. Other echoes west of radar now more intense and grouping.

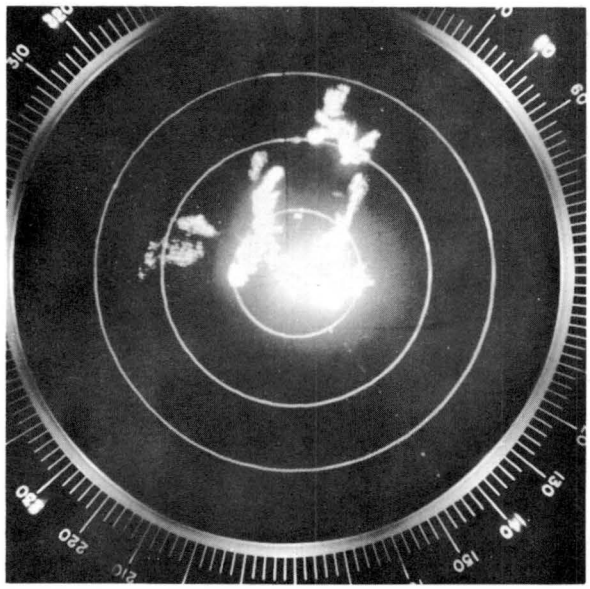


G. 1503: Echo in south area appears to have 'hook' development on south end. Severe hail and high winds reported on surface at this time. Echoes west appear to be forming line with E. movement.



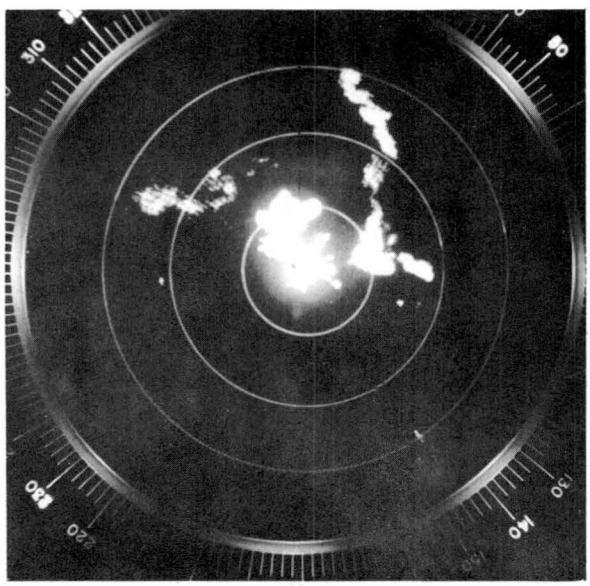
H. 1535: Notice tiny echoes in development stage along east edge of echo south of radar. Echoes north now seem to be moving southeast again. Developments west are erratic and remain severe.

FIG. 4. (cont'd) Photos of radar scope - 13 July 1962

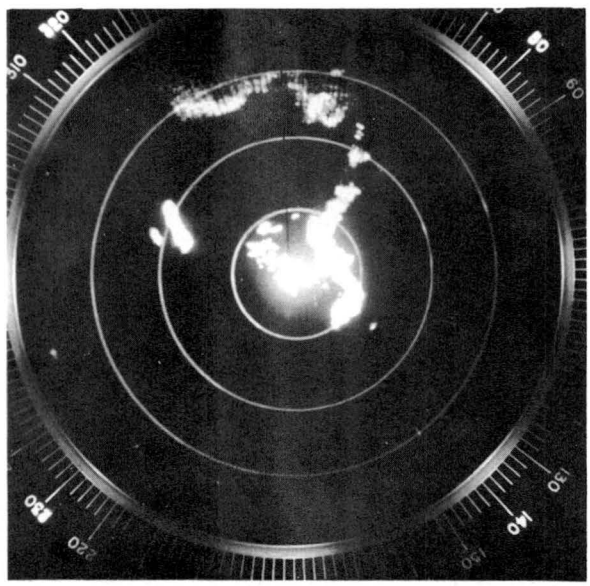


I. 1605: Echoes west are now well oriented into squall line with easterly movement. Echo tops are near 48,000 feet msl. Hail is falling in three or four locations along this line at this time. Strong echo west is still producing hail.

J. 1605: Ice crystal canopy from line west of radar. View is looking easterly from radar so dimension of canopy must be 40 miles diameter. Weather shelter holds hygrothermograph and box holds wind recorders.

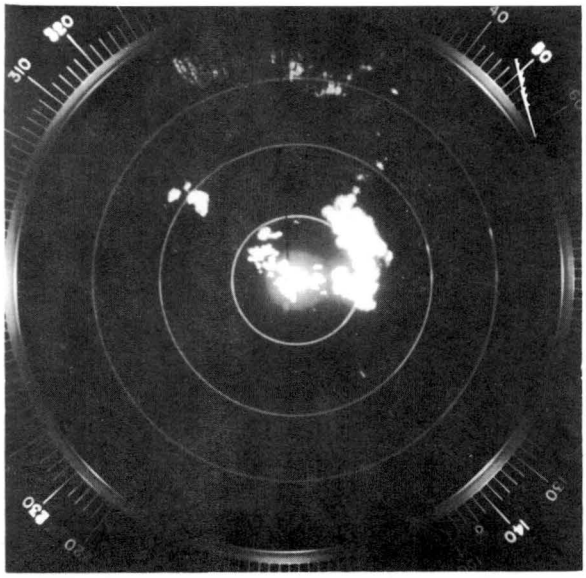


K. 1640: Echoes north and east now appear to be forming squall line. Complex movement and development of cells is common in areas where numerous intense echoes are born.

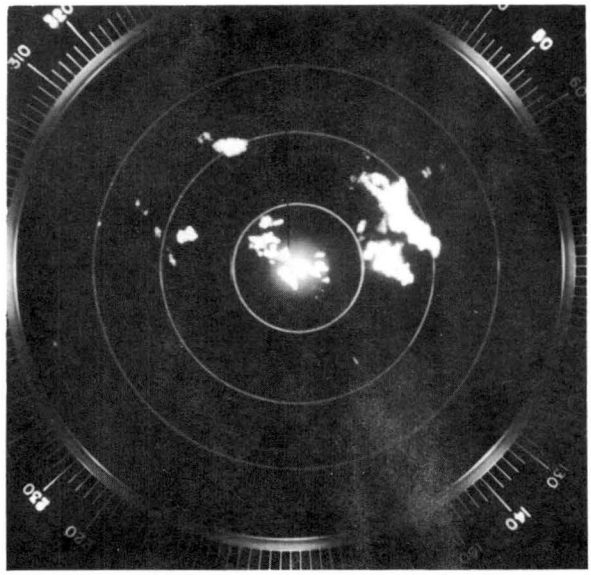


L. 1745: Echoes east in previous photo have now dissipated and new squall line has developed immediately east of radar. Hook shape in south end of line is common with intense activity.

FIG. 4. (cont'd) Photos of radar scope - 13 July 1962

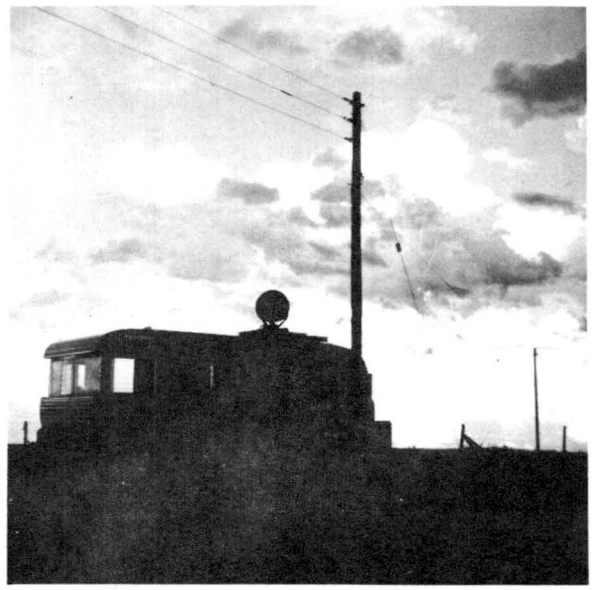


M. 1815: Most all cells now have met at common convergence point east of radar. Severe intensity persists. Hail is still falling from this echo. Most intense areas in lines of this type are frequently found near southern tip of echo.



N. 1835: Echo now has broken into two individual parts. Echo tops are still above 50,000 feet msl and hail is falling from two or three locations within the precipitation area. Points of convergence are unpredictable.

O. 1850: View shows clouds east of radar. Notice water droplet development still persists along back side of main precipitation area.



P. 1850: View looking east of radar site. Radar trailer has air conditioning to keep equipment operating in 70° environment.

FIGURE 5.

HAIL DAMAGE NEAR SNYDER, COLORADO - JULY 13, 1962

View looking across bean field toward the town of Snyder, Colorado. Town and surrounding area gives impression of winter scene. Leaves were stripped from trees and most crops were completely devastated.

Closer view of bean field shows Dorene Walker of New Raymer, Colorado, looking at the effects of the hailstorm. Hailstones were not exceptionally large - $\frac{1}{2}$ to $\frac{3}{4}$ inch diameter were most common sizes but the number of stones per unit volume of air was excessive.

FIGURE 5. (cont'd)

HAIL DAMAGE NEAR SNYDER, COLORADO - JULY 13, 1962

Snyder schoolhouse suffered extreme damage from the hailstones. Windows were shattered, screens stripped, and blinds torn apart by the force of wind and hail. Notice roof damage left of center. Damage estimated to be about $20,000 on this building.

Trees which had been at the prime of their summer growth had every leaf removed. Notice the bird nest still intact within the tree boughs. Many birds were killed in this storm yet the construction of bird nests was good enough to withstand the tremendous pounding of hail.

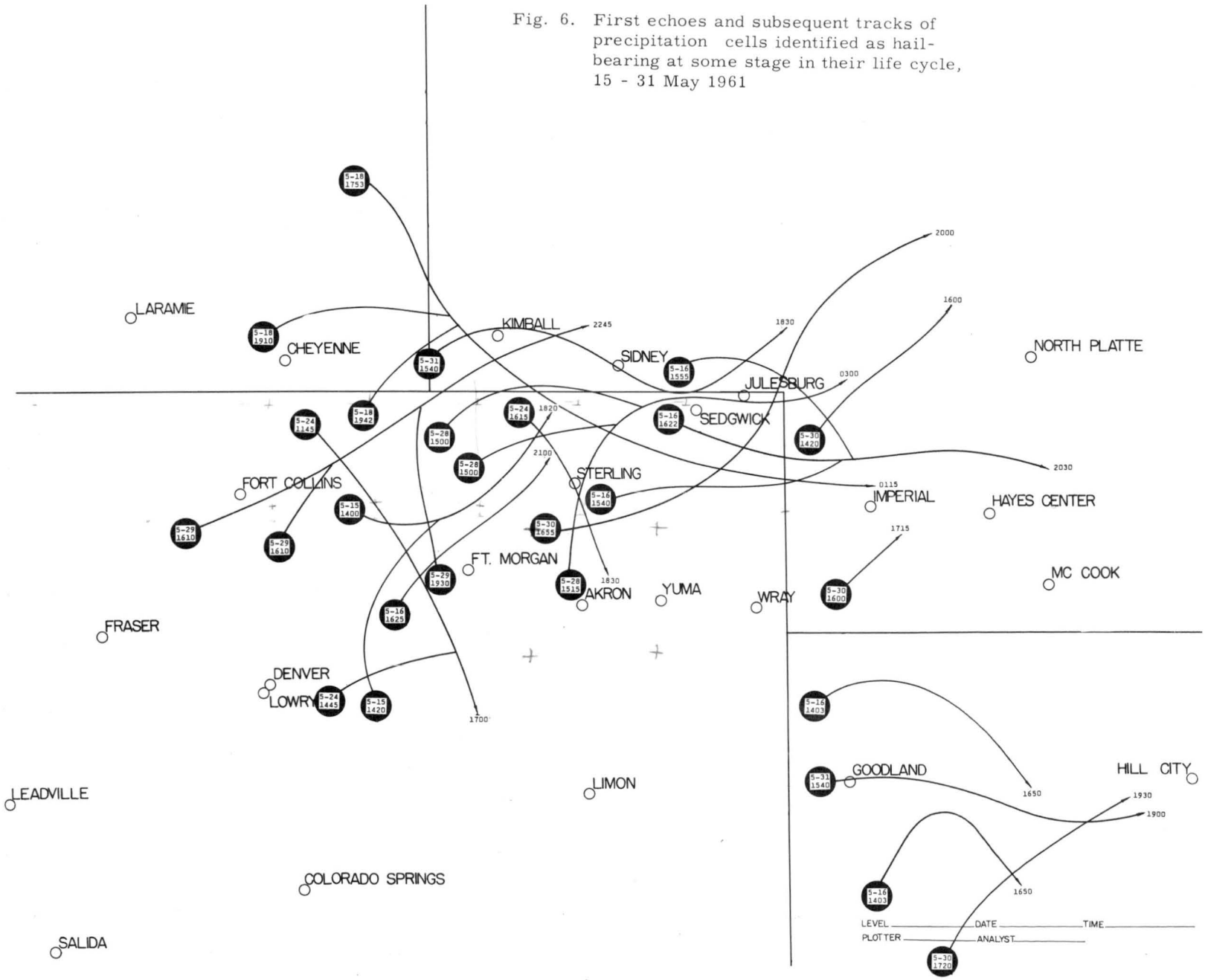


Fig. 6. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle, 15 - 31 May 1961

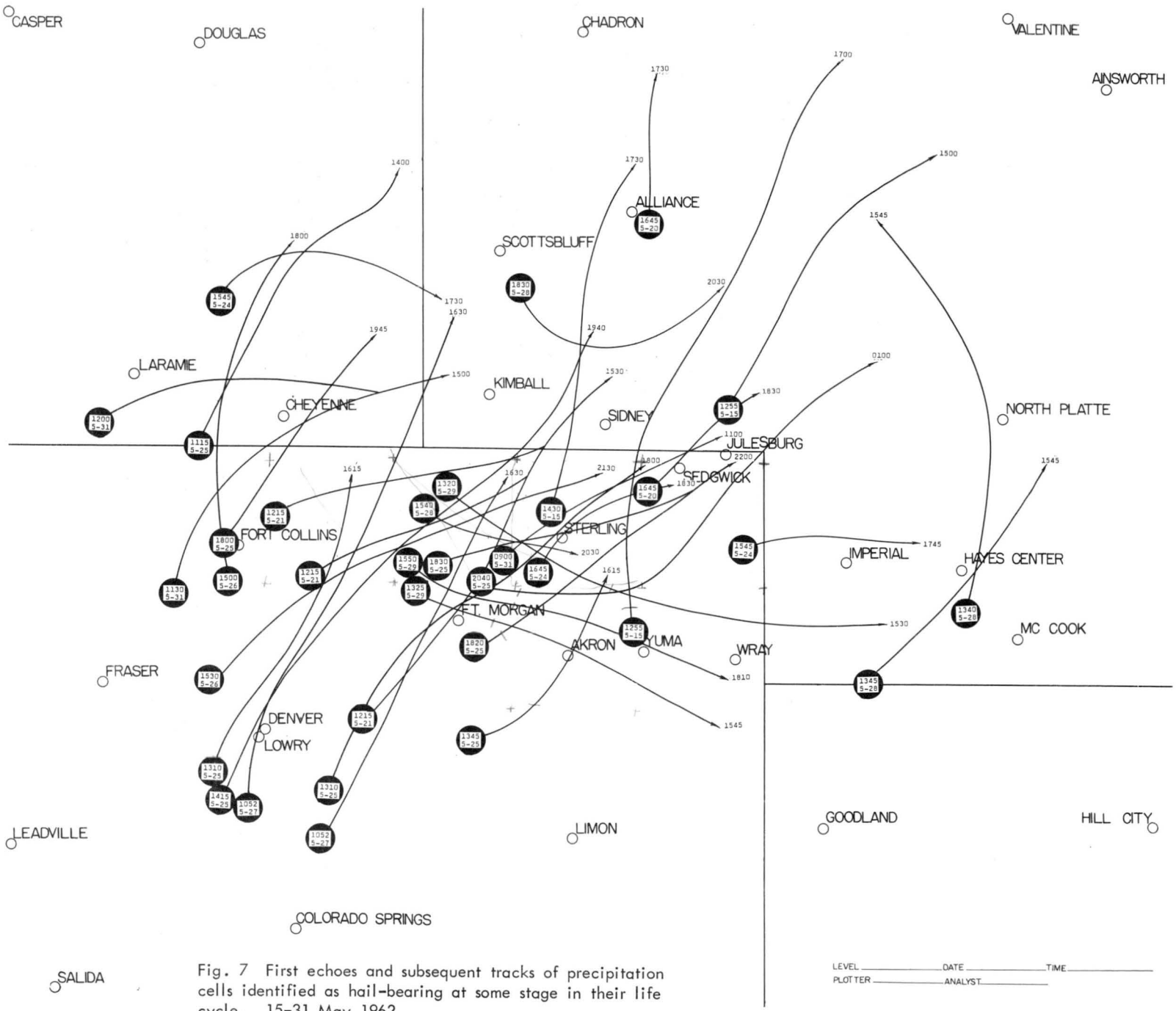


Fig. 7 First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 15-31 May 1962

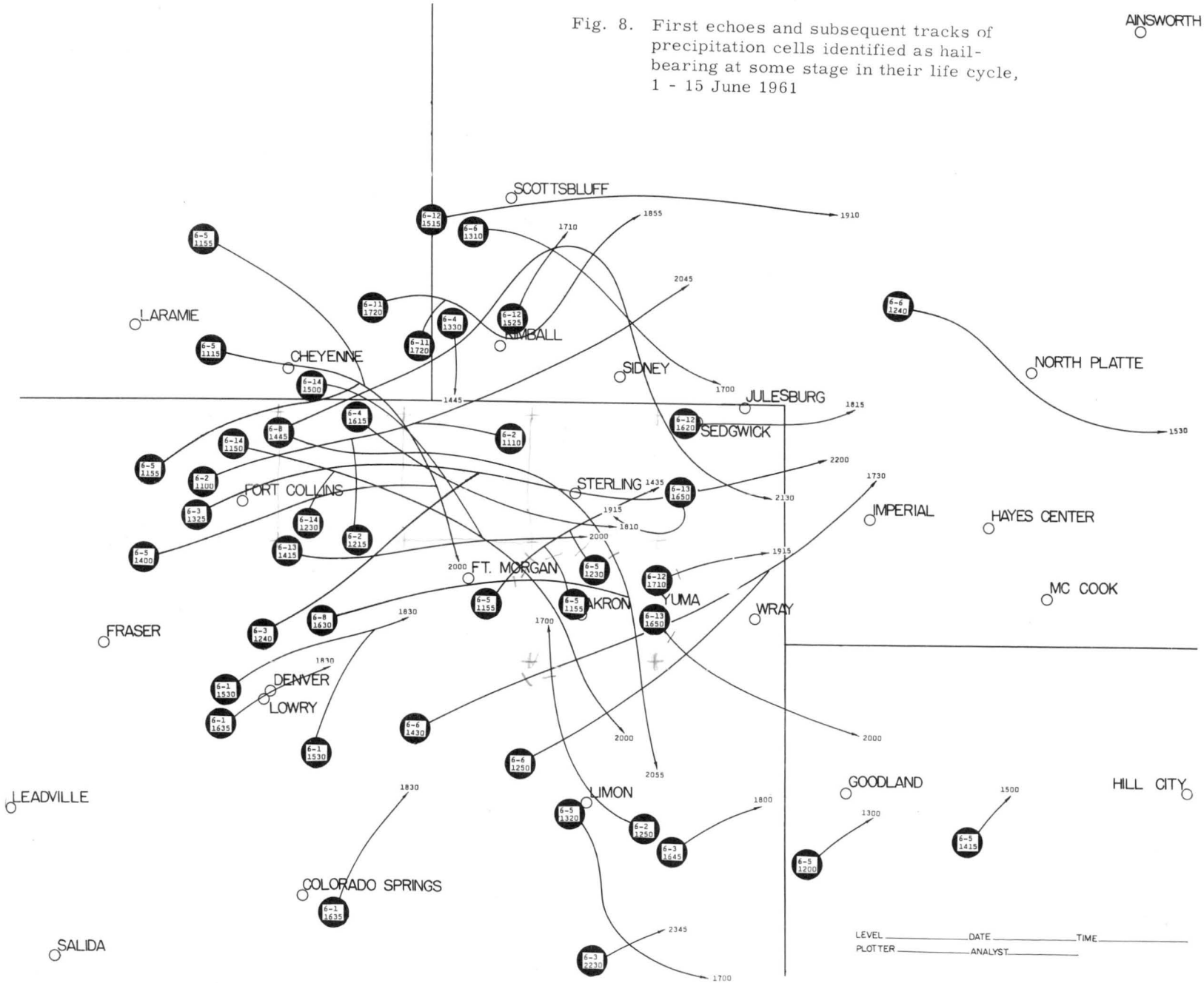


Fig. 8. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle, 1 - 15 June 1961

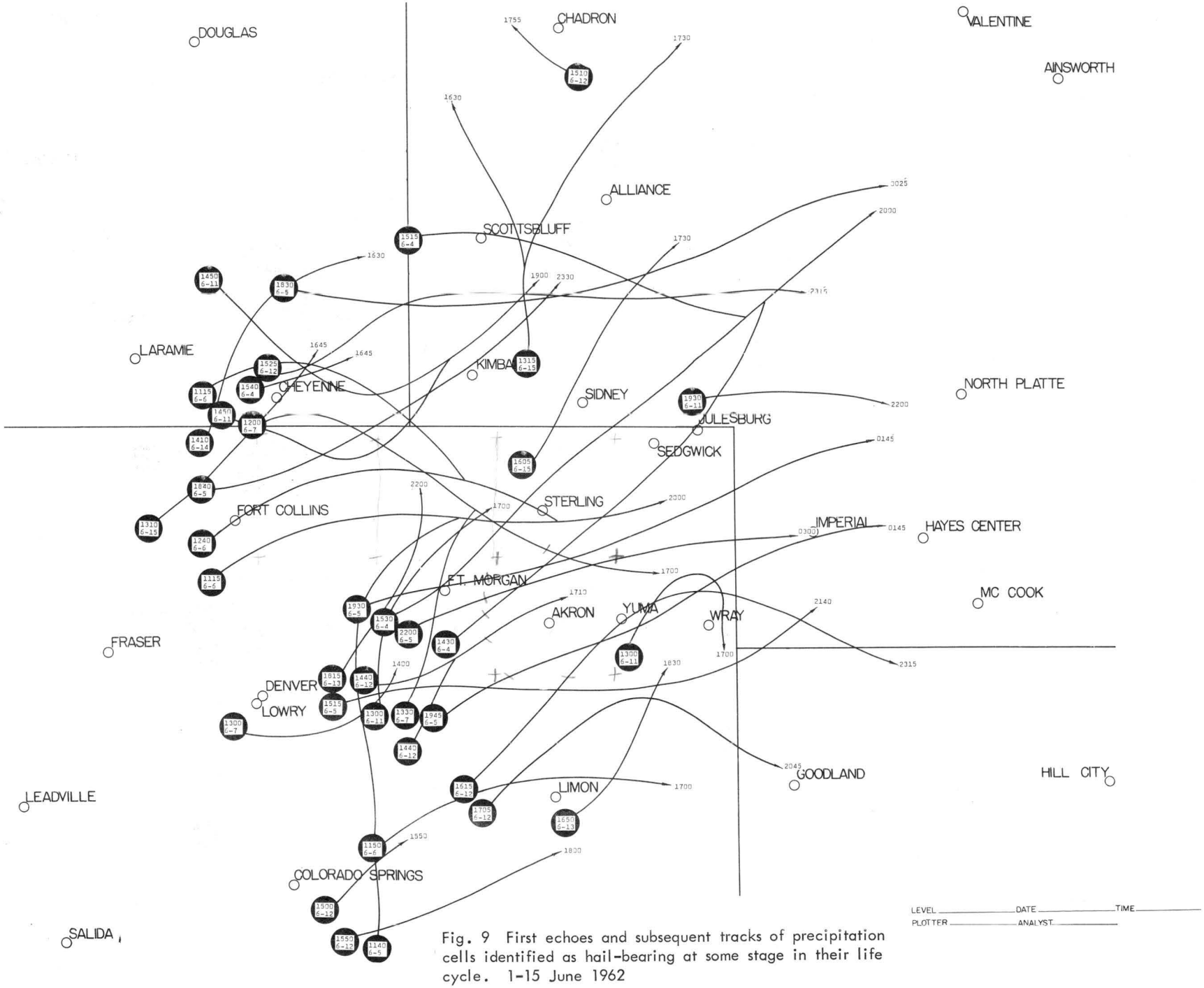


Fig. 9 First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 1-15 June 1962

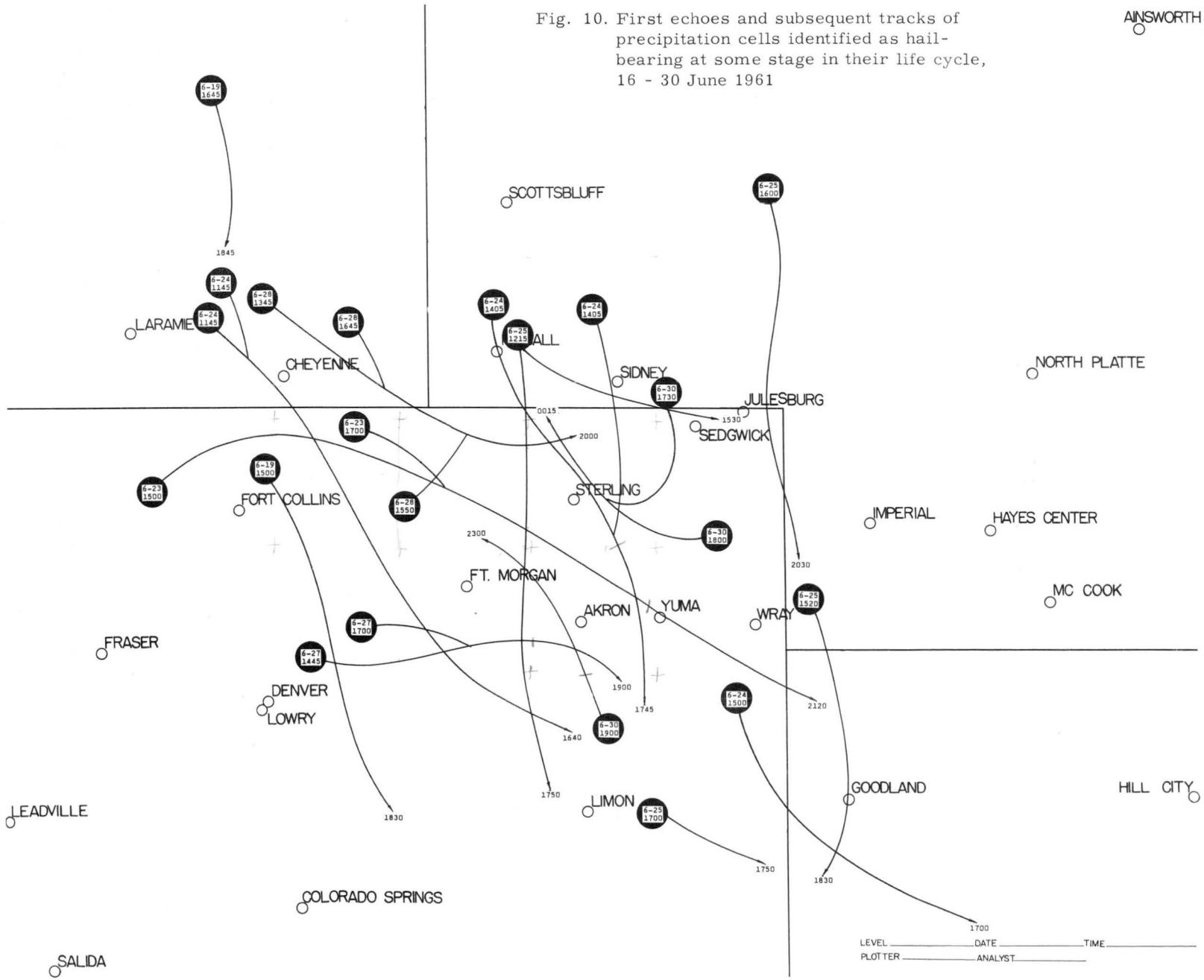


Fig. 10. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle, 16 - 30 June 1961

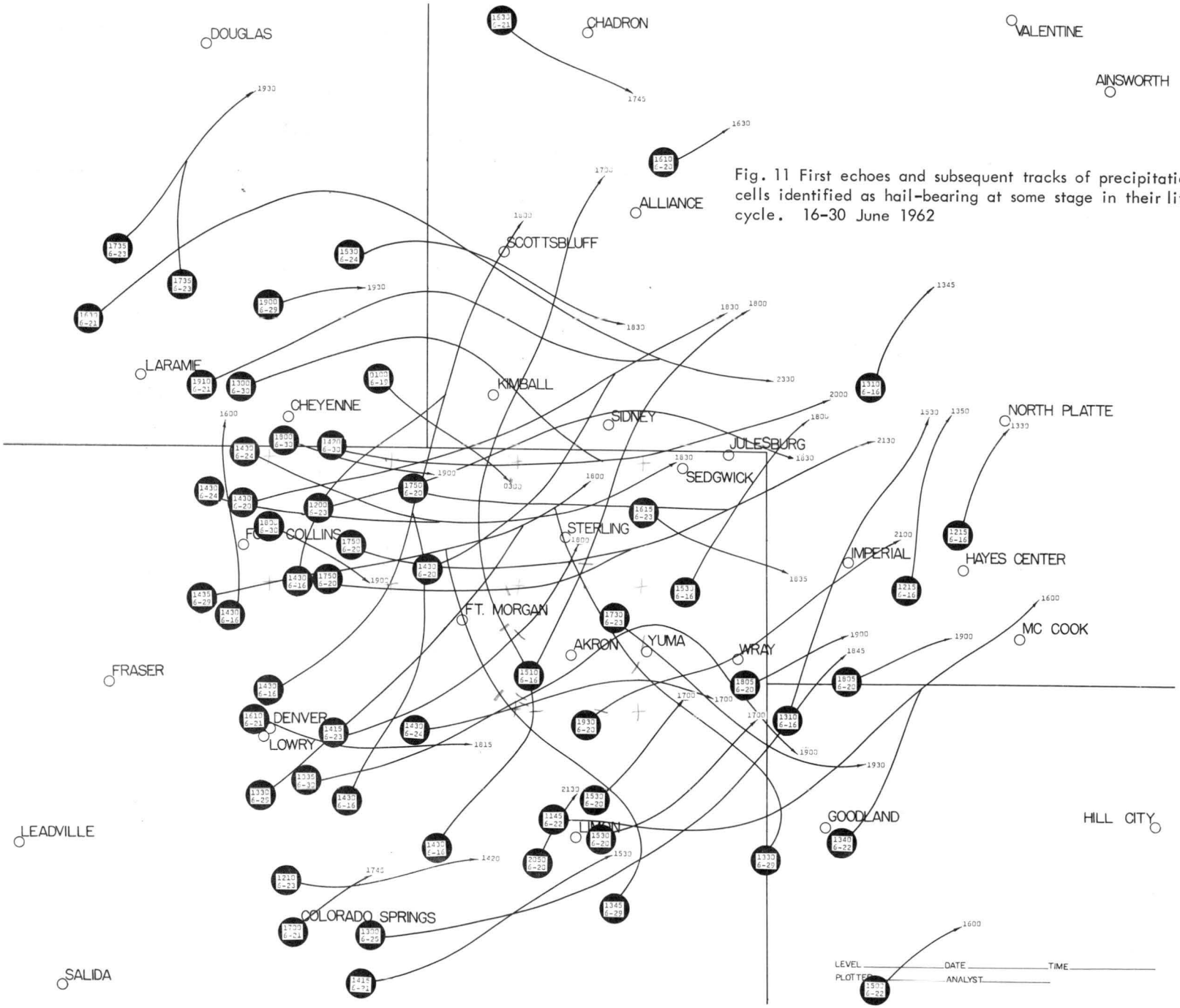


Fig. 11 First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 16-30 June 1962

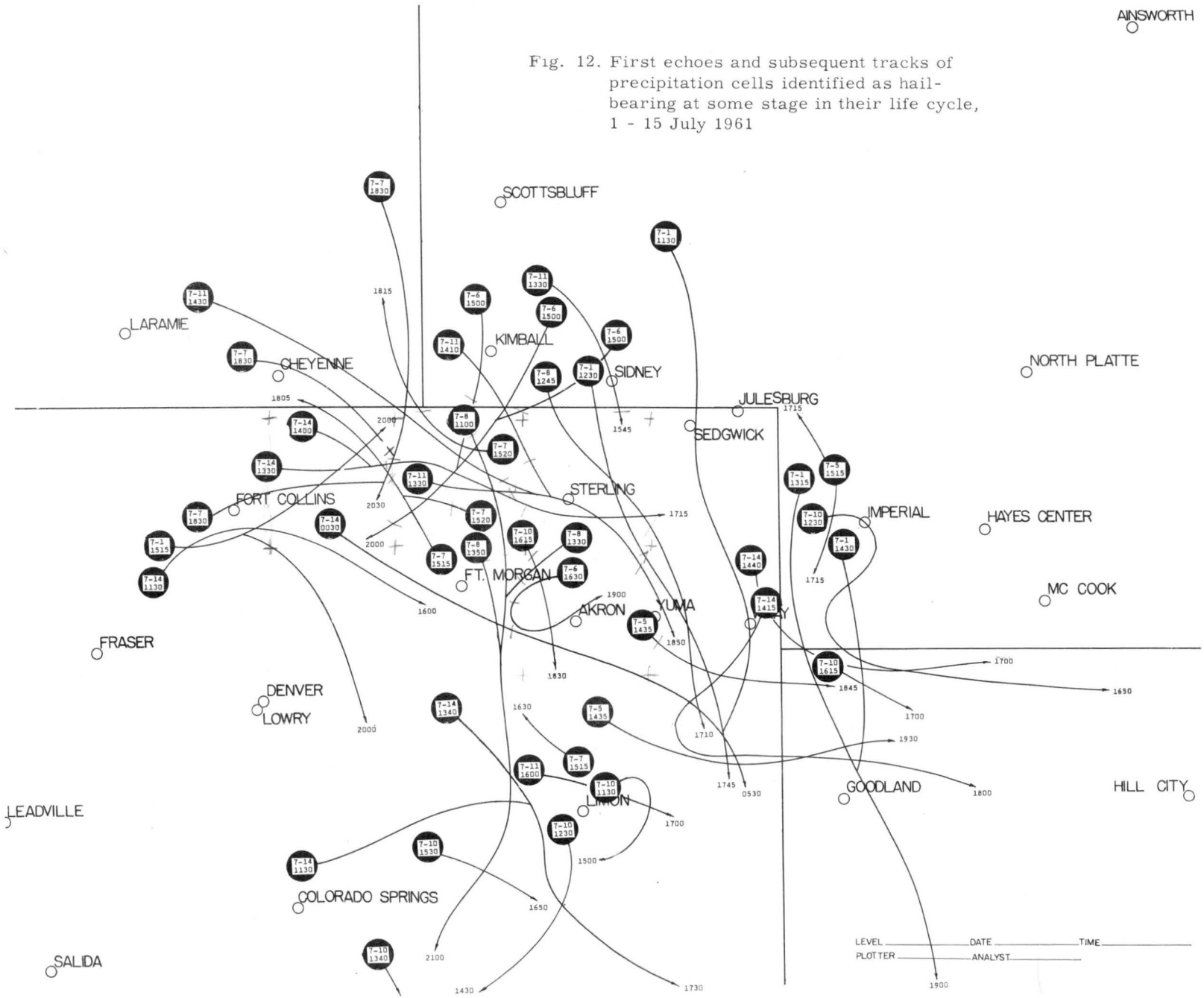


Fig. 12. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle, 1 - 15 July 1961

