T H E   U N I V E R S I T Y   O F   M I C H I G A N

COLLEGE OF ENGINEERING
Department of Meteorology and Oceanography

Progress Report No. 6

RAIN SCAVENGING STUDIES

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ABSTRACT

The field phase of the year's effort was divided among (1) the move from Chickasha, Oklahoma, to Clinton, Illinois, (2) a construction and instrument installation period at Clinton, and (3) the measurement and sampling of rain in coordination with collaborators at Clinton during the period 16 May - 15 June, 1969. Data obtained are sparse, and opportunity for good tracer experiments (using In flares) did not appear, because of a severely dry season in central Illinois. Those data that were obtained are presented in terms of tables, graphs, weather maps, and radar photographs.

Laboratory work has also gone forward under previously developed routines, but also strongly in the improvement of our neutron activation analysis procedure. Results of this latter effort are the subjects of two papers that have been accepted for publication. Measurements of the particle size distribution of the flare-generated indium tracer have given a bimodal curve which is not clearly understood and calls for further experiments. Calibration of the drop-size spectrometer has been repeated, but improved means of producing uniform small drops for this purpose is needed.

The work of the project has been reported in four conferences during the year, and presented briefly or partially in each of three conference proceedings volumes, and two formal papers have been published. Four additional papers have been submitted for publication, and two of these have been accepted at this writing.

I. Field Program Activities

The field phase of the project was essentially composed of three parts: (1) the move of our field station facility from Oklahoma to Illinois, (2) a construction and instrument installation period at the new station, and (3) the operation of the facility and the coordination of our field crews with those of the Illinois State Water Survey and our aviation contractor in obtaining storm data.

1. The move from Chickasha, Oklahoma, to Clinton, Illinois

In launching the 1969 field program, the usual complement of instruments, materials, and supplies had to be transported from Ann Arbor to the new field site, and, in addition, all of the project material that had been stored in Chickasha had to be collected, and returned to Clinton, and the abandonment of the station installation at Chickasha had to be completed in orderly fashion. The project director and 3 student assistants, Messrs. J.E. Fairobent, J.T. Goll, and S.M. Jermaine, devoted the period 30 April through 5 May mainly to the transportation and abandonment jobs. The magnitude of this project was such that it was necessary to rent an 18-foot van from Hertz in Oklahoma City in addition to the two Ford Econoline vans retained as project mobile units.

A fortunate circumstance, from our point of view, developed in that Mr. Roy Poag agreed to remove the Chickasha station structure. Although we needed to remove from it our three large fiberglass collecting funnels, it would have been a much larger and nastier assignment if we had also to demolish and/or remove the structure ourselves. The friendly cooperation, interest, and support that the project had from its beginning in 1964 from Mr. Cecil Neville and from his farm operator, Mr. Gilbert Unruh, is here noted for the official record. The role played by King's Inn in housing, feeding and hosting our crews over these several years is also acknowledged as a real contribution, beyond that ordinarily expected, to the well being, and productivity of the project personnel.

2. Construction and instrument installation

A pre-fabricated garage unit was constructed for our use at Clinton, Illinois, under the direction of the Illinois State Water Survey (Fig. 1 and 2). Upon our return from Chickasha, it was necessary to undertake the tasks of fitting this structure for use as our field station. Addition of the three large fiberglass funnels on a suitable attached supporting structure was one of these tasks. The installation of suitable built-in counters, shelves, and water-handling facilities, and the addition of the external instrument pads, radio antenna, etc., consumed the week 5-12 May. During this period Glenn Stout and his personnel were as helpful as they could be, and personal relationships among the crews were launched in a favorable manner.

The stages of this phase of the operation were recorded photographically, and are shown in Figures 3 through 8.

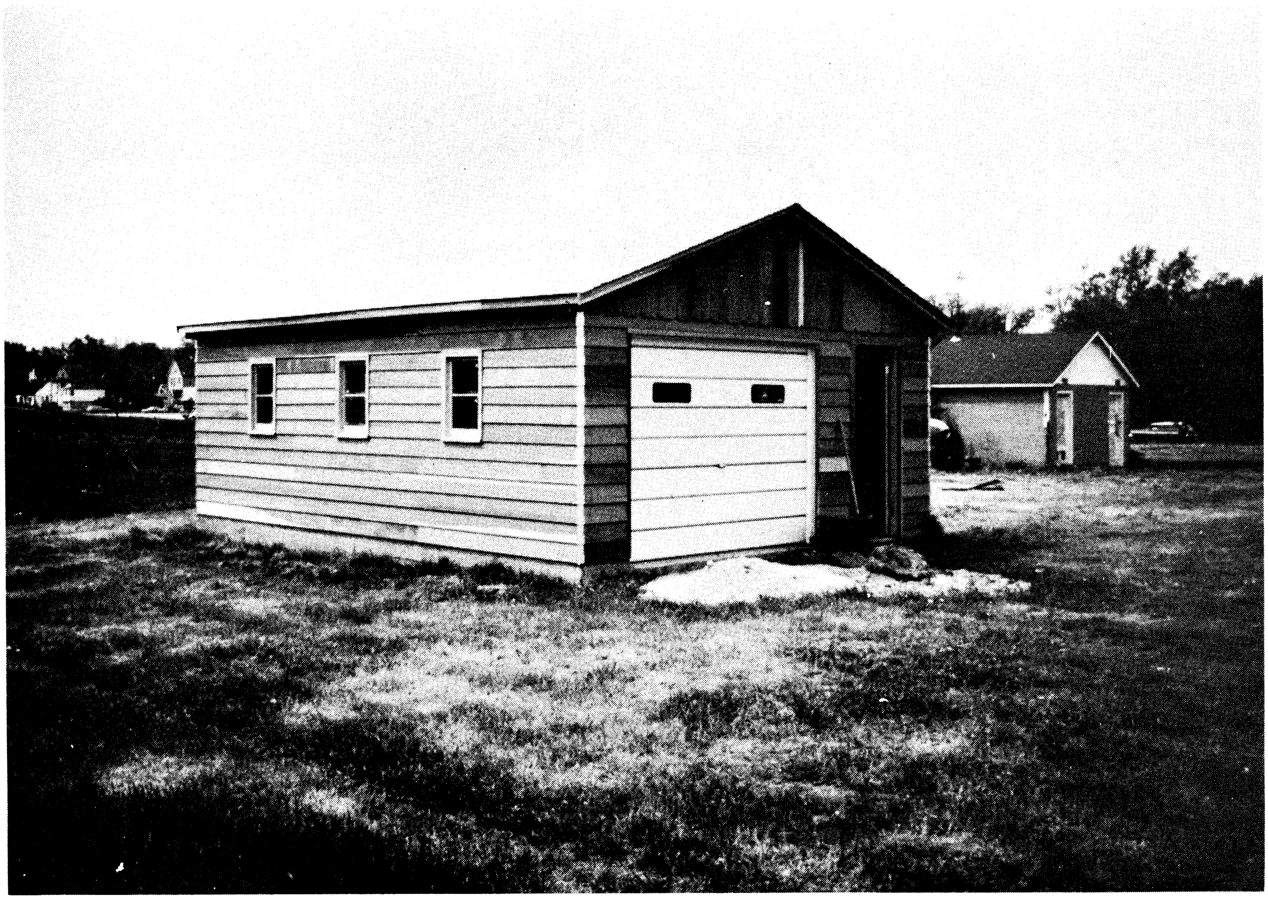


Figure 1. Pre-fabricated garage before conversion into Michigan Base Station.

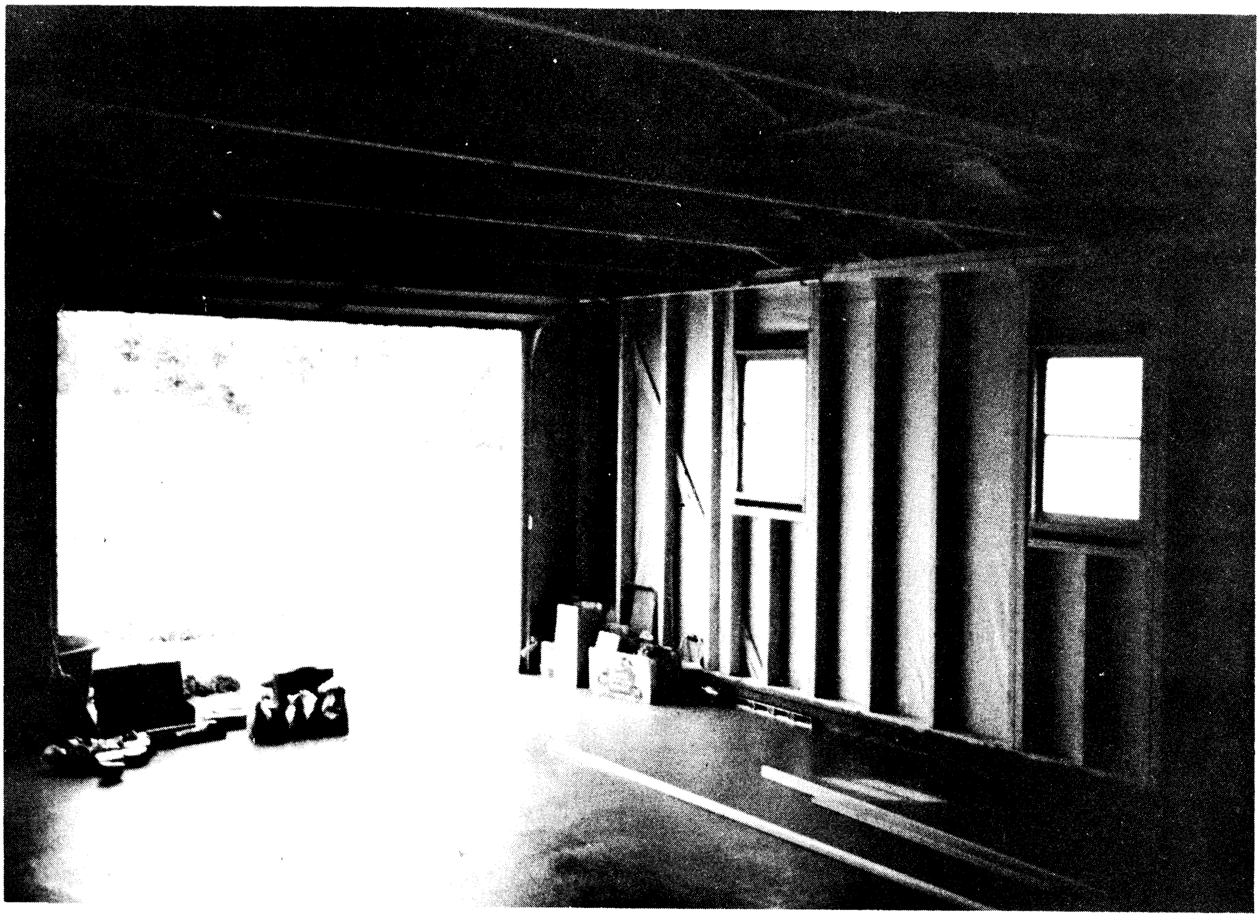
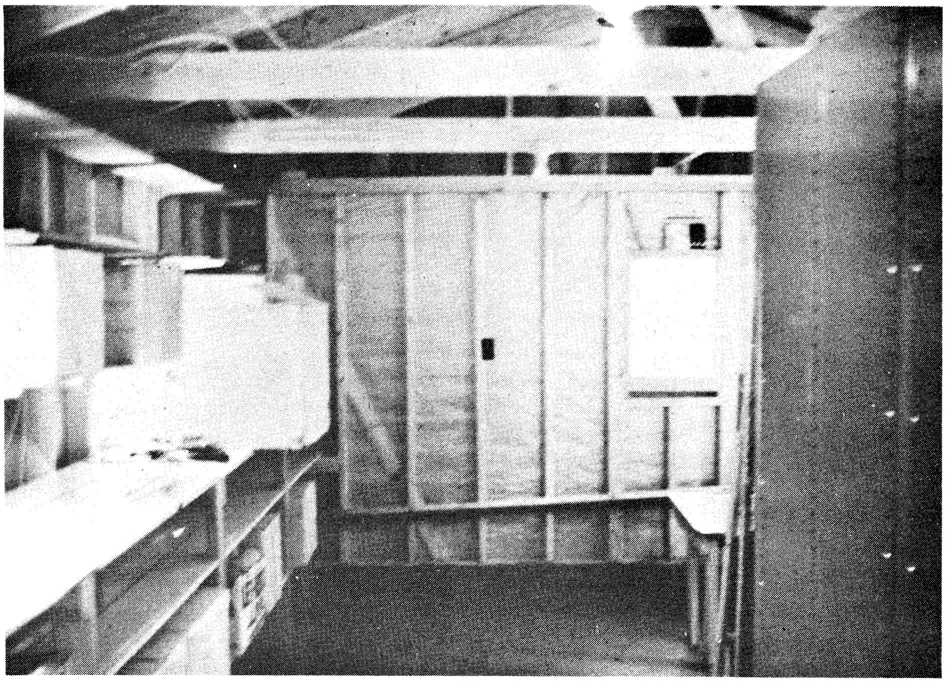
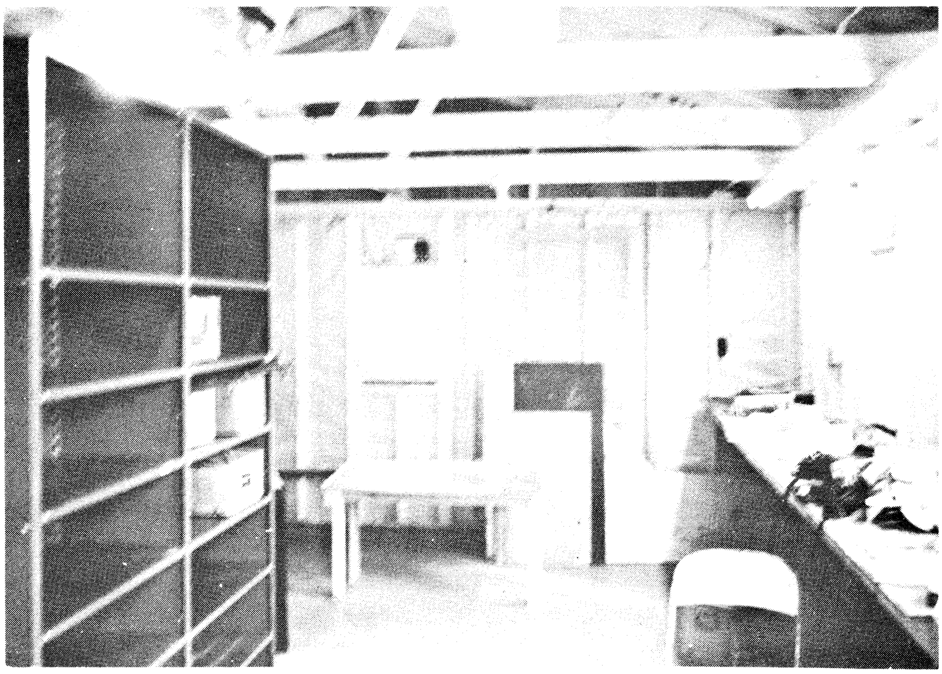


Figure 2. Interior view of building prior to Michigan crew alterations.

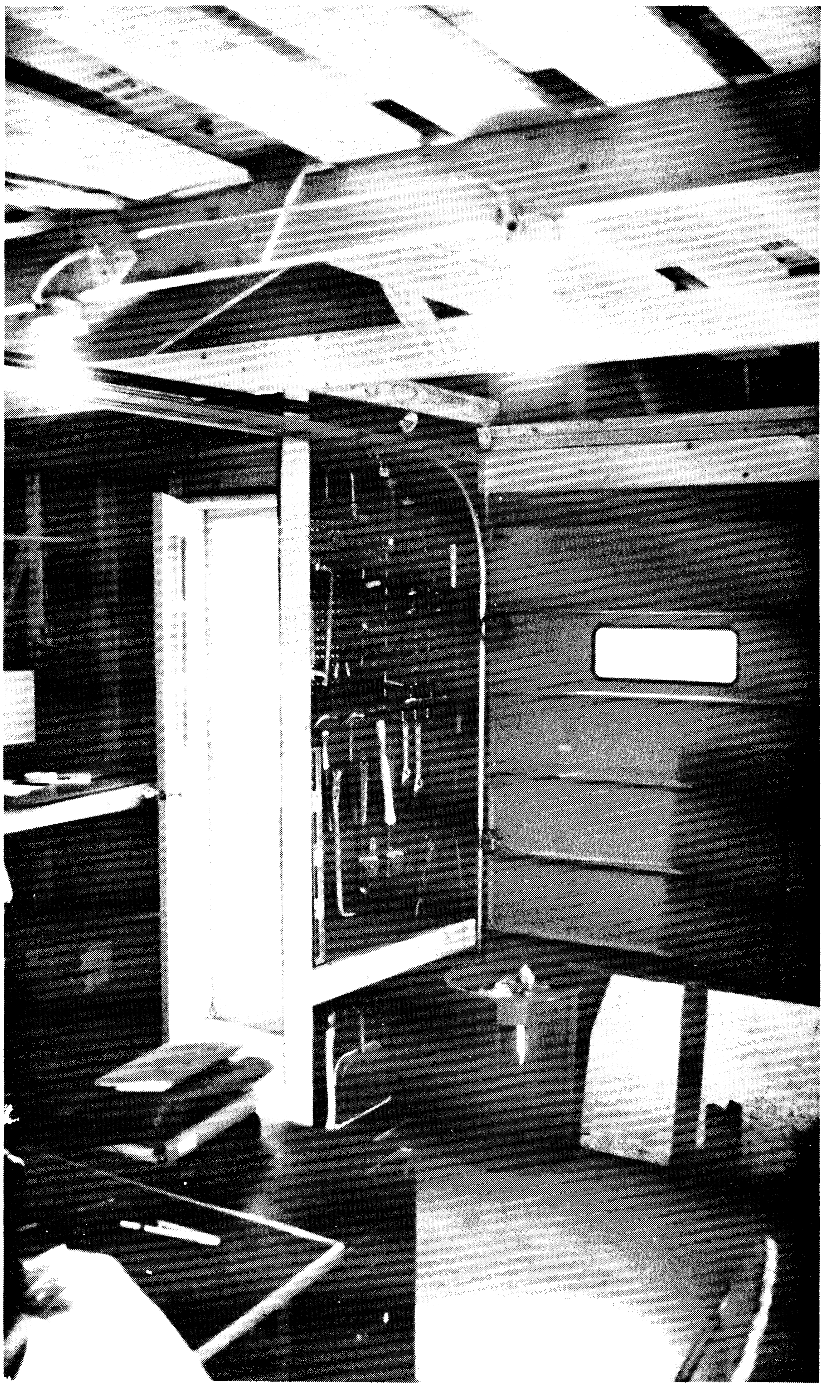


(a) Counter installation on east side of building and drain from bottling station on the south end.