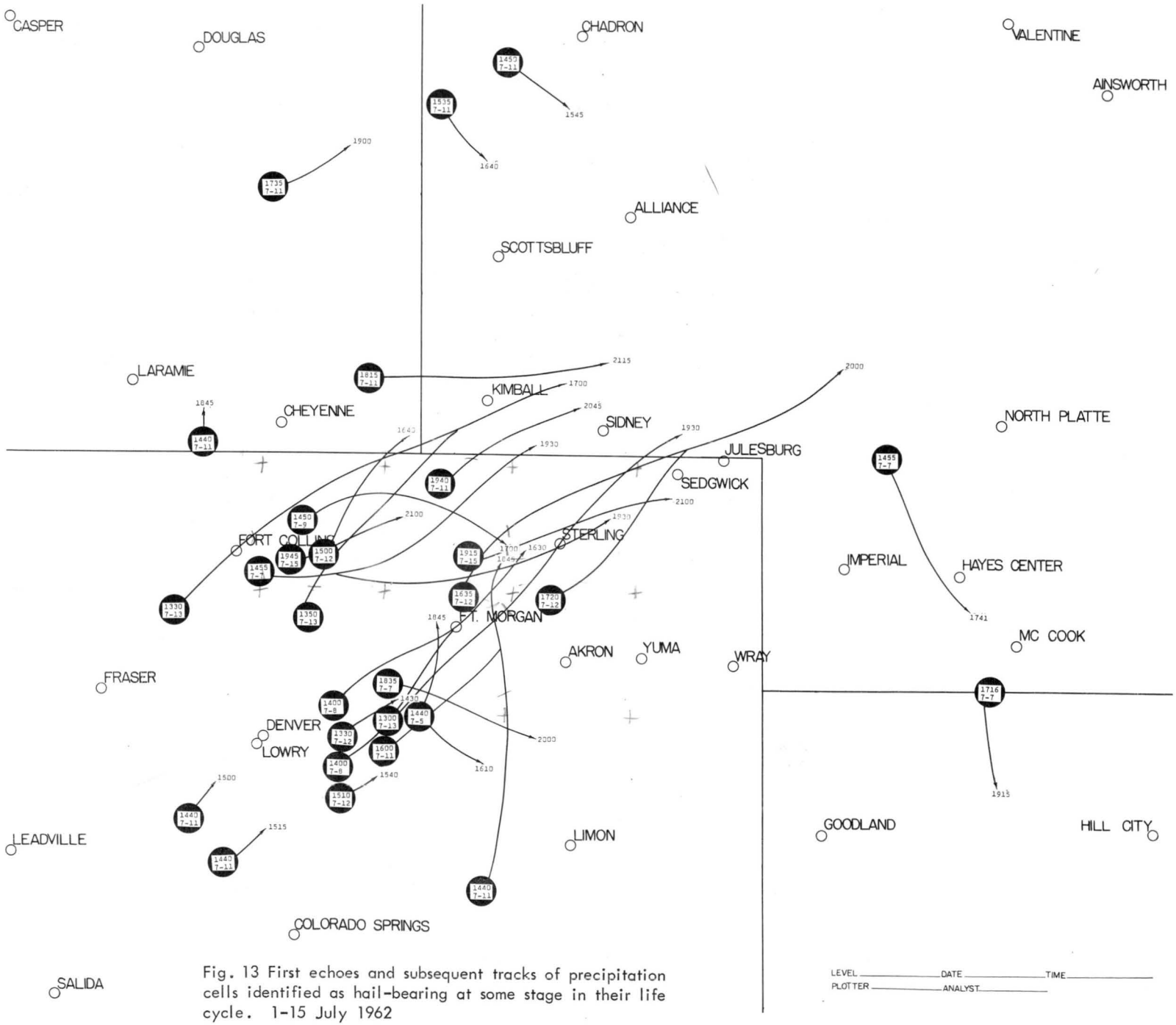


Fig. 13 First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 1-15 July 1962

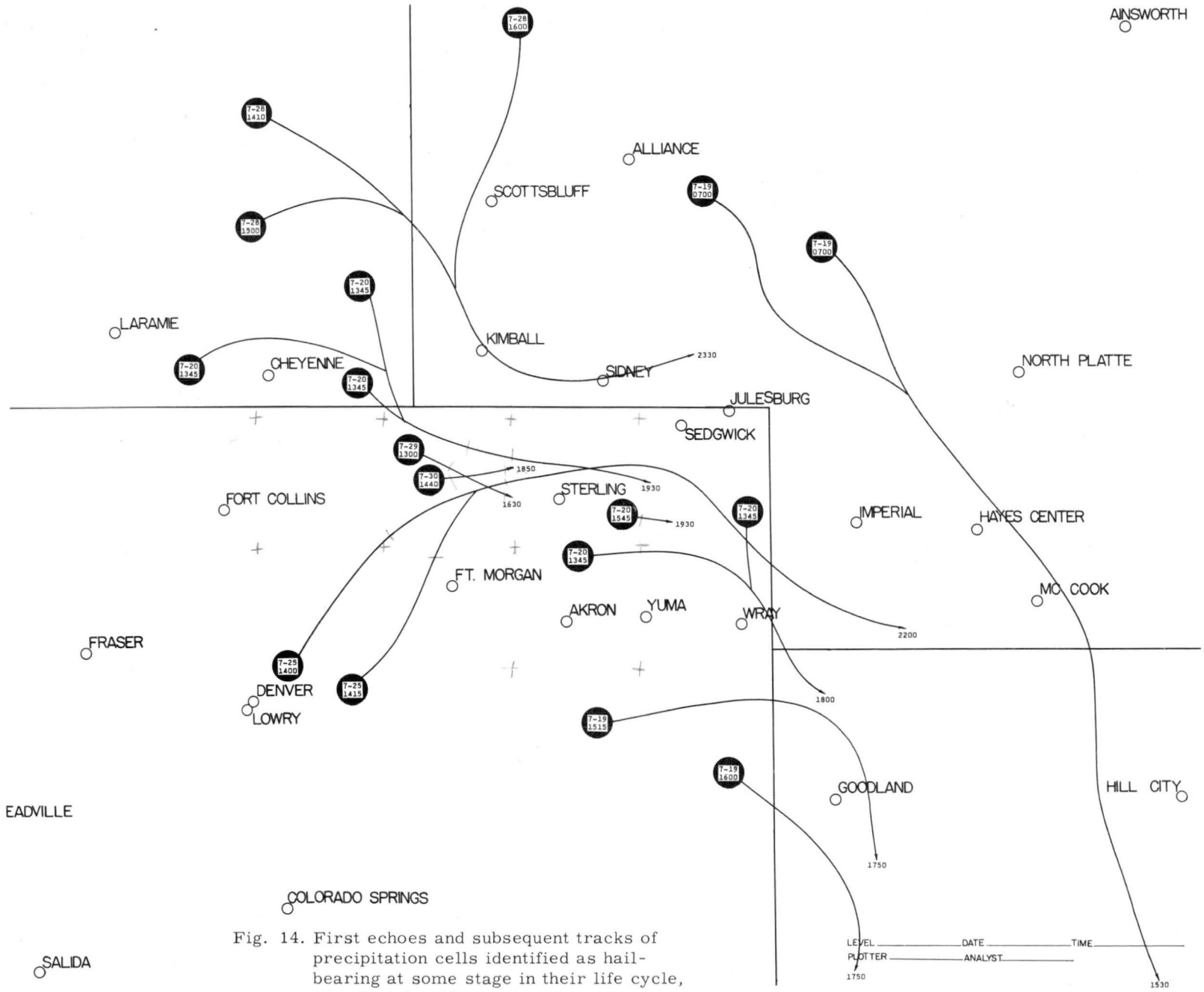


Fig. 14. First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle, 16 - 31 July 1961

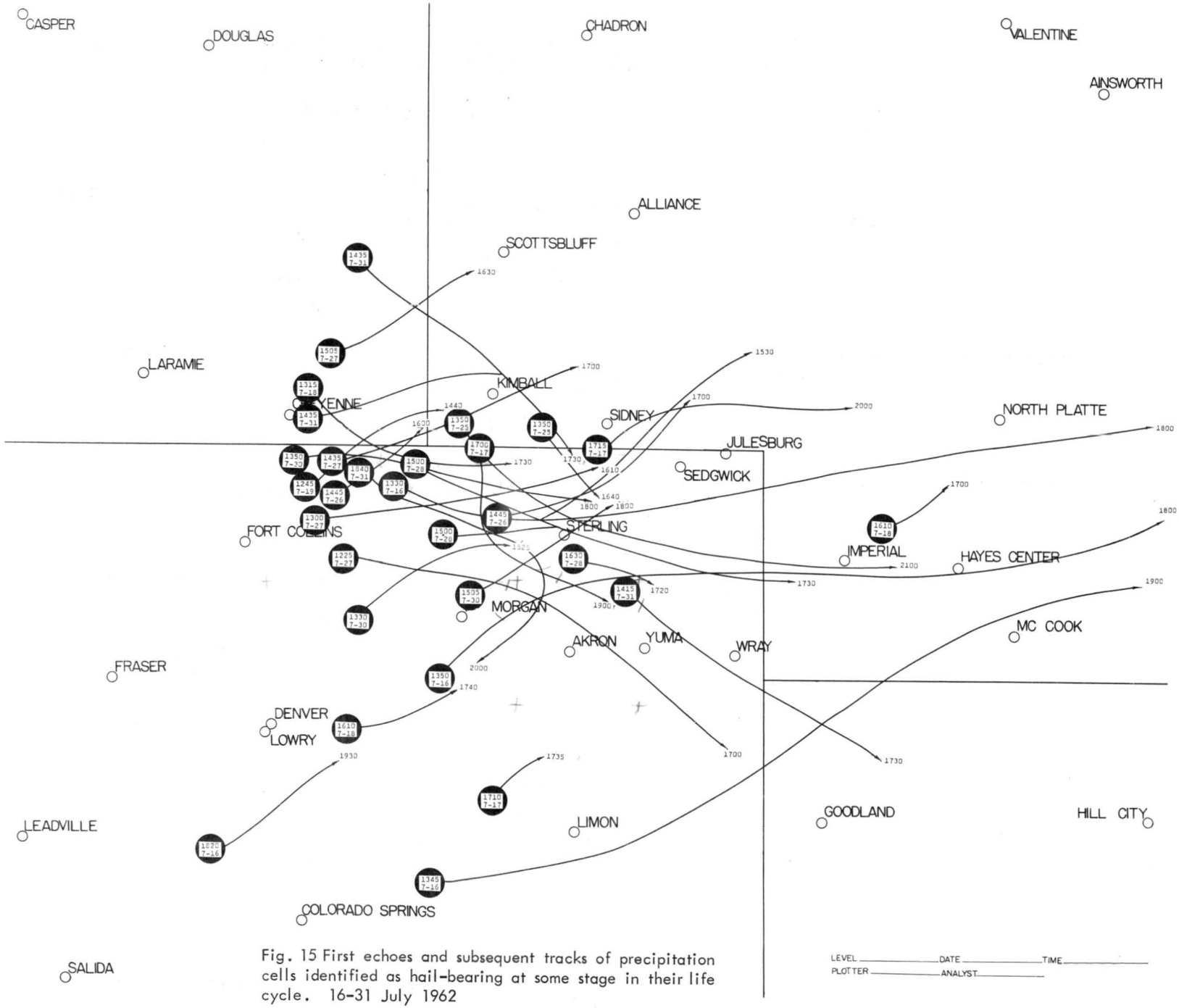


Fig. 15 First echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle. 16-31 July 1962

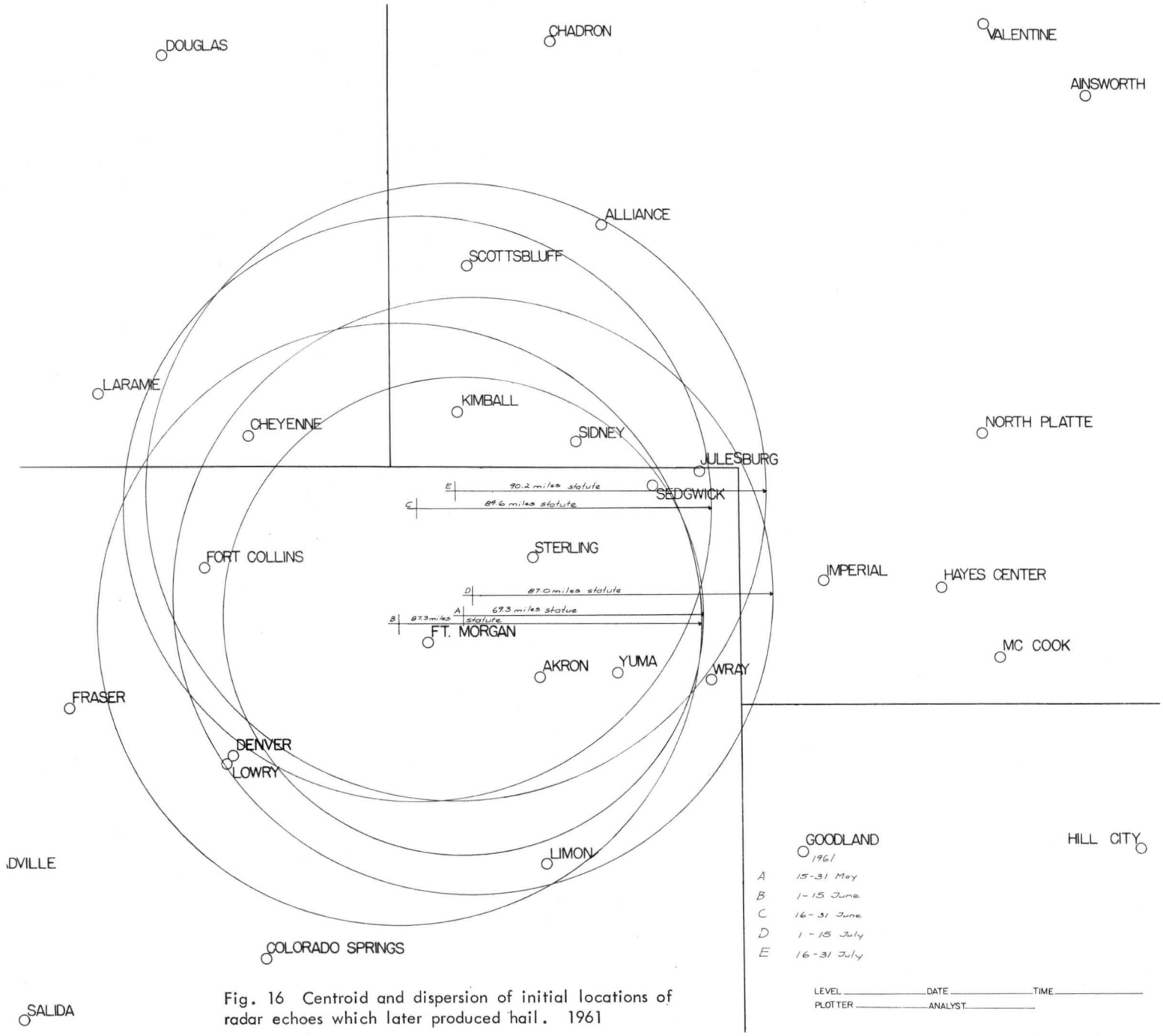


Fig. 16 Centroid and dispersion of initial locations of radar echoes which later produced hail. 1961

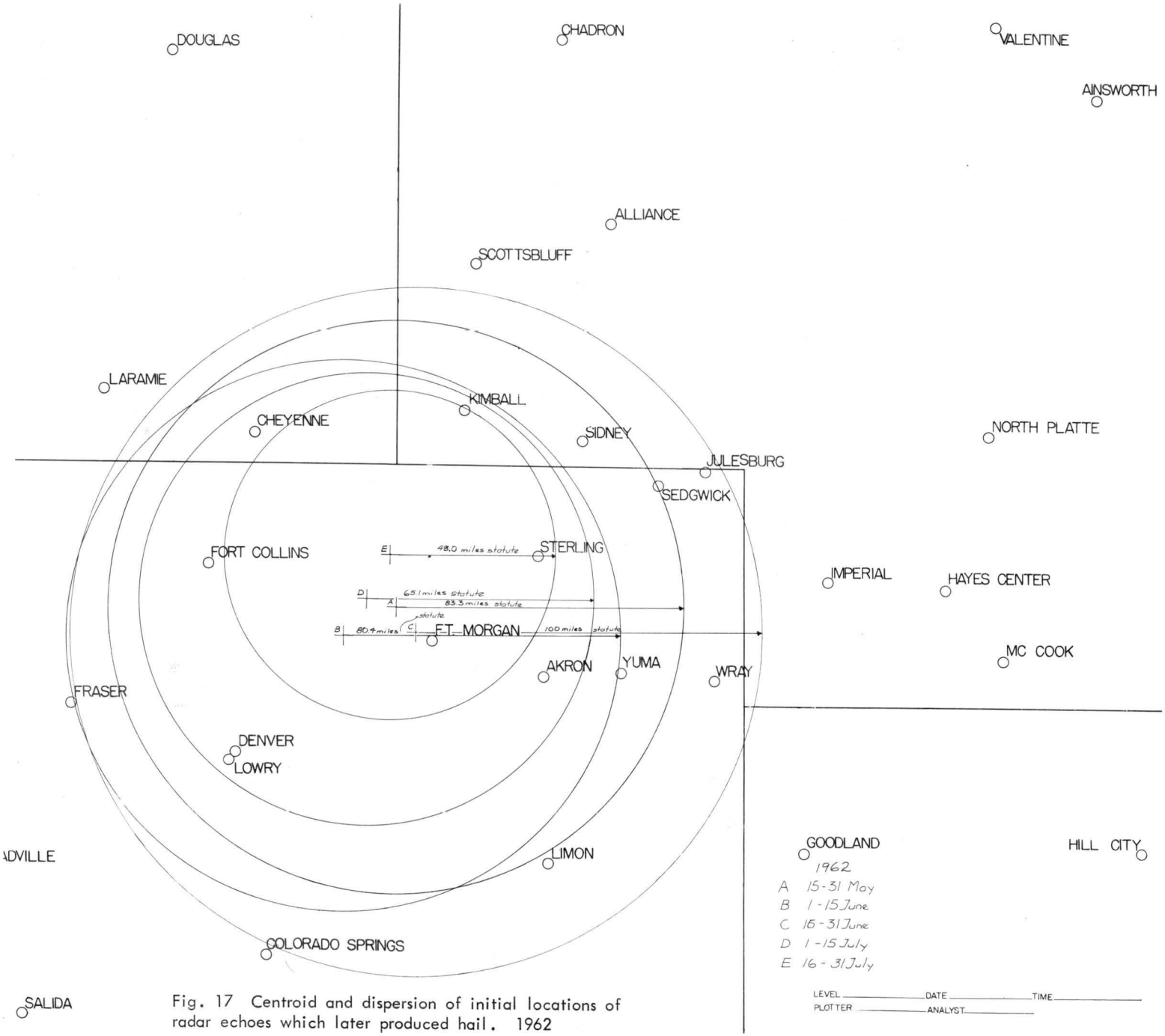


Fig. 17 Centroid and dispersion of initial locations of radar echoes which later produced hail. 1962

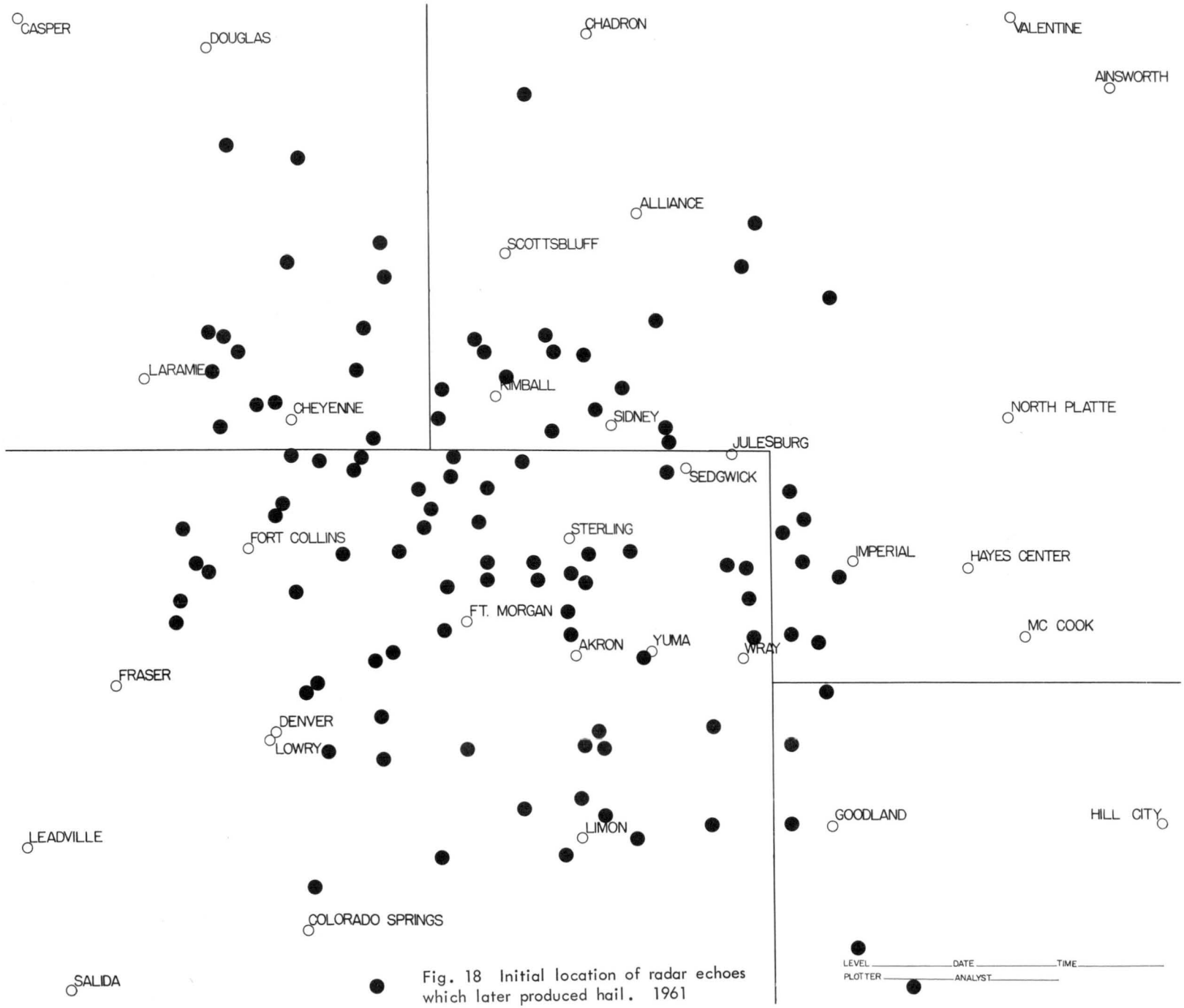


Fig. 18 Initial location of radar echoes which later produced hail. 1961

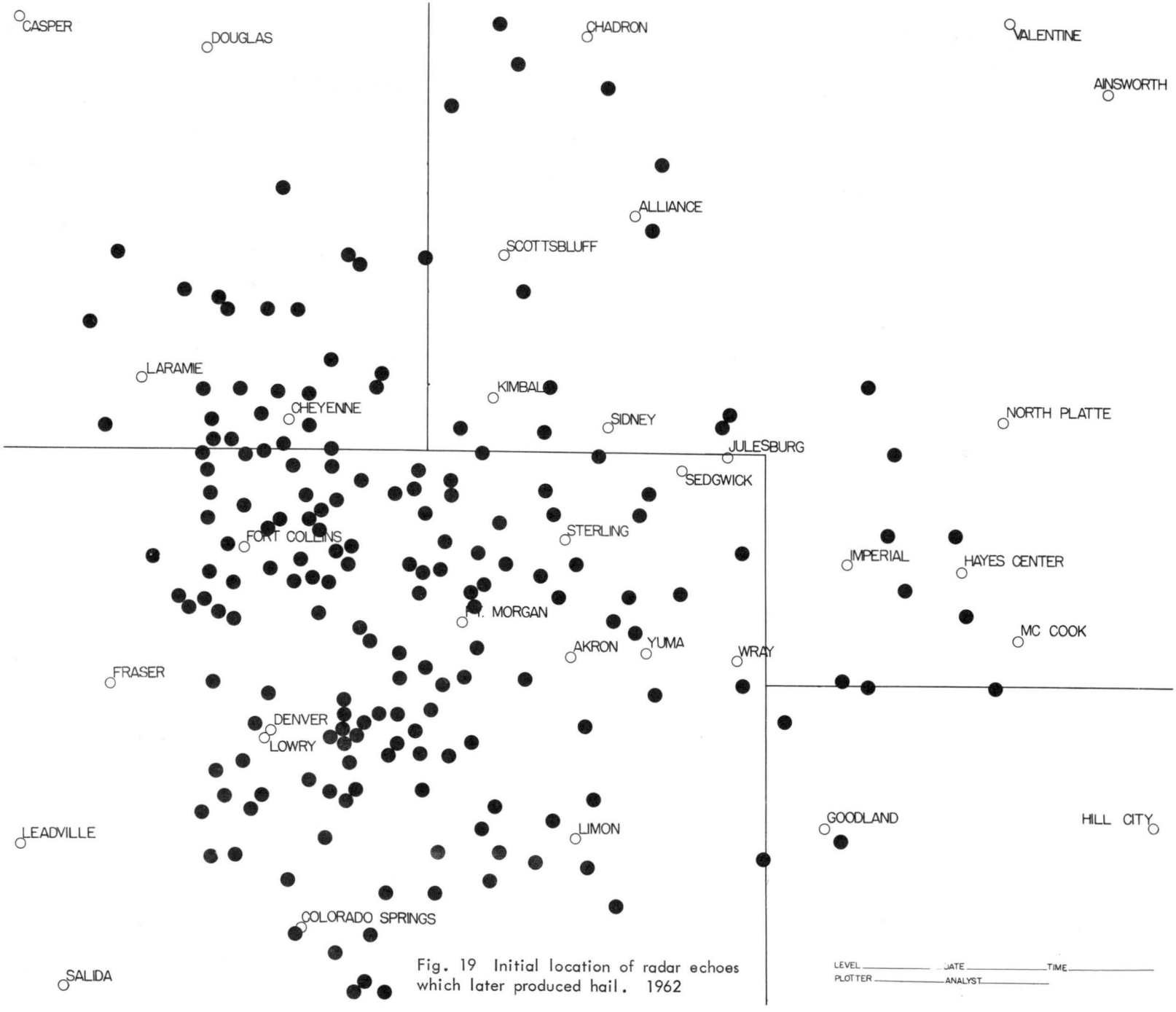


Fig. 19 Initial location of radar echoes which later produced hail. 1962

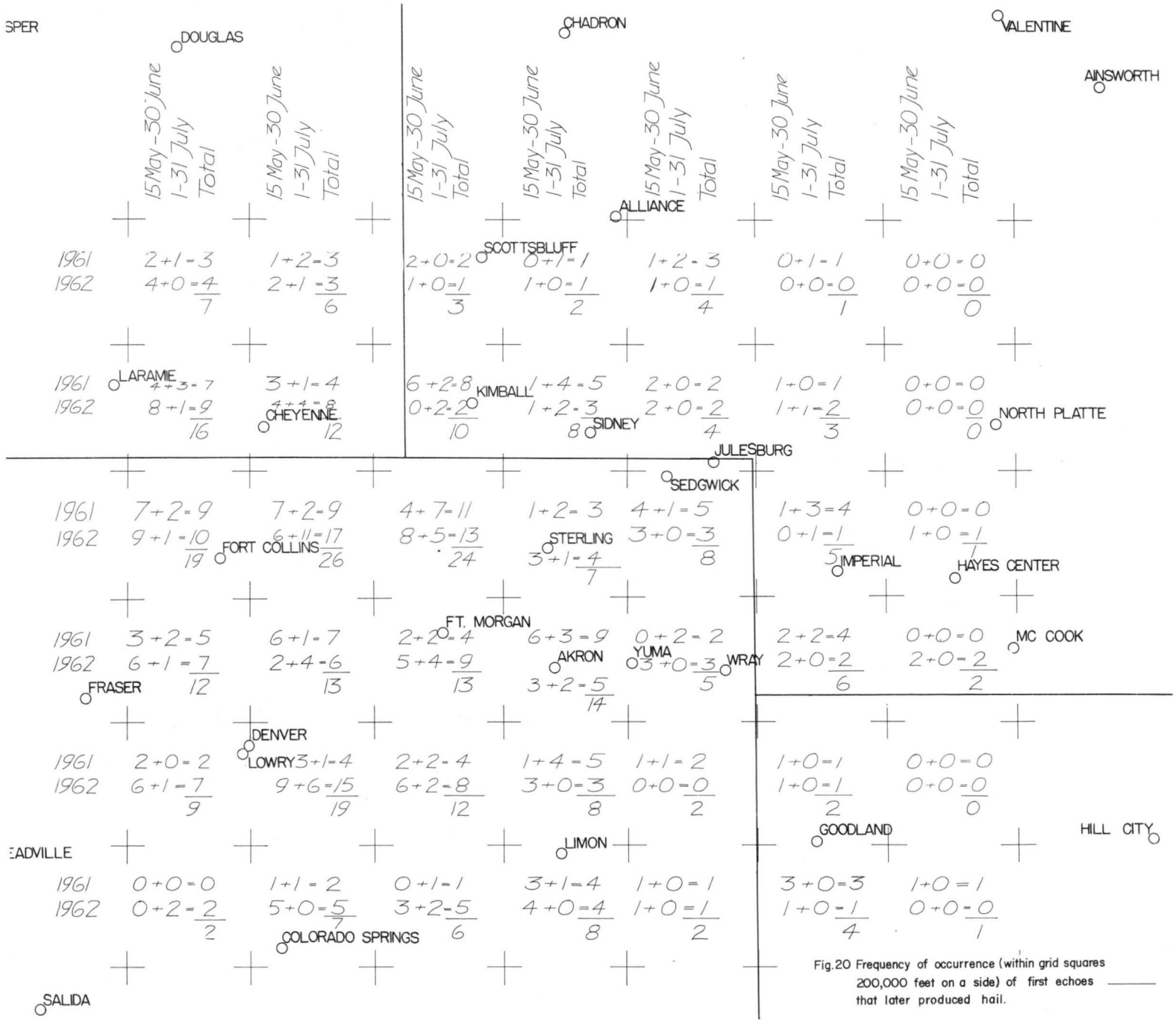


Fig.20 Frequency of occurrence (within grid squares 200,000 feet on a side) of first echoes ——— that later produced hail.

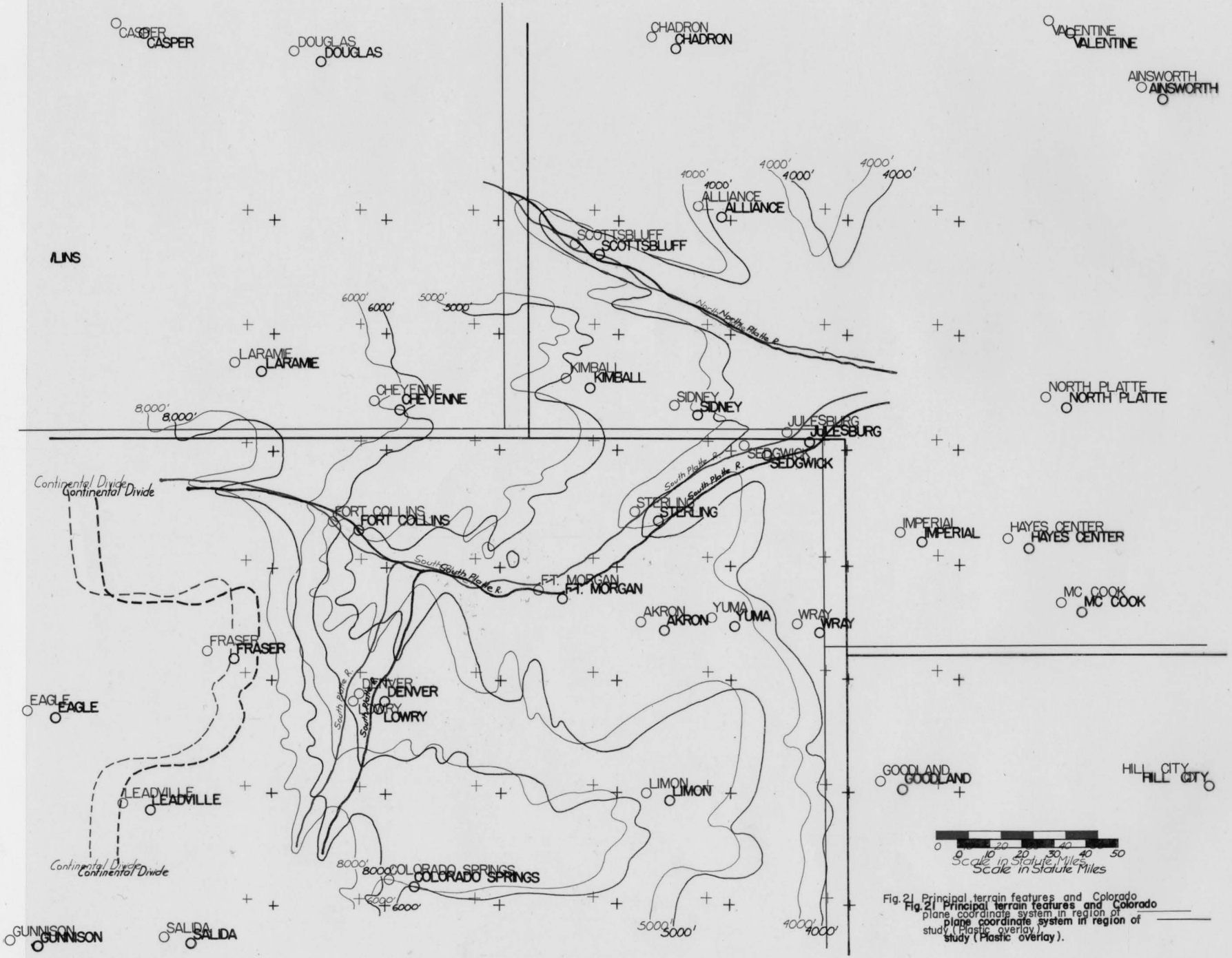
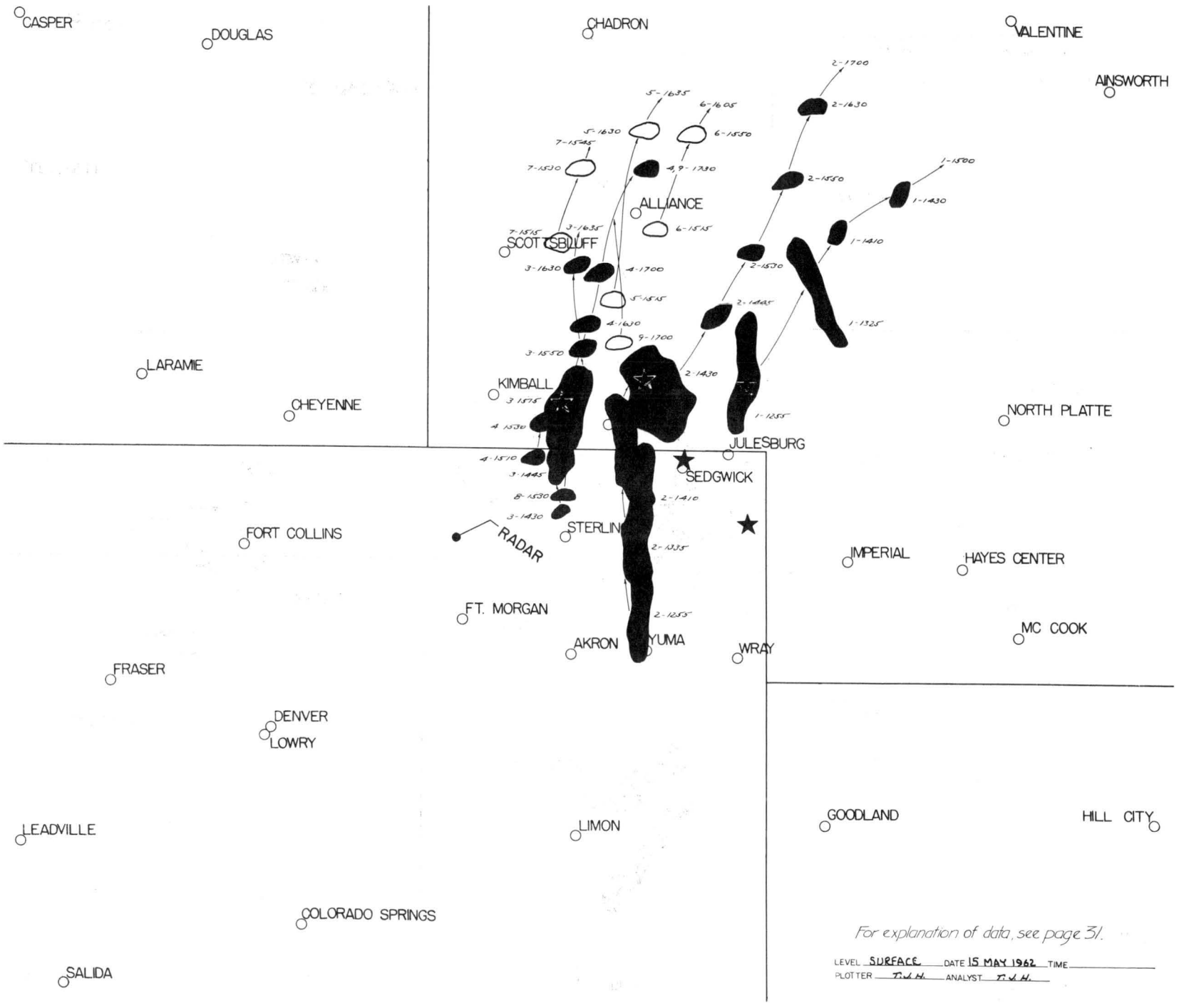


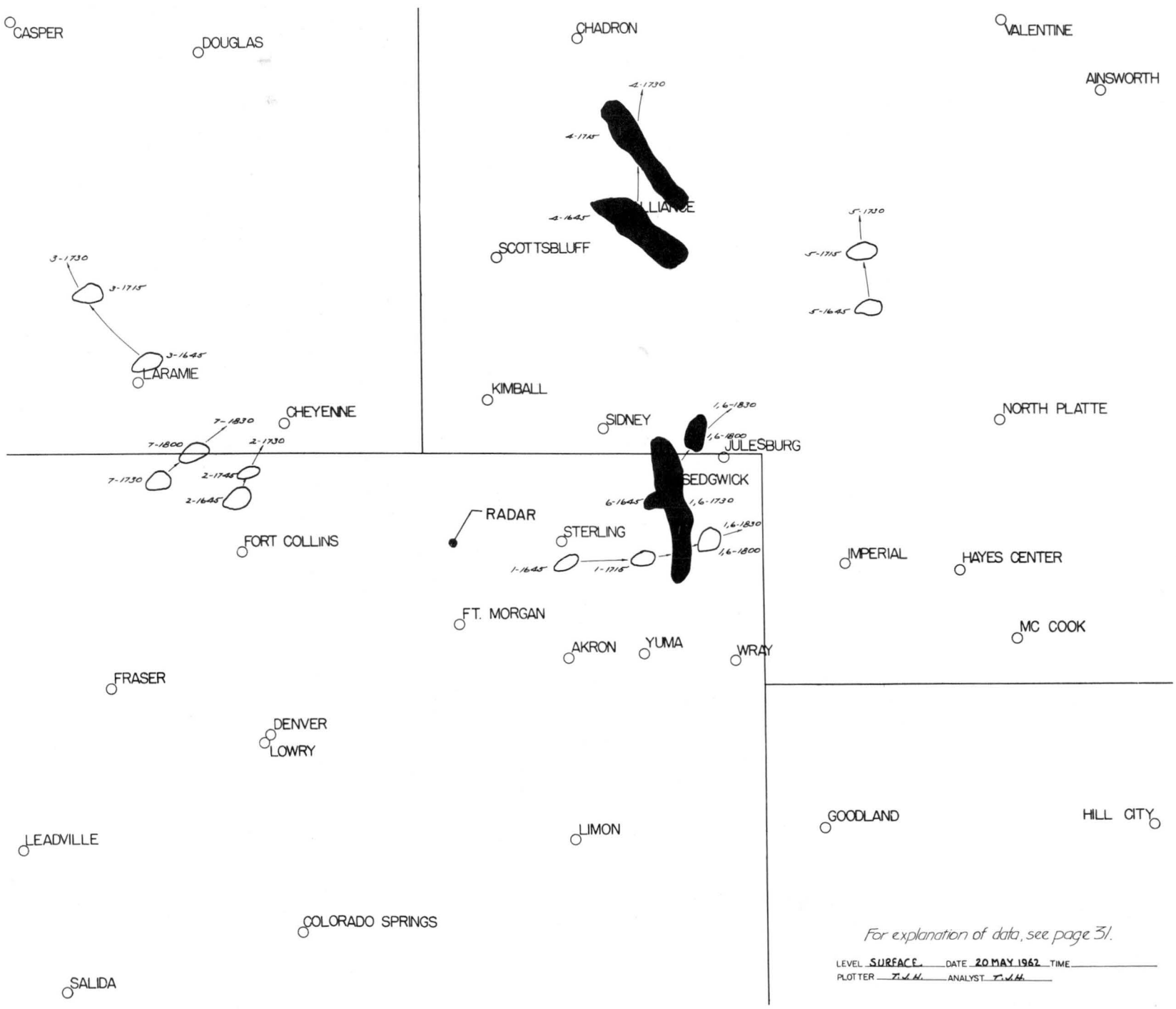
Fig. 21 Principal terrain features and Colorado plane coordinate system in region of study (Plastic overlay).