(b) Counter installation on west side of the building and bottling station on south end.

Figure 3. Interior view of building.



(c) Tool board and doors at north-west corner of building.

Figure 3. Concluded.

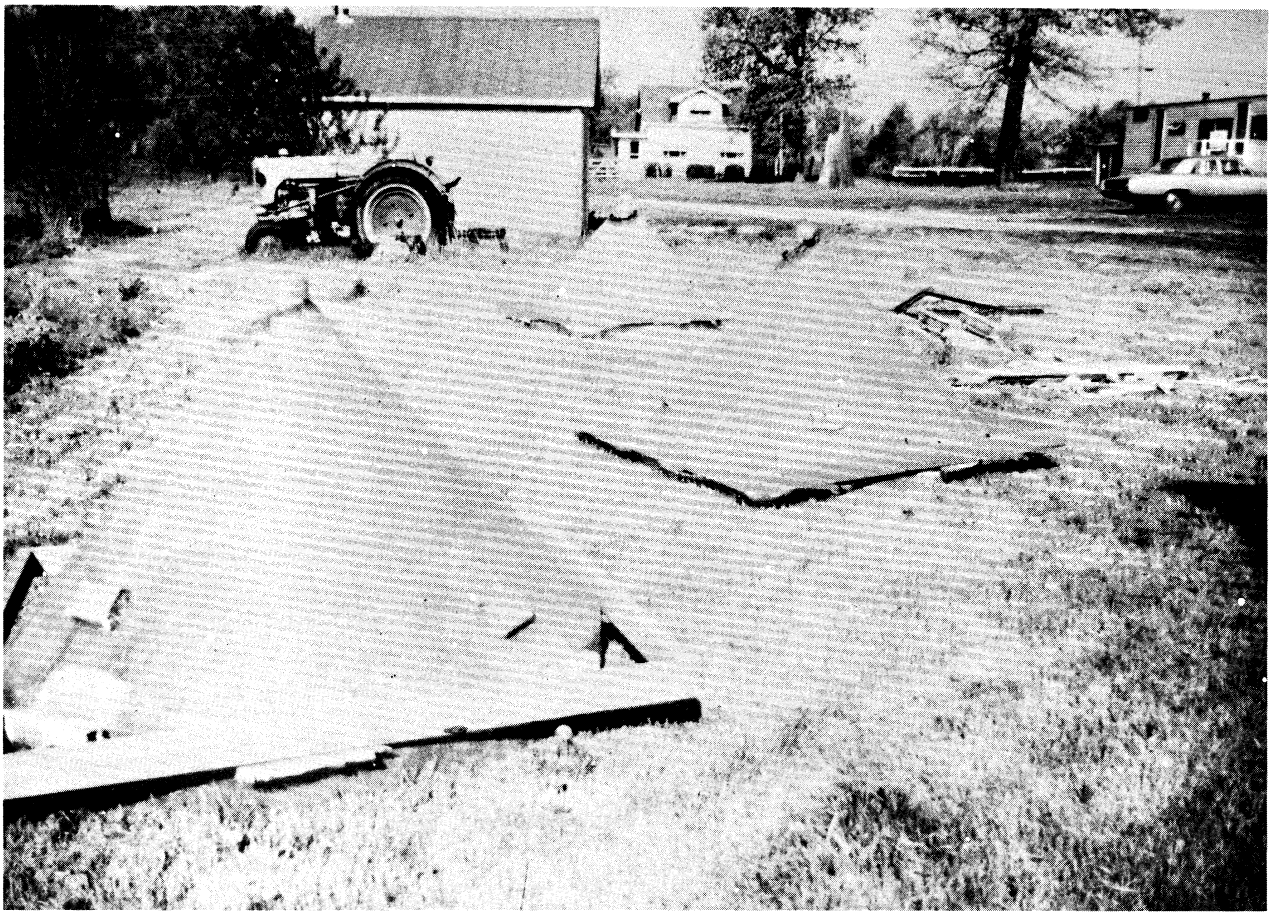


Figure 4. Fibre-glass funnels with new red-wood frames before being mounted on south side of building.

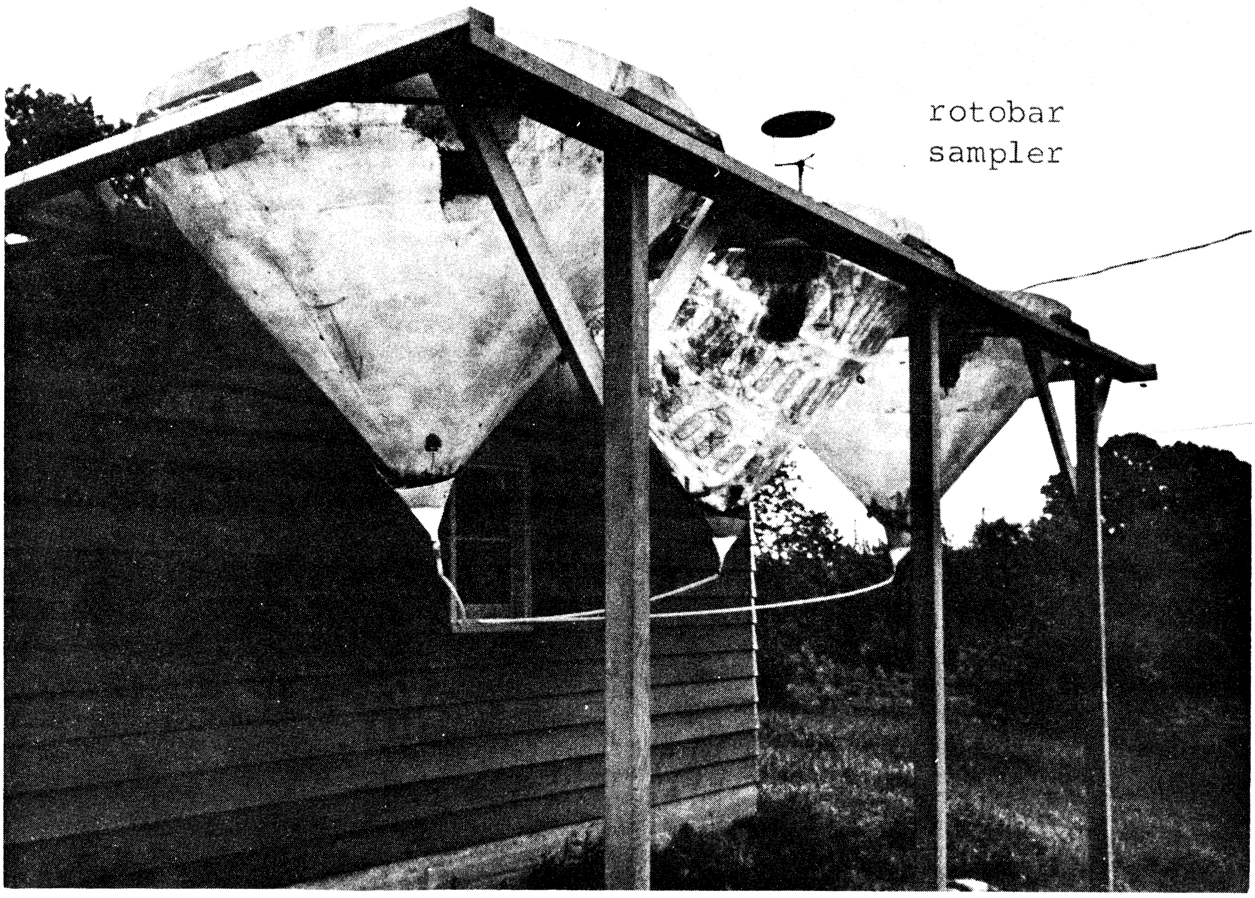


Figure 5. Fibre-glass funnels attached to structure on south side of building with polyethylene tubes leading from funnels to bottling station. Also indicated is rotobar sampler mounted near the south-east corner of the building. (WSI photograph)

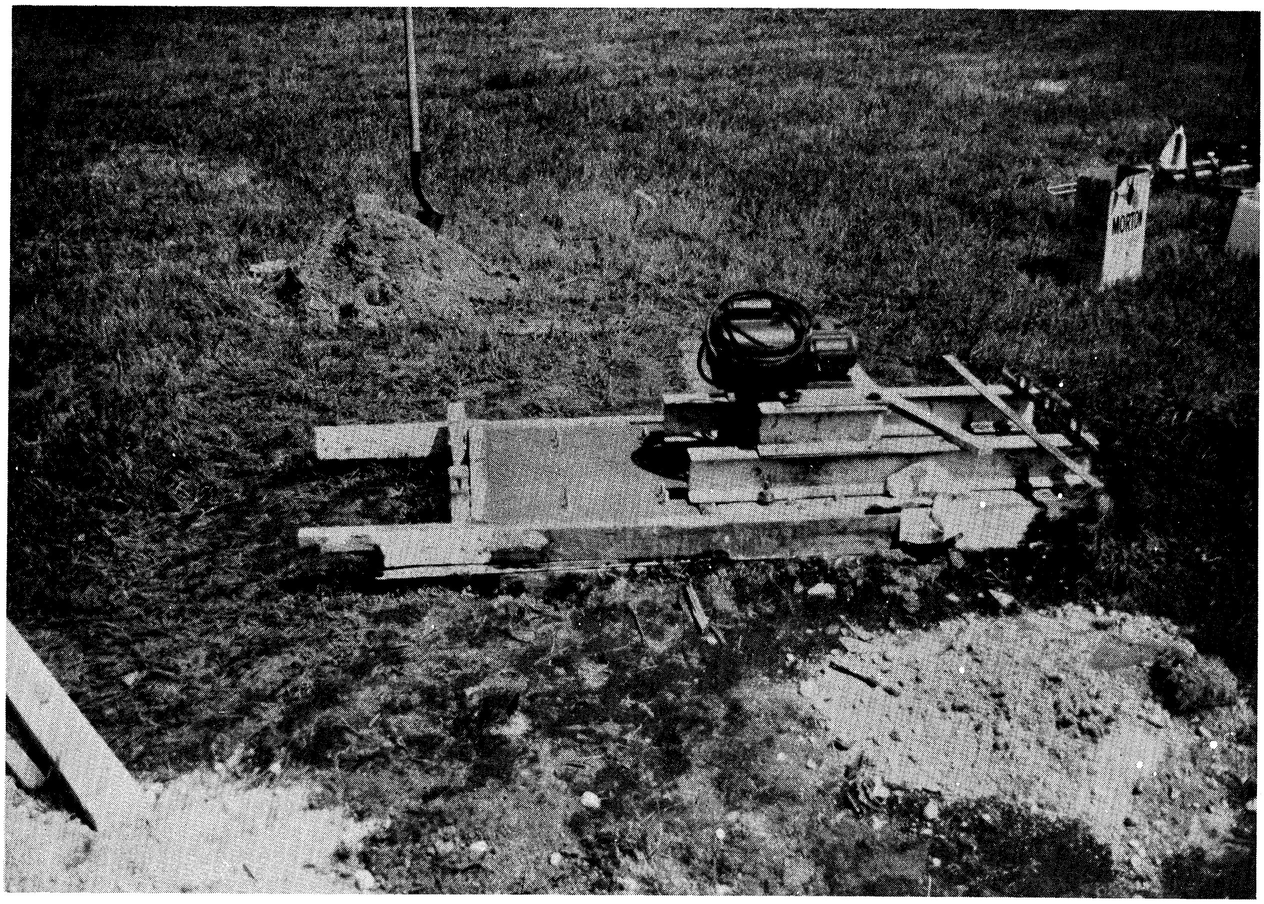


Figure 6. Concrete slab for photoelectric rain-drop size spectrometer.

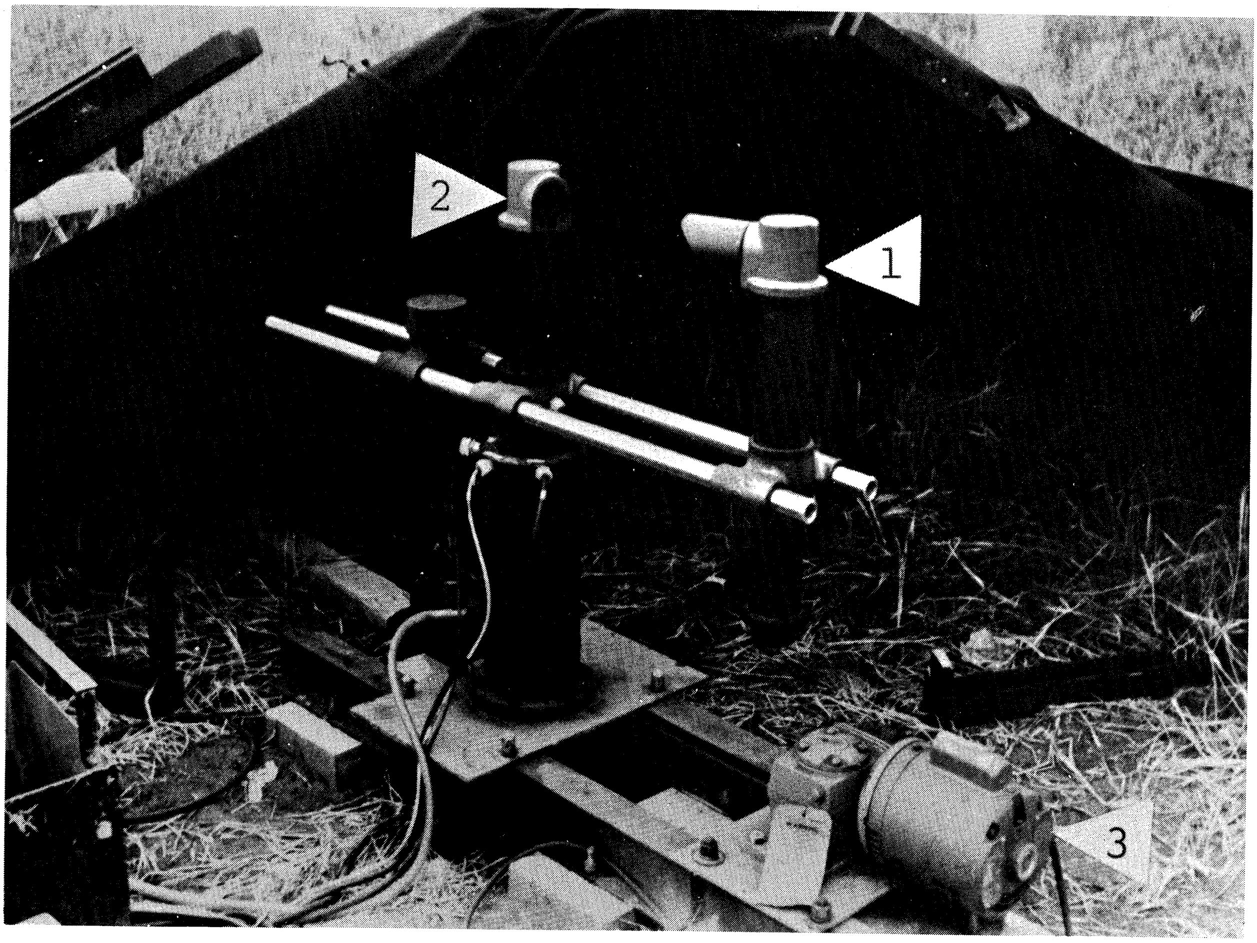


Figure 7. Photoelectric rain-drop size spectrometer viewed through the open tent. Indicated on the picture are: (1) photometer housing; (2) light source (& axis of rotation); (3) drive motor for rotation.

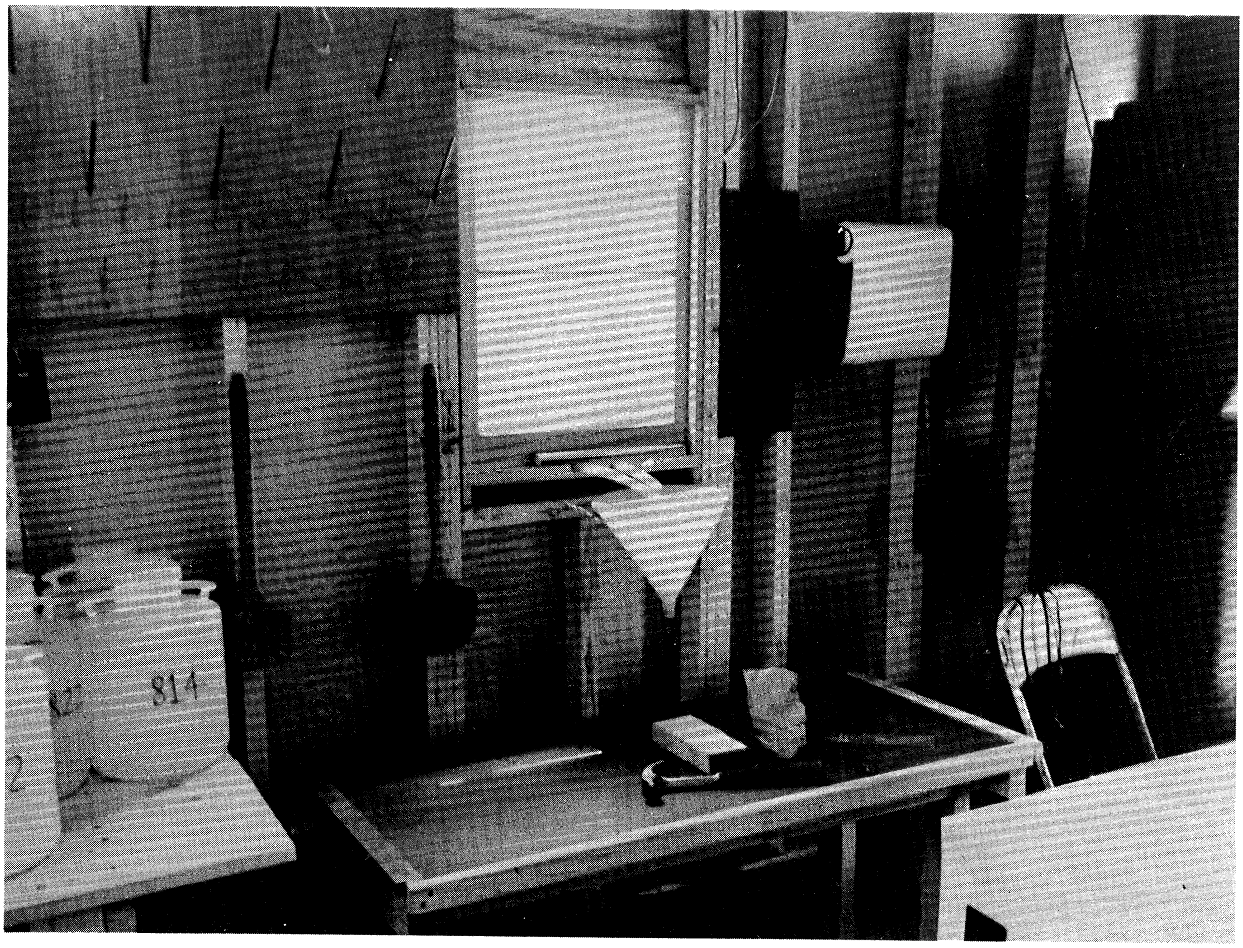


Figure 8. Rain water bottling area on south side of building. Polyethylene tubes from large fibre-glass funnels enter the building just under window. (WSI photograph)

On 12 May the additional complement of men required to complete our installation and testing of instruments and procedures prior to field operations arrived from Ann Arbor. These included our analytical chemist, Dr. K.S. Bhatki, our electrical engineer, Mr. R.E. Crabtree, and our fourth student assistant, Mr. David G. Curtin. The following several days were devoted to instrument installation, testing calibration, and rehearsal of operations under rain, completing these activities on 15 May. The photographic record of this stage is shown in Figures 9 through 13.

During this period the process of basic preparation of the facility was pressed vigorously, allowing only minimal time for conferences with the ISWS group related to our joint operation. Our basic objective was to be ready for rain events by 15 May, and this required an "all-out" effort on the part of each Michigan crew member.

3. <u>Field operations and data acquired</u>

The procedure for all field operations may be logically organized in terms of three stages with respect to each rain event: (1) the alert stage, prior to an event but anticipating rain within 2 to 24 hours; (2) the scramble, from 2 hours before onset through the rain occurrence; and (3) the pickup, immediately following the rain and continuing through timely chemical treatment and packaging of samples for analysis.

A. The alert stage

Synoptic and radar monitoring of the weather situations

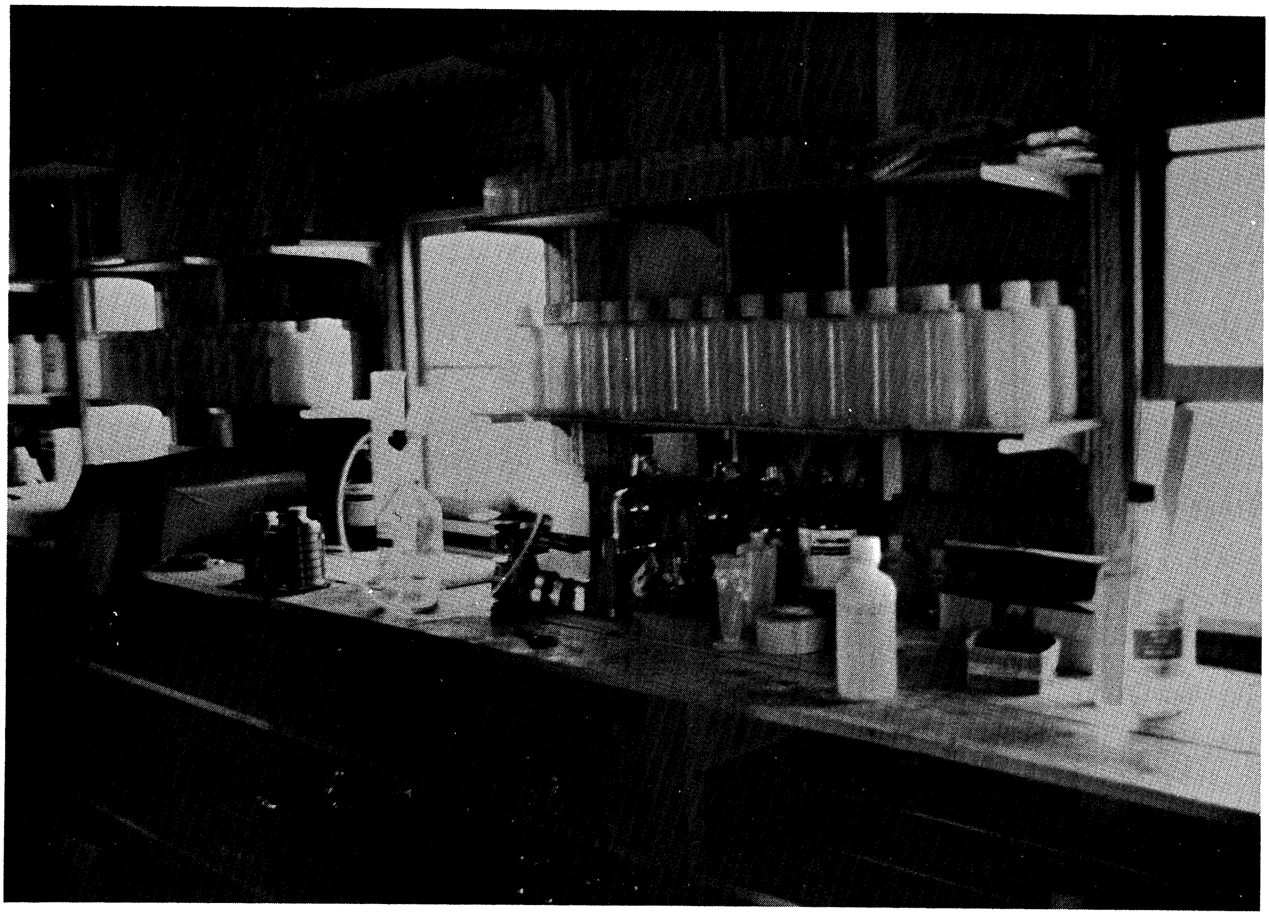


Figure 9. Area used for weighing, chemical treatment, and filtration of rain water on east side of building.

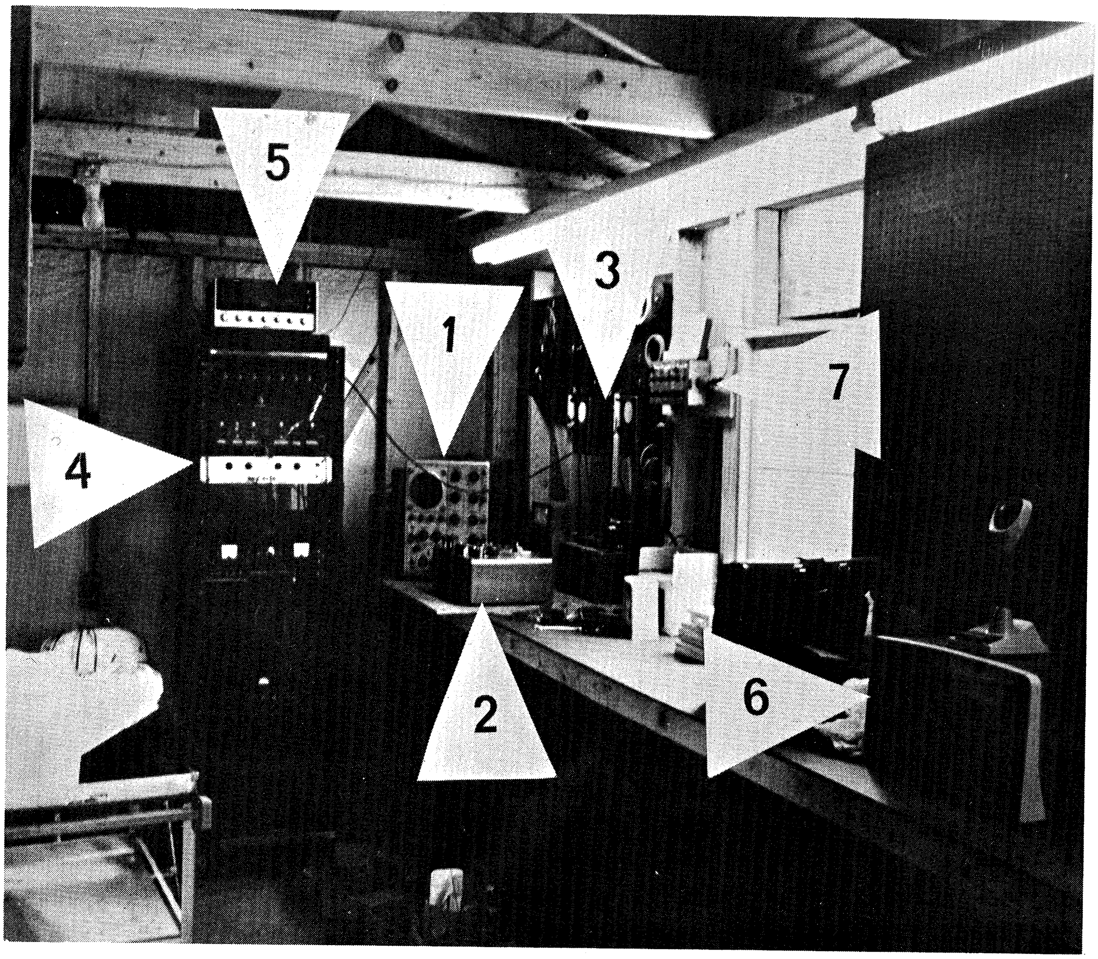


Figure 10. Electronics and communications area at south-west corner of building. Indicated are: (1) oscilloscope; (2) modified Tandberg tape recorder; (3) signal tracers; (4) electric console; (5) radio for WWV reception; (6) FM communication unit and microphone; (7) controls for spectrometer operation. (WSI photograph)

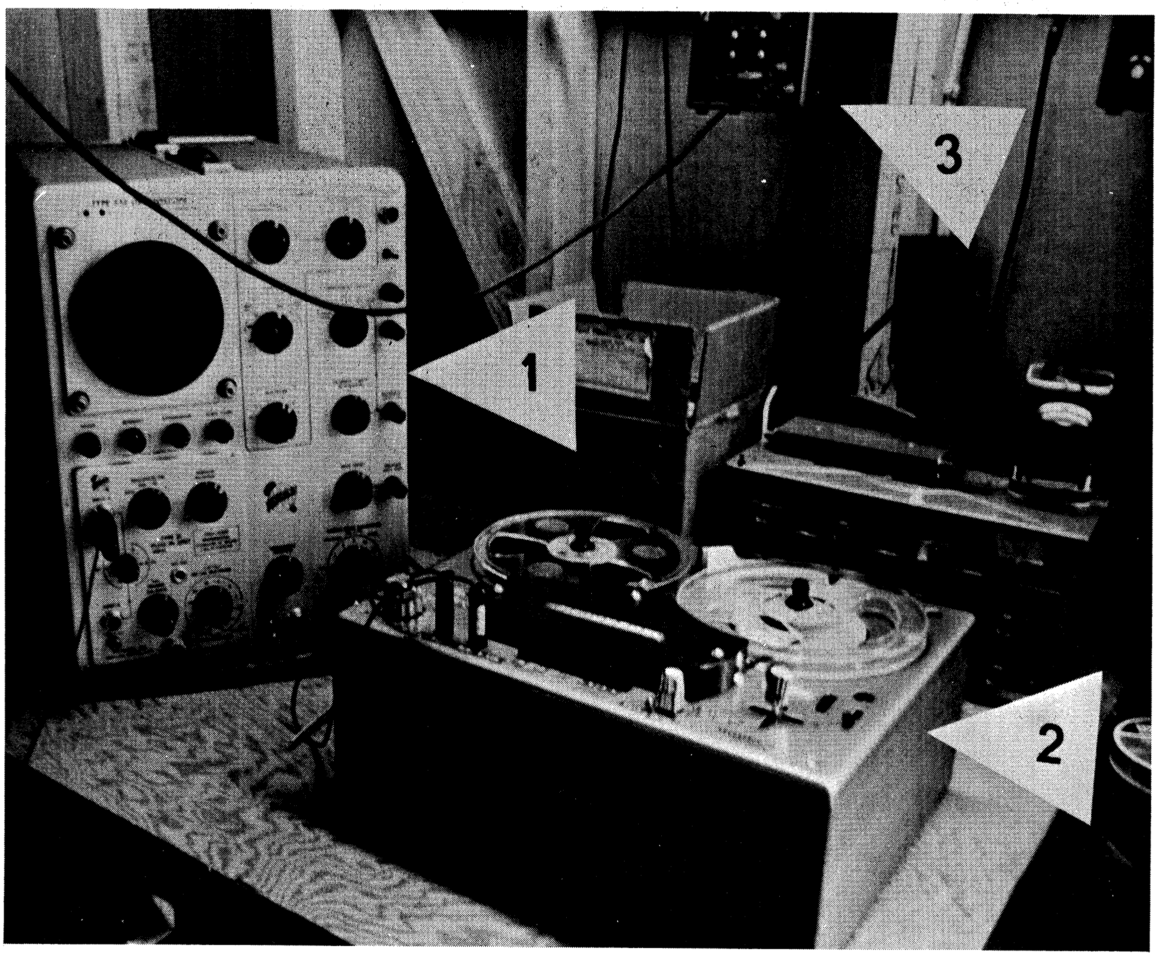
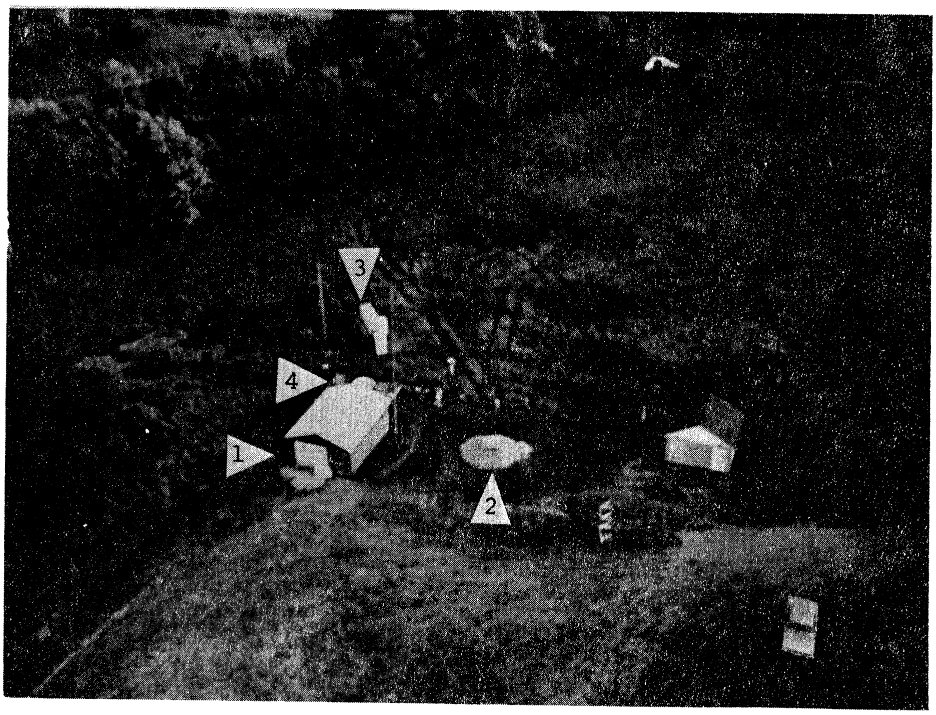
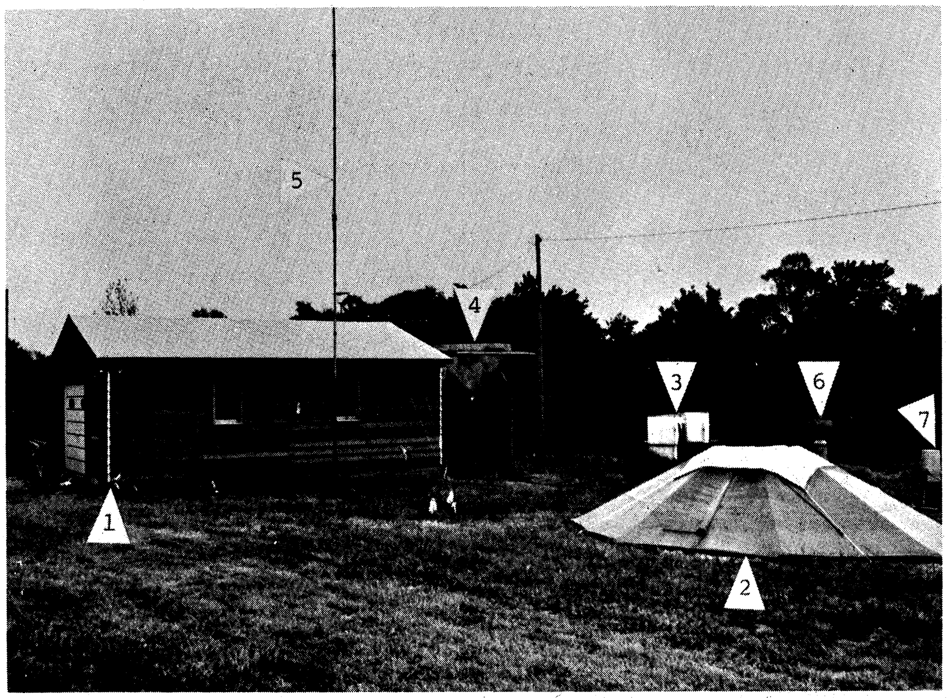


Figure 11. Photograph showing: (1) oscilloscope; (2) modified Tandberg tape recorder; (3) bottom portion of signal tracer. (WSI photograph)



(a) Aerial view indicating: (1) building; (2) rain-drop spectrometer tent; (3) Illinois rain-drop size camera; (4) three fibre-glass funnels positioned at south end of building. (WSI photograph)

Figure 12. Views of Michigan Base Station and grounds.