Fig. 21 Principal terrain features and Colorado plane coordinate system in region of study (Plastic overlay).



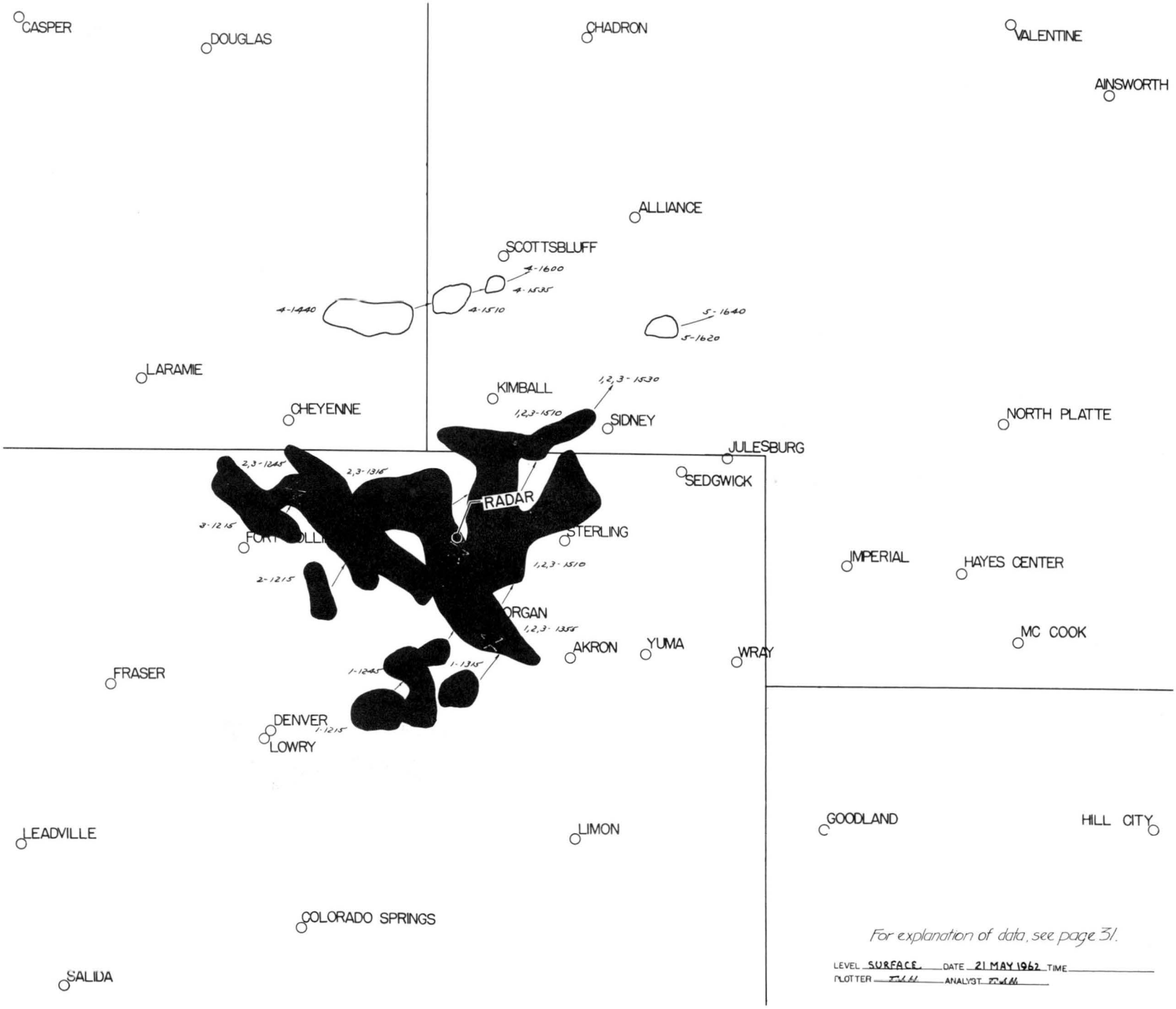
For explanation of data, see page 31.

LEVEL SURFACE DATE 15 MAY 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.



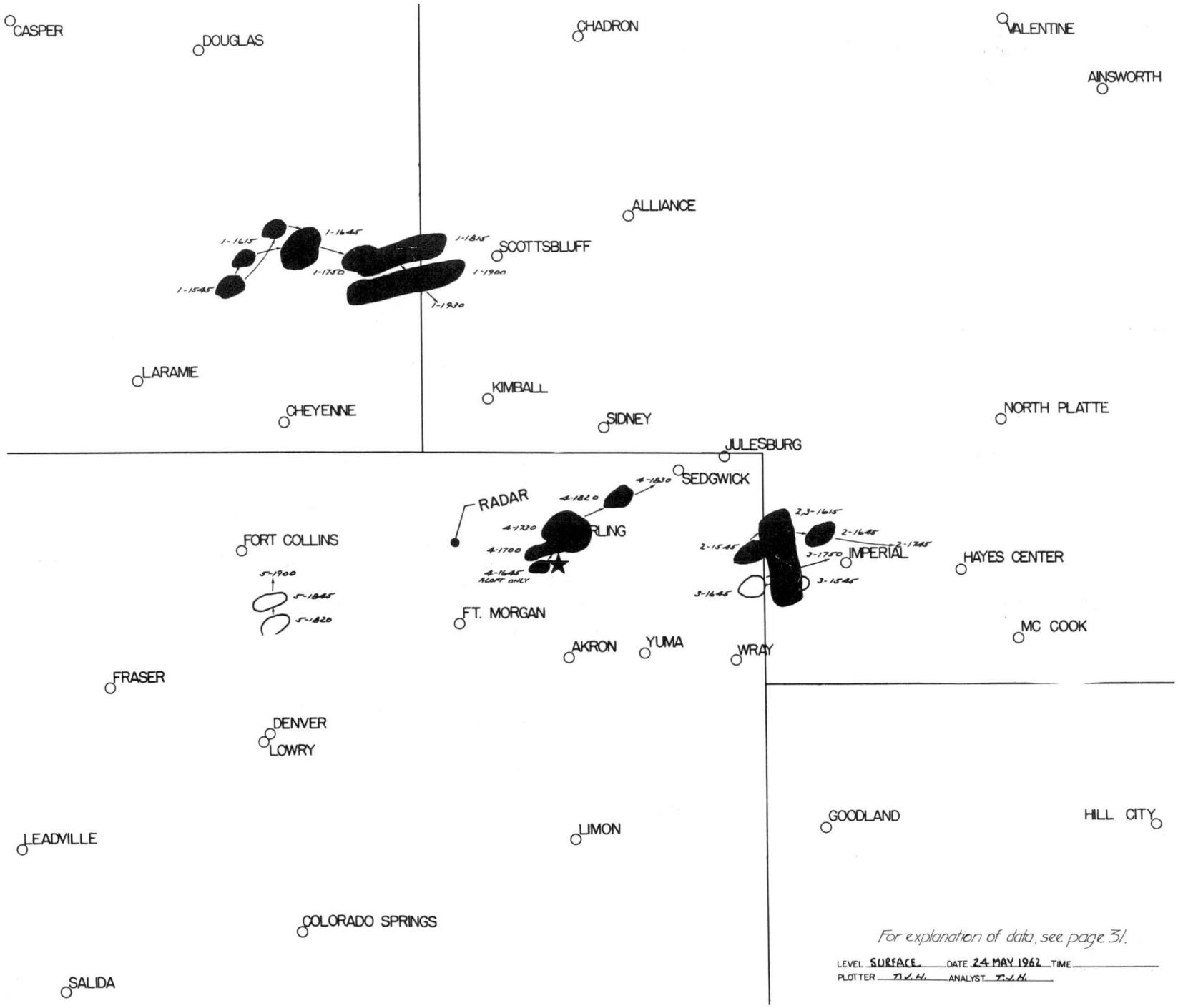
For explanation of data, see page 31.

LEVEL SURFACE DATE 20 MAY 1962 TIME
PLOTTER T.V.H. ANALYST T.V.H.



For explanation of data, see page 31.

LEVEL SURFACE DATE 21 MAY 1962 TIME
PLOTTER TKH ANALYST TKH



For explanation of data, see page 31.

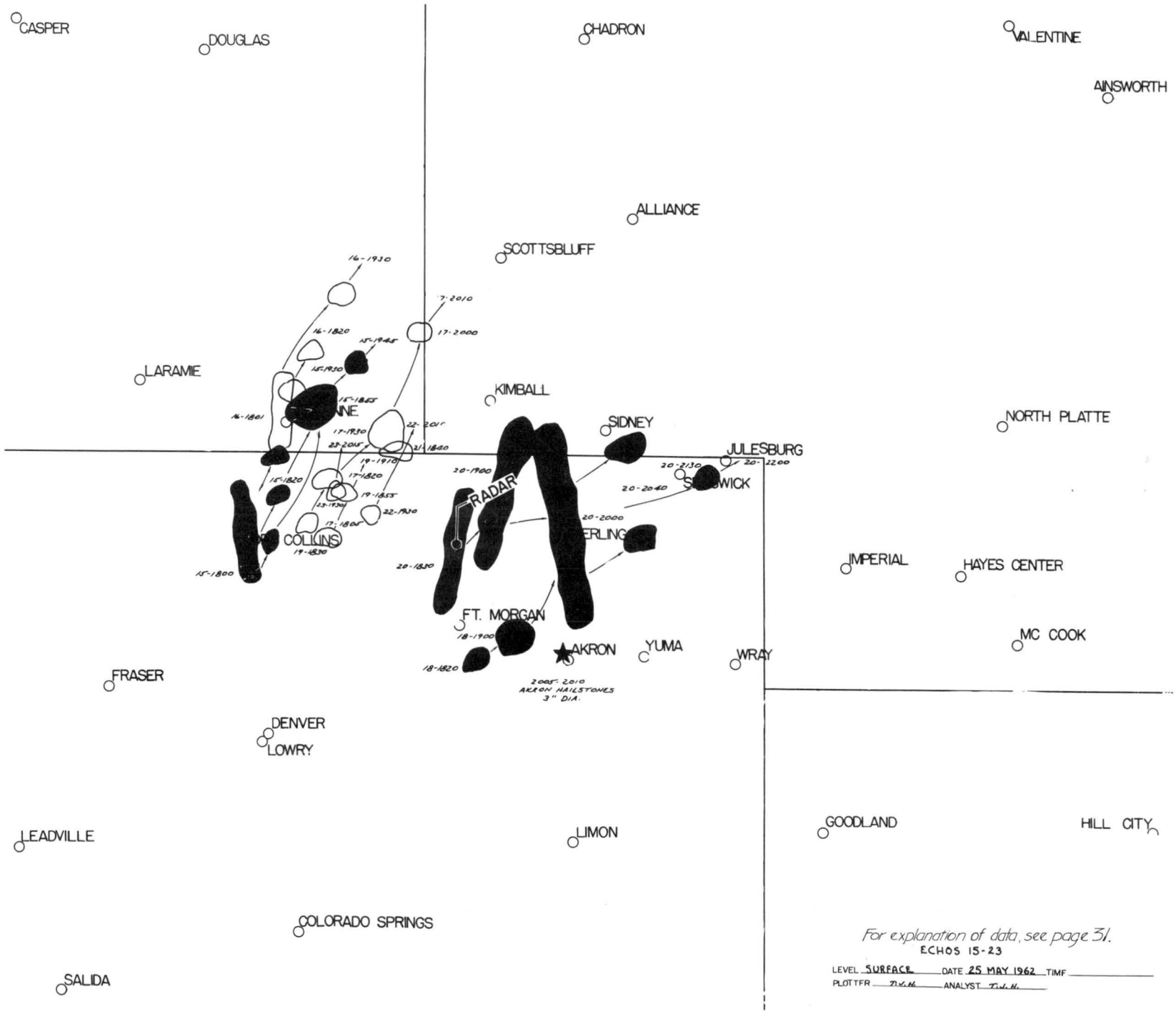
LEVEL SURFACE DATE 24 MAY 1962 TIME _____
PLOTTER T.V.H. ANALYST T.V.H.

For explanation of data, see page 31.

ECHOS 1-14

LEVEL SURFACE DATE 25 MAY 1962 TIME

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

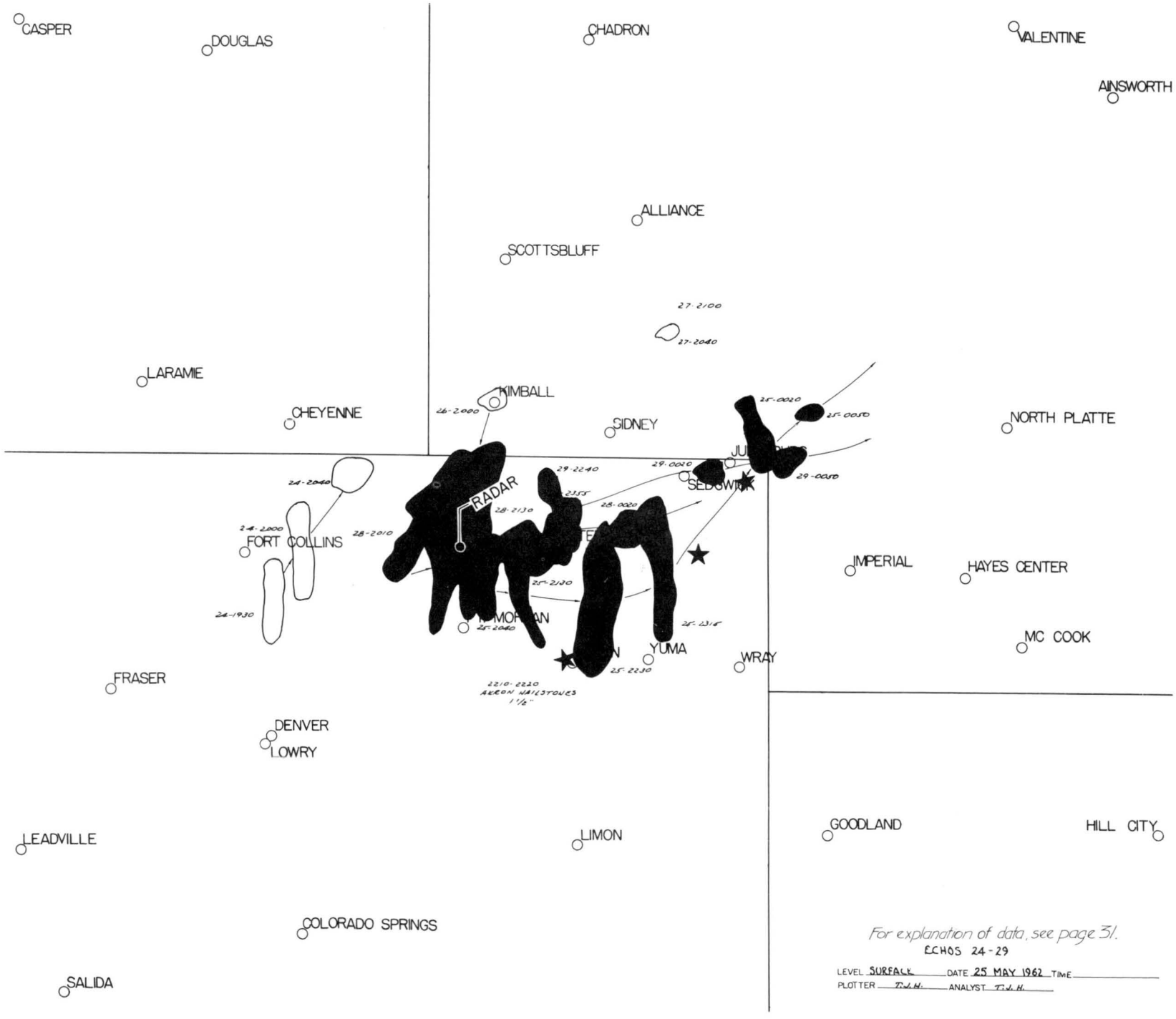


For explanation of data, see page 31.

ECHOS 15-23

LEVEL SURFACE DATE 25 MAY 1962 TIME _____

PLOTTER T.V.N. ANALYST T.V.N.

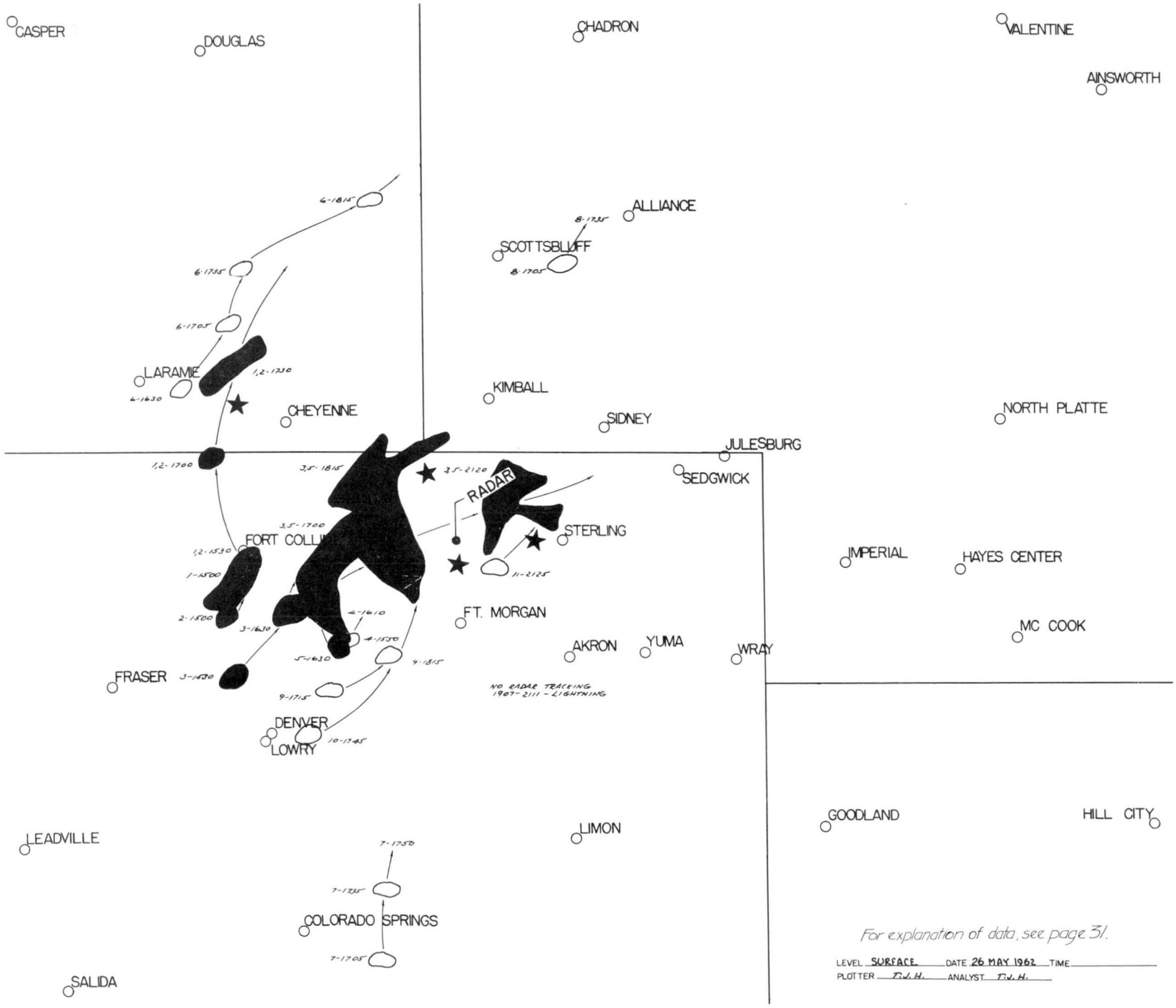


For explanation of data, see page 31.

ECHOS 24-29

LEVEL SURFACE DATE 25 MAY 1962 TIME

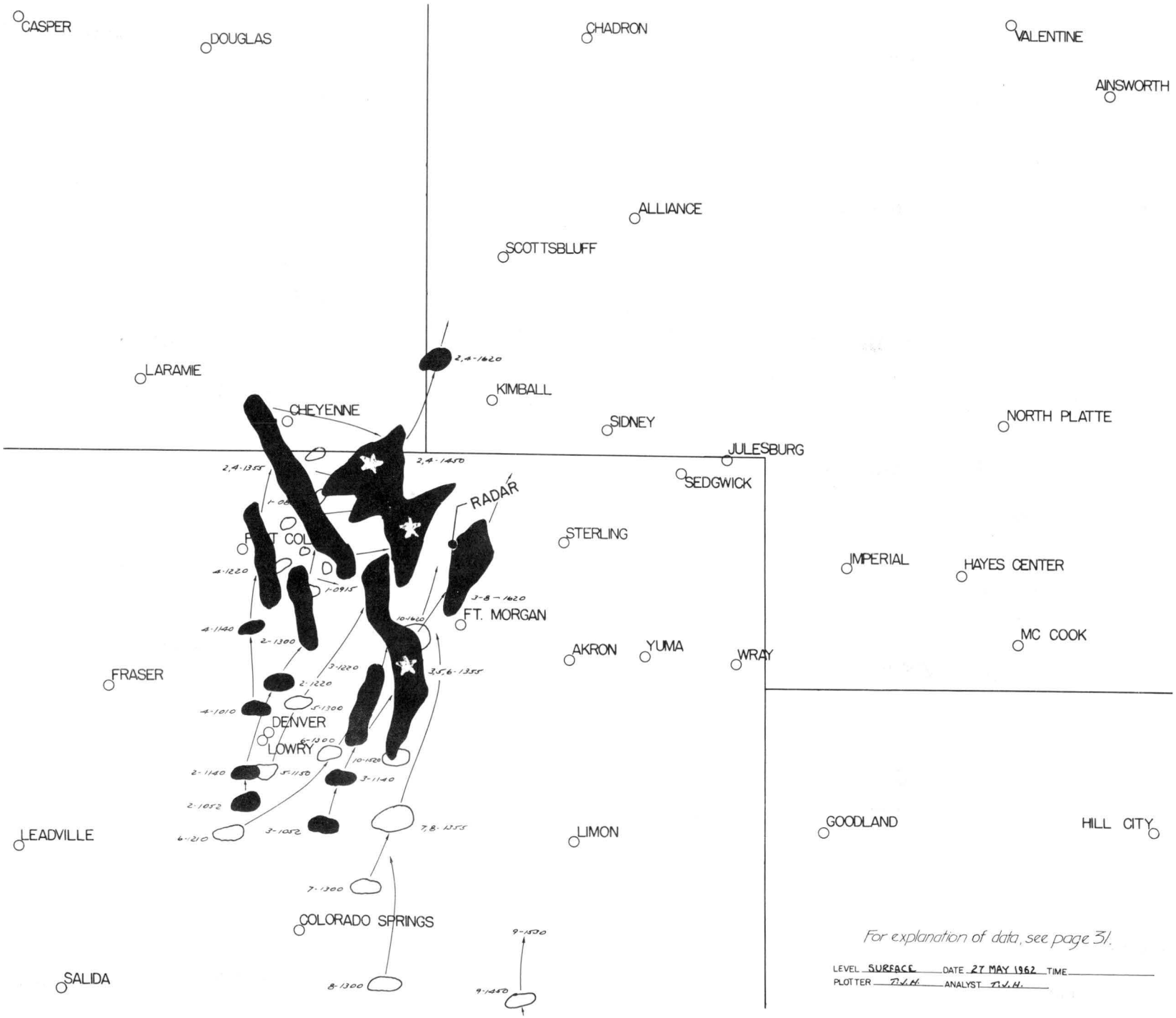
PLOTTER T.J.H. ANALYST T.J.H.



For explanation of data, see page 31.

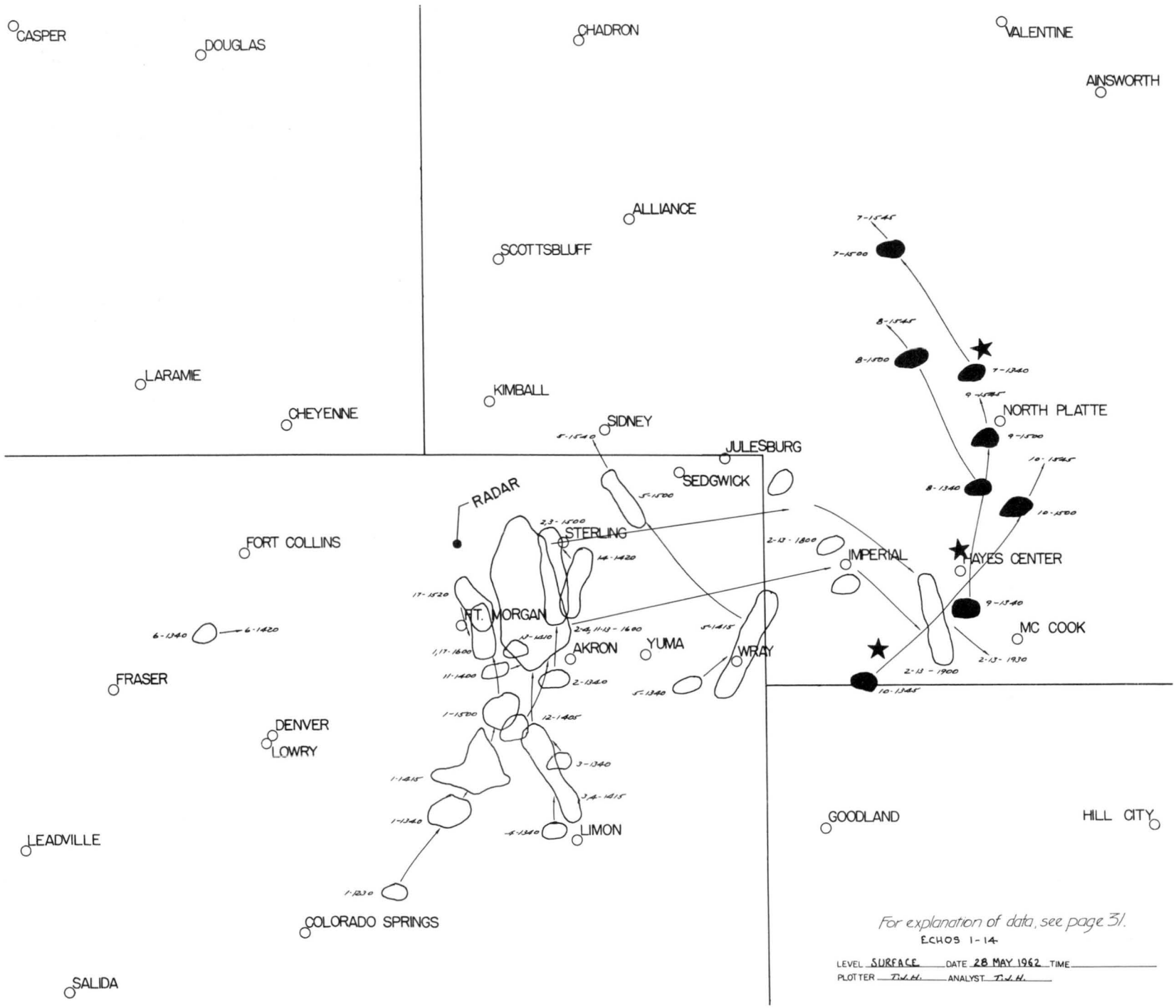
LEVEL SURFACE DATE 26 MAY 1962 TIME _____

PLOTTER T.W.H. ANALYST T.W.H.



For explanation of data, see page 31.

LEVEL SURFACE DATE 27 MAY 1962 TIME
PLOTTER T.V.H. ANALYST T.V.H.

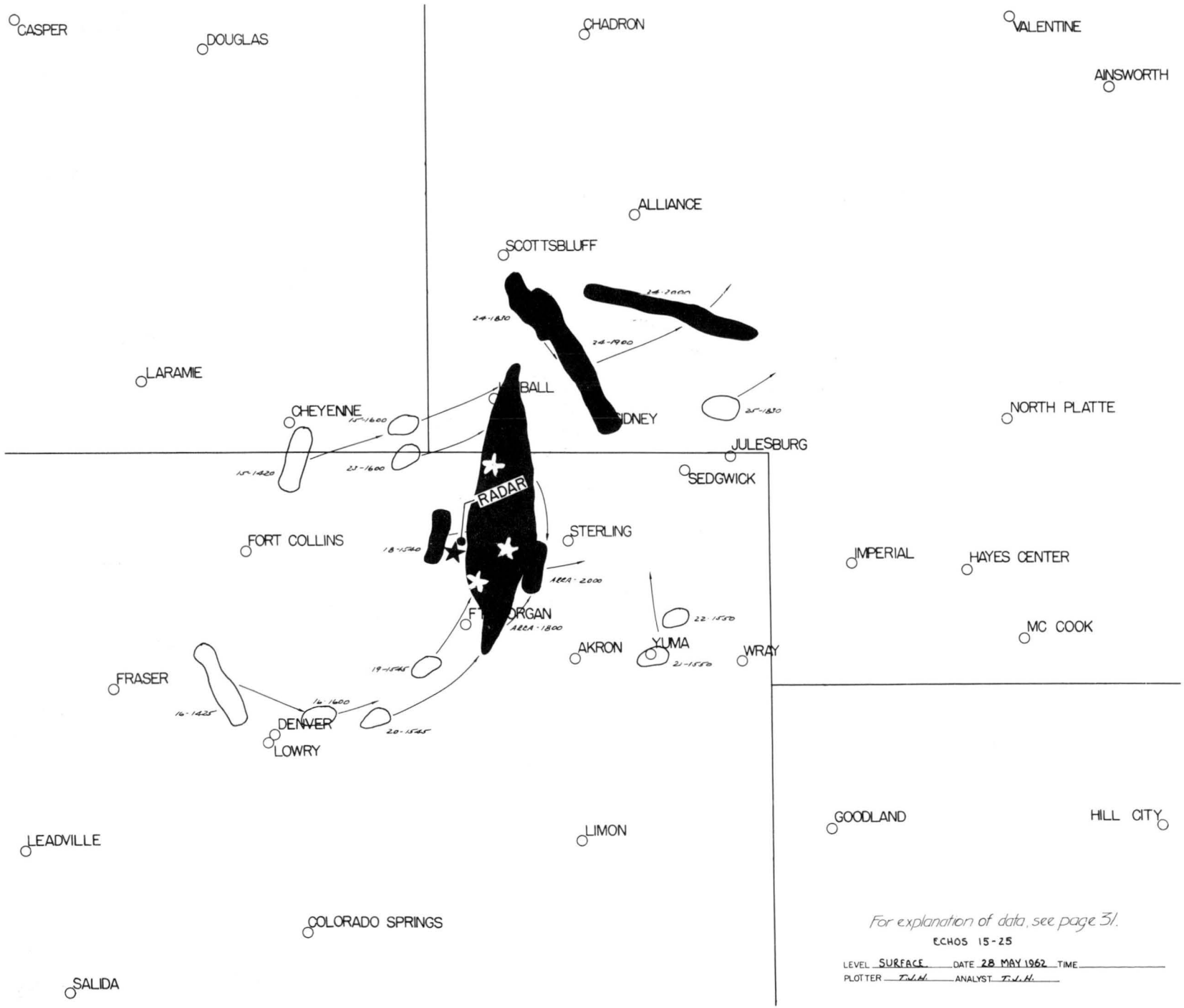


For explanation of data, see page 31.

ECHOS 1-14

LEVEL SURFACE DATE 28 MAY 1962 TIME

PLOTTER T.W.H. ANALYST T.W.H.