(b) Ground level view showing: (1) building; (2) rain-drop size spectrometer tent; (3) Illinois rain-drop size camera; (4) fibre-glass funnel; (5) aerial for FM communicator; (6) weighing rain gauge; (7) tipping bucket rain gauge. (WSI photograph)

Figure 12. Concluded.

Figure 13. One of two University of Michigan Mobile units with rooftop rain collector. (WSI photograph)

for the project is entirely in the hands of ISWS. Our regular project procedure calls for daily briefing at 1000 to 1030 CDT by telephone contact with the ISWS weather surveillance center. At this time comprehensive 24-hour forecasts are made and discussed, and coordination of field crew (mobile operations on the network, mainly) activities is arranged. In the event that rain is anticipated, the nature of the operation to take place is decided, and contact times and procedures (radio, telephone, etc.) are agreed upon.

Lead time provided by the predictions is used to set and/or reline samplers at the network stations, all of which are serviced within the 2 to 24-hour period prior to anticipated rain. In 1969 operations The University of Michigan crews maintained a network in the immediate vicinity of Clinton consisting of 103 samplers, including the ISWS sampling stations within the total area of about 230 sq. mi. This area was divided roughly into quadrants, each of which could be traversed by a mobile crew (driver and assistant) in 75 to 90 min. starting from and returning to the base station (see maps, Figures 14 through 17). The procedure during alert periods was to set the samplers in the upstream quadrants first, then the downstreams quadrants, each mobile unit handling two quadrants or "loops".

Because of dust collection by the open samplers over time, it was necessary to adopt some criterion by which sample

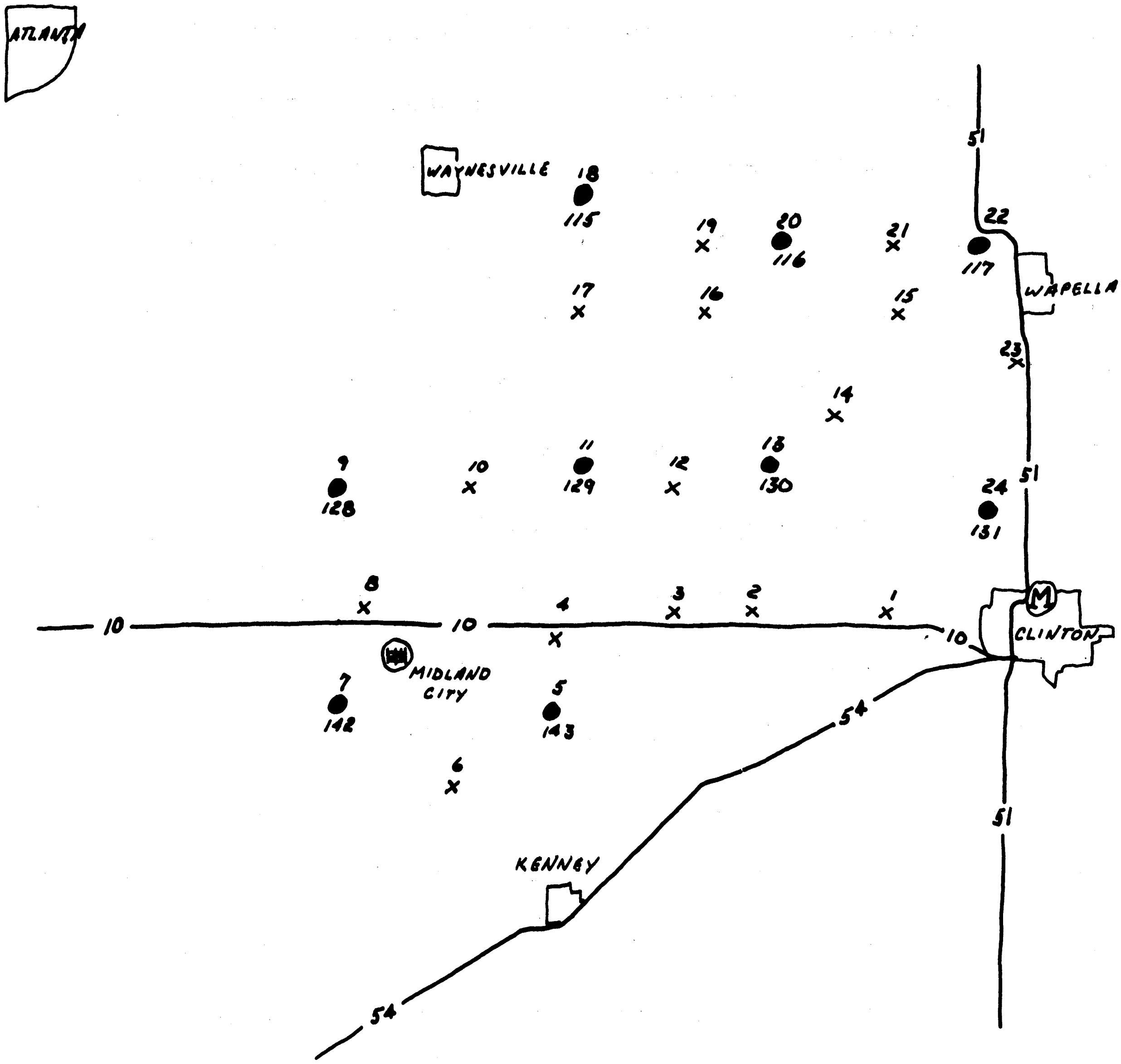


Figure 14. "Northwest loop" of rain-collecting network around Clinton, Illinois, in the spring of 1969.

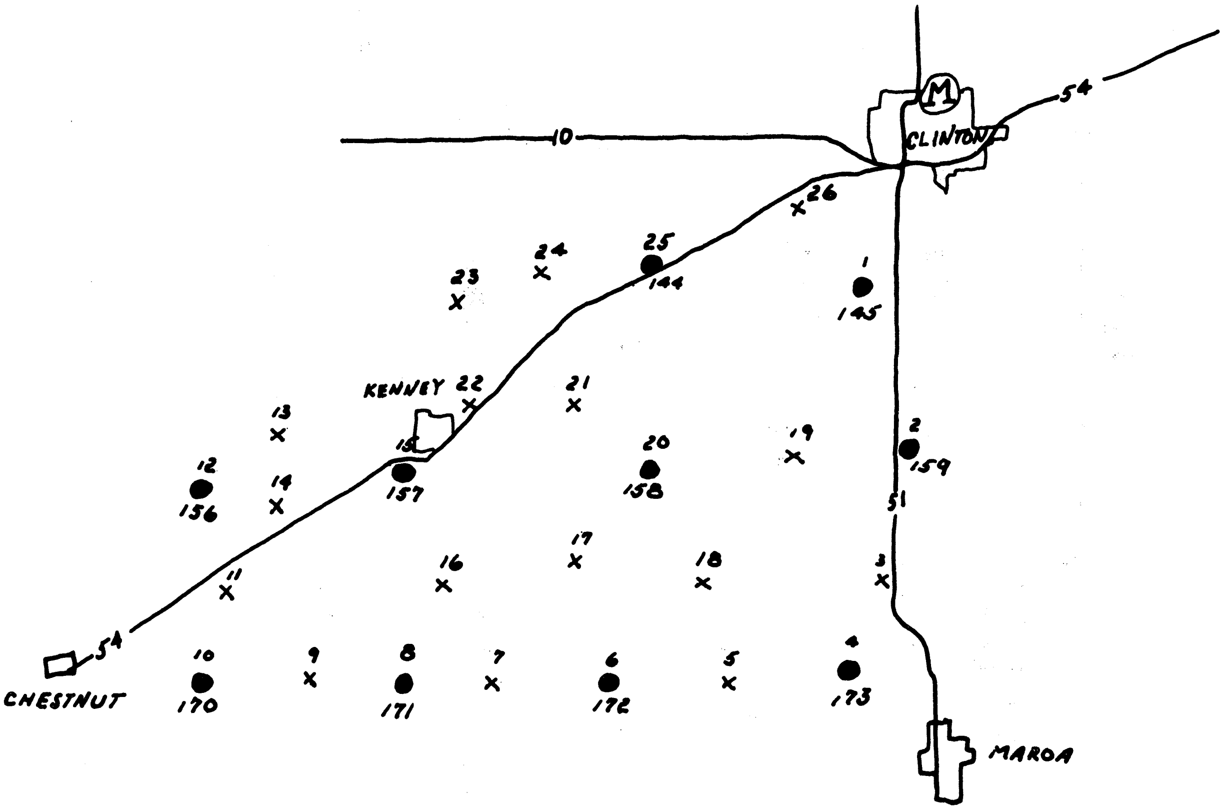


Figure 15. "Southwest loop" of rain-collecting network around Clinton, Illinois, in the spring of 1969.

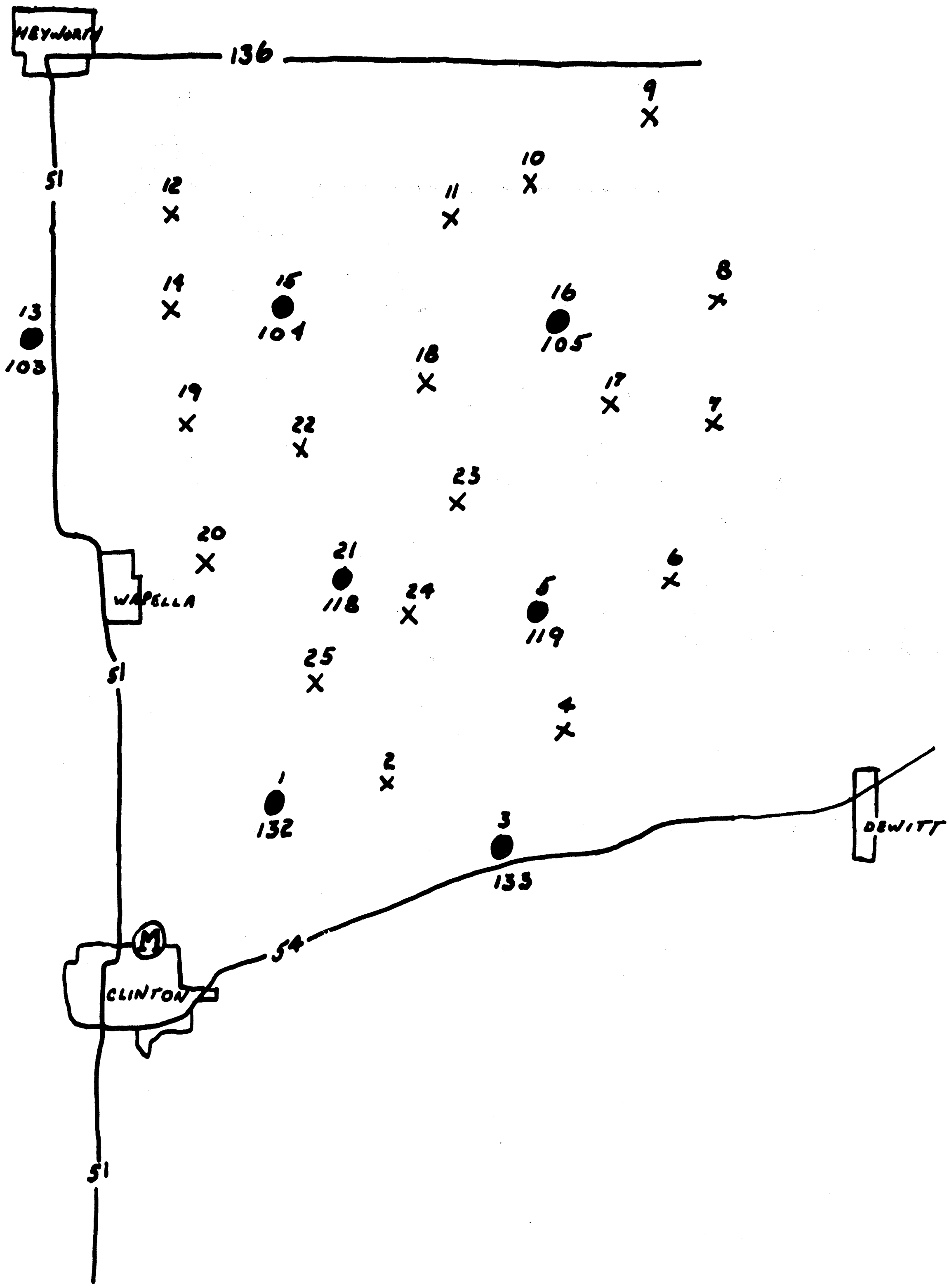


Figure 16. "Northeast loop" of rain-collecting network around Clinton, Illinois, in the spring of 1969.

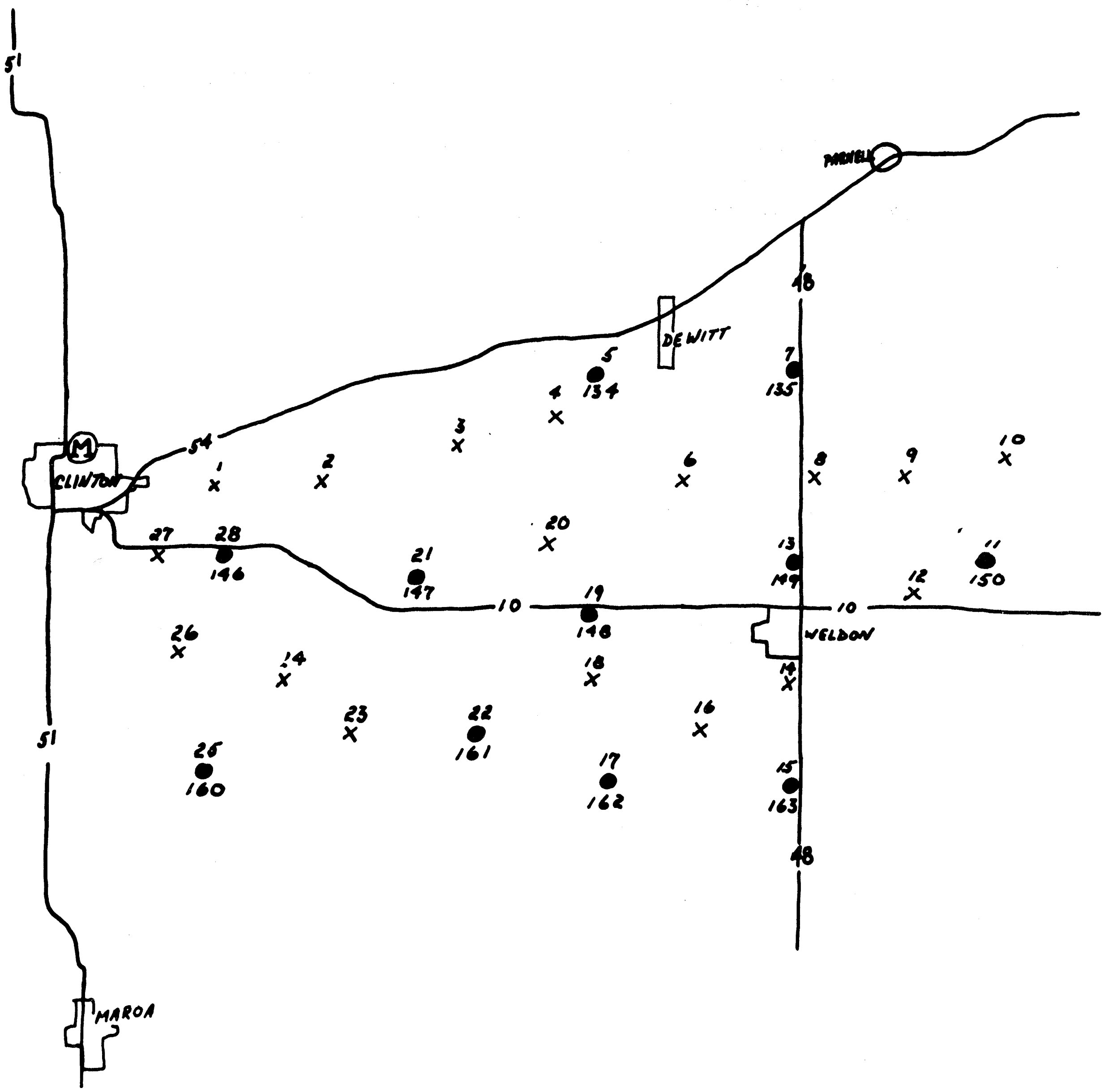


Figure 17. "Southeast loop" of rain-collecting network around Clinton, Illinois, in the spring of 1969.

liners would be declared contaminated. It was estimated that 2 or 3 days' accumulation of dry fallout would render samplers unfit to collect rain samples for rain scavenging measurements. Separate experiments were conducted to determine the amount and identity of the materials deposited as dry fallout near Clinton. These are described below.

B. The scramble

Within 2 hours of a predicted storm and anticipated operation, the radar usually shows the extent and approximate intensity of approaching rain-producing systems, and principal direction of project activities resides in the radar meteorologist. The flight crew maintains close contact with the weather center where definition of the area of operation of the aircraft is agreed upon. This area of operation, or "box", is chosen so that the probable trajectory of tracer material released there will carry it to the sampling network, the target center being The University of Michigan station. Upon reaching the operational "box", the aircraft becomes the control center, maintaining radio contact with the radar, The University of Michigan base station, and the two Michigan mobile units. It then becomes the responsibility of the aircraft crew to spot promising convective systems, select one for tracer innoculation, and direct the mobile units to the areas most likely to lie under the path of the innoculated storm. At this point in the operation the mobile units move out to increase the density of that part of the sampling network estimated to be in the path of the innoculated storm, and to station themselves, prior to the onset of rain, in downwind positions for sequential sample collection as the storm passes them. The design of this sampling procedure then provides for a network of whole-storm samples having special density near the path of the storm, plus three sequential sampling series through the storm. The timeliness of the operations in this period is crucial for success, and the action is intense.

C. The pickup

To avoid extraneous dilution or contamination of rain samples, it is essential that they be collected as promptly as possible following the trace-innoculated rain event. Further, to prevent adsorption of the trace materials upon container walls, it is necessary to treat the samples chemically without delay. The mobile crews are therefore required to pick network samples up as soon as the experimental rain has passed, returning them to the base station for acidification and initial filtration. These steps are directed and helped by the cognizant person (in 1969, Dr. K.S. Bhatki) in charge of chemical procedures.

Throughout all operations, the recording equipment at the base station is used to record both the events that occur there and the conversations with the aircraft and the mobile units. In addition notes are written in log-books kept for the purpose in each mobile unit and at the base station. Portable tape recorders are also used by the mobile crews to document their activities in those periods when time does not permit writing comments, observations, etc. These are transcribed at the earliest possible time following each operation so as to avoid any loss of information relevant to the operation.

D. Experiments

The experiments actually conducted are determined primarily by the weather experience of the area during the period of field operations. In 1969 central Illinois was visited by drought of unusual intensity during our field program. No ideal case for tracer operation occurred. This made possible a certain amount of dry weather experimentation, i.e., the study of dry fallout of various species of contaminant. At this writing, the data are not all reduced but the experiments are described below, and the state of the data reduction for each is presented.

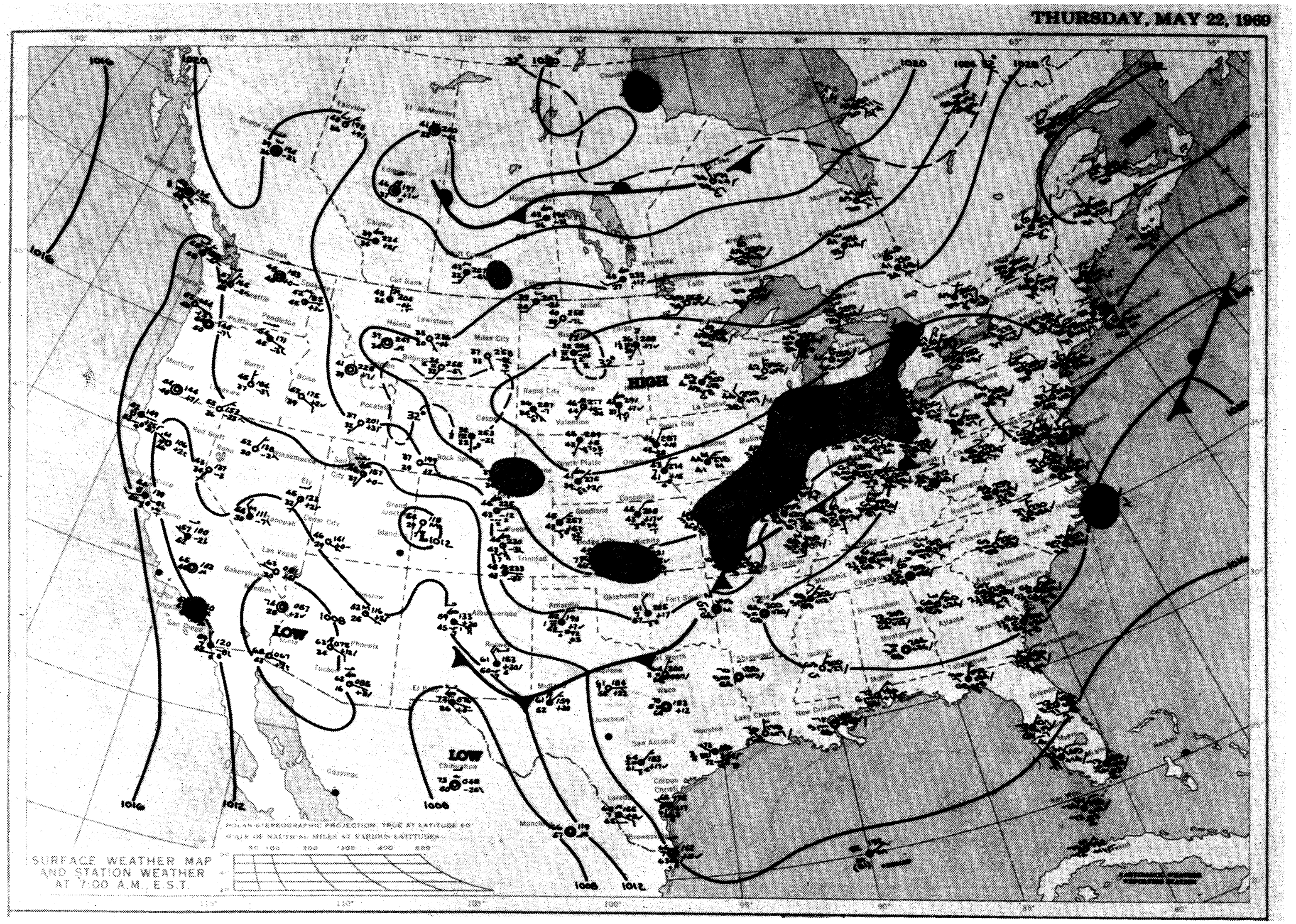
16-28 May, 1969

Repeatedly during this period, frontal systems approached the area, requiring the preparation of the sampling network (alert stage), but failed to produce weather suitable for tracer experiments. This enabled our crews to become thoroughly acquainted with the roads and the network stations, and to resolve operational problems by rehearsing the operation.

Such a situation was that of 22 May 1969 (Fig. 18a, b) which produced only intermittent drizzle, but which held the possibility of convective activity if the stationary front had begun to progress northward. On this occasion all four loops were prepared, but the weather did not cooperate.

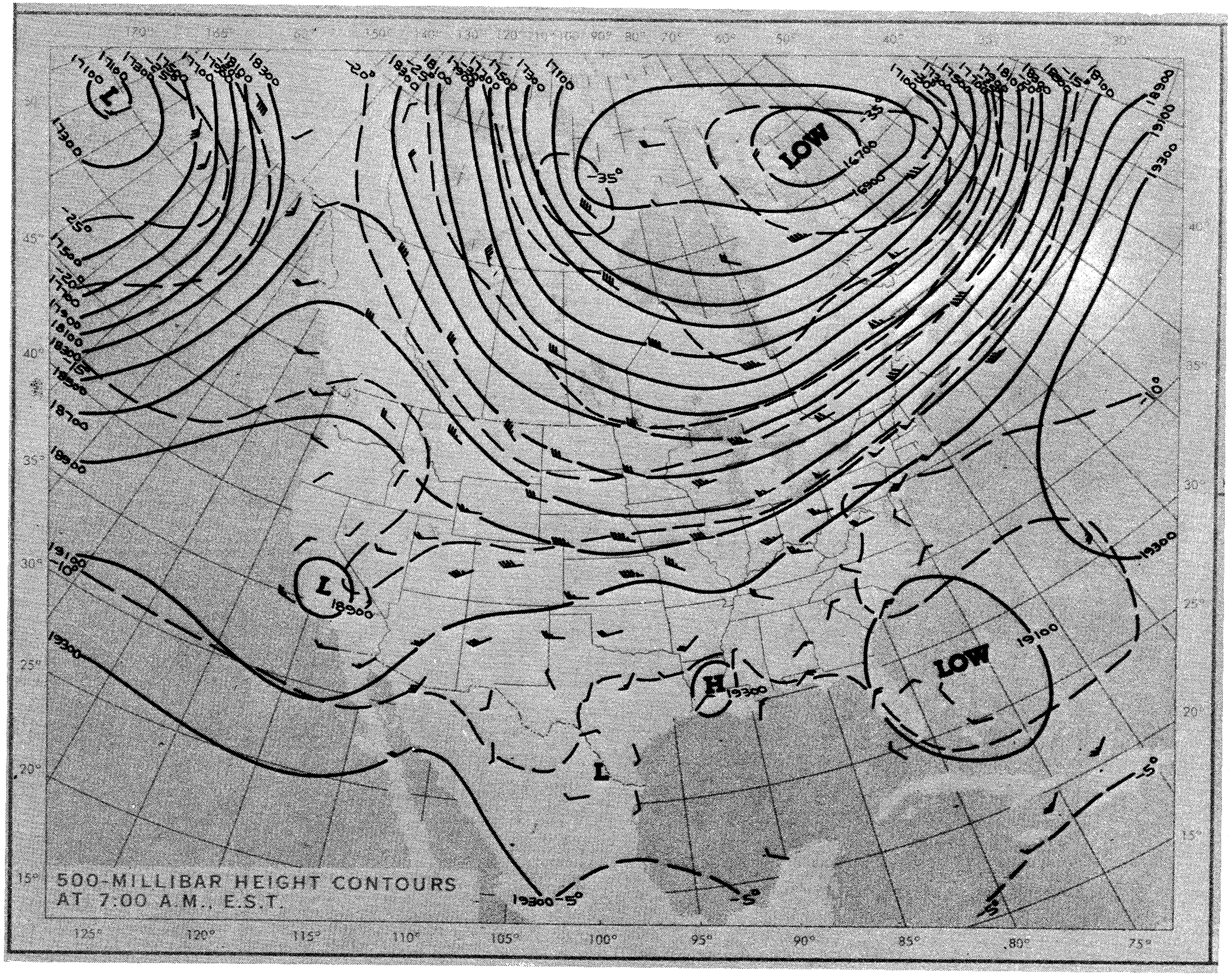
Again on 25 May (Sunday) some cumulus activity appeared from our local observations to be developing, despite a forecast of no rain. Radar observed a shower to form about 12 mi north of Michigan base, move southward and split north of Clinton. One cell then moved slightly southwestward and dissipated west of the base station giving no appreciable rain, while the other moved eastward and dissipated about 20 miles west of Champaign, giving a small amount of rain in a narrow streak across the network north and east of Clinton. Our contract aircraft probed one cumulus tower at an altitude of 12,000 ft. finding a temperature of -2°C and an updraft of 800 ft min^{-1} in the cloud, but not below it.

There was occasional nocturnal rain, which again made additional network servicing necessary because we could not



(a) Surface map.

Figure 18. Weather maps, 0700 CDT, for 22 May, 1969.



(b) 500 mb map.

Figure 18. Concluded.

do tracer experiments at night. Late on the 28th the synoptic situation appeared to be shifting, so a special alert was called for 29 May.

29 May, 1969

The synoptic charts for 0700 CDT is shown in Figure 19a, b.

Contact with ISWS radar was initiated at 0840 CDT. It was learned that the cold front was expected to pass Clinton, Illinois, between 1400 & 1800, and that the front was preceded by a squall line running roughly 100 mi. ahead. Activity on the squall line the evening of 28 May had produced a tornado in northern Wisconsin.

The two westward loops had been serviced after noon on 28 May. The eastward loops were set during the morning of 29 May.

Contact was maintained continuously, all systems ready to operate, at 1400 the time of frontal passage was predicted to be 1700. At 1555, ISWS radar reported the cold front almost stalled north of Peoria, with a few small showers appearing and dissipating about 20 mi. north of the ISWS network. Next contact was scheduled for 1715.

At 1732, observing from Michigan base station the advance of major cloud formations from the northwest, we called ISWS. Breakdown of the radar for 1 hour had interrupted their monitoring, and the aircraft was waiting for vectors and orders.

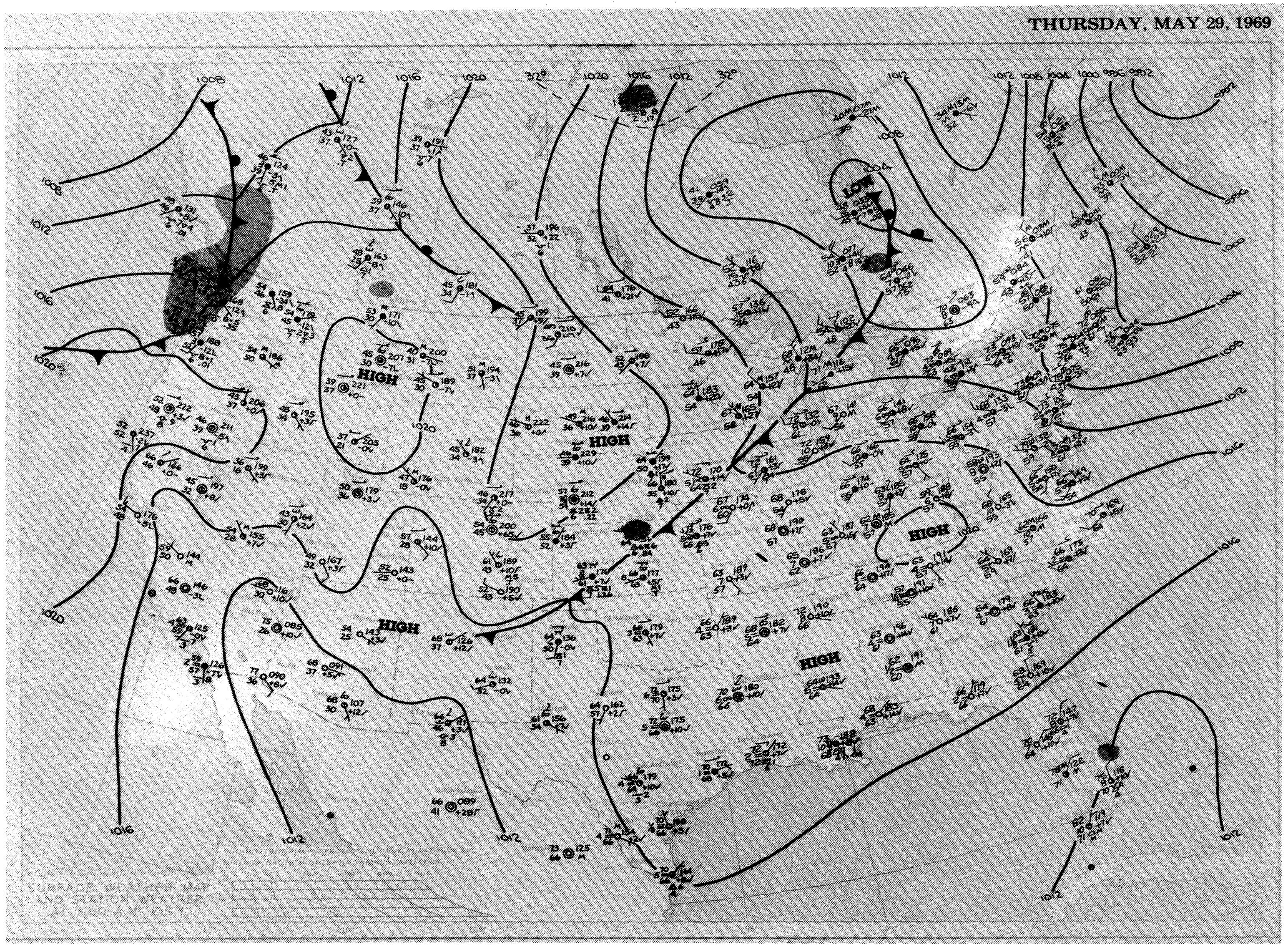
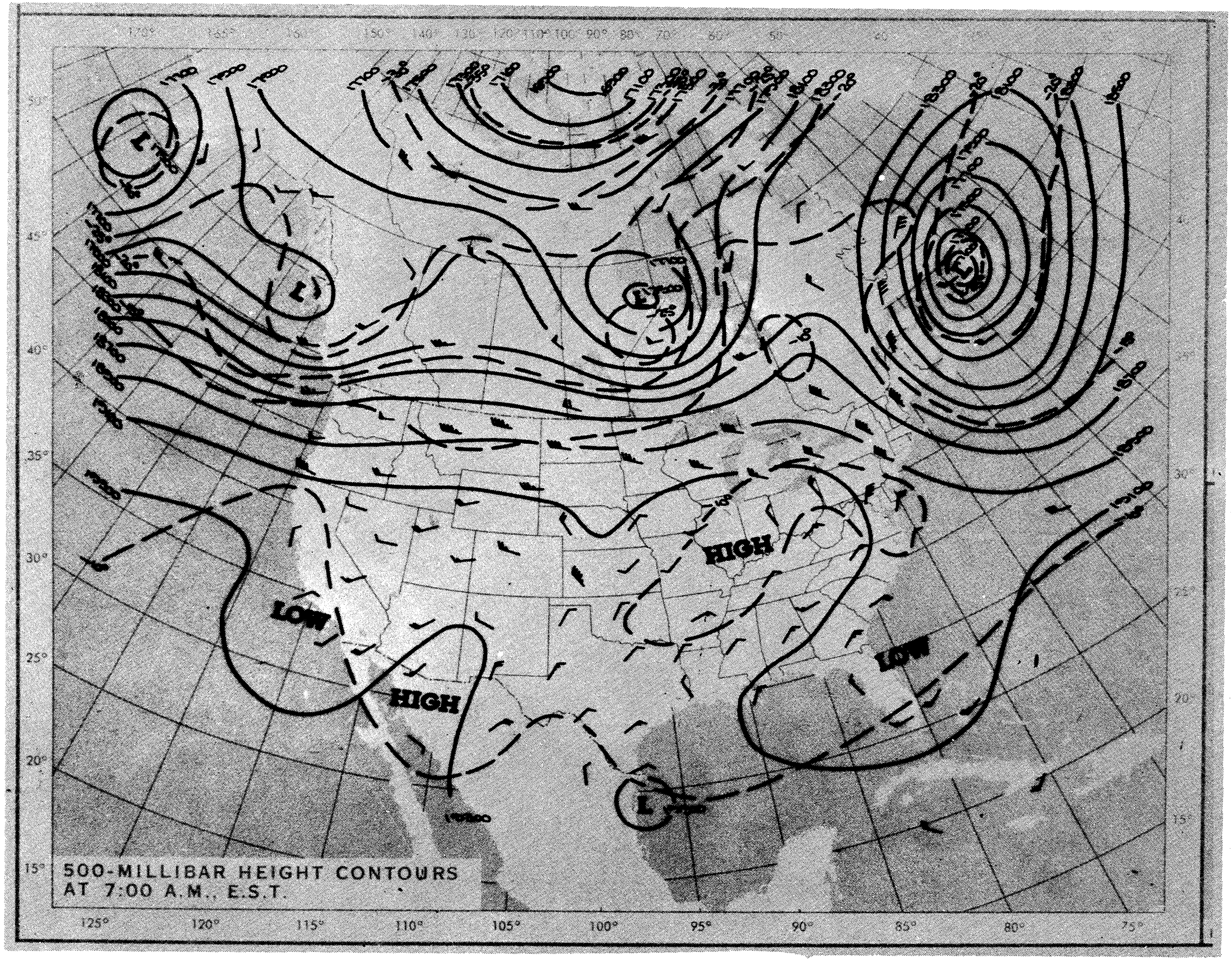


Figure 19. Weather maps, 0700 CDT, for 29 May, 1969.



(b) 500 mb map.

Figure 19. Concluded.