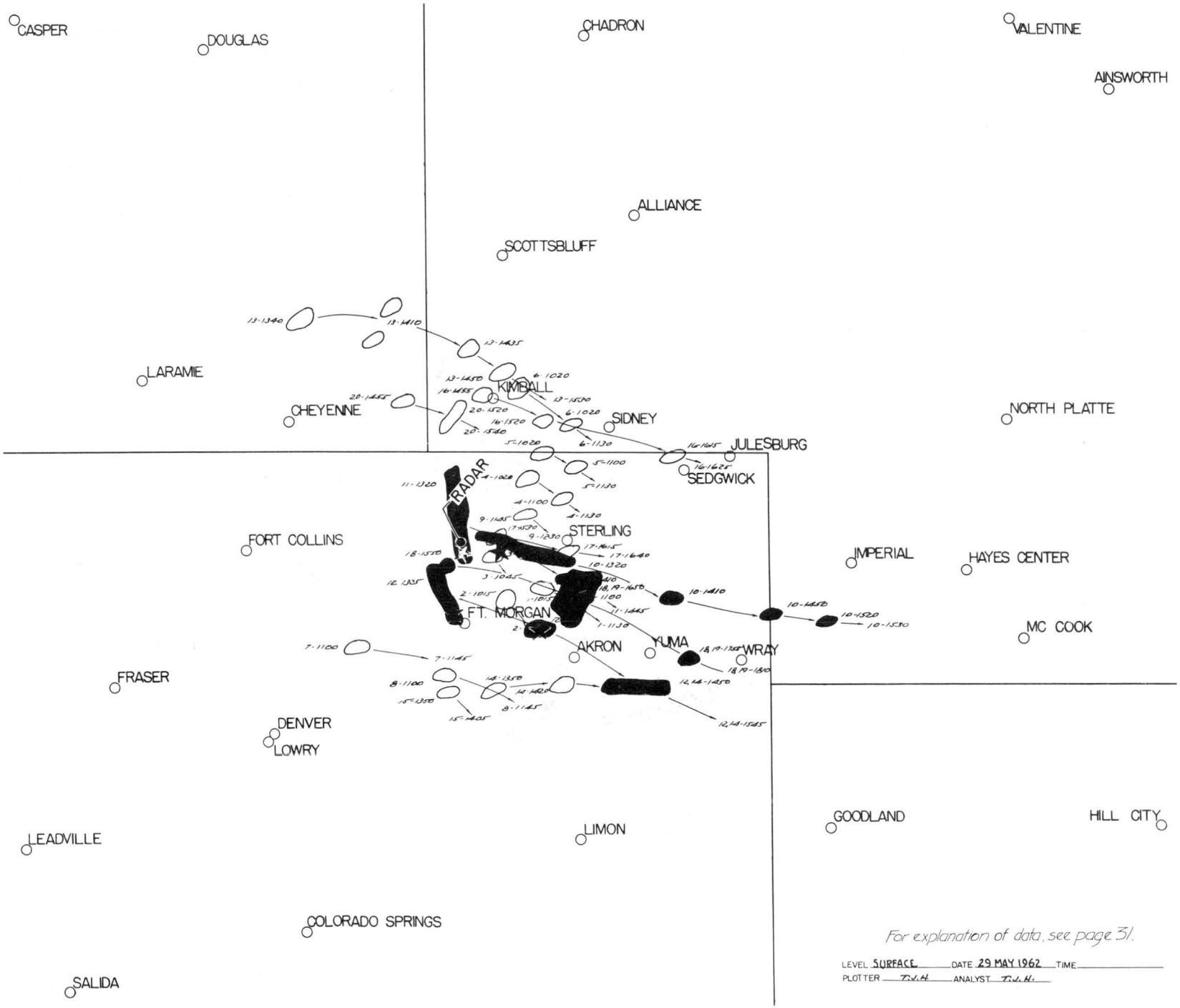


For explanation of data, see page 31.

ECHOS 15-25

LEVEL SURFACE. DATE 28 MAY 1962 TIME _____

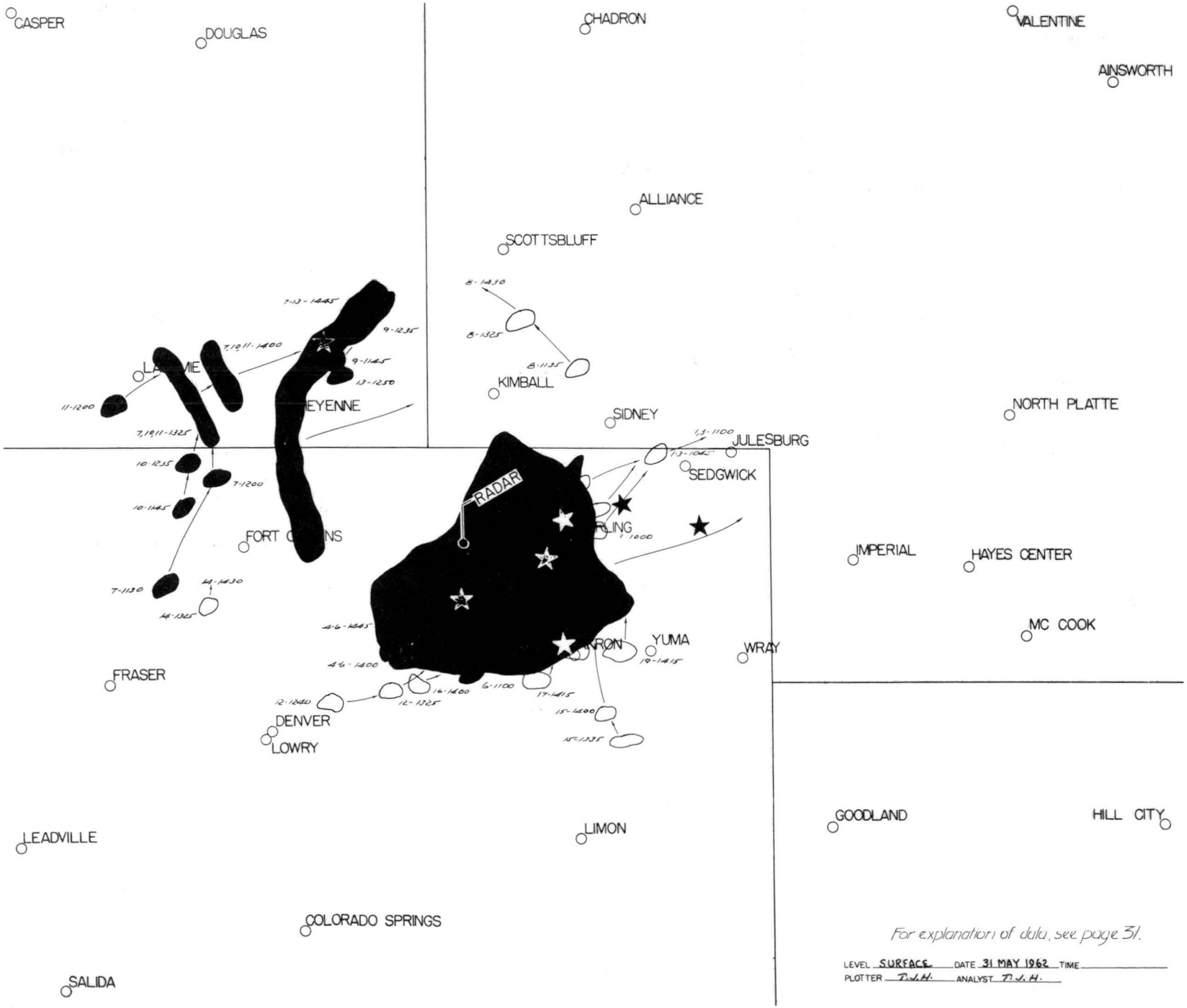
PLOTTER T.W.H. ANALYST T.W.H.



For explanation of data, see page 31.

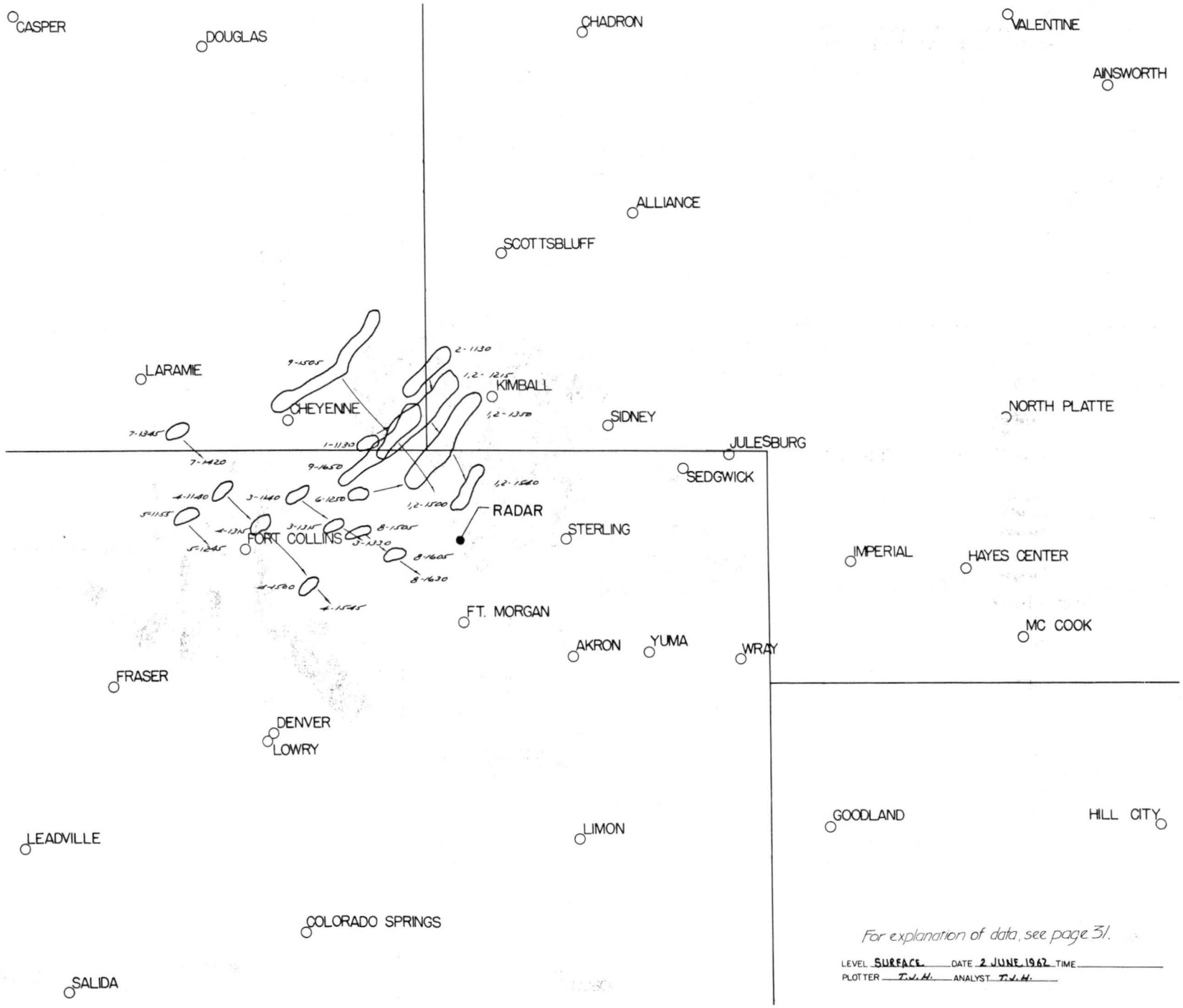
LEVEL SURFACE DATE 29 MAY 1962 TIME

PLOTTER T.W.H. ANALYST T.W.H.



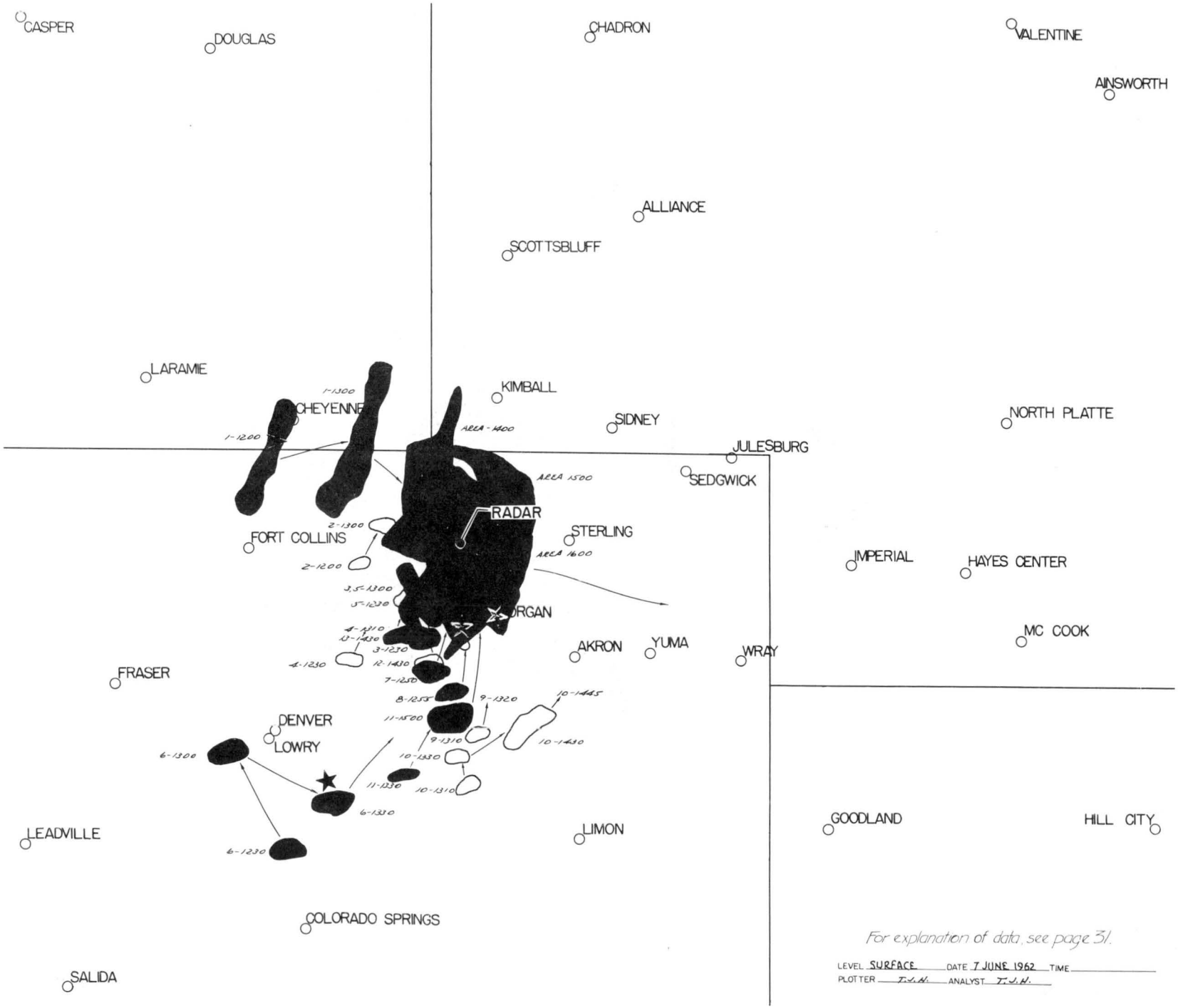
For explanation of data, see page 31.

LEVEL SURFACE DATE 31 MAY 1962 TIME
PLOTTER T.J.H. ANALYST T.J.H.



For explanation of data, see page 31.

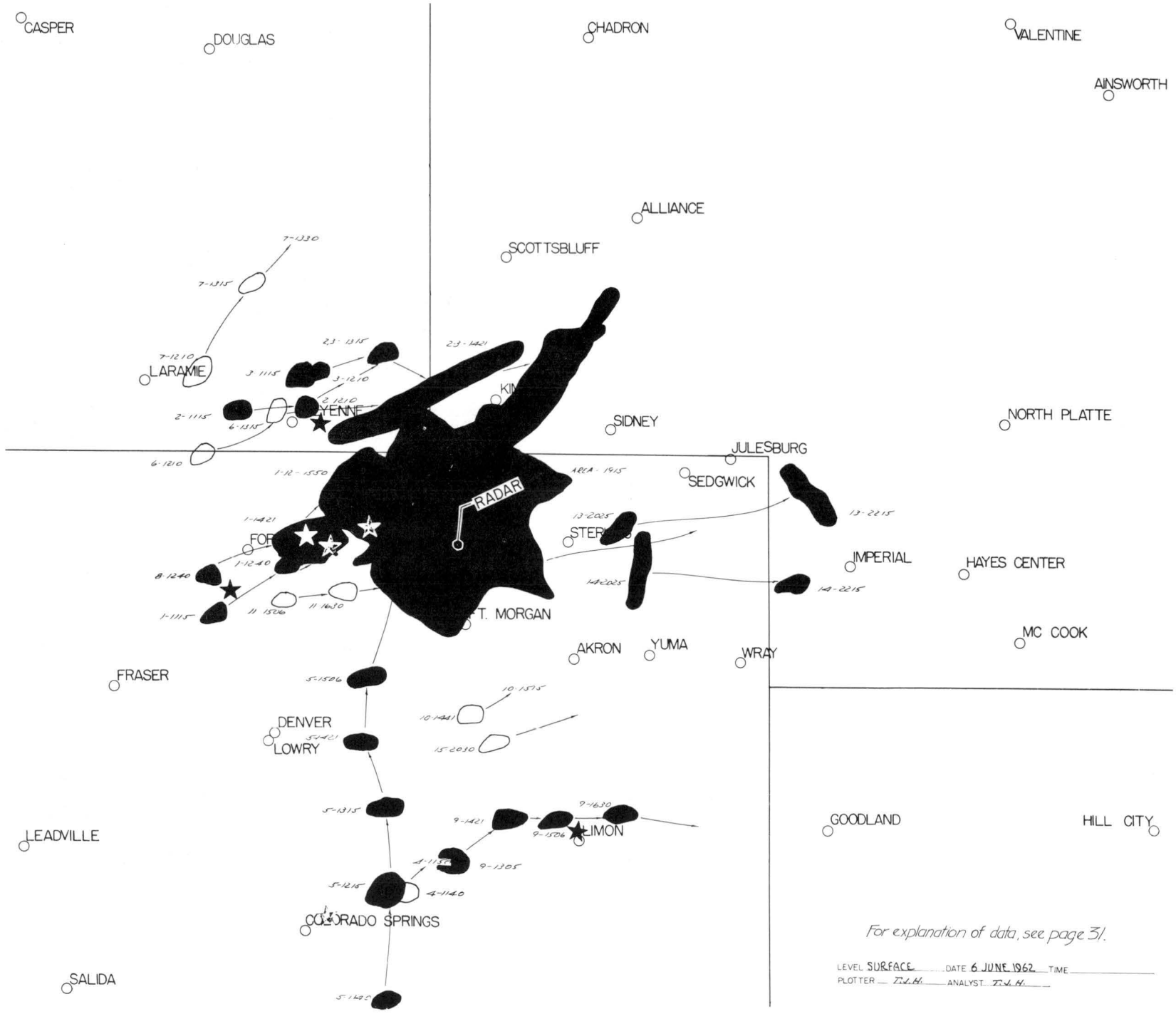
LEVEL SURFACE. DATE 2 JUNE 1962 TIME _____
PLOTTER T.V.H. ANALYST T.V.H.



For explanation of data, see page 31.

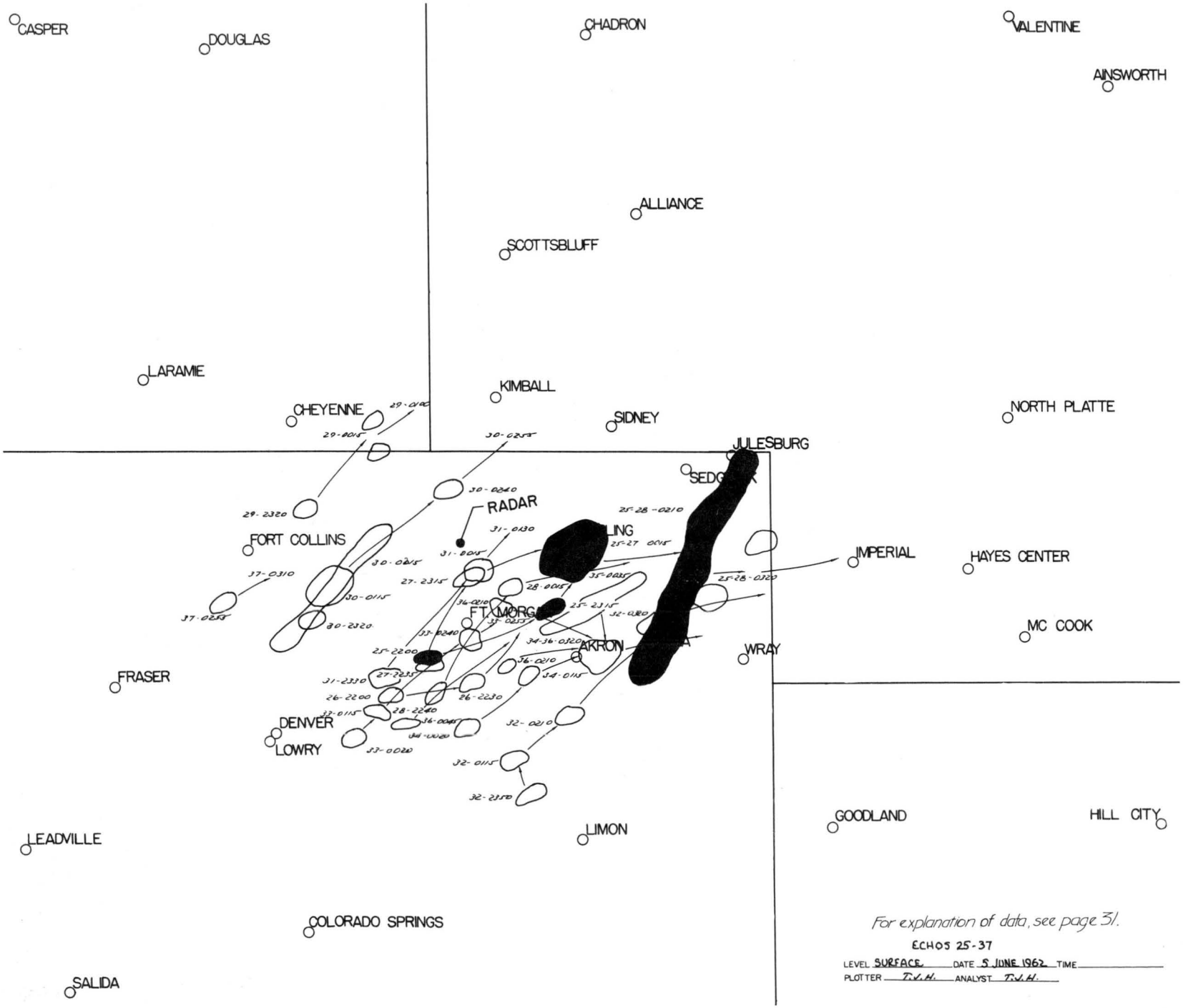
LEVEL SURFACE DATE 7 JUNE 1962 TIME _____

PLOTTER T.J.N. ANALYST T.J.N.



For explanation of data, see page 31.

LEVEL SURFACE DATE 6 JUNE 1962 TIME
PLOTTER T.V.H. ANALYST T.V.H.

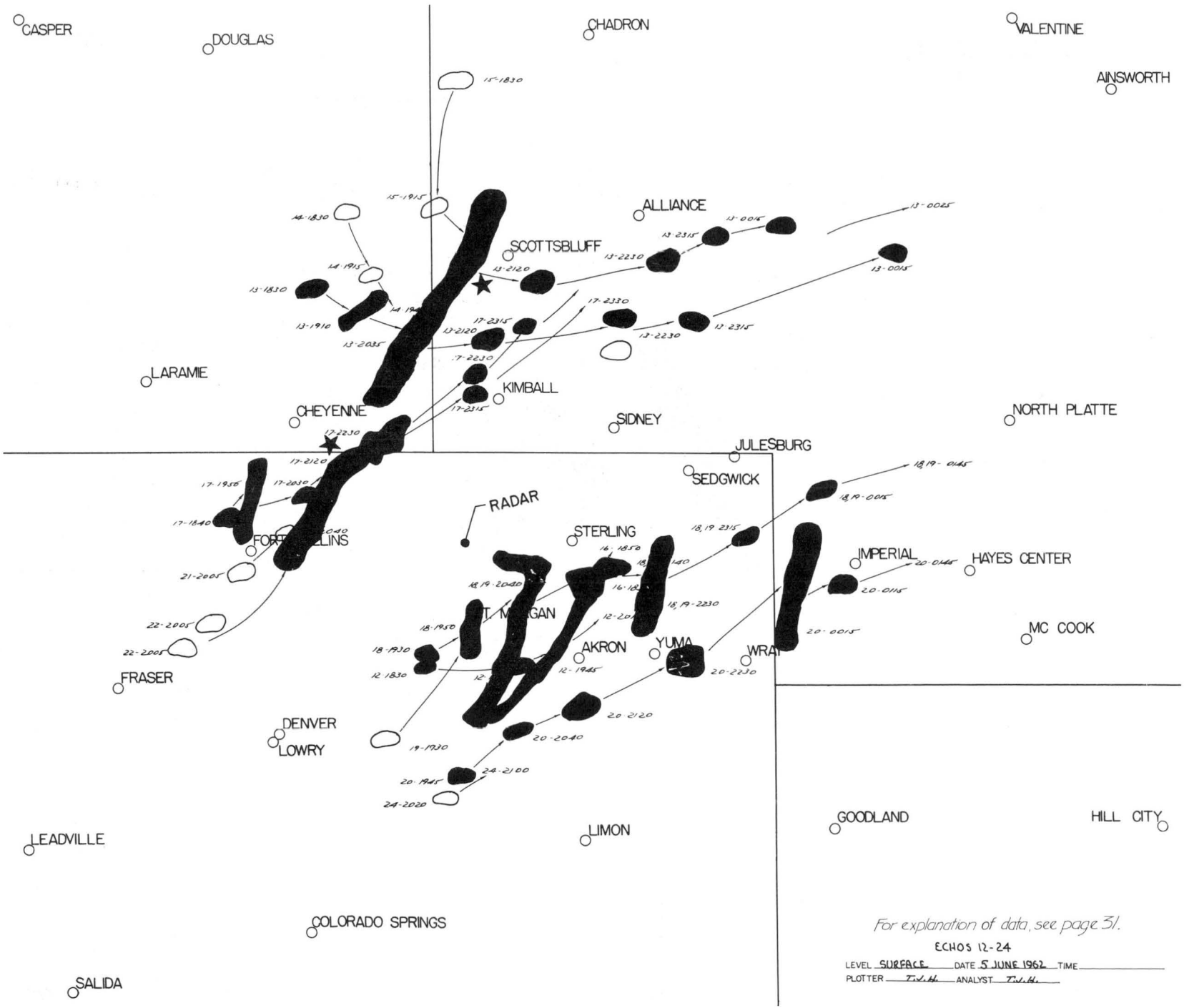


For explanation of data, see page 31.

ECHOS 25-37

LEVEL SURFACE DATE 5 JUNE 1962 TIME _____

PLOTTER T.V.H. ANALYST T.V.H.

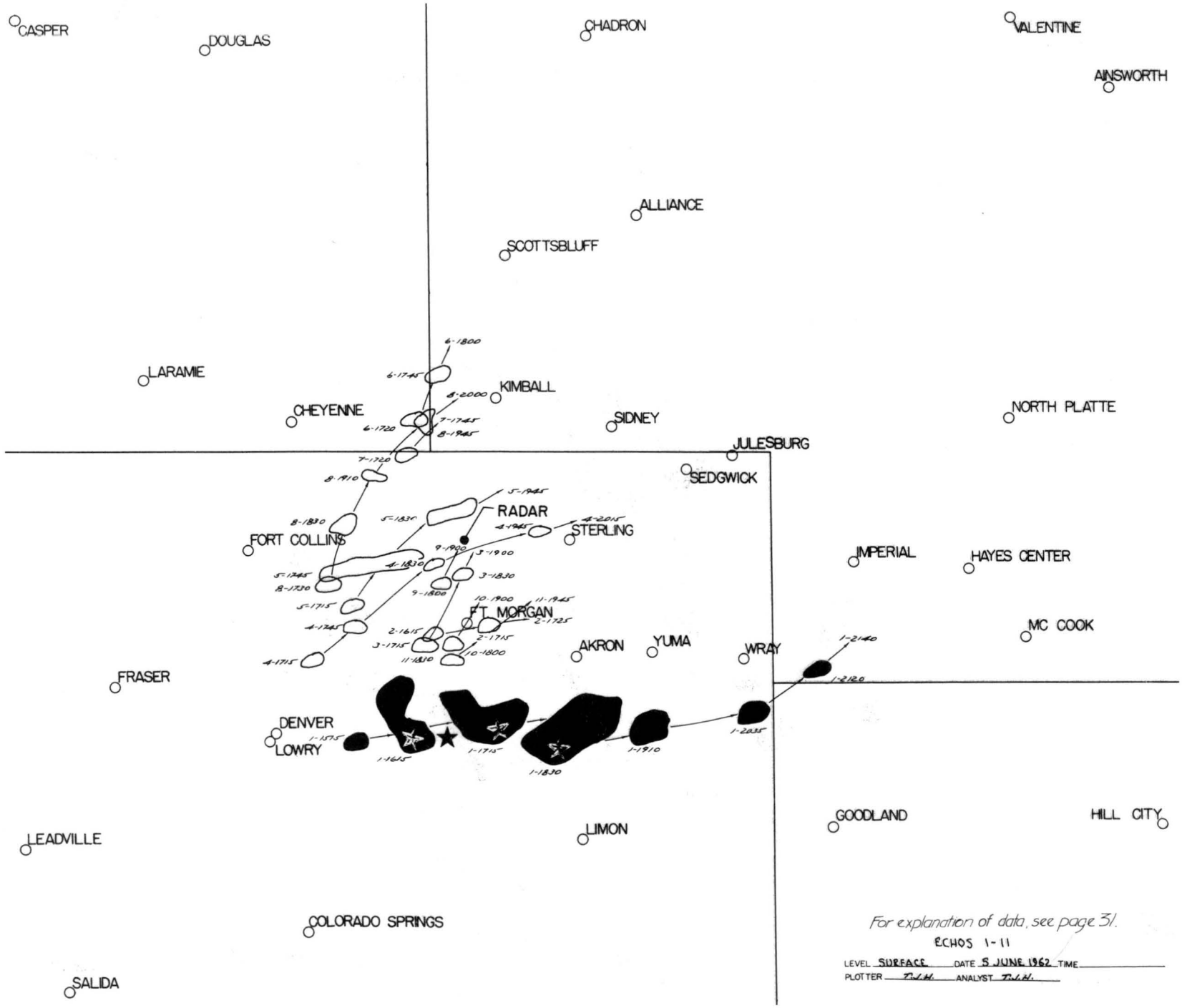


For explanation of data, see page 31.

ECHOS 12-24

LEVEL SURFACE DATE 5 JUNE 1962 TIME

PLOTTER T.V.H. ANALYST T.V.H.

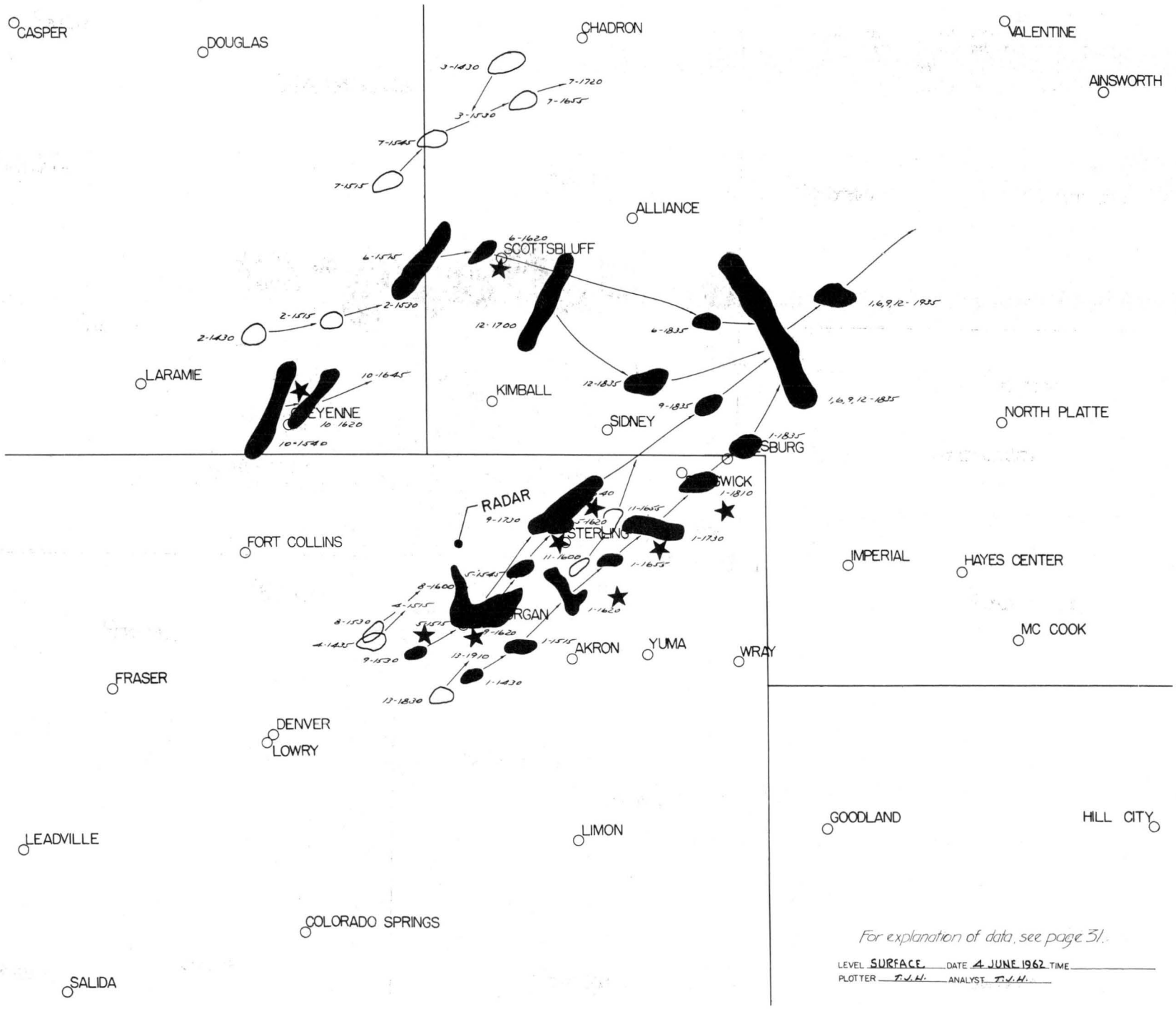


For explanation of data, see page 31.