Radar was just back in service; decision to be reached in 5 min.

At 1850 first thunder was heard at Michigan base, radio static was increasing, stormcloud had advanced southeastward 5 to 6 miles (estimated from visual observations), and aircraft was dispatched.

At 1810 first radio contact with the aircraft was made, reporting slow southward progress of squall line, currently located just north of ISWS network.

At 1817 Michigan base experienced a sharp wind shift from the indraft to the storm to the outdraft from the storm, which was towering mightily, but still about 15 mi. north-northwest of the station.

At 1830 the aircraft located a strong updraft of 800 to 1000 ft. $\min^{-1}$ about 5 mi. northeast of Lincoln (18 mi. west-northwest of Michigan base), but the propagation was toward northeast, and dissipation soon set in. At this point, roughly, the whole squall line went into a dissipating phase.

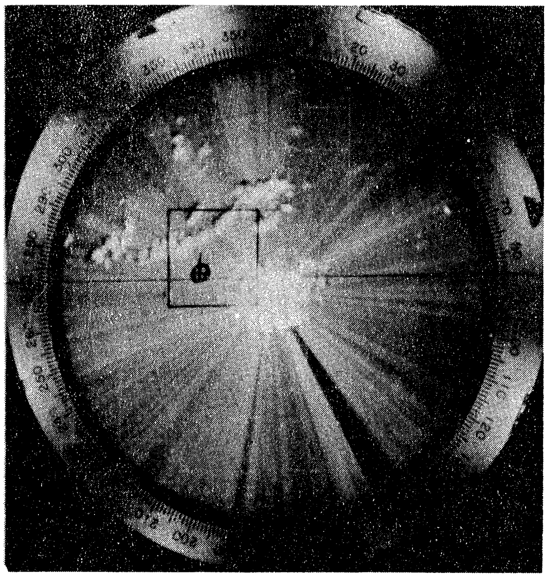
At 1850 new small convective cells, having no orderly distribution, began to breakout about 3 mi. southwest of the Michigan base station. The mobile units were redirected to the south to intercept this activity, having been dispatched eastward and northeastward at 1831.

Tracer indium flares were fired at 1900 and burned in an area 3-4 mi. south of Michigan base until 1906 (14 flares in all giving a total of 260 gm of indium)', but the field of small showers was so badly disorganized that no individual shower could be identified or traced either by aircraft or radar. Samplers were distributed over the area, however, and these were collected and returned for preliminary chemical processing by 2100.

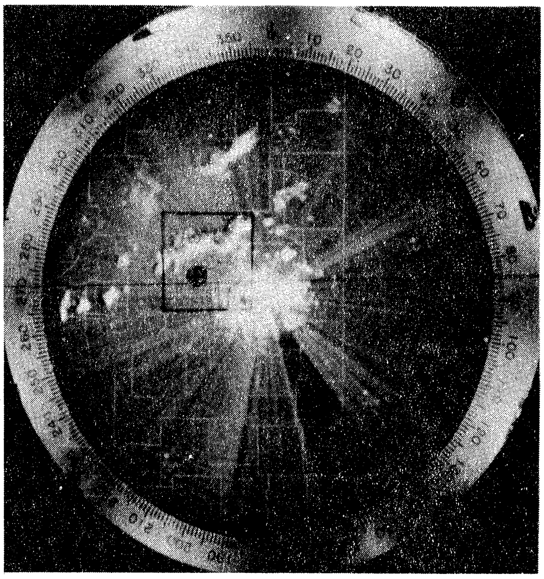
Radar echoes are shown in relation to the Michigan station and the ISWS neteork at the critical period, in Figure 20a, b, c, d. The Michigan base station received only a few drops of spray as the precipitation system leap frogged past. The experience is recorded here in detail as an example of the project coordination that is necessary and attainable despite a non-cooperative behavior of the weather. This particular experience did provide some tracer-tagged samples (see below), but the interpretation of the data remains to be studied. Meanwhile it stimulated the proposal of several new modifiers for the cloud name "cumulonimbus" such as "dissapointalus", "eraticus", "distractus", deflatatus", etc.

30 May through 1 June 1969

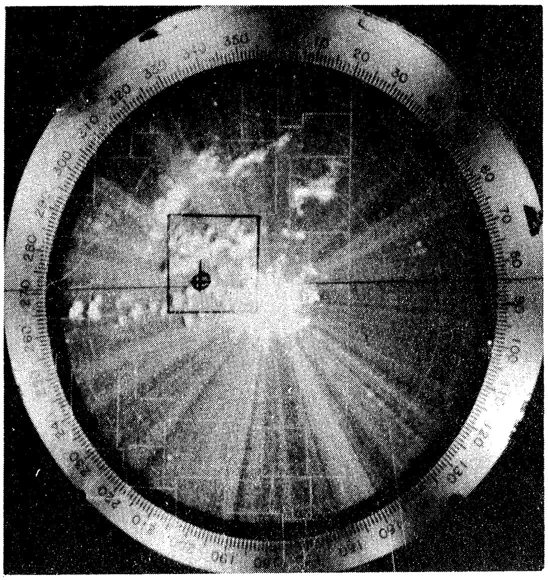
The cold front of 29 May had stalled south of our station, and there was indication that it might move back northward giving thunderstorm activity in the warm air south of the front (see synoptic charts, Figure 21a, b) with the expected diurnal heating. Although alert status was maintained, the



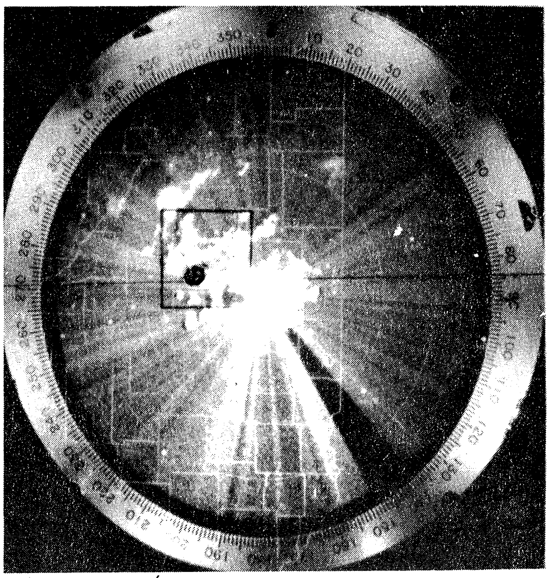
Time: 1749 CDT
Range: 100 mi.



Time: 1834 CDT
Range: 100 mi.

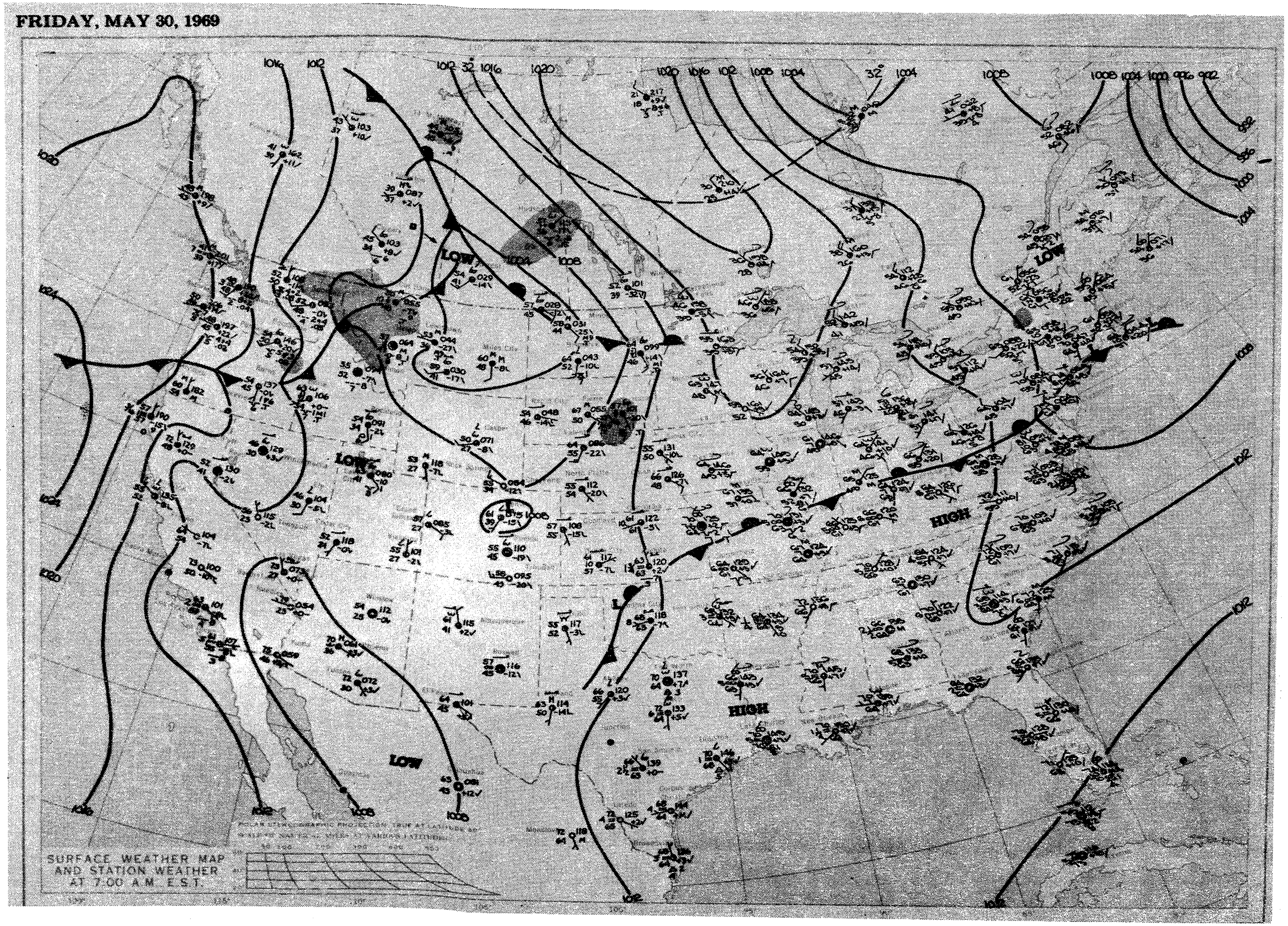


Time: 1859 CDT
Range: 100 mi.



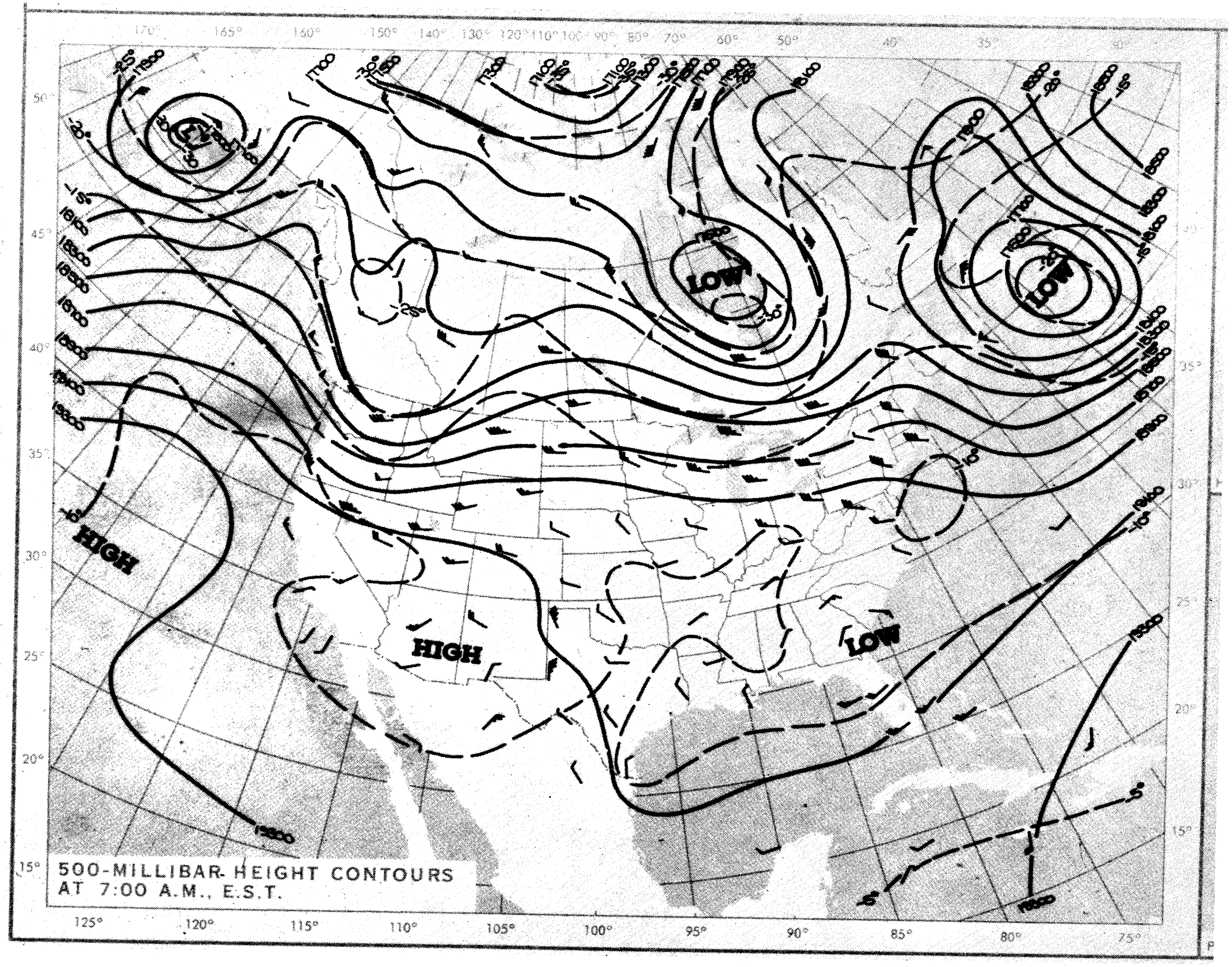
Time: 1920 CDT
Range: 100 mi.

Figure 20. Radar echoes of 29 May, 1969, from 1749 CDT to 1920 CDT.



(a) Surface map.

Figure 21. Weather maps, 0700 CDT, for 30 May, 1969.



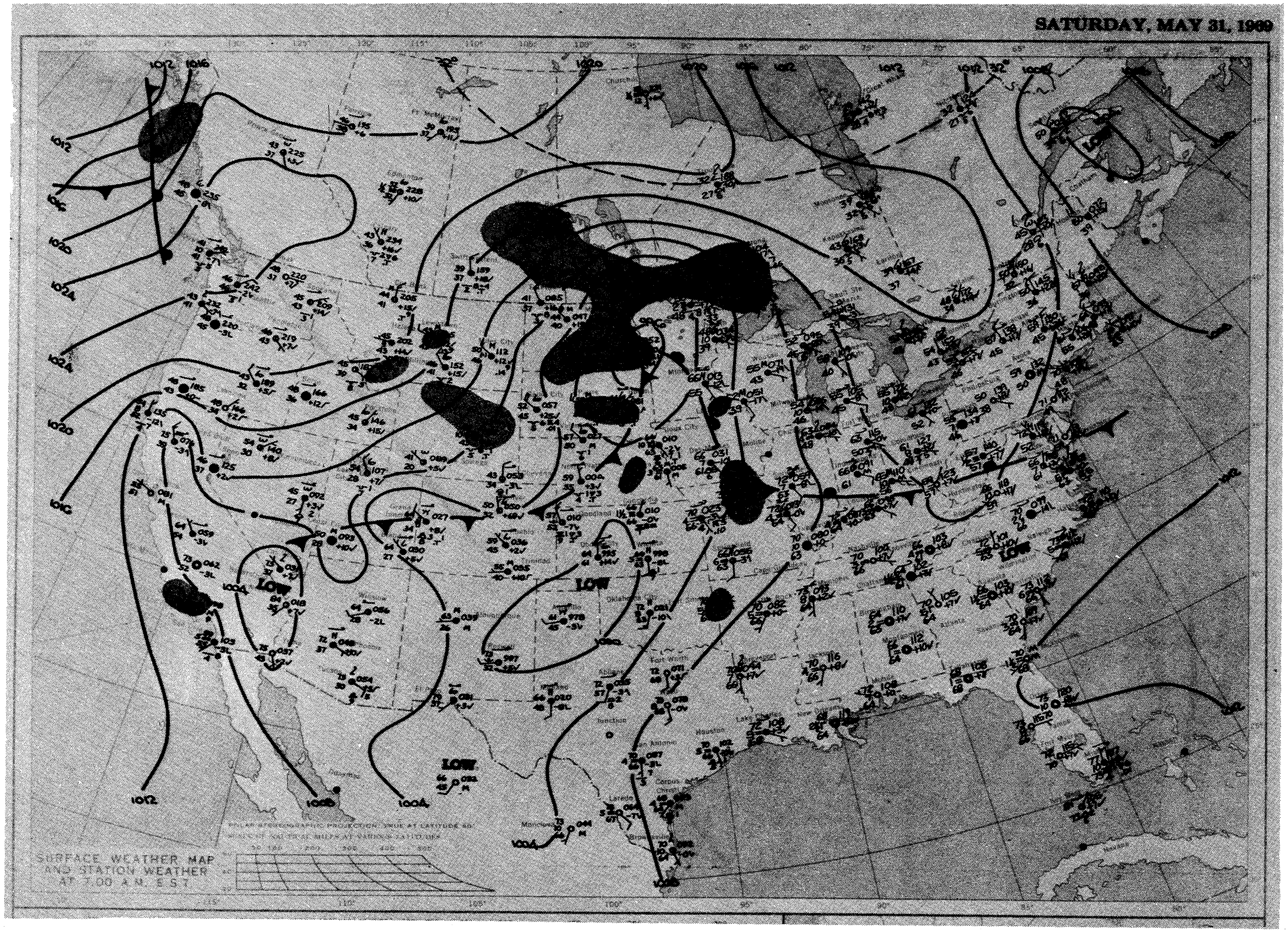
(b) 500 mb map.

Figure 21. Concluded.

system again behaved somewhat like that of 22 May and no workable opportunities developed, although a 45-min duration shower was observed by radar about 80 mi. southwest of Champaign. General alert status was continued to Saturday, 31 May (Figure 22a, b) and Sunday, 1 June (Figure 23a, b).

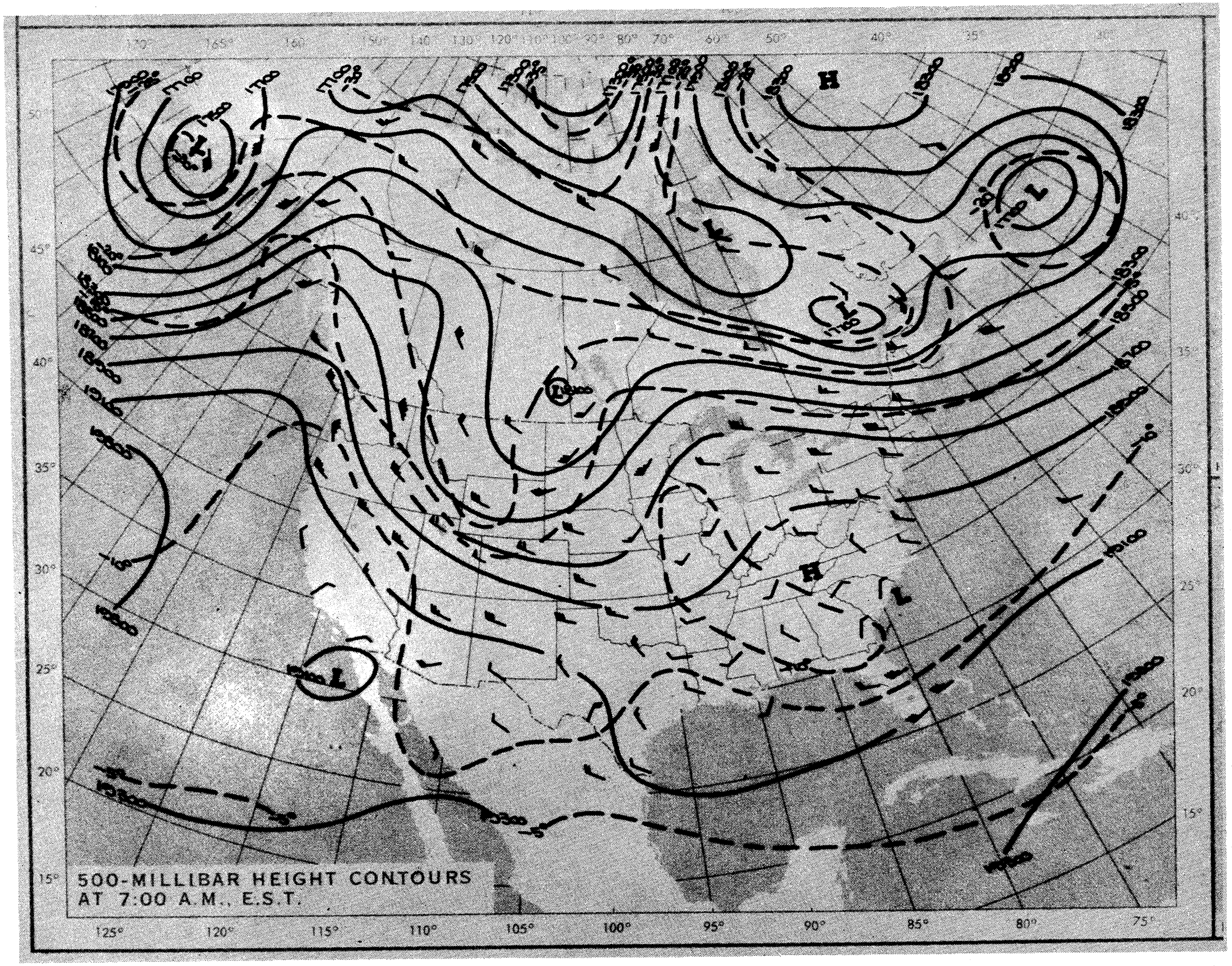
Morning of the 31st found us back in the warm air with SW wind, a slowly falling barometer, Fs and Ns clouds, with widely scattered light rain, and some audible thunder. This cloud deck broke up about 1445 revealing Cu towers west and northwest of Clinton. Best possible weather monitoring by radar and by long distance communications with the Military Weather Warning Center, Kansas City, Mo., led to predictions of a possibly workable frontal passage on Sunday morning, 1 June, but no workable system before sunset on 31 May. During the night thundershowers contributed 0.12 in. of rain at Michigan base.

The aircraft was in the air by about 0930 on 1 June. No promising activity was located, although intermittent light showers occurred at Michigan base station, and the aircraft returned to Champaign for fuel and a new briefing at 1130. additional rain fell, but the situation failed to develop favorably for tracer work, and the alert status was removed at noon. Network samples were collected, treated and subdivided for the various analyses (see below).



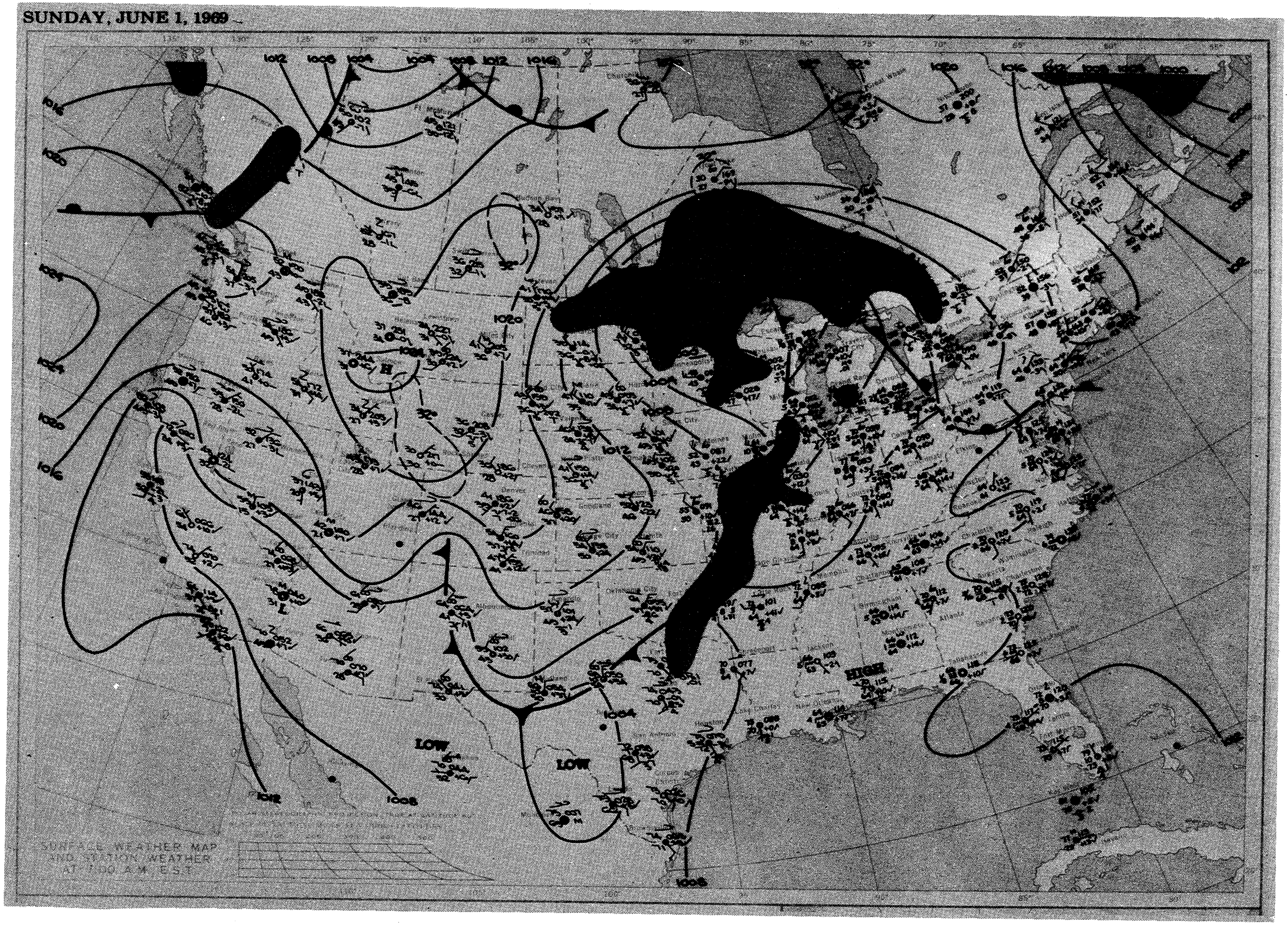
(a) Surface map.

Figure 22. Weather maps, 0700 CDT, for 31 May, 1969.



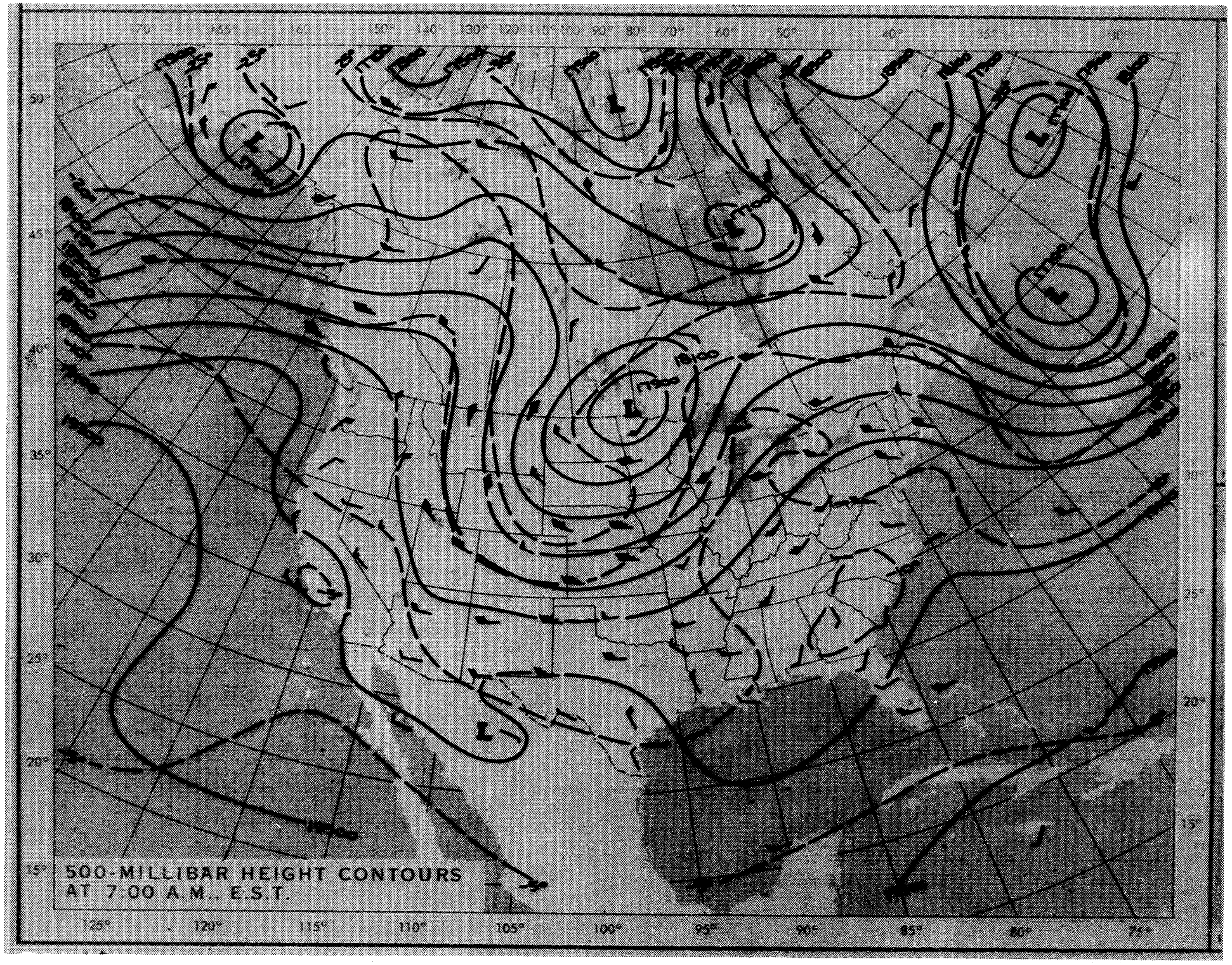
(b) 500 mb map.

Figure 22. Concluded.



(a) Surface map.

Figure 23. Weather maps, 0700 CDT, for 1 June, 1969.



(b) 500 mb map.

Figure 23. Concluded.

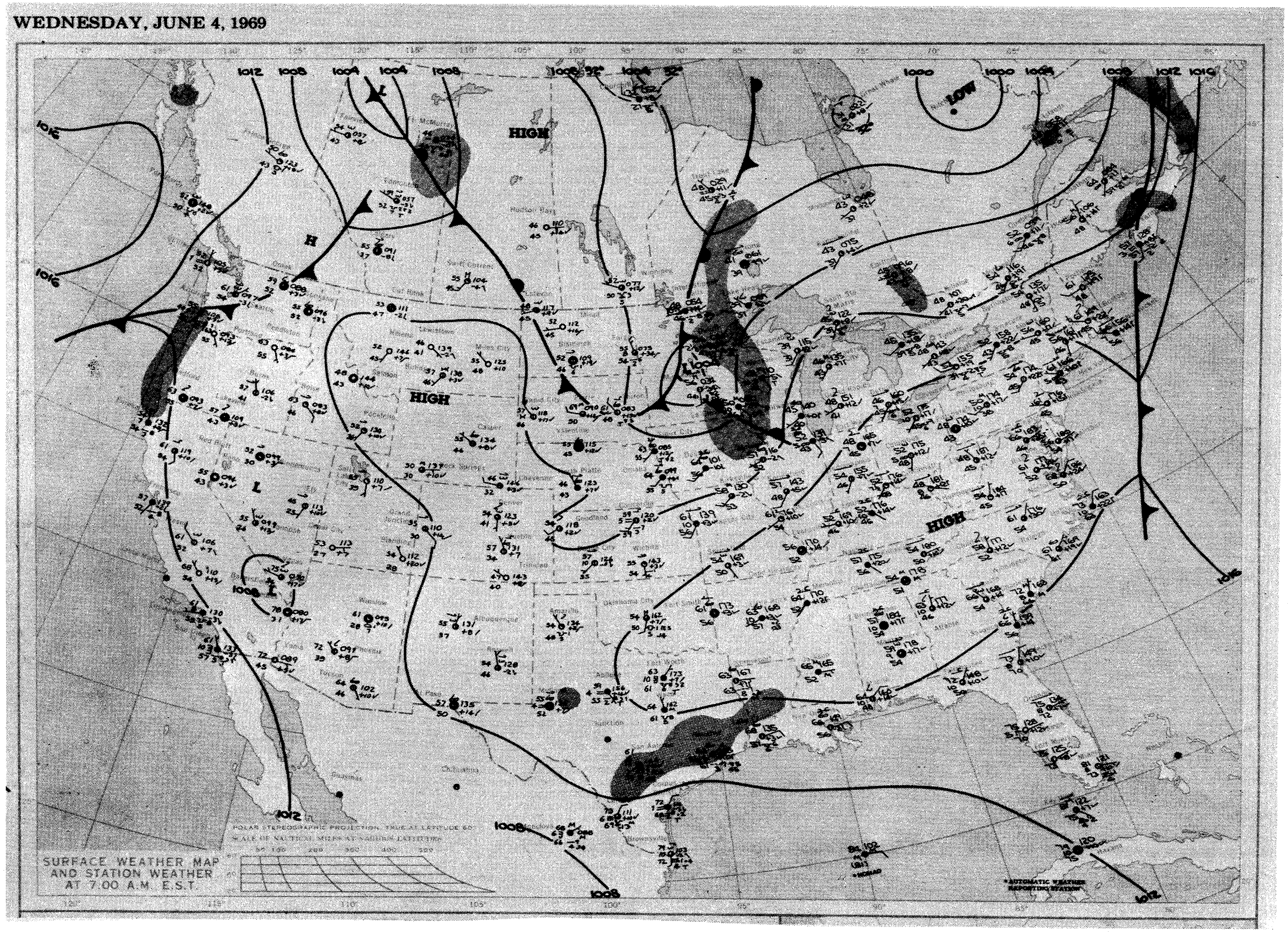
4 June 1969

A rain shower occurred over the SW loop in the period 1500-1530. Samples were collected from the network for analysis. This set of data has the advantage that the samplers were placed after noon just prior to the shower, and retrieved promptly. The relevant synoptic data are shown in Figures 24a, b and 25a, b.