ECHOS 1-11

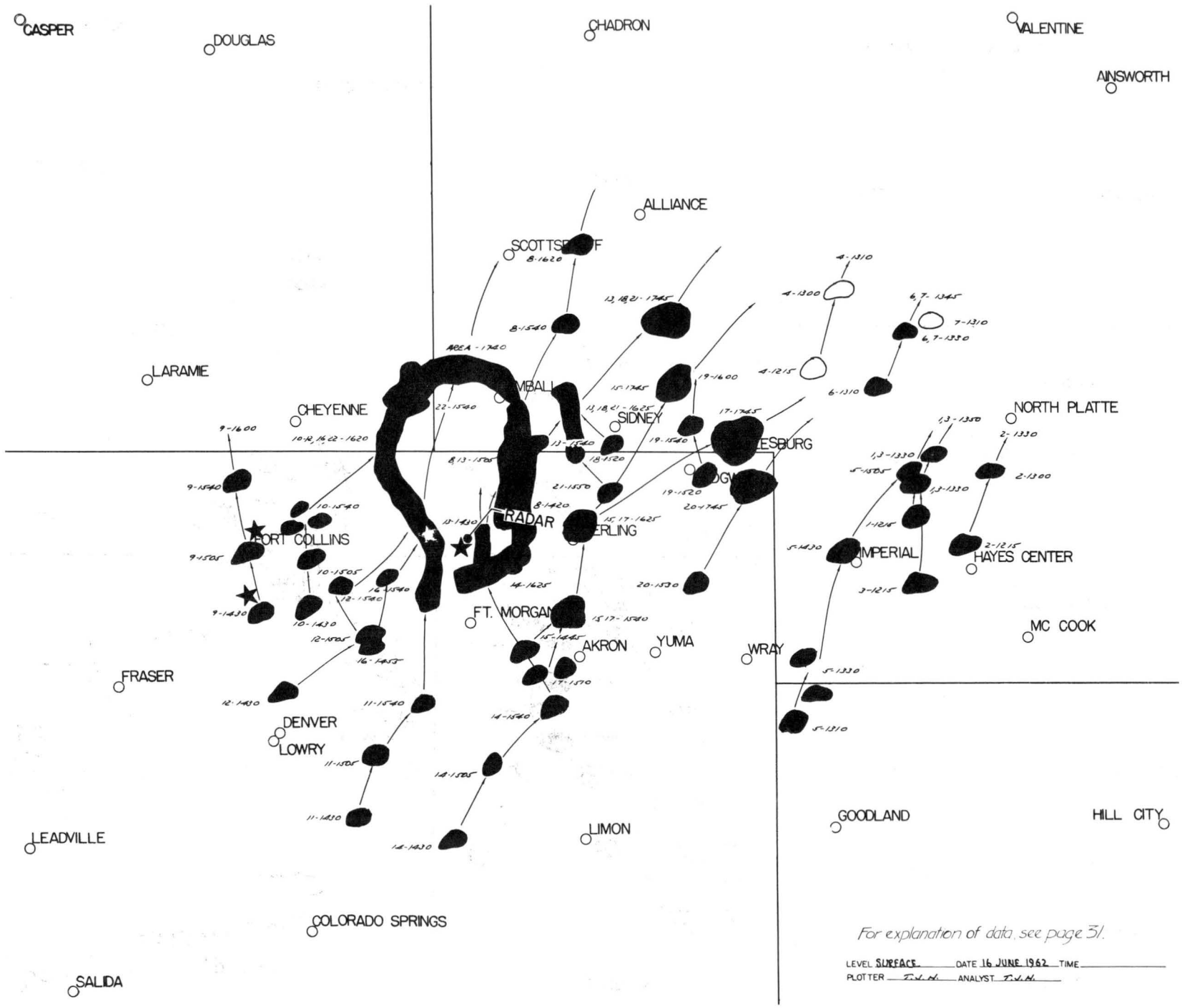
LEVEL SURFACE DATE 5 JUNE 1962 TIME

PLOTTER T.W.H. ANALYST T.W.H.



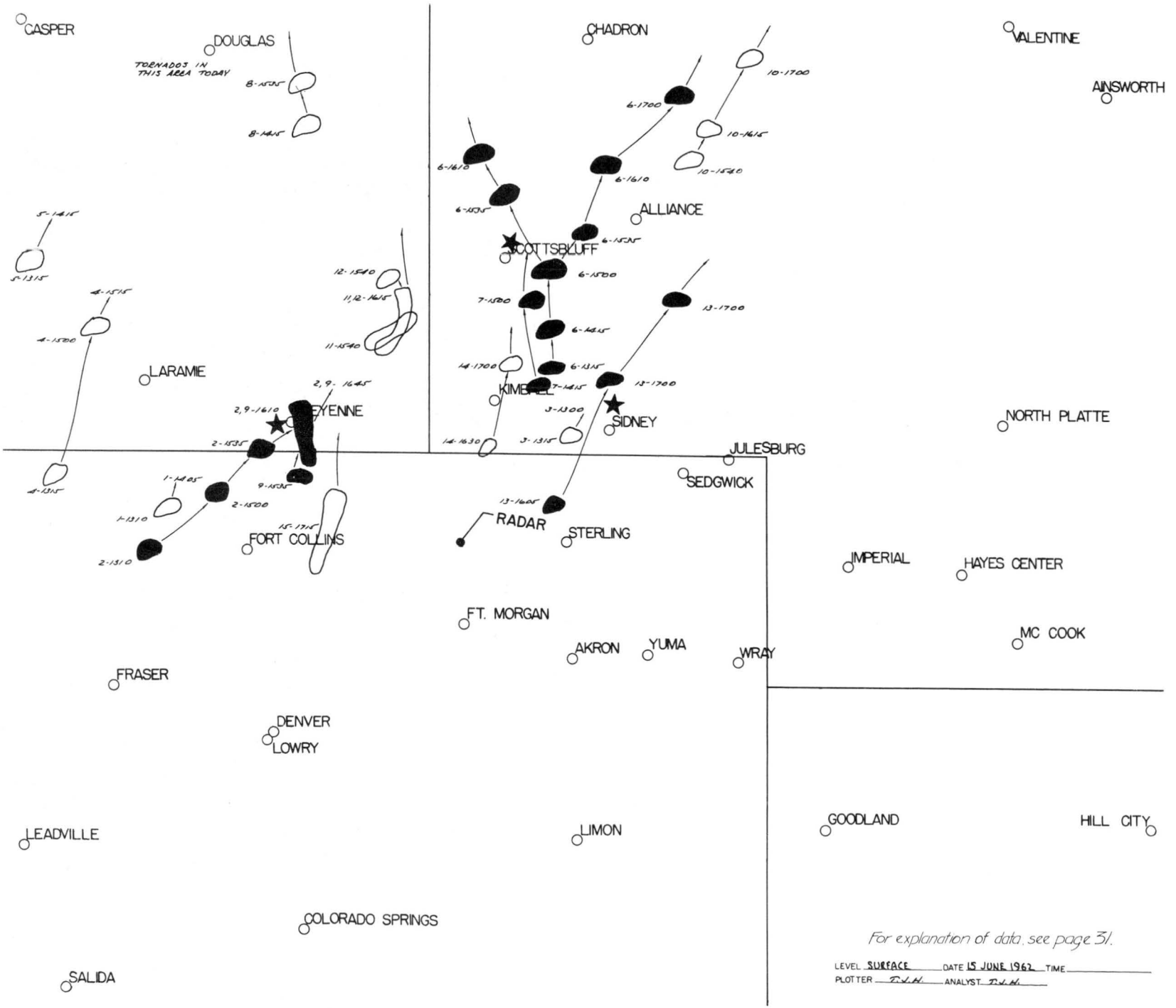
For explanation of data, see page 31.

LEVEL SURFACE DATE 4 JUNE 1962 TIME
PLOTTER T.V.H. ANALYST T.V.H.



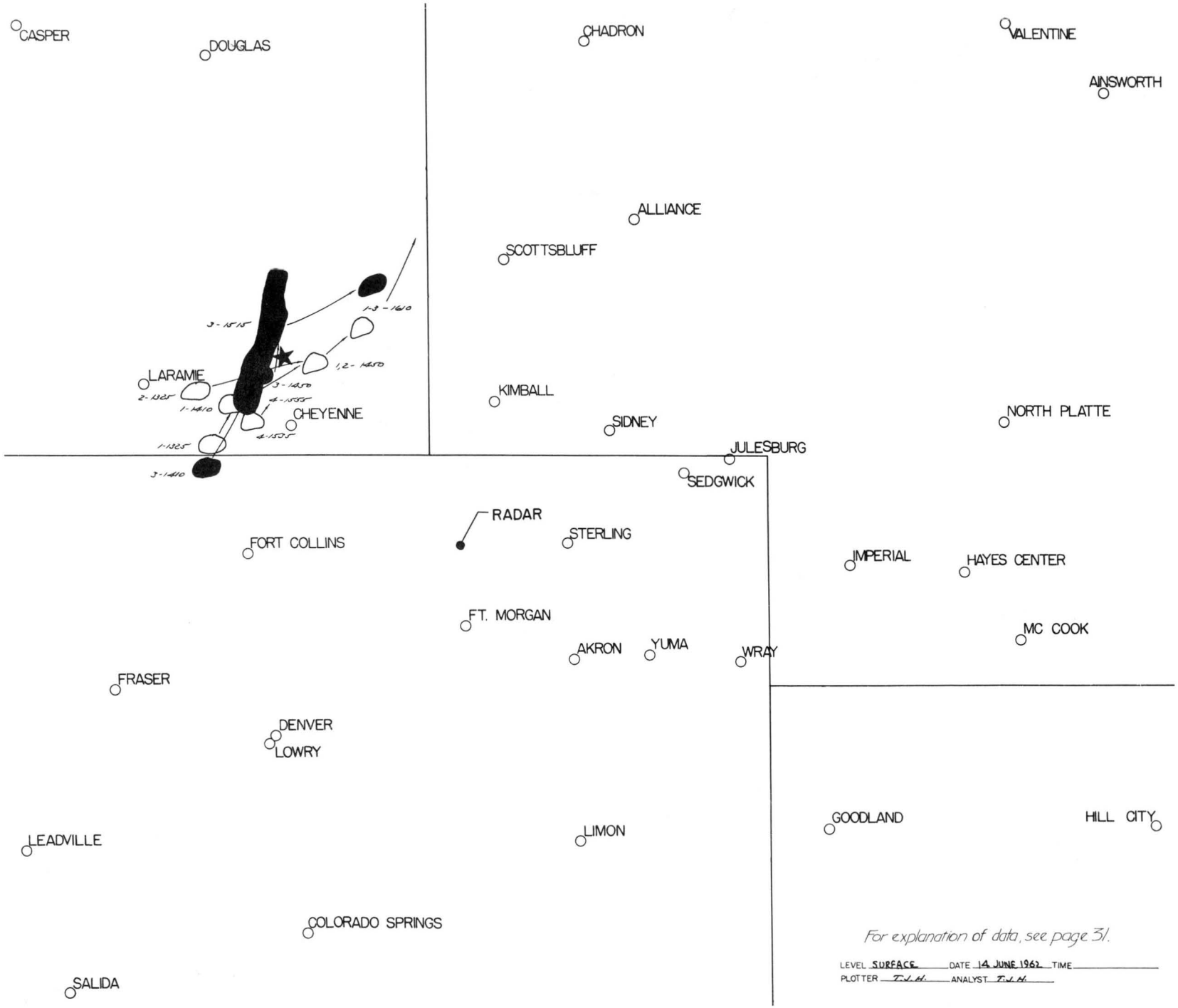
For explanation of data, see page 31.

LEVEL SURFACE DATE 16 JUNE 1962 TIME _____
PLOTTER T.V.N. ANALYST T.V.N.



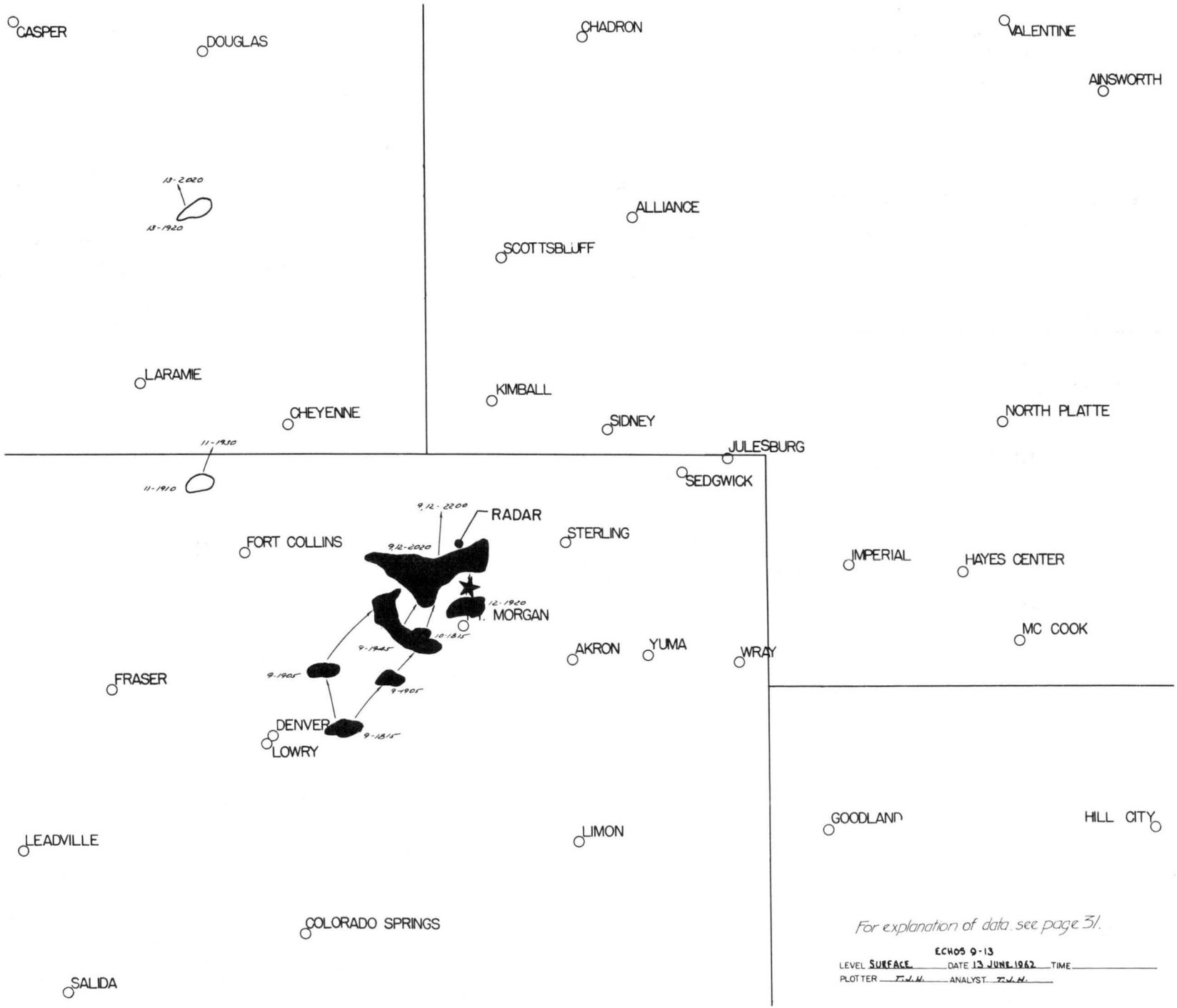
For explanation of data, see page 31.

LEVEL SURFACE DATE 15 JUNE 1962 TIME _____
PLOTTER D.V.H. ANALYST D.V.H.



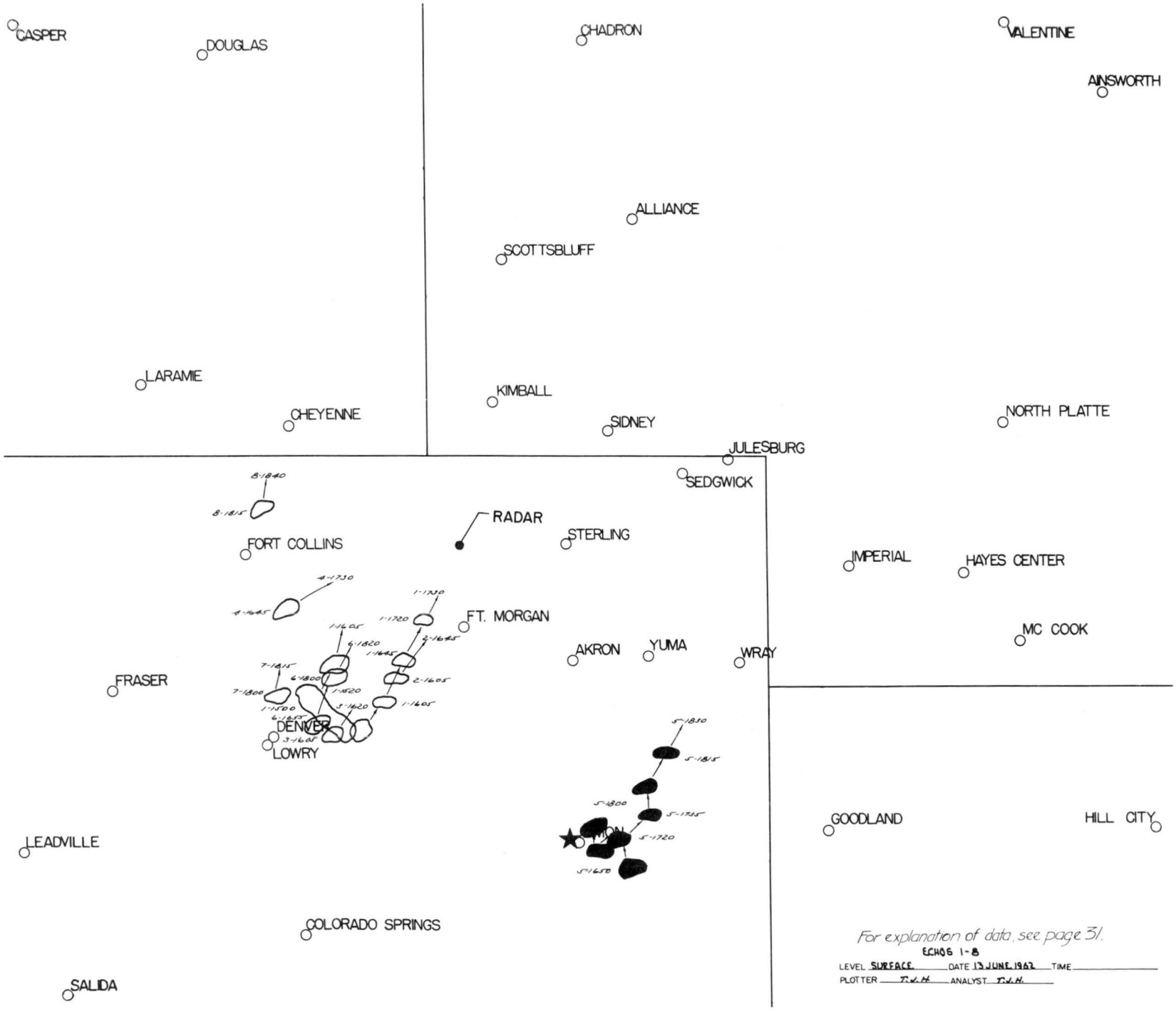
For explanation of data, see page 31.

LEVEL SURFACE DATE 14 JUNE 1962 TIME _____
PLOTTER T.V.H. ANALYST T.V.H.



For explanation of data, see page 31.

ECHOS 9-13
LEVEL SURFACE DATE 13 JUNE 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.



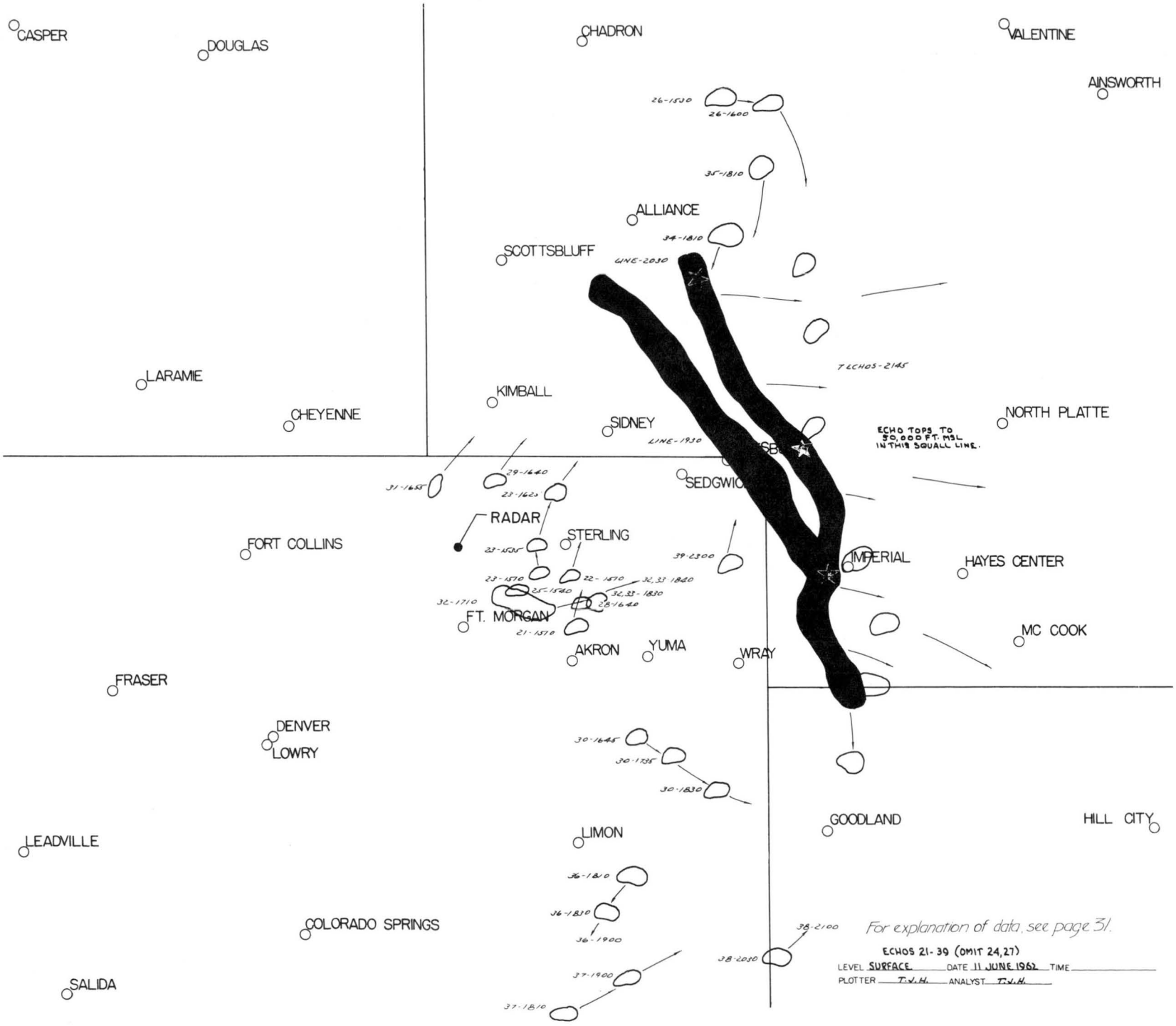
For explanation of data, see page 31.

ECHOS 1-8

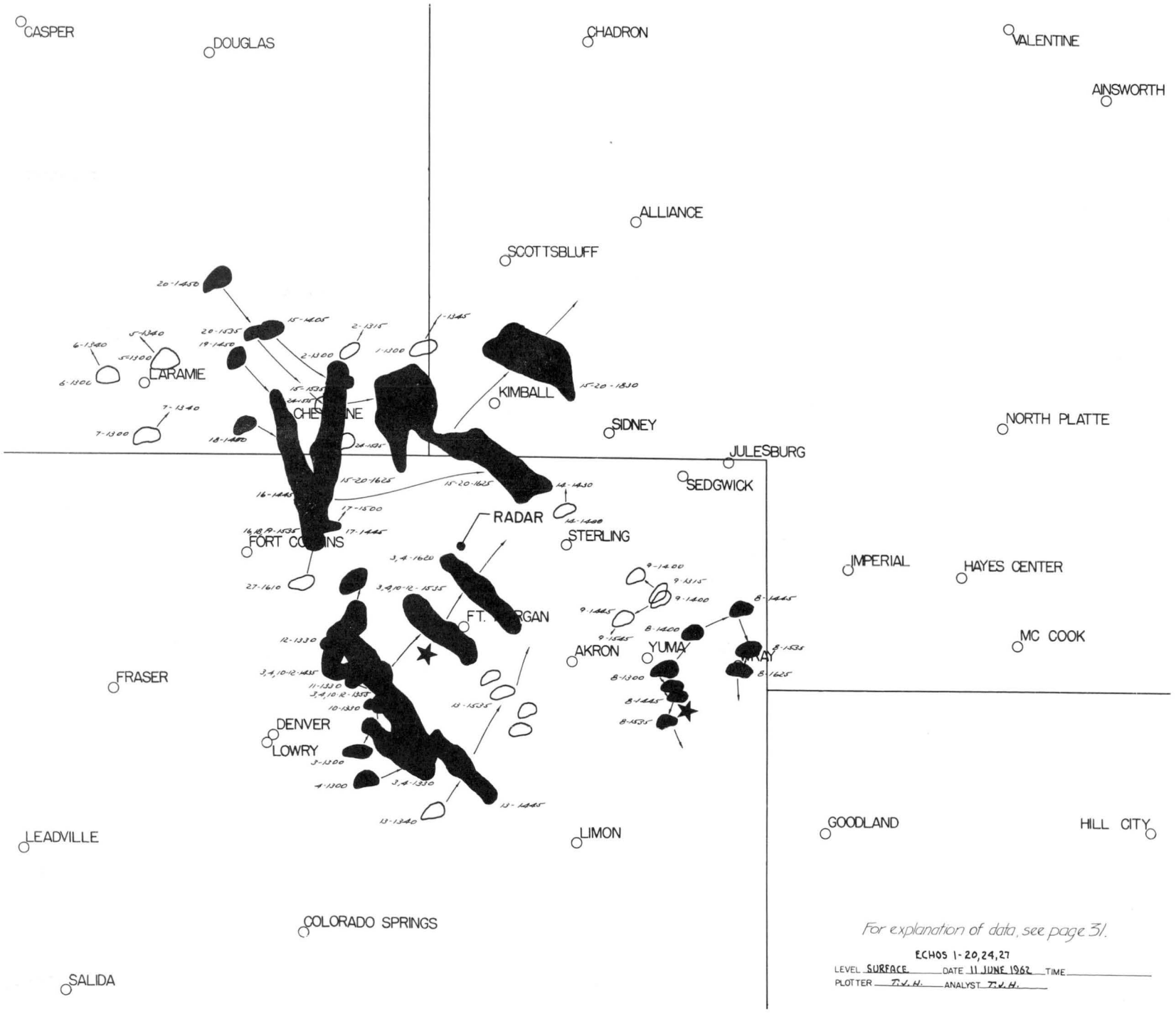
LEVEL SURFACE DATE 13 JUNE 1962 TIME _____

PLOTTER T.W.H. ANALYST T.W.H.


CASPER
DOUGLAS
CHADRON
VALENTINE
AINSWORTH
ALLIANCE
SCOTTSBLUFF
LARAMIE
CHEYENNE
KIMBALL
SIDNEY
NORTH PLATTE
JULESBURG
SEDGWICK
RADAR
FORT COLLINS
STERLING
IMPERIAL
HAYES CENTER
FT. MORGAN
AKRON
MC COOK
FRASER
DENVER
LOWRY
LEADVILLE
LIMON
GOODLAND
HILL CITY
COLORADO SPRINGS
SALIDA
For explanation of data, see page 31.
LEVEL SURFACE DATE 12 JUNE 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.



For explanation of data, see page 31.

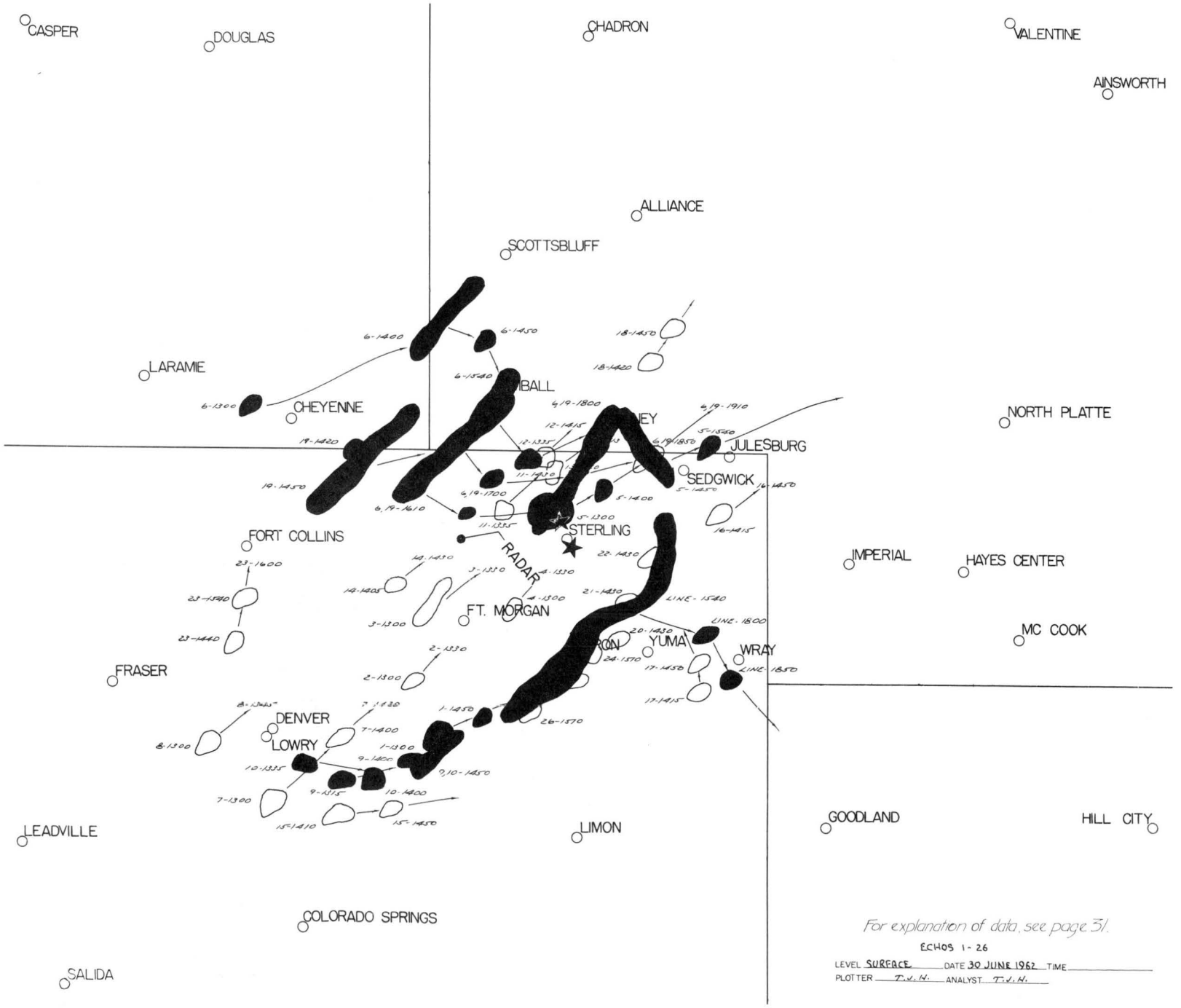


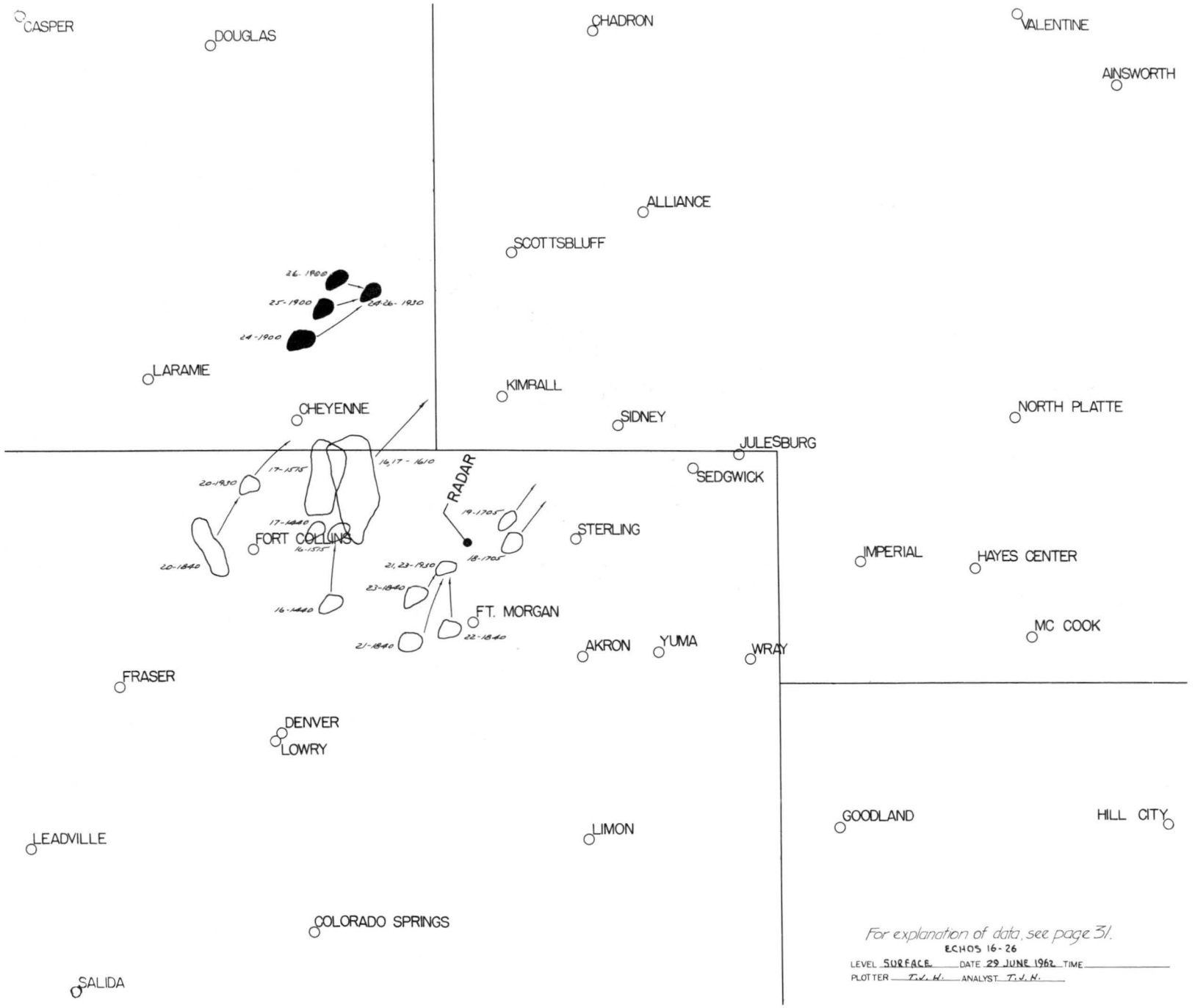
For explanation of data, see page 31.

ECHOS 1-20, 24, 27

LEVEL SURFACE DATE 11 JUNE 1962 TIME

PLOTTER T.V.H. ANALYST T.V.H.


CASPER
DOUGLAS
CHADRON
VALENTINE
AINSWORTH
ALLIANCE
SCOTTSBLUFF
LARAMIE
CHEYENNE
IBALL
JULESBURG
SEDGWICK
NORTH PLATTE
STERLING
FORT COLLINS
RADAR
IMPERIAL
HAYES CENTER
FT. MORGAN
MC COOK
YUMA
WRAY
FRASER
DENVER
LOWRY
GOODLAND
HILL CITY
LEADVILLE
LIMON
COLORADO SPRINGS
SALIDA
For explanation of data, see page 31.
ECHOS 1-26
LEVEL SURFACE DATE 30 JUNE 1962 TIME
PLOTTER T.J.H. ANALYST T.J.H.

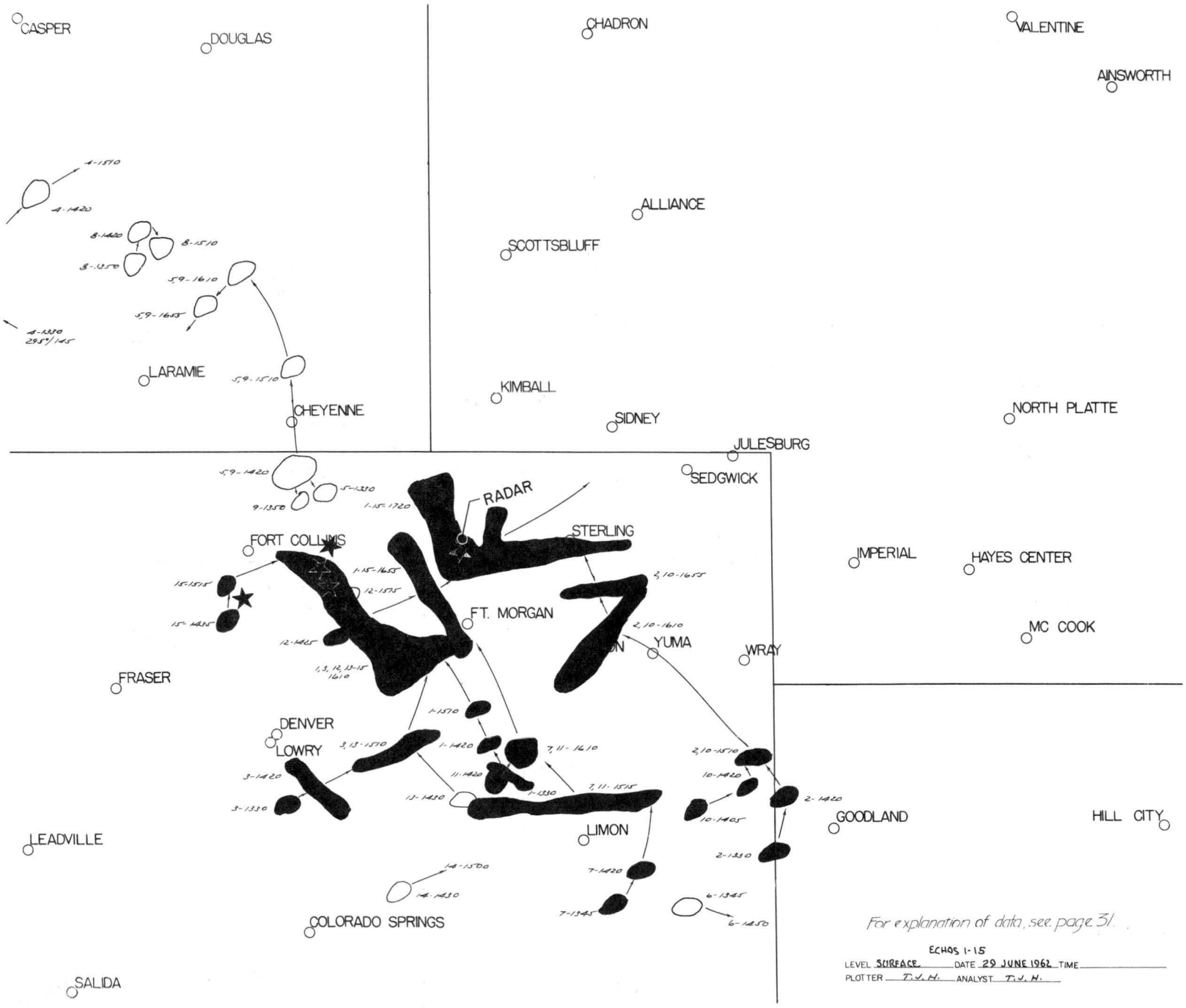


For explanation of data, see page 31.

ECHOS 16-26

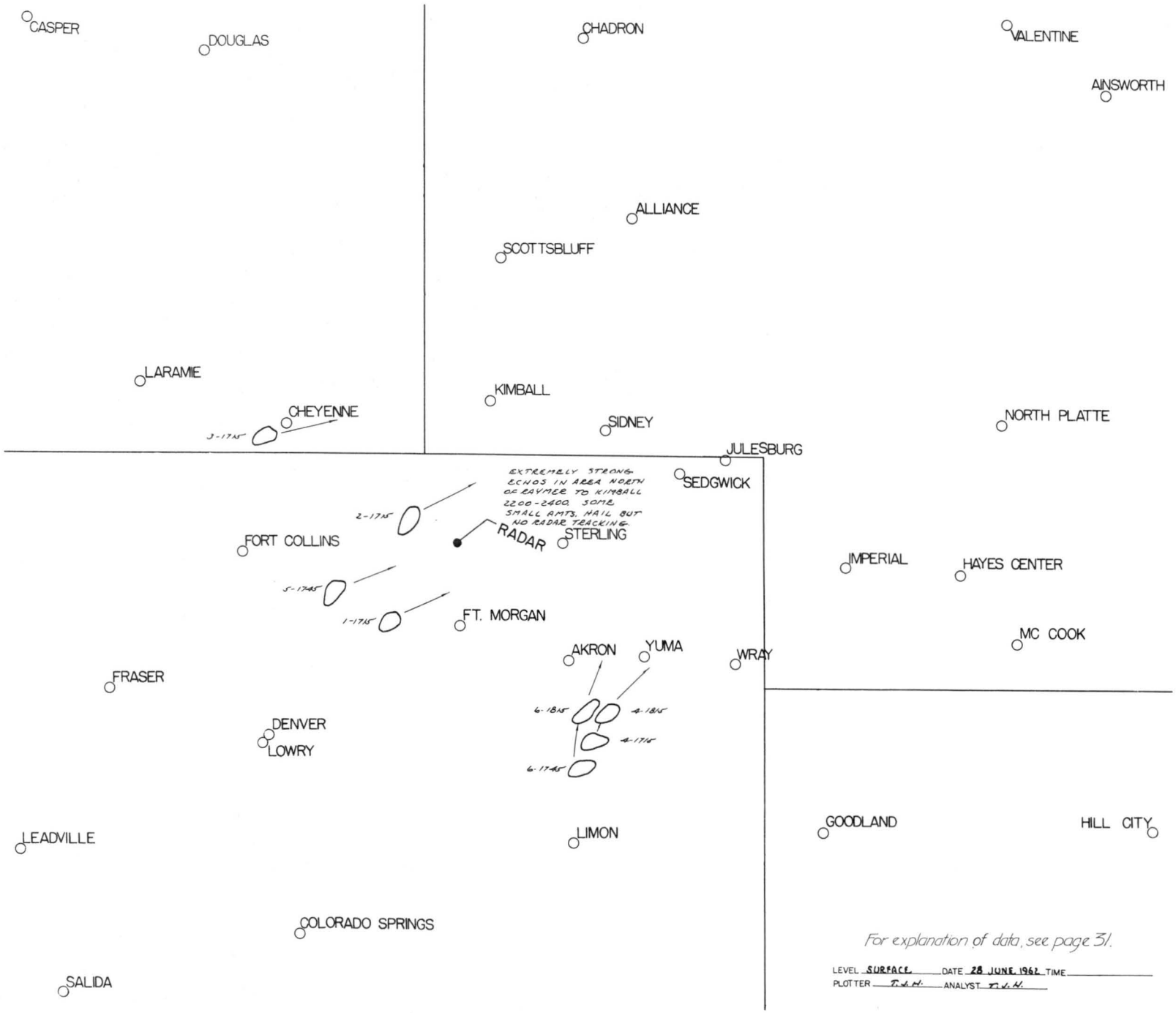
LEVEL SURFACE DATE 29 JUNE 1962 TIME

PLOTTER T.V.H. ANALYST T.J.N.



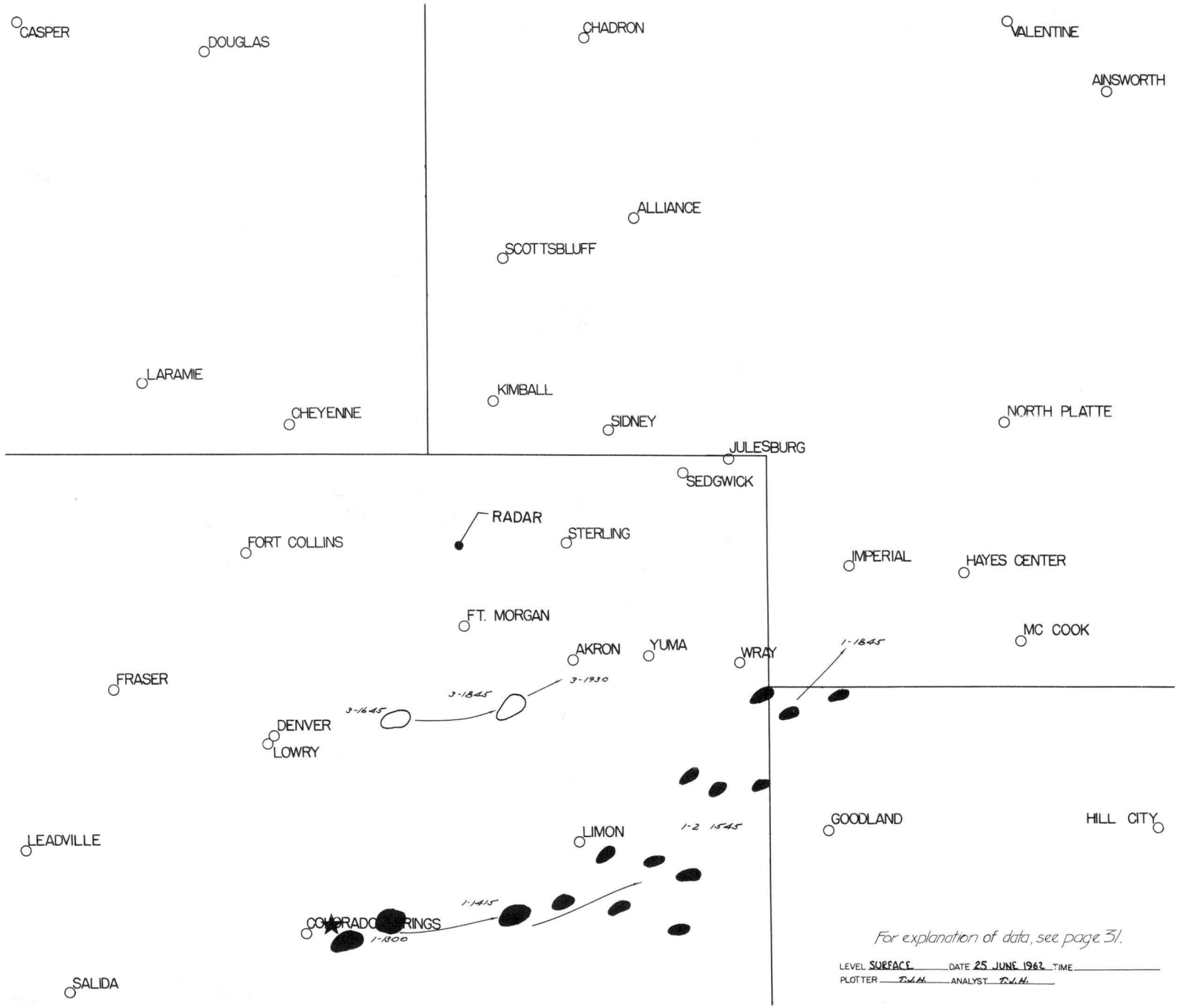
For explanation of data, see page 31.

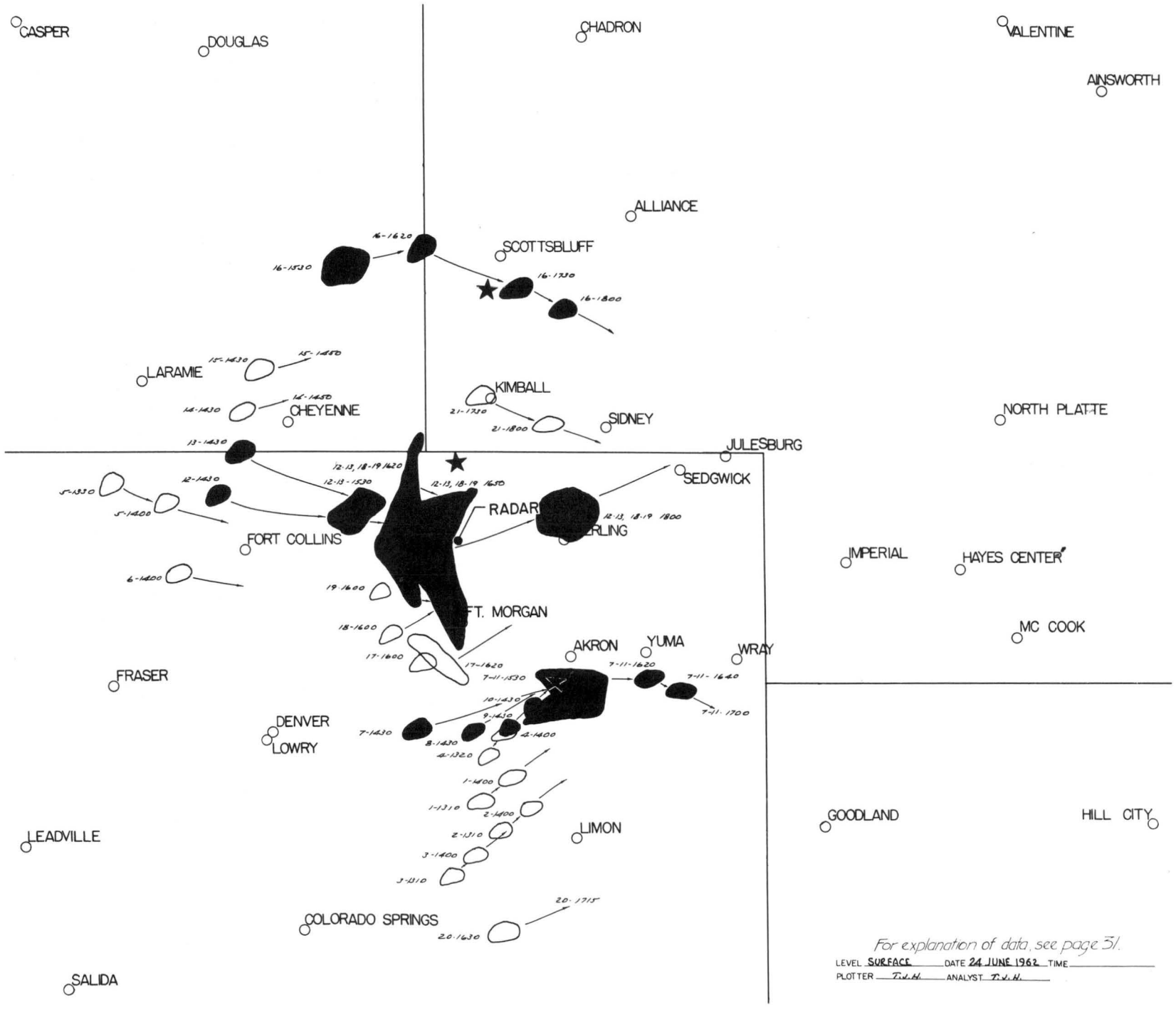
ECHOS 1-15
LEVEL SURFACE DATE 29 JUNE 1962 TIME
PLOTTER T.J.H. ANALYST T.J.H.



For explanation of data, see page 31.

LEVEL SURFACE DATE 28 JUNE 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.

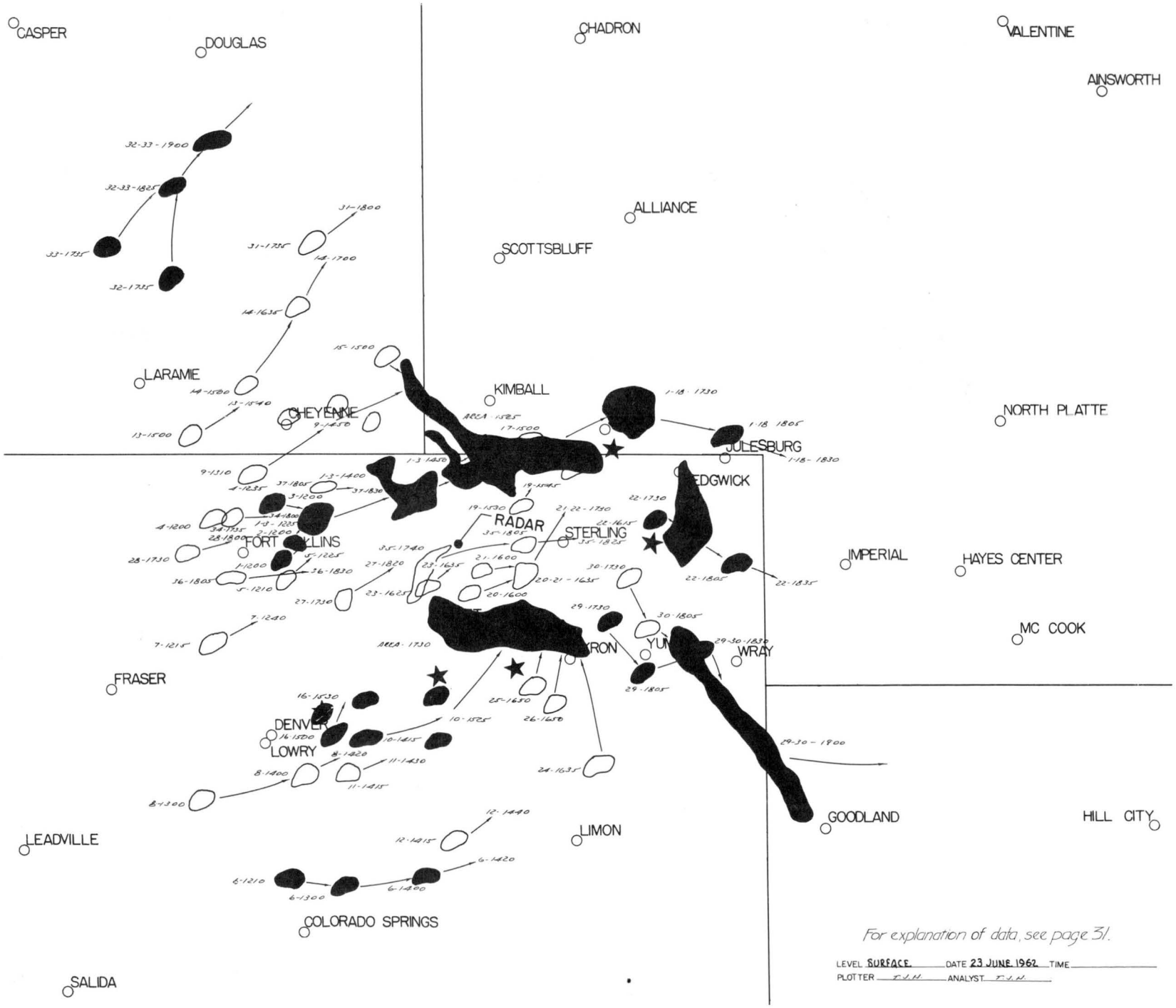

CASPER
DOUGLAS
CHADRON
VALENTINE
AINSWORTH
ALLIANCE
SCOTTSBLUFF
LARAMIE
KIMBALL
CHEYENNE
SIDNEY
NORTH PLATTE
JULESBURG
SEDGWICK
RADAR
FORT COLLINS
STERLING
IMPERIAL
HAYES CENTER
FT. MORGAN
MC COOK
AKRON
YUMA
WRAY
1-1845
FRASER
3-1930
3-1845
3-1645
DENVER
LOWRY
LEADVILLE
LIMON
1-2 1545
GOODLAND
HILL CITY
1-1415
COLORADO SPRINGS
1-1800
SALIDA
For explanation of data, see page 31.
LEVEL SURFACE DATE 25 JUNE 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.



For explanation of data, see page 31.

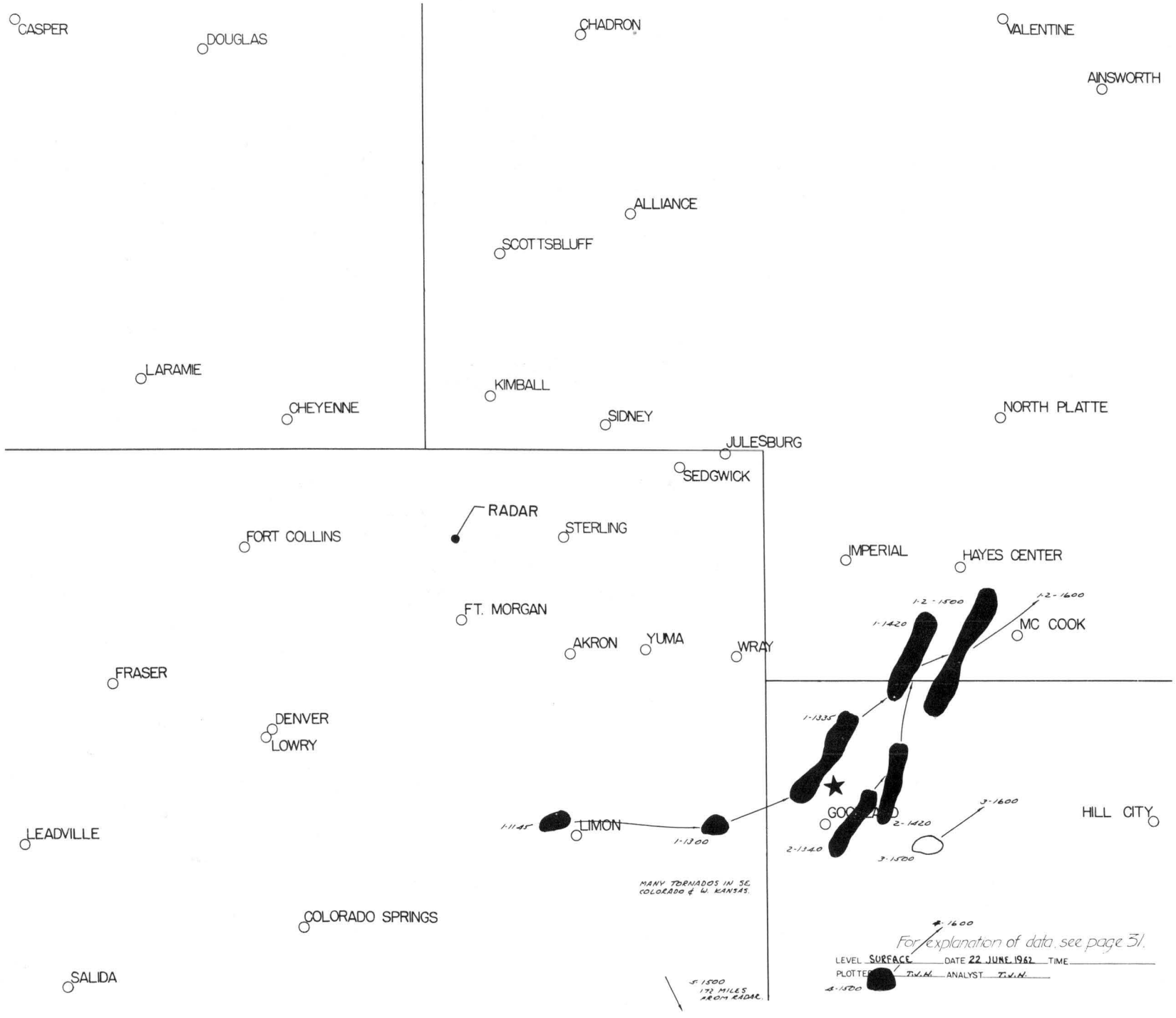
LEVEL SURFACE DATE 24 JUNE 1962 TIME

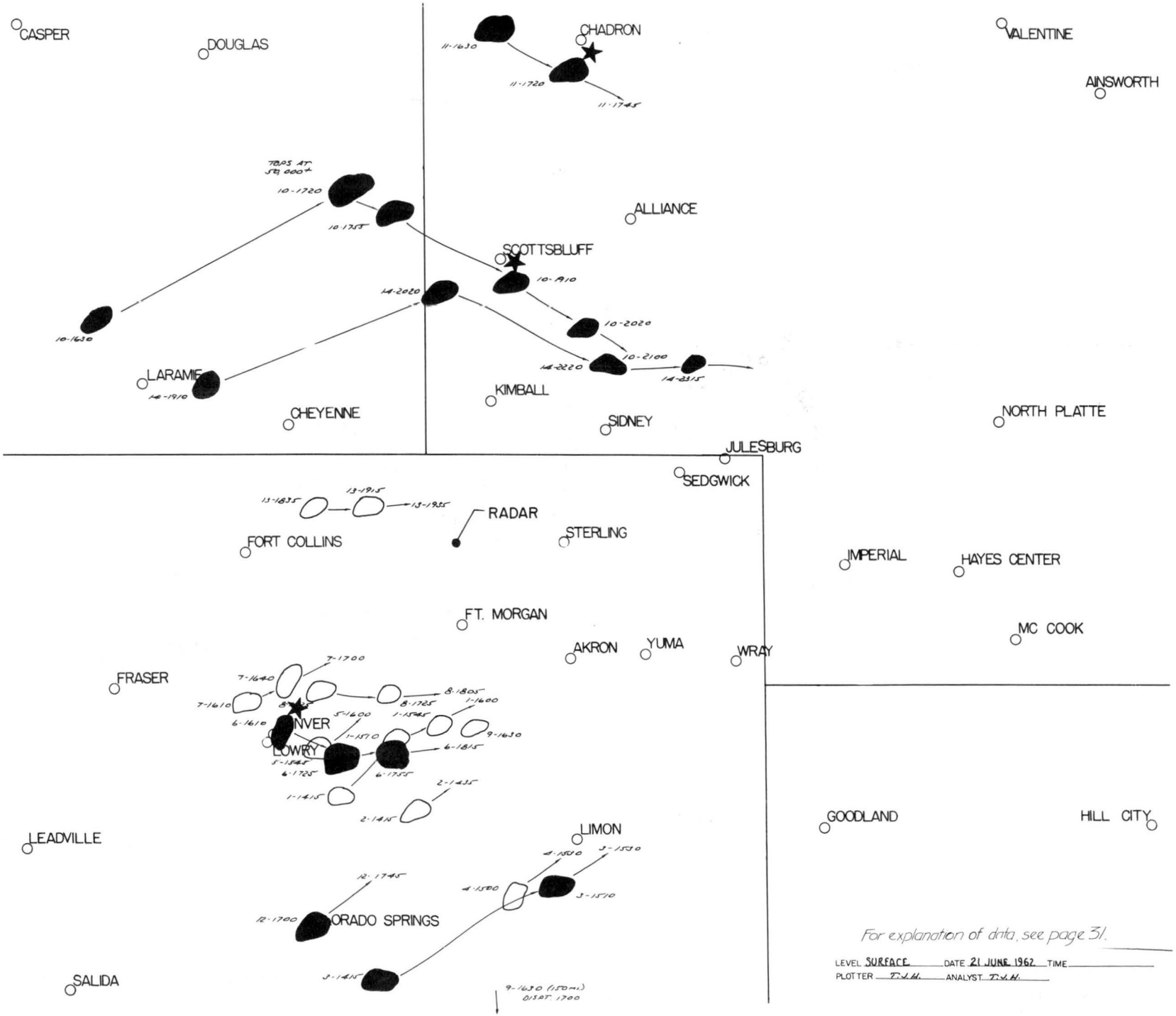
PLOTTER T.V.H. ANALYST T.V.H.



For explanation of data, see page 31.

LEVEL SURFACE. DATE 23 JUNE 1962. TIME _____
PLOTTER T.J.N. ANALYST T.J.N.

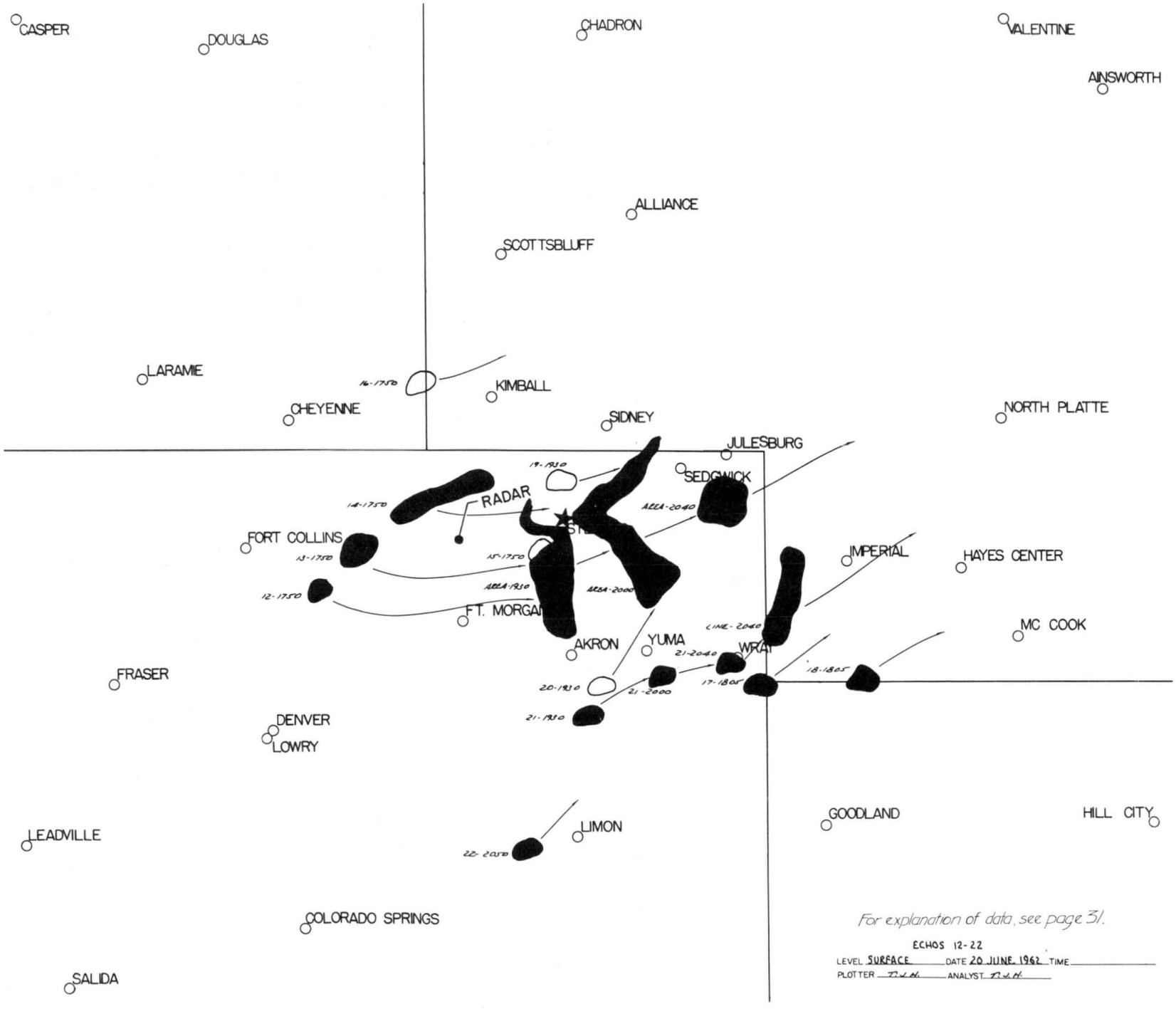

CASPER
DOUGLAS
CHADRON
VALENTINE
AINSWORTH
ALLIANCE
SCOTTSBLUFF
LARAMIE
KIMBALL
CHEYENNE
SIDNEY
NORTH PLATTE
JULESBURG
SEDGWICK
RADAR
FORT COLLINS
STERLING
IMPERIAL
HAYES CENTER
FT. MORGAN
MC COOK
AKRON
YUMA
WRAY
FRASER
DENVER
LOWRY
LEADVILLE
LIMON
HILL CITY
COLORADO SPRINGS
SALIDA
1-2-1500
1-2-1600
1-1420
1-1335
1-1145
1-1300
2-1420
2-1340
3-1600
3-1500
4-1600
5-1500
MANY TORNADOS IN SE. COLORADO & W. KANSAS.
173 MILES FROM RADAR.
For explanation of data, see page 31.
LEVEL SURFACE DATE 22 JUNE 1962 TIME
PLOTTER T.V.N. ANALYST T.V.N.



For explanation of data, see page 31.

LEVEL SURFACE DATE 21 JUNE 1962 TIME

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

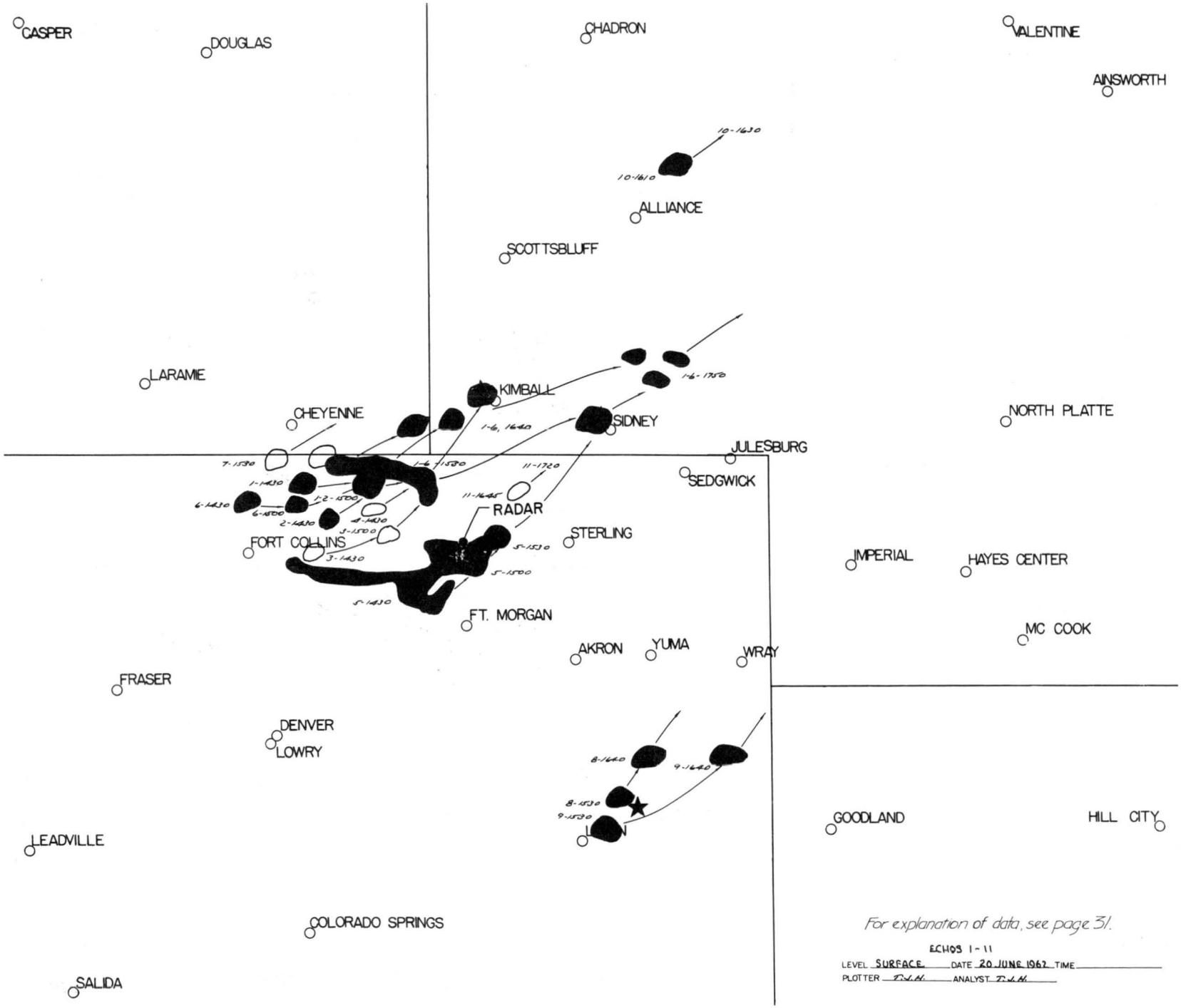


For explanation of data, see page 31.

ECHOS 12-22

LEVEL SURFACE DATE 20 JUNE 1962 TIME _____

PLOTTER T.J.N. ANALYST T.J.N.

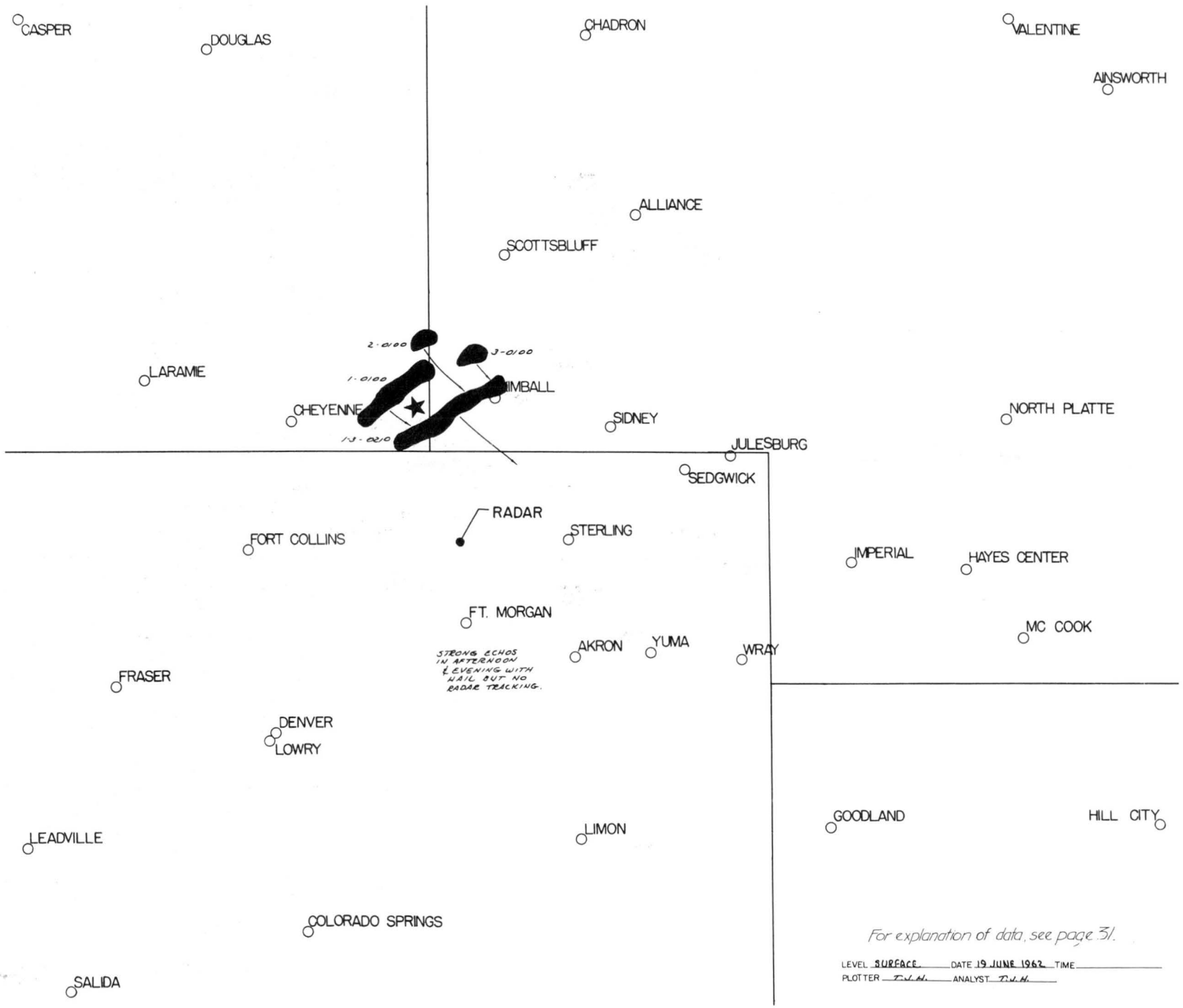


For explanation of data, see page 31.

ECHOS I - II

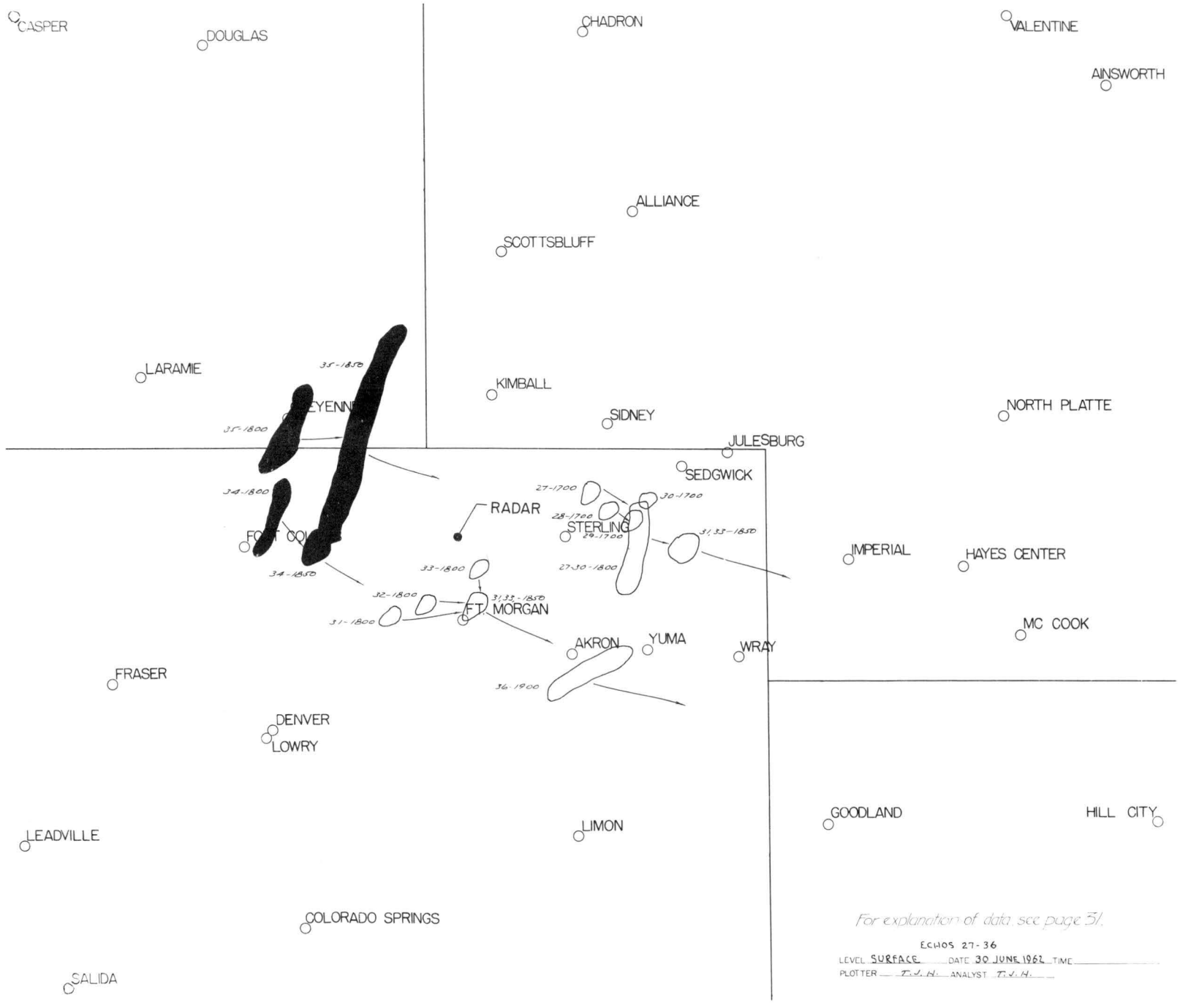
LEVEL SURFACE DATE 20 JUNE 1962 TIME _____

PLOTTER T.V.H. ANALYST T.V.H.



For explanation of data, see page 31.

LEVEL SURFACE DATE 19 JUNE 1962 TIME
PLOTTER T.V.N. ANALYST T.V.N.



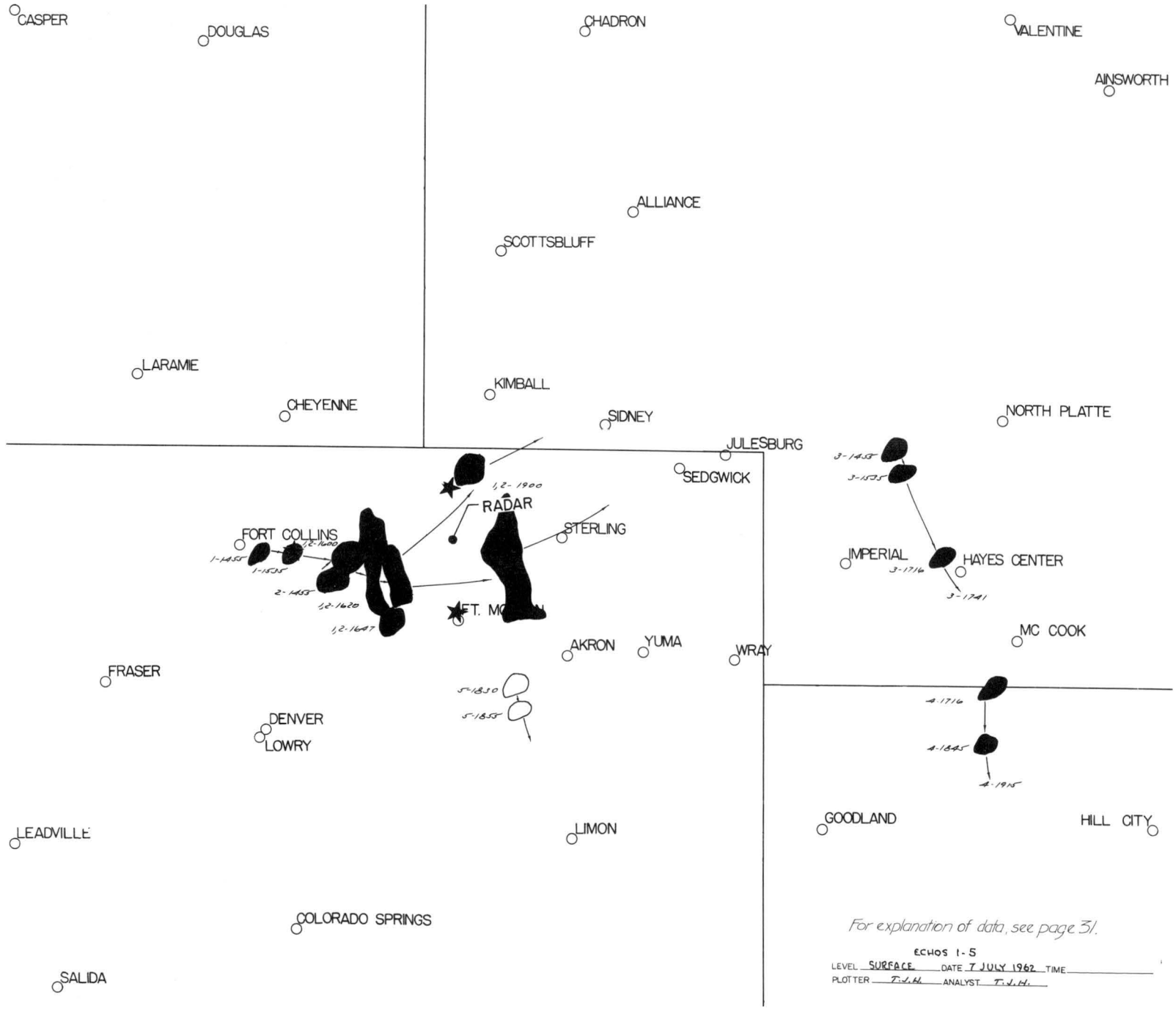
For explanation of data, see page 31.

ECHOS 27-36

LEVEL SURFACE DATE 30 JUNE 1962 TIME

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


CASPER
DOUGLAS
CHADRON
VALENTINE
AINSWORTH
ALLIANCE
SCOTTSBLUFF
LARAMIE
KIMBALL
CHEYENNE
SIDNEY
NORTH PLATTE
JULESBURG
SEDGWICK
RADAR
FORT COLLINS
STERLING
IMPERIAL
HAYES CENTER
FT. MORGAN
MC COOK
AKRON
YUMA
WRAY
3-1450
3-1430
FRASER
1-1440
1-1330
DENVER
LOWRY
1-1600
1-1610
2-1330
2-1440
2-1450
LIMON
GOODLAND
HILL CITY
LEADVILLE
COLORADO SPRINGS
4-1620
SALIDA
5-1620
1787/1425
For explanation of data, see page 51.
LEVEL SURFACE DATE 5 JULY 1962 TIME
PLOTTER T.J.H. ANALYST T.J.H.

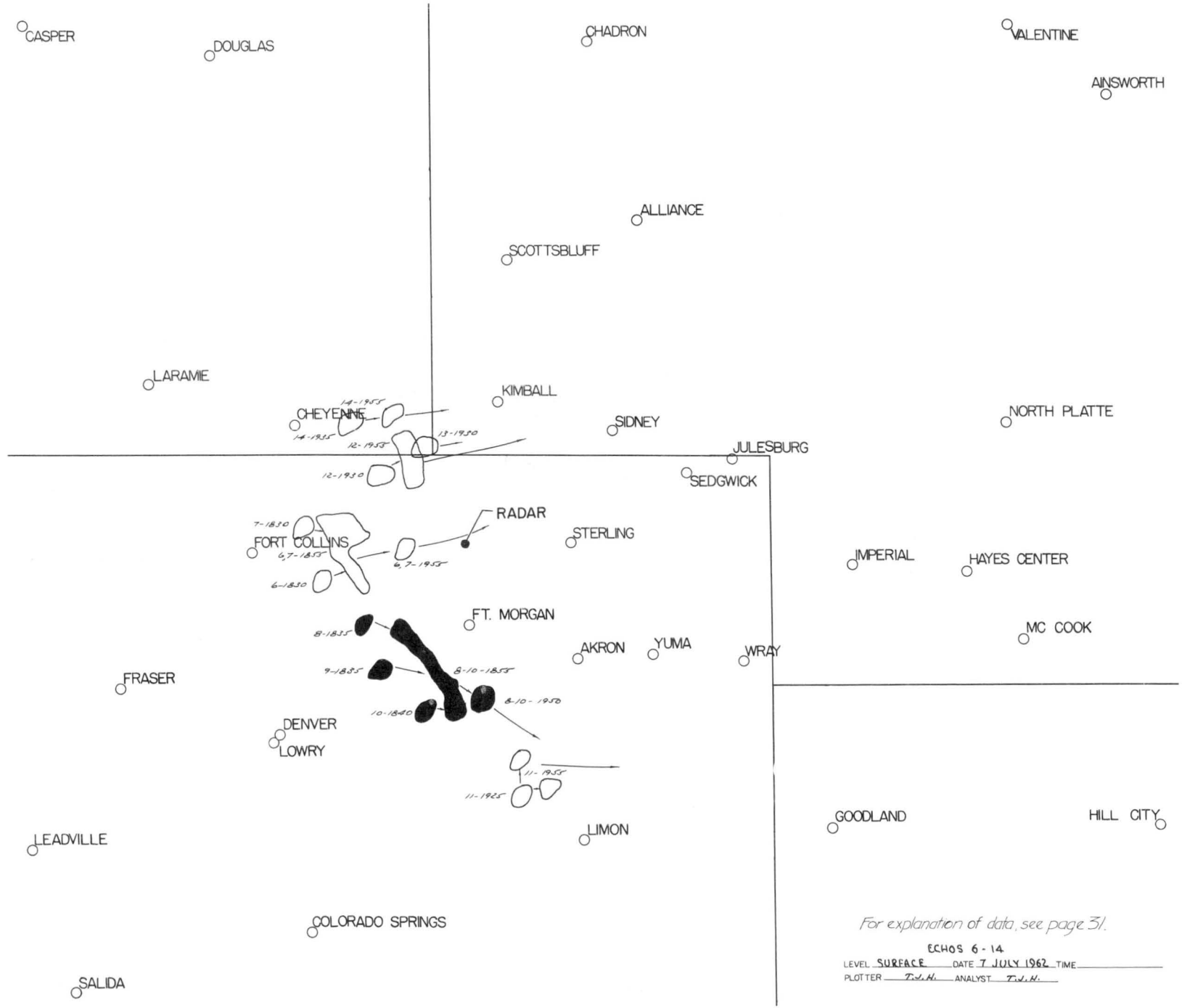


For explanation of data, see page 31.

ECHOS 1-5

LEVEL SURFACE DATE 7 JULY 1962 TIME

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

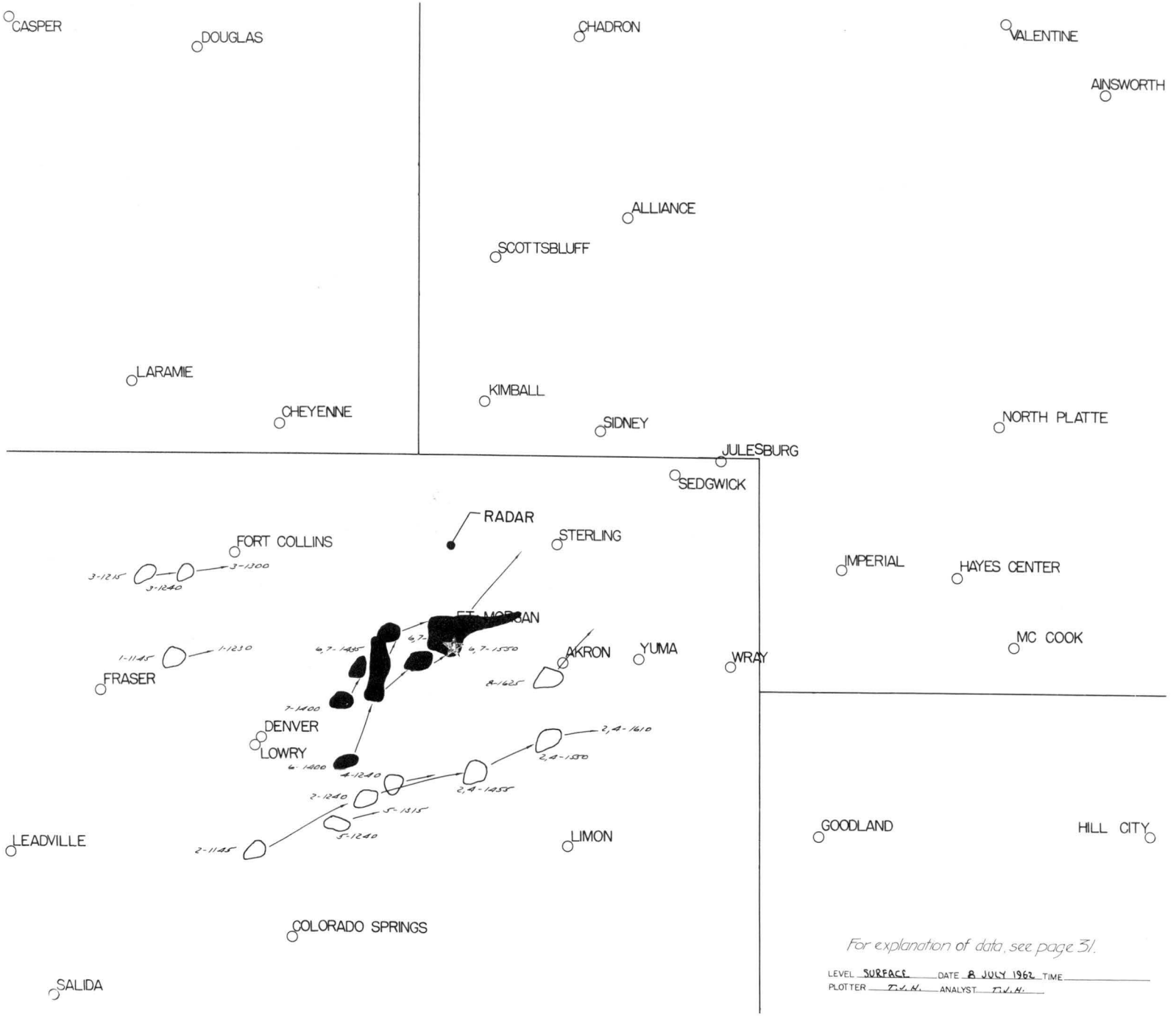


For explanation of data, see page 31.

ECHOS 6-14

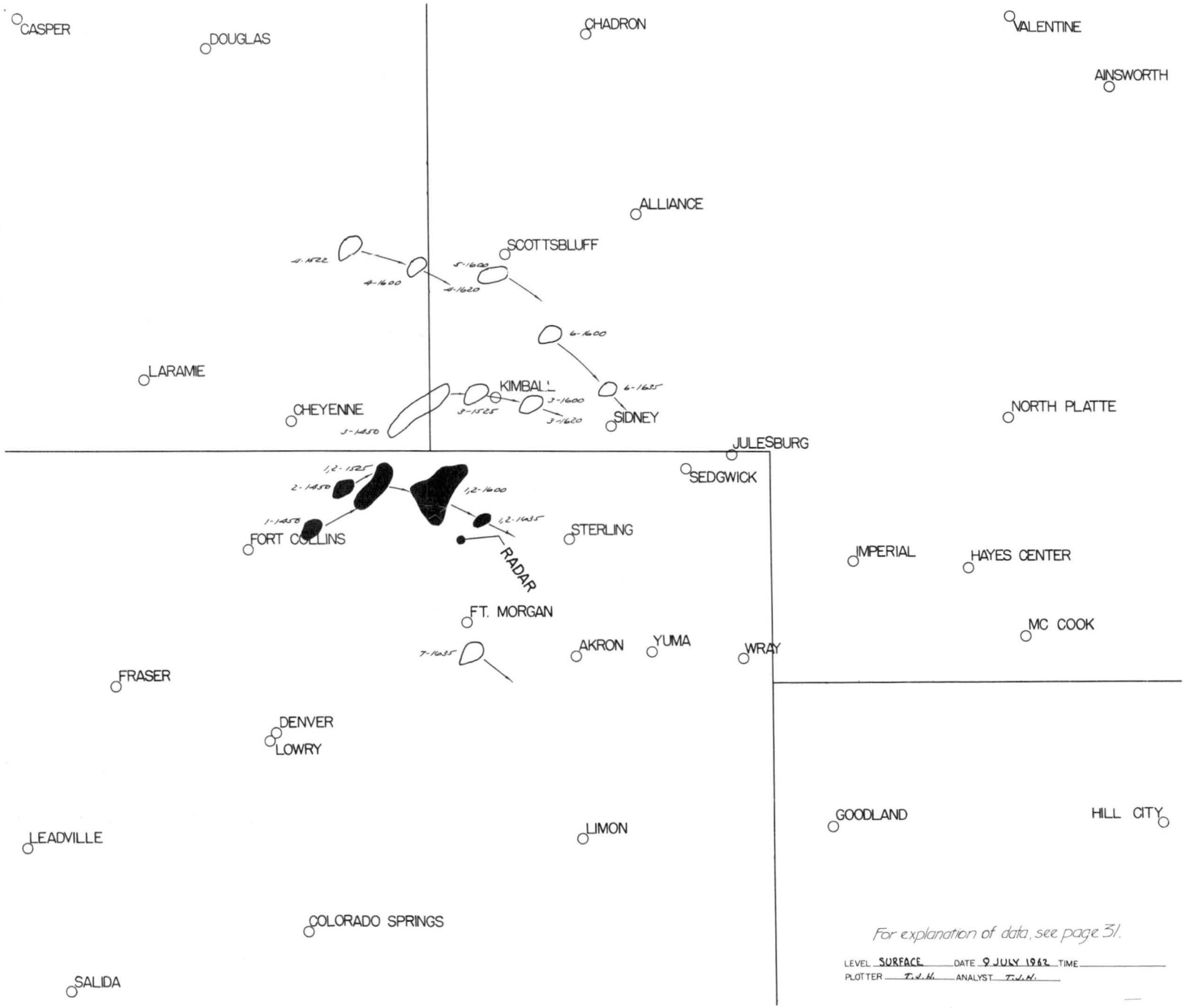
LEVEL SURFACE DATE 7 JULY 1962 TIME

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



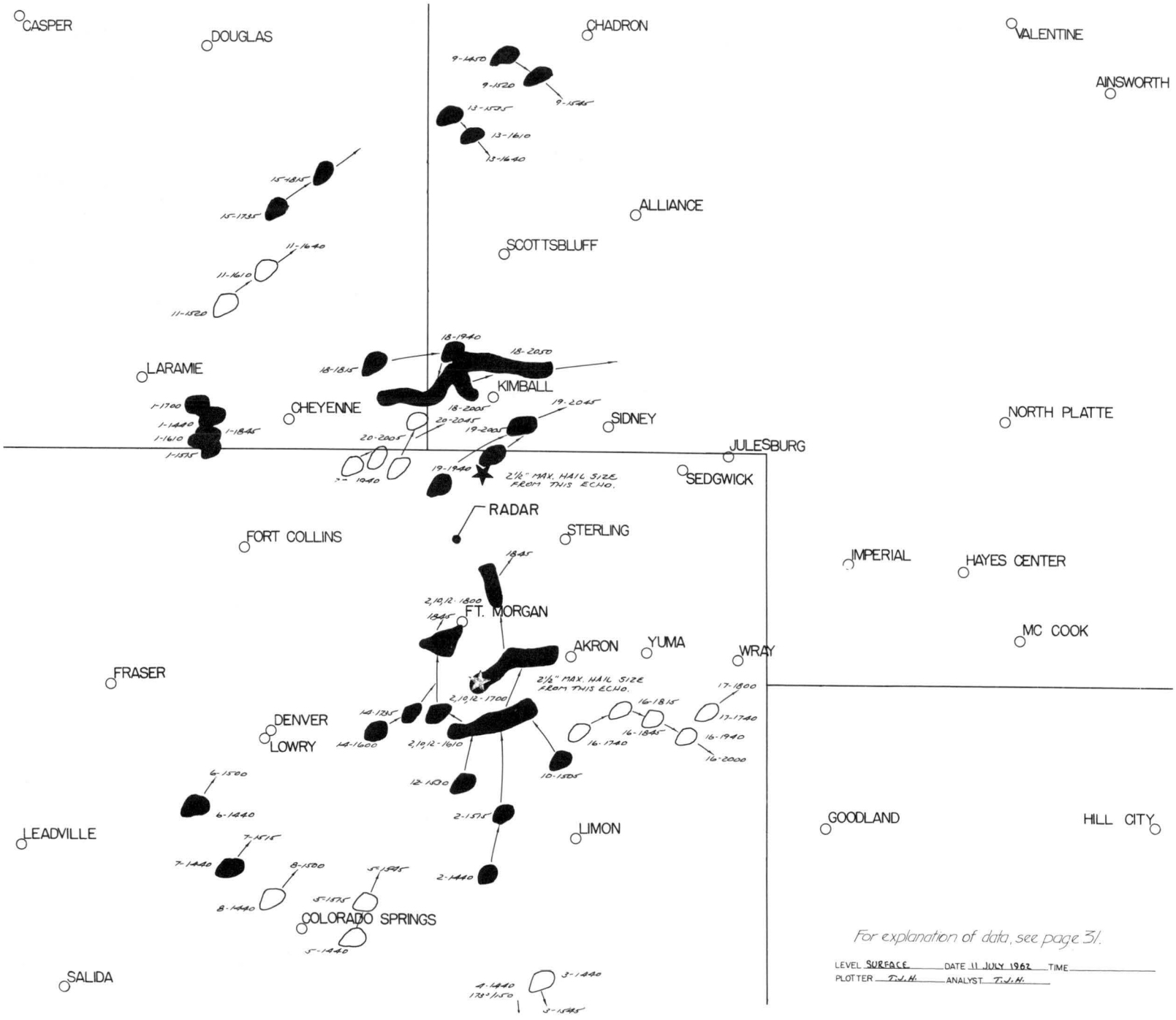
For explanation of data, see page 31.

LEVEL SURFACE DATE 8 JULY 1962 TIME
PLOTTER T.V.H. ANALYST T.V.H.



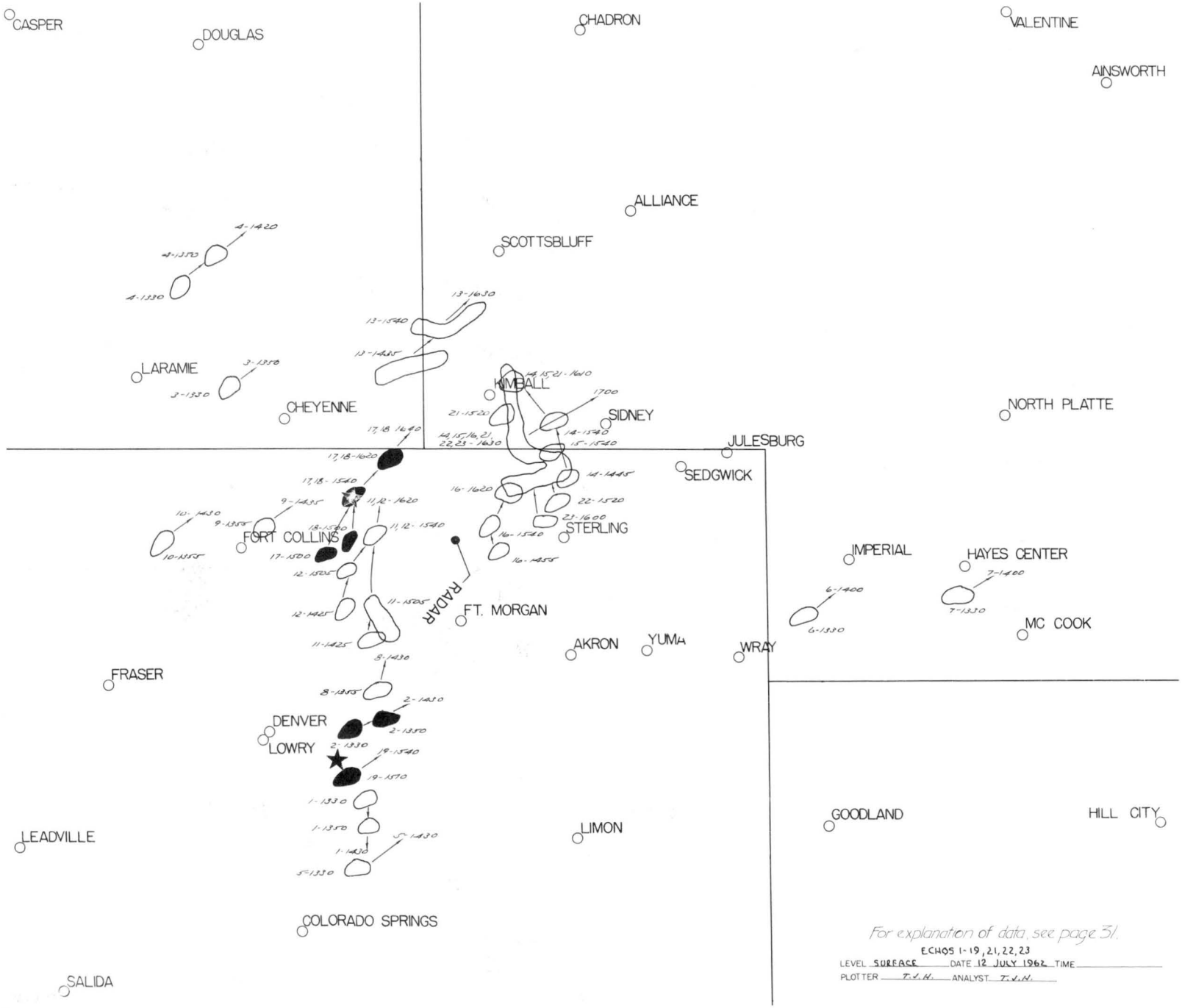
For explanation of data, see page 31.

LEVEL SURFACE DATE 9 JULY 1963 TIME
PLOTTER T.V.H. ANALYST T.V.H.



For explanation of data, see page 31.

LEVEL SURFACE DATE 11 JULY 1962 TIME
PLOTTER T.J.H. ANALYST T.J.H.



For explanation of data, see page 31.

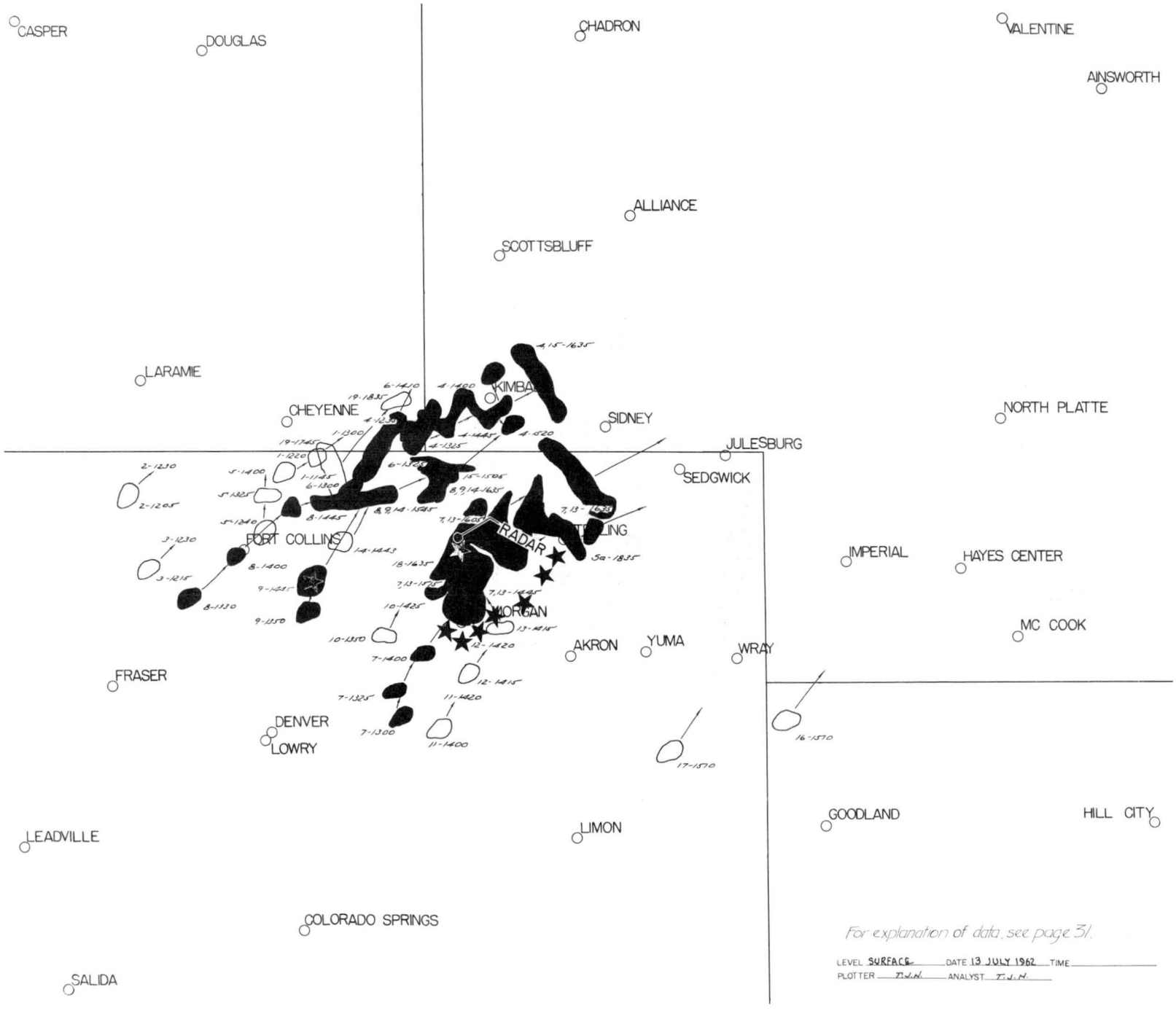
ECHOS 1-19, 21, 22, 23

LEVEL SURFACE DATE 12 JULY 1962 TIME

PLOTTER T.V.N. ANALYST T.V.N.

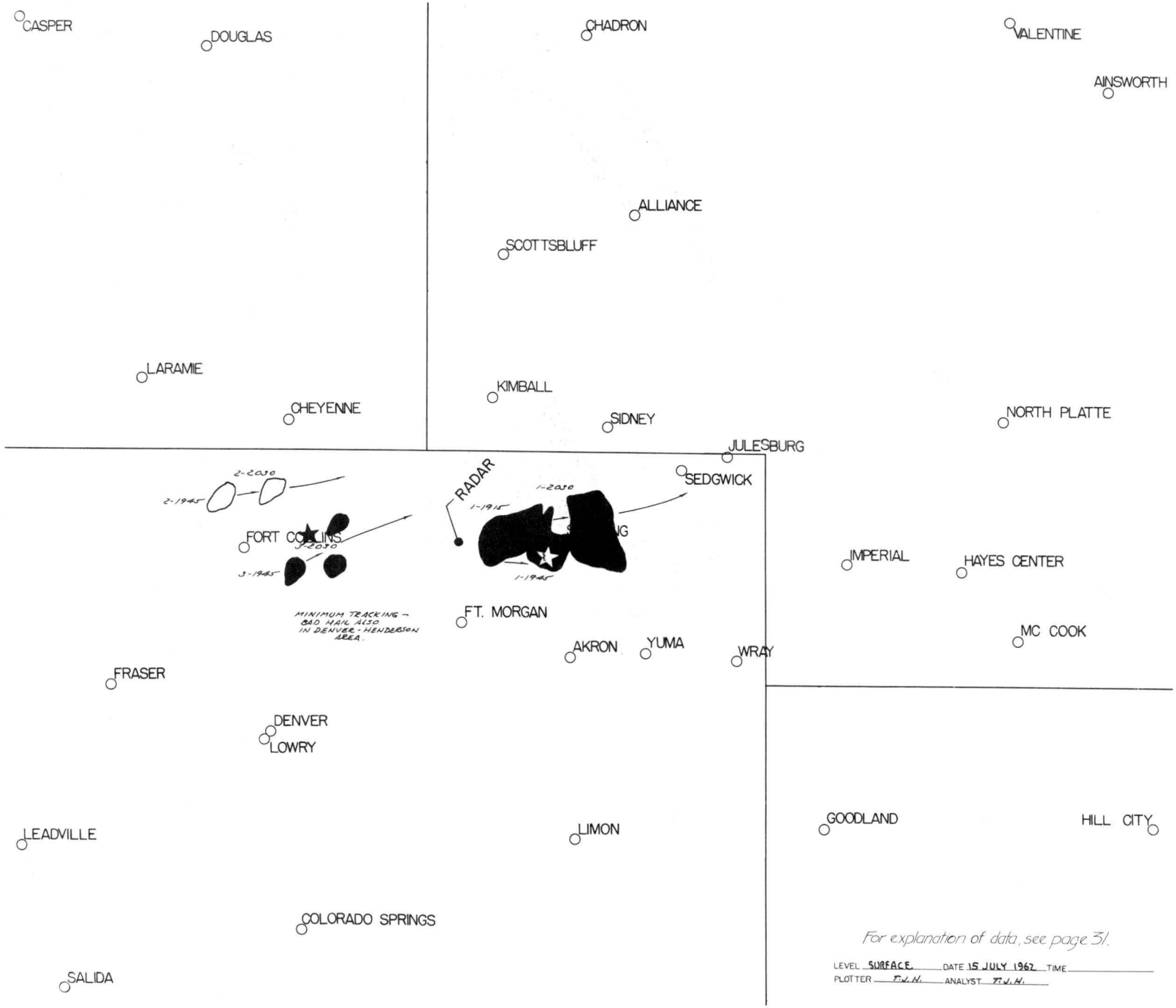
For explanation of data, see page 31.

ECHOS 20 & 24-30
LEVEL SURFACE DATE 12 JULY 1962 TIME
PLOTTER T.J.H. ANALYST T.J.H.



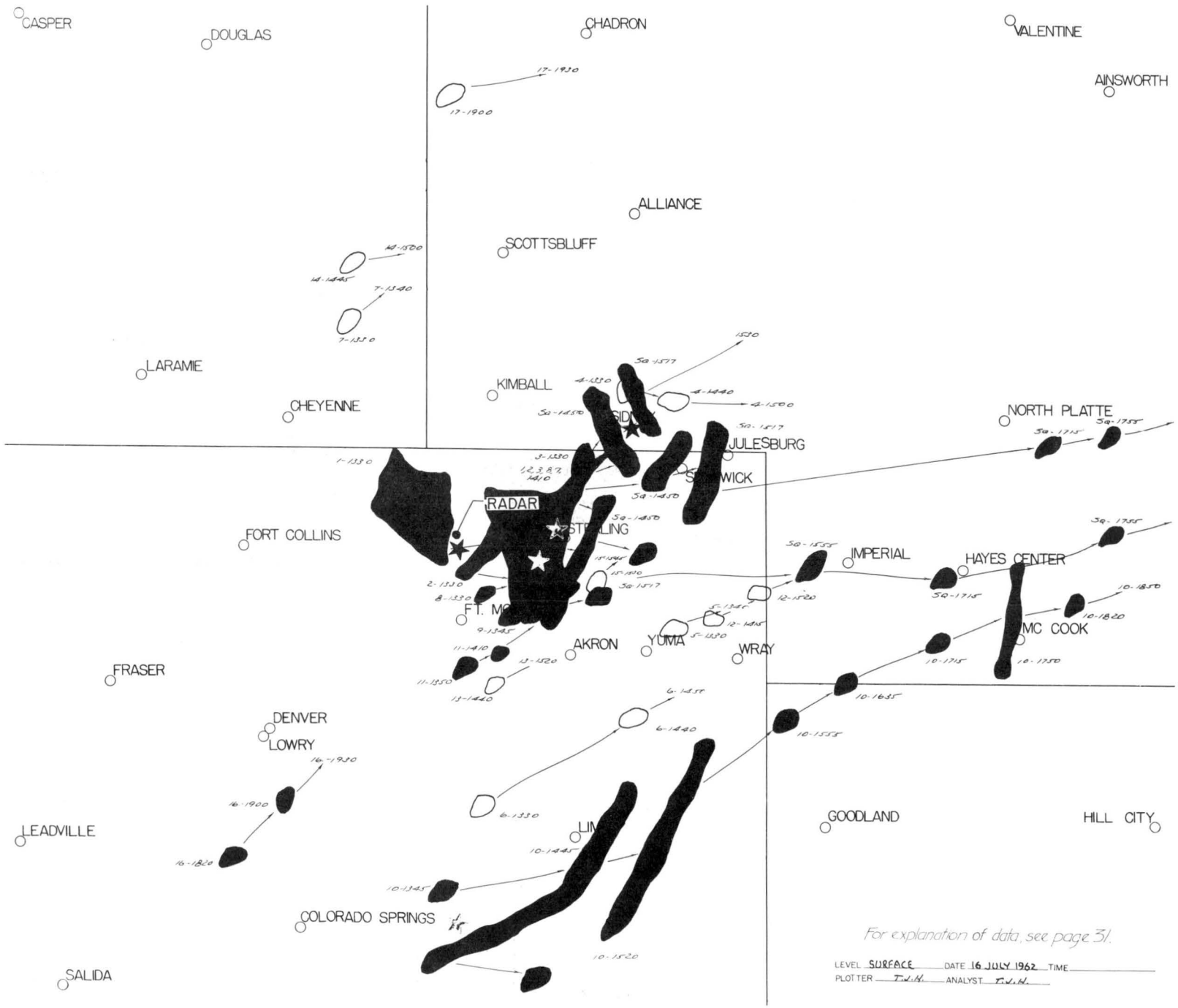
For explanation of data, see page 31.

LEVEL SURFACE DATE 13 JULY 1962 TIME
PLOTTER T.J.N. ANALYST T.J.N.



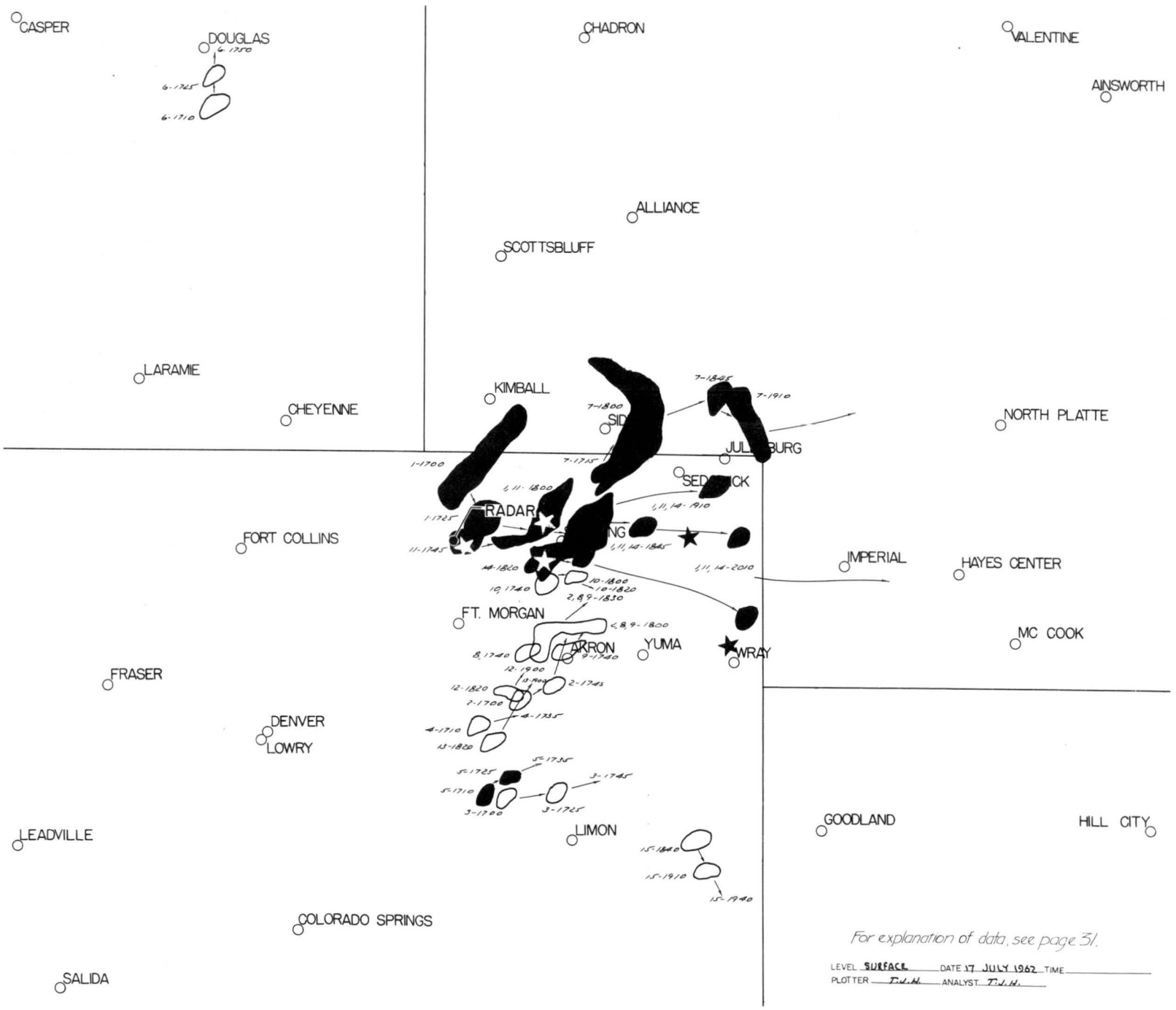
For explanation of data, see page 31.

LEVEL SURFACE. DATE 15 JULY 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.



For explanation of data, see page 31.

LEVEL SURFACE DATE 16 JULY 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.

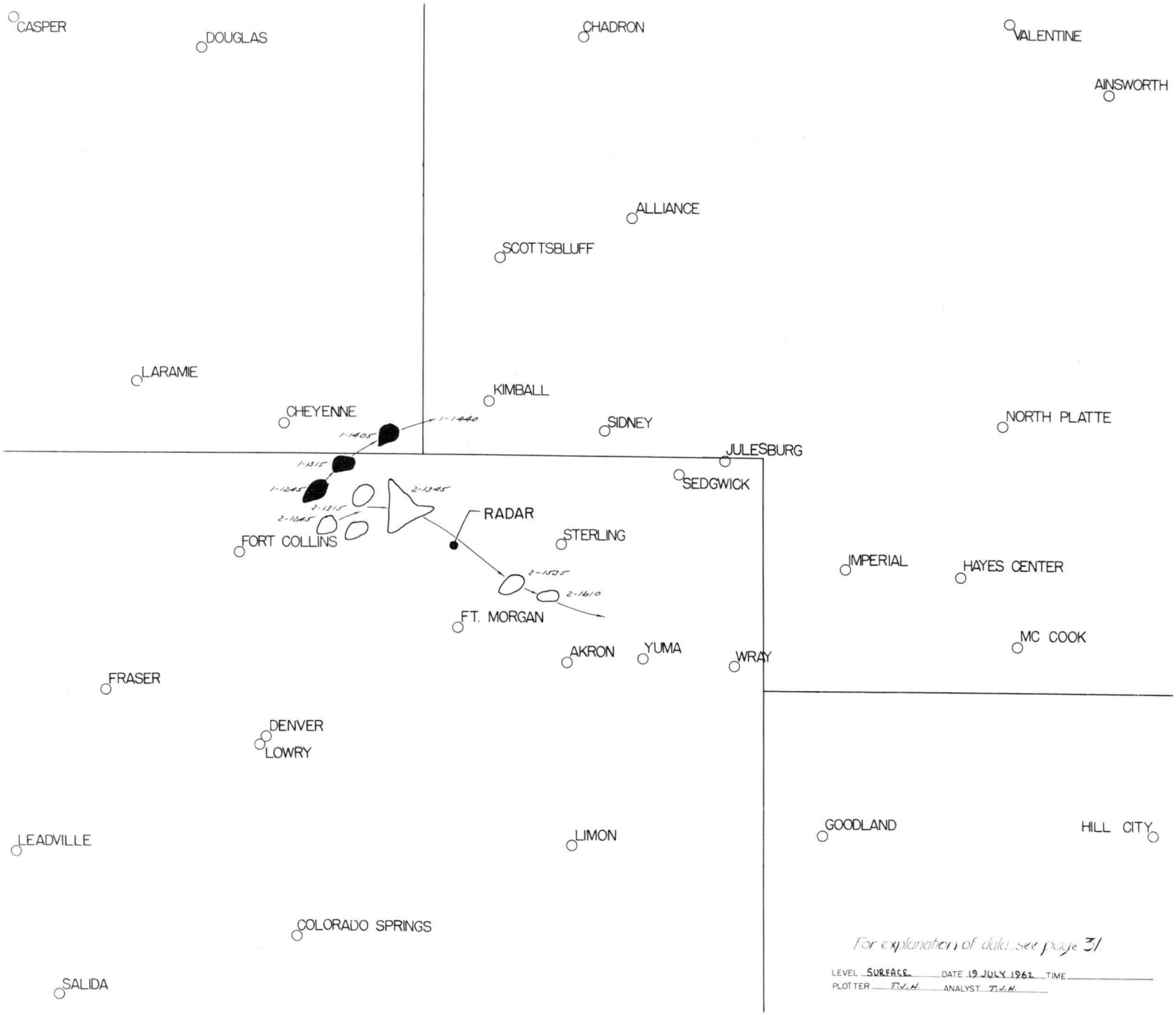


For explanation of data, see page 31.

LEVEL SURFACE DATE 17 JULY 1962 TIME
PLOTTER T.V.H. ANALYST T.V.H.

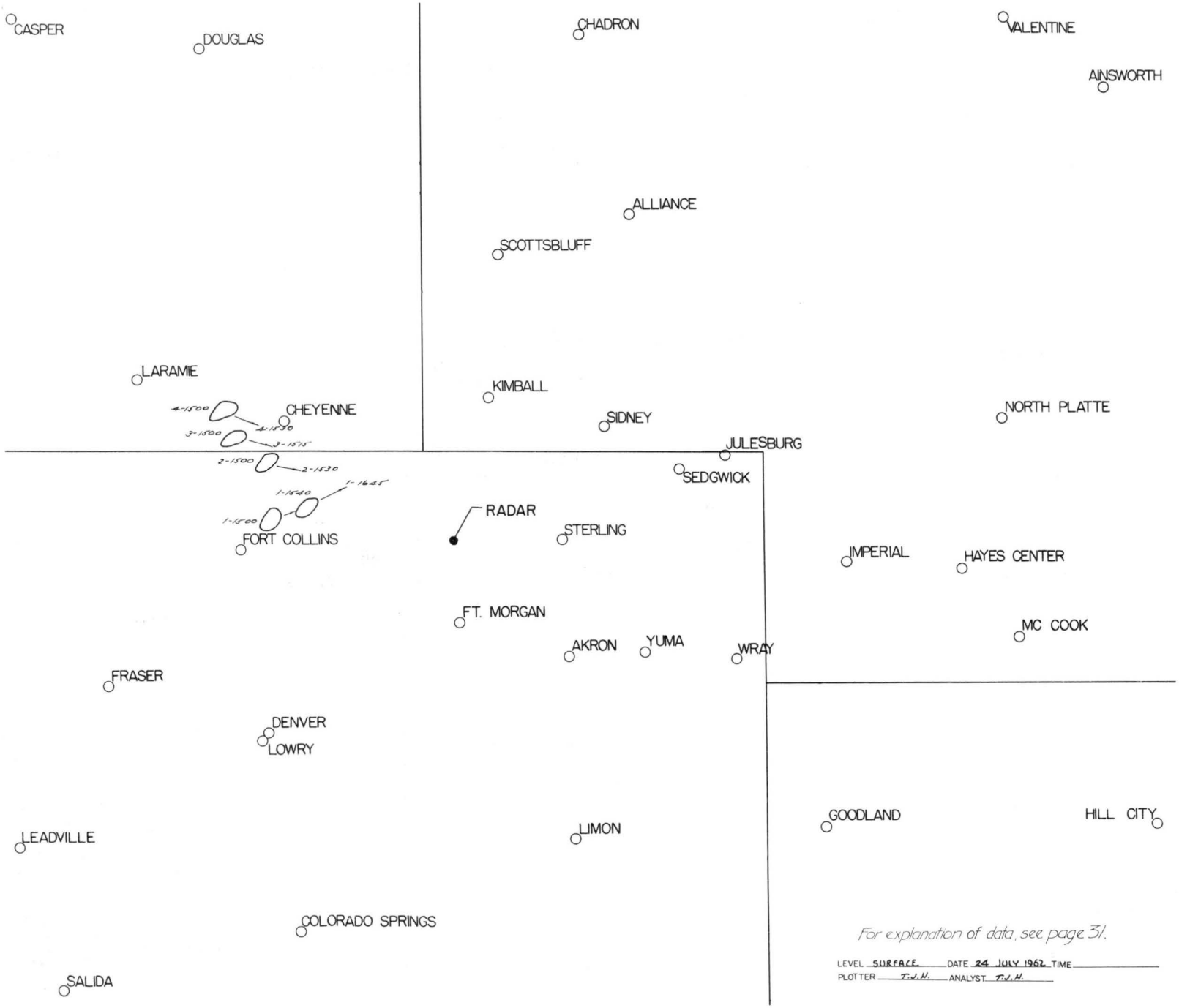
For explanation of data, see page 31.

LEVEL SURFACE DATE 18 JULY 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.



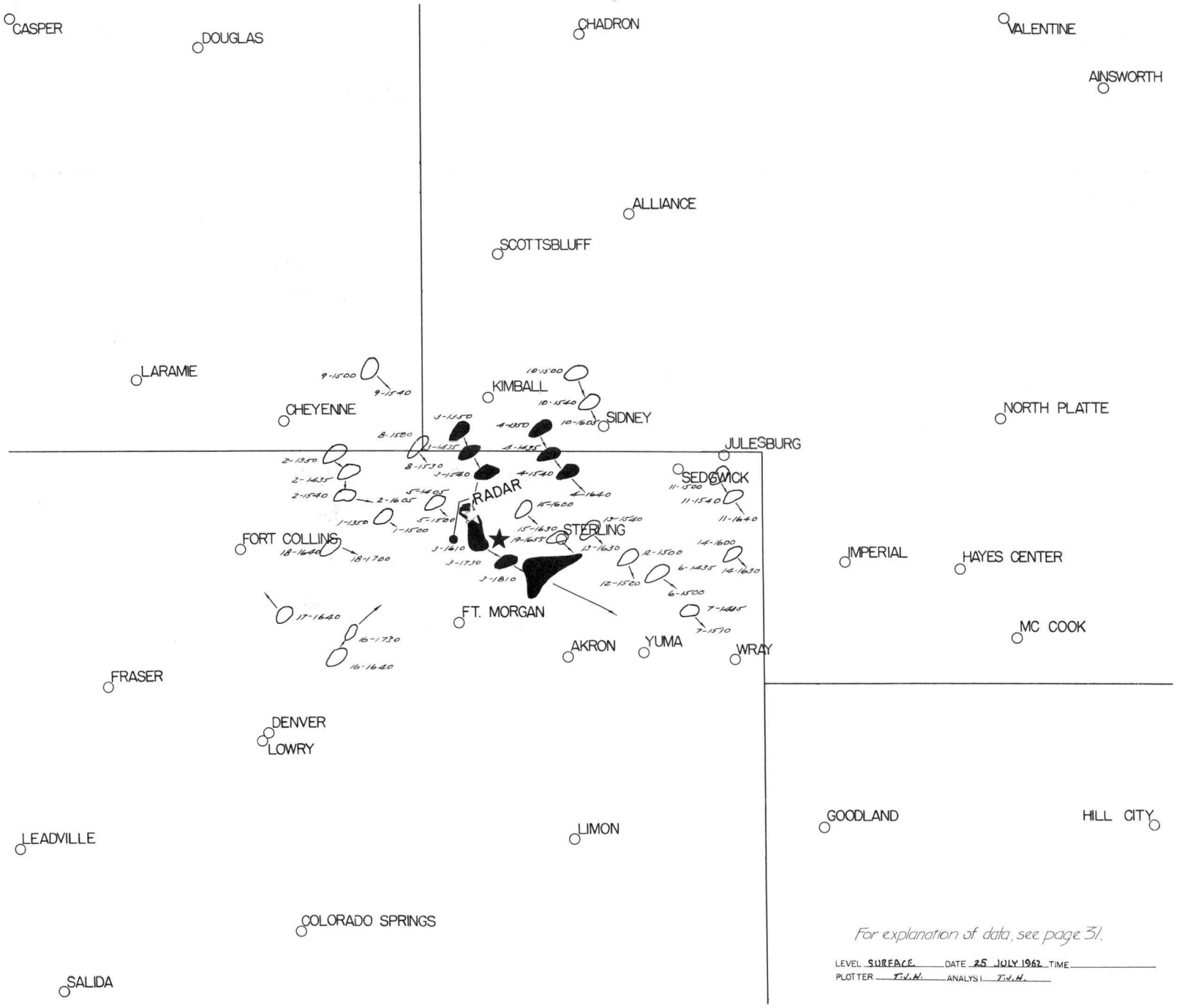
For explanation of data see page 31

LEVEL SURFACE DATE 19 JULY 1962 TIME
PLOTTER T.V.N. ANALYST T.V.N.



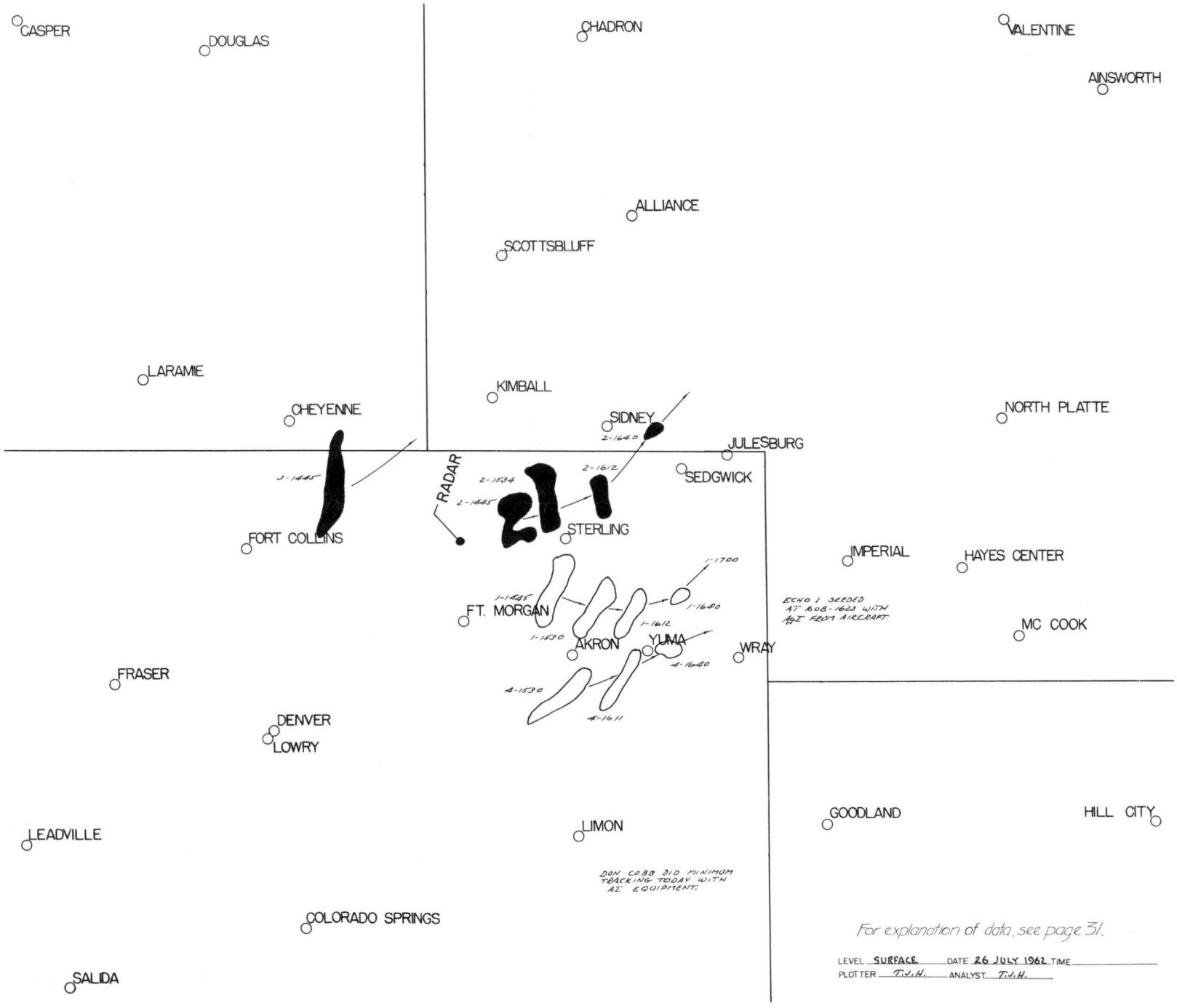
For explanation of data, see page 31.

LEVEL SURFACE DATE 24 JULY 1962 TIME
PLOTTER T.W.H. ANALYST T.W.H.



For explanation of data, see page 31.

LEVEL SURFACE DATE 25 JULY 1962 TIME
PLOTTER T.V.H. ANALYST T.V.H.



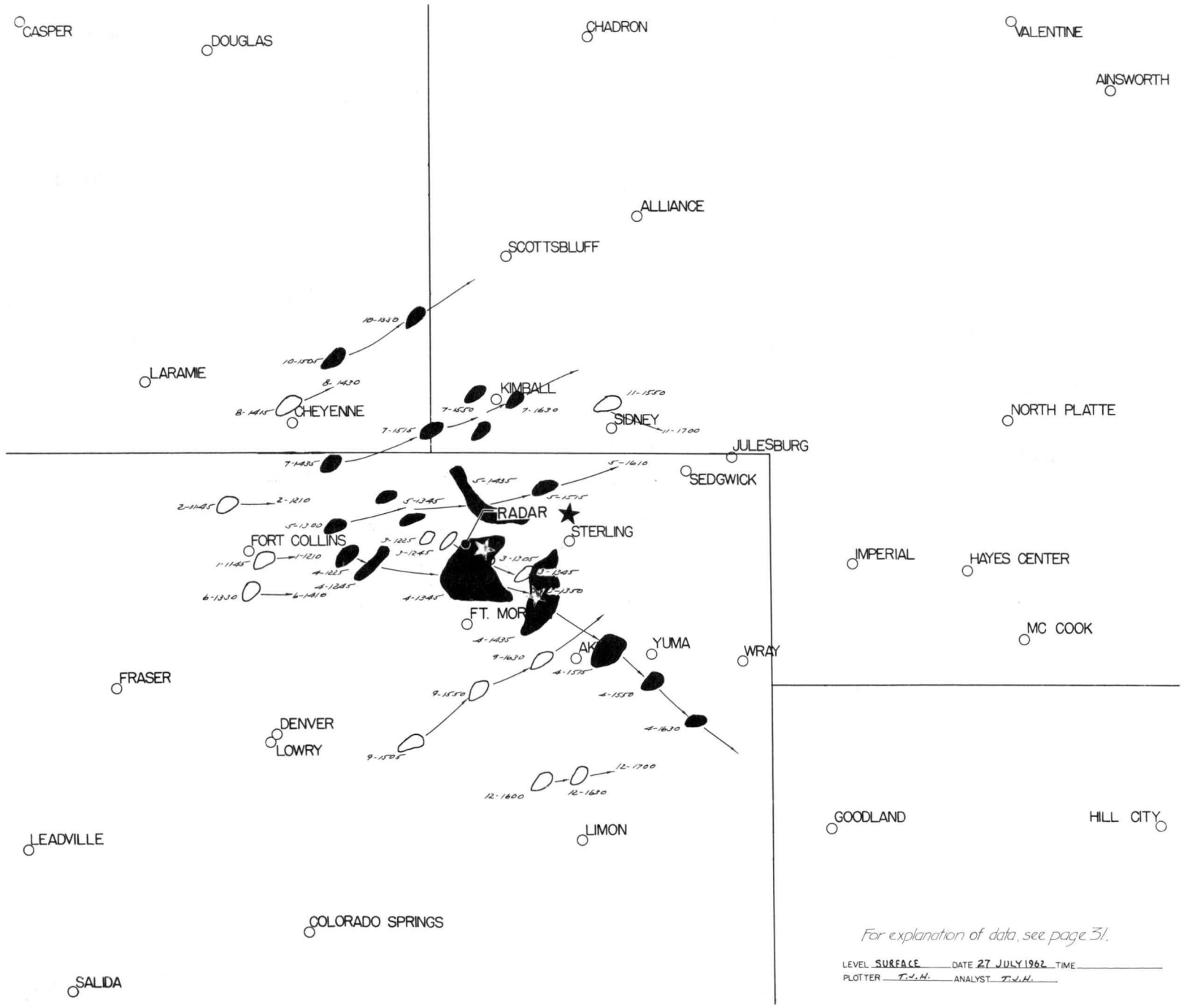
ECHO I SEEDED AT 808-1603 WITH AgI FROM AIRCRAFT.

DON COBB DID MINIMUM TRACKING TODAY WITH AI EQUIPMENT.

For explanation of data, see page 31.

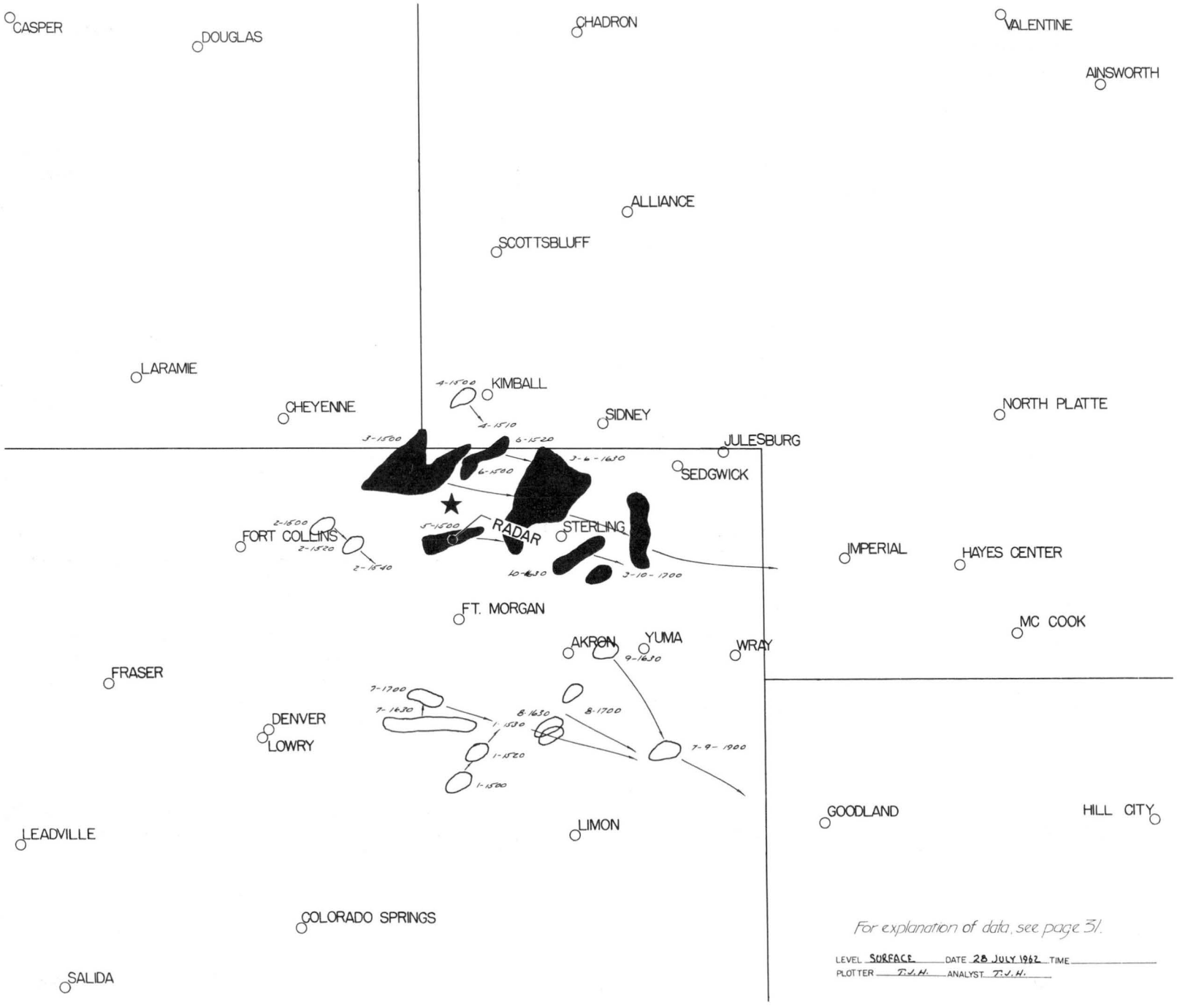
LEVEL SURFACE DATE 26 JULY 1962 TIME

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



For explanation of data, see page 31.

LEVEL SURFACE DATE 27 JULY 1962 TIME
PLOTTER T.V.H. ANALYST T.V.H.

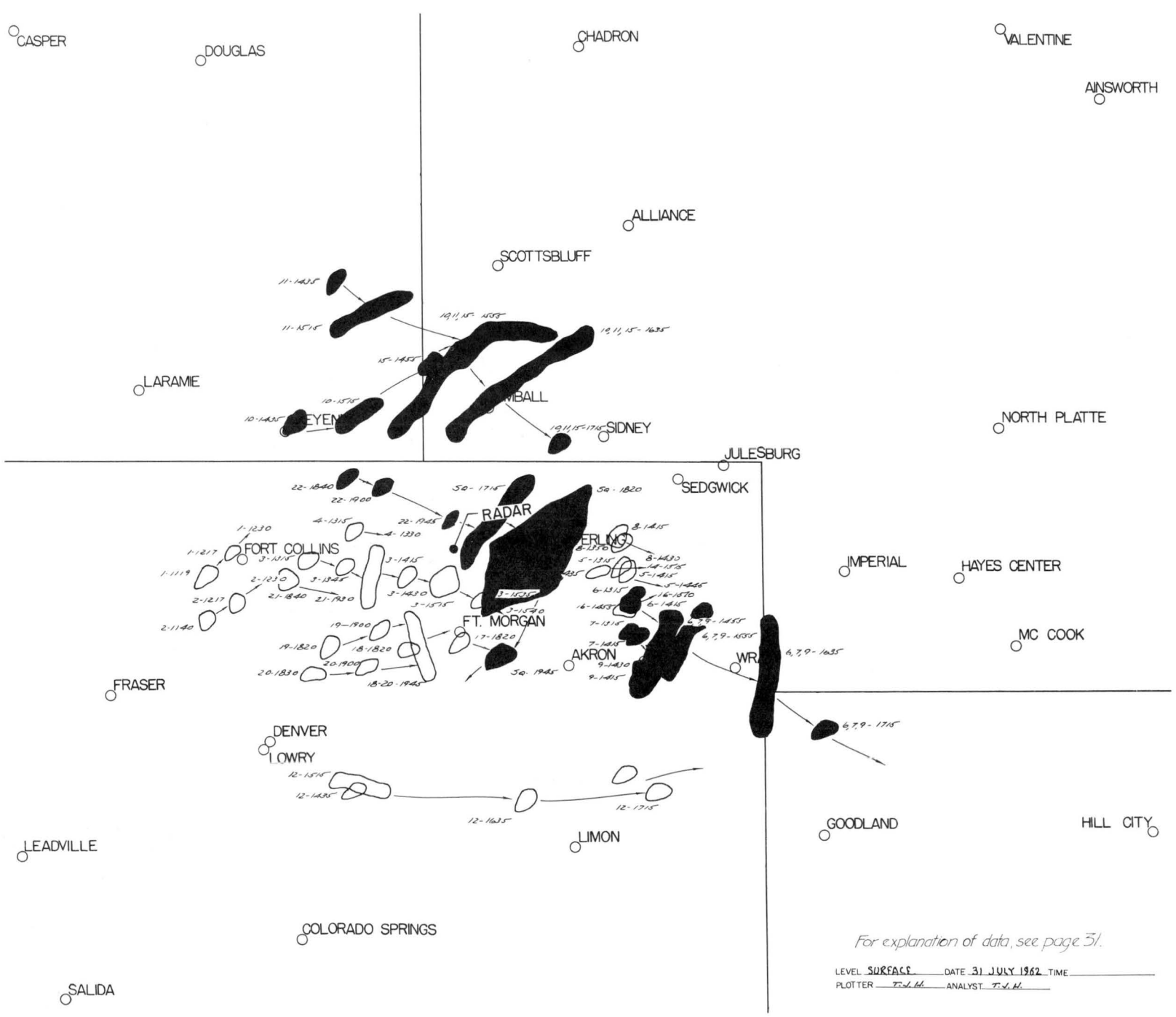


For explanation of data, see page 31.

LEVEL SURFACE DATE 28 JULY 1962 TIME _____
PLOTTER T.J.H. ANALYST T.J.H.

For explanation of data, see page 31.

LEVEL SURFACE. DATE 30 JULY 1962 TIME
PLOTTER T.J.H. ANALYST T.J.H.



For explanation of data, see page 31.

LEVEL SURFACE DATE 31 JULY 1962 TIME _____
PLOTTER T.J.H. ANALYST T.J.H.