5-13 June 1969

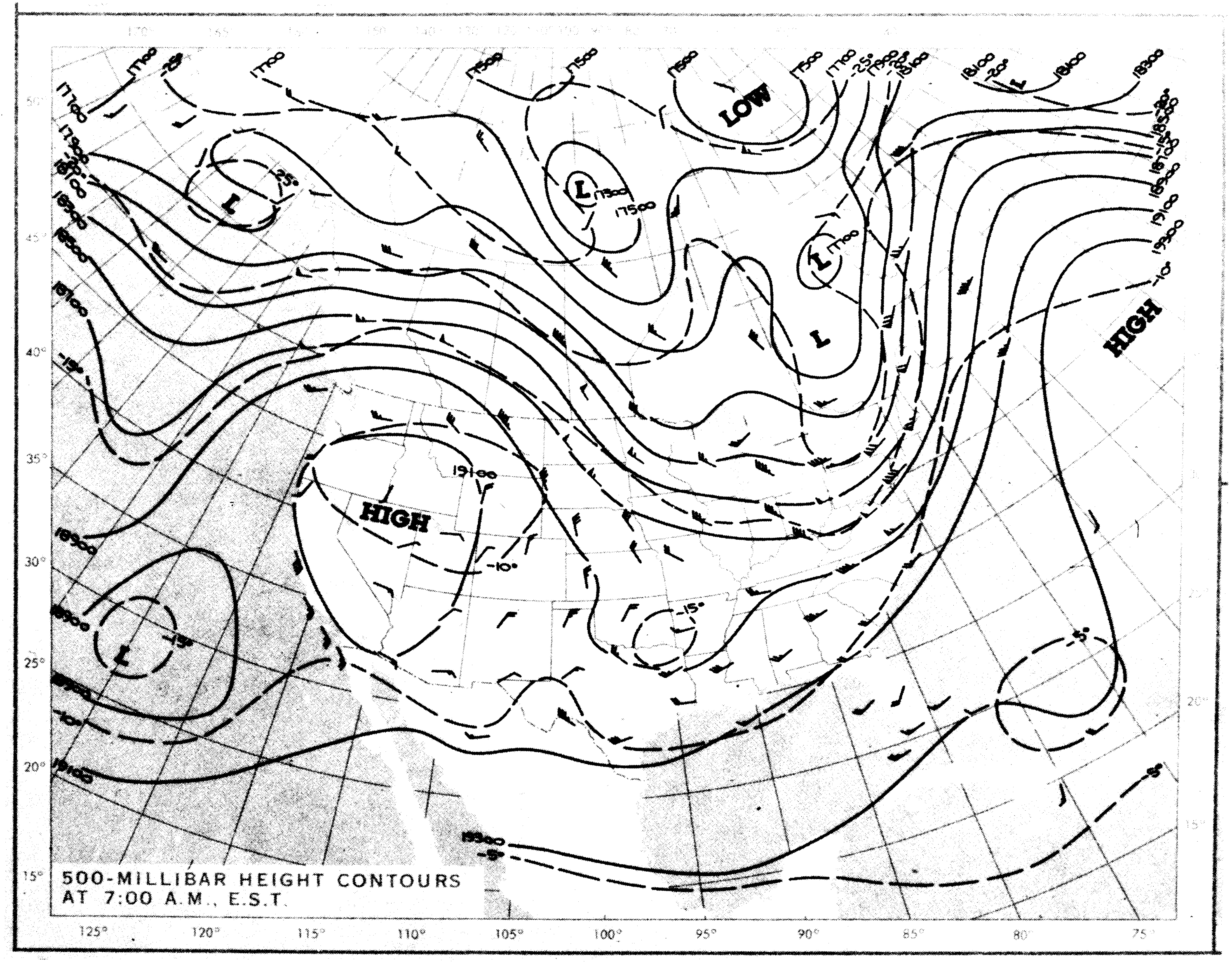
During this period the drought intensified. Alerts were called on 6, 7, 8, 11 & 12 June; samplers were serviced on 8 and 11 & 12 June; aircraft flew, scouting cloud systems, on 6, 8, and 12 June. Radar echo tops reached 28,000 ft. on the 6th, but cloud bases were at 10,000 ft. On the 8th echoes and showers were again present, but bases were at 10,000 ft. or so, and very little rain reached the ground anywhere over the network.

The situation developed in such a manner on 11 June that Col. R.C. Miller, USAF (Ret.), observed it to be the "... first good family outbreak..." situation "... this spring for this area...". And on 12 June (Fig. 26a, b) we were advised "...if you don't get it today, you may as well pack up and go home." One radar echo south of Champaign was observed to reach 40,000 ft, but Cu tops over the network were growing only to about 14,000 ft before shearing off. The Michigan



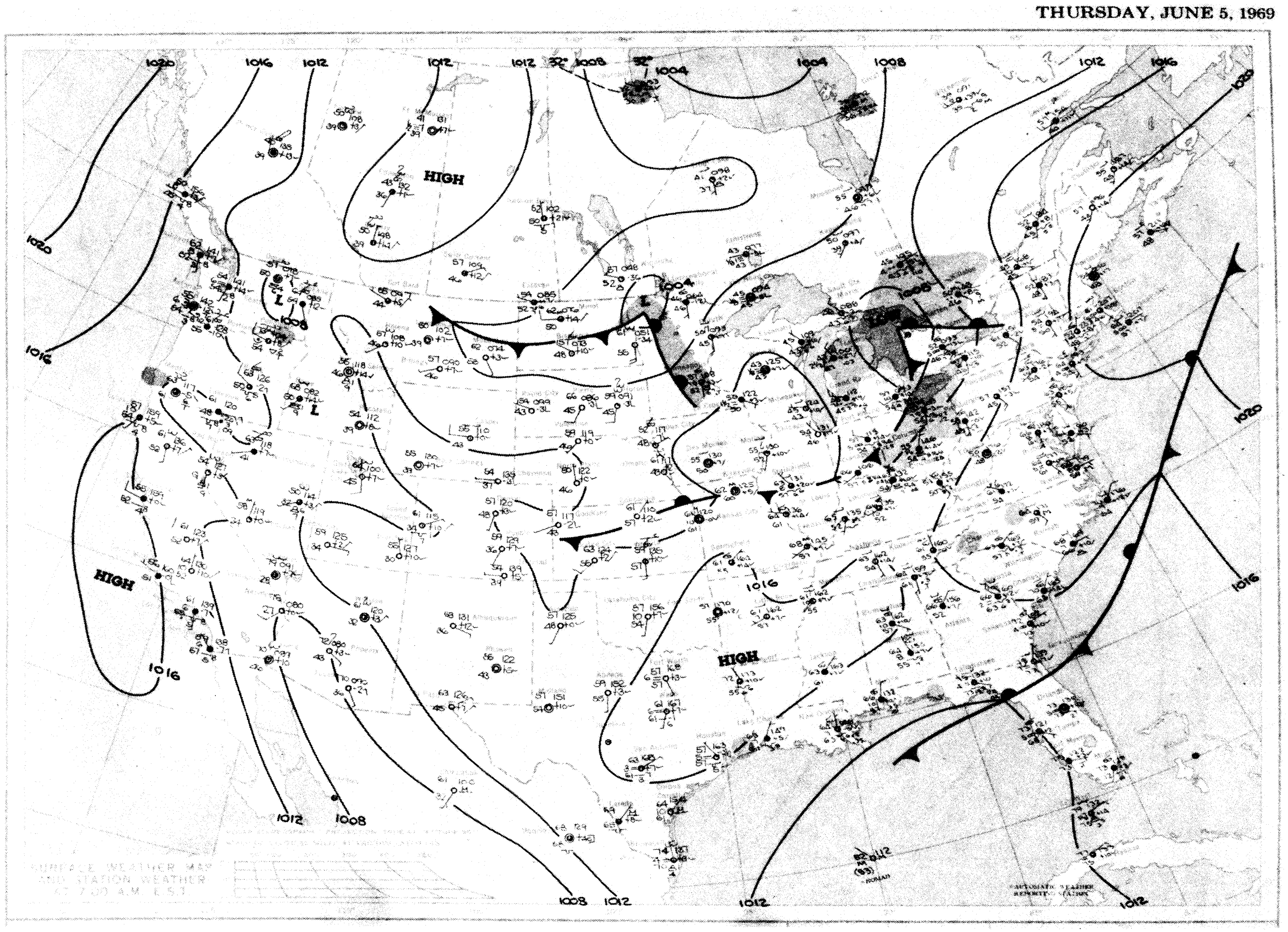
(a) Surface map.

Figure 24. Weather maps, 0700 CDT, for 4 June, 1969.



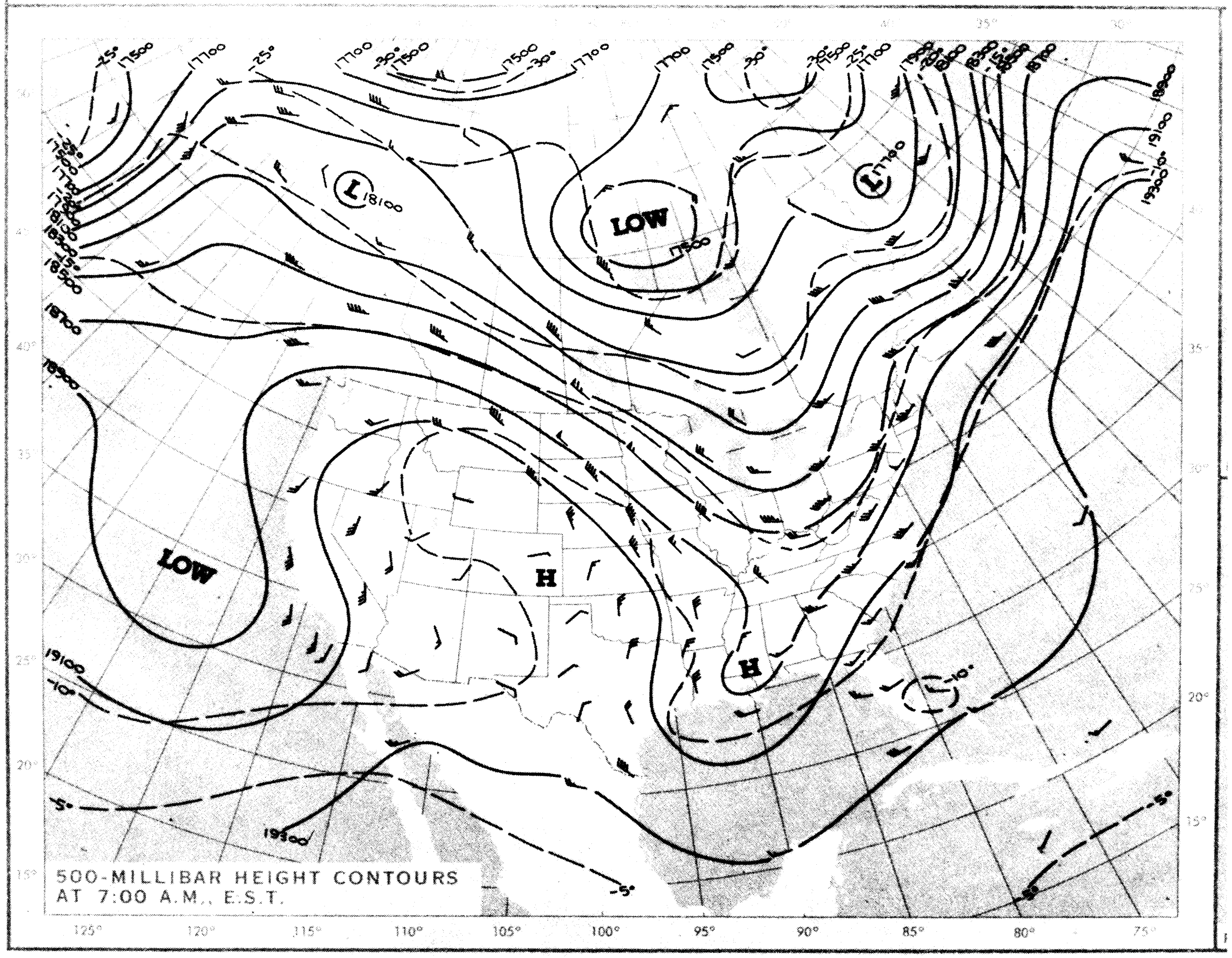
(b) 500 mb map.

Figure 24. Concluded.



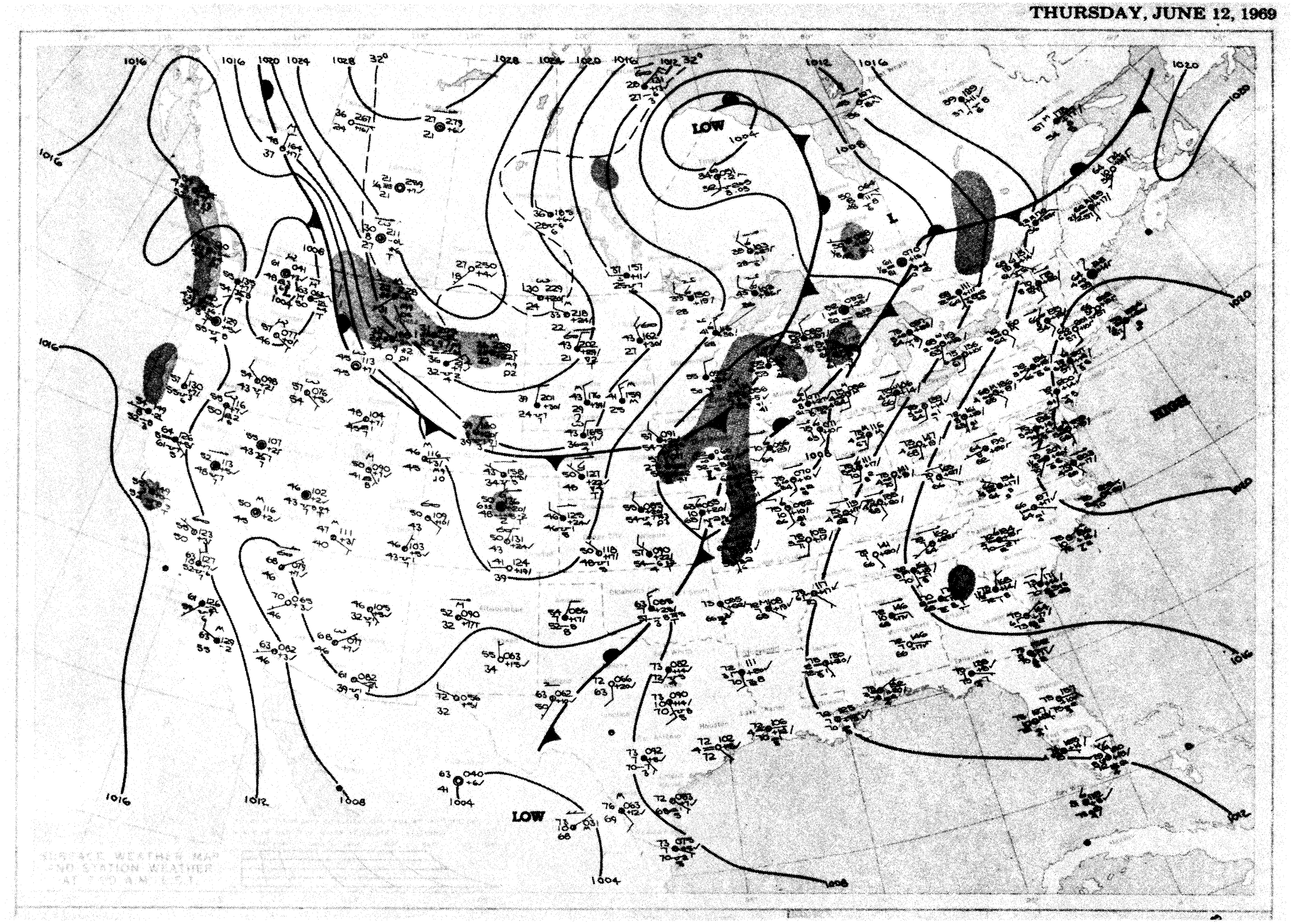
(a) Surface map.

Figure 25. Weather maps, 0700 CDT, for 5 June, 1969.



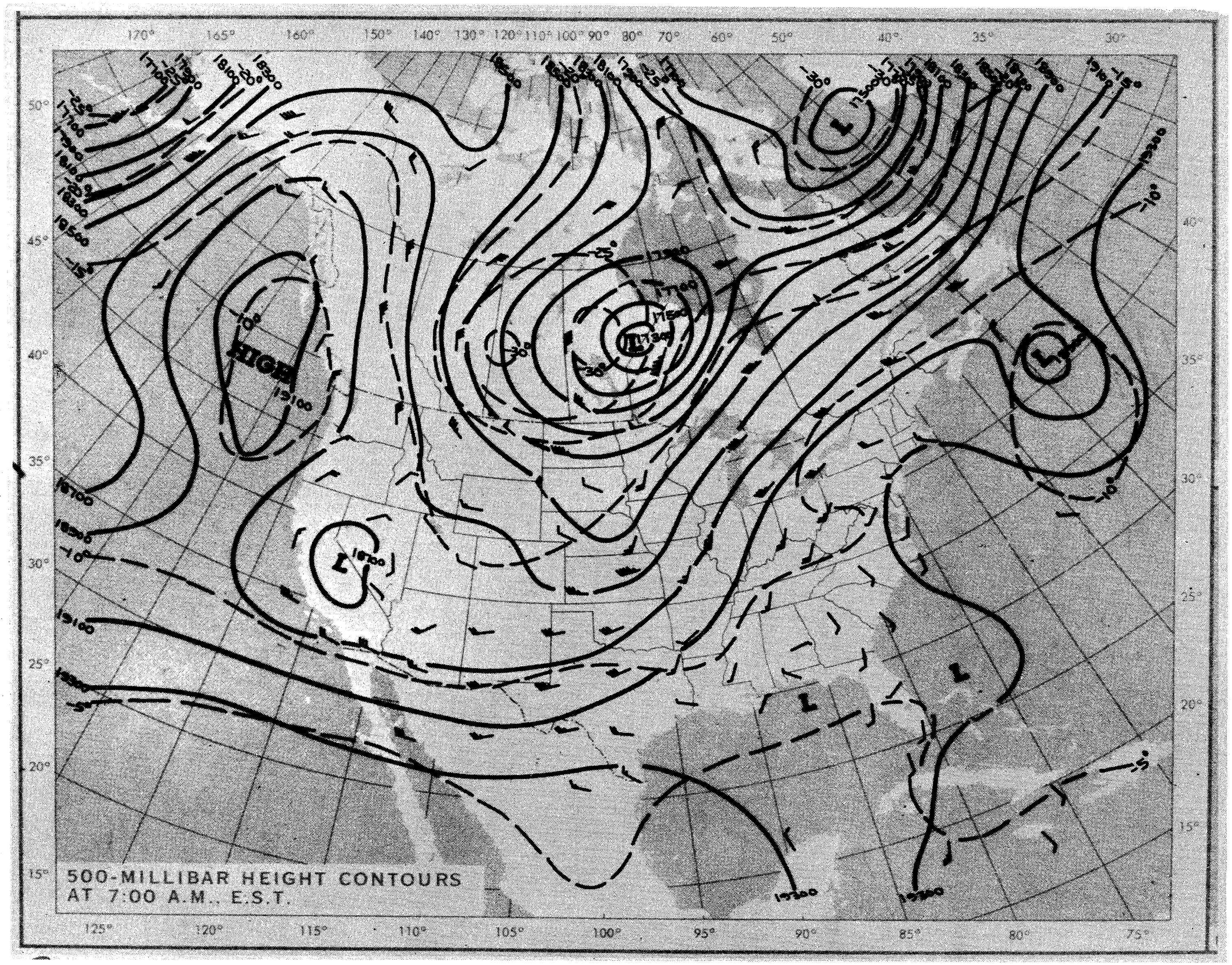
(b) 500 mb map.

Figure 25. Concluded.



(a) Surface map.

Figure 26. Weather maps, 0700 CDT, for 12 June, 1969.



(b) 500 mb map.

Figure 26. Concluded.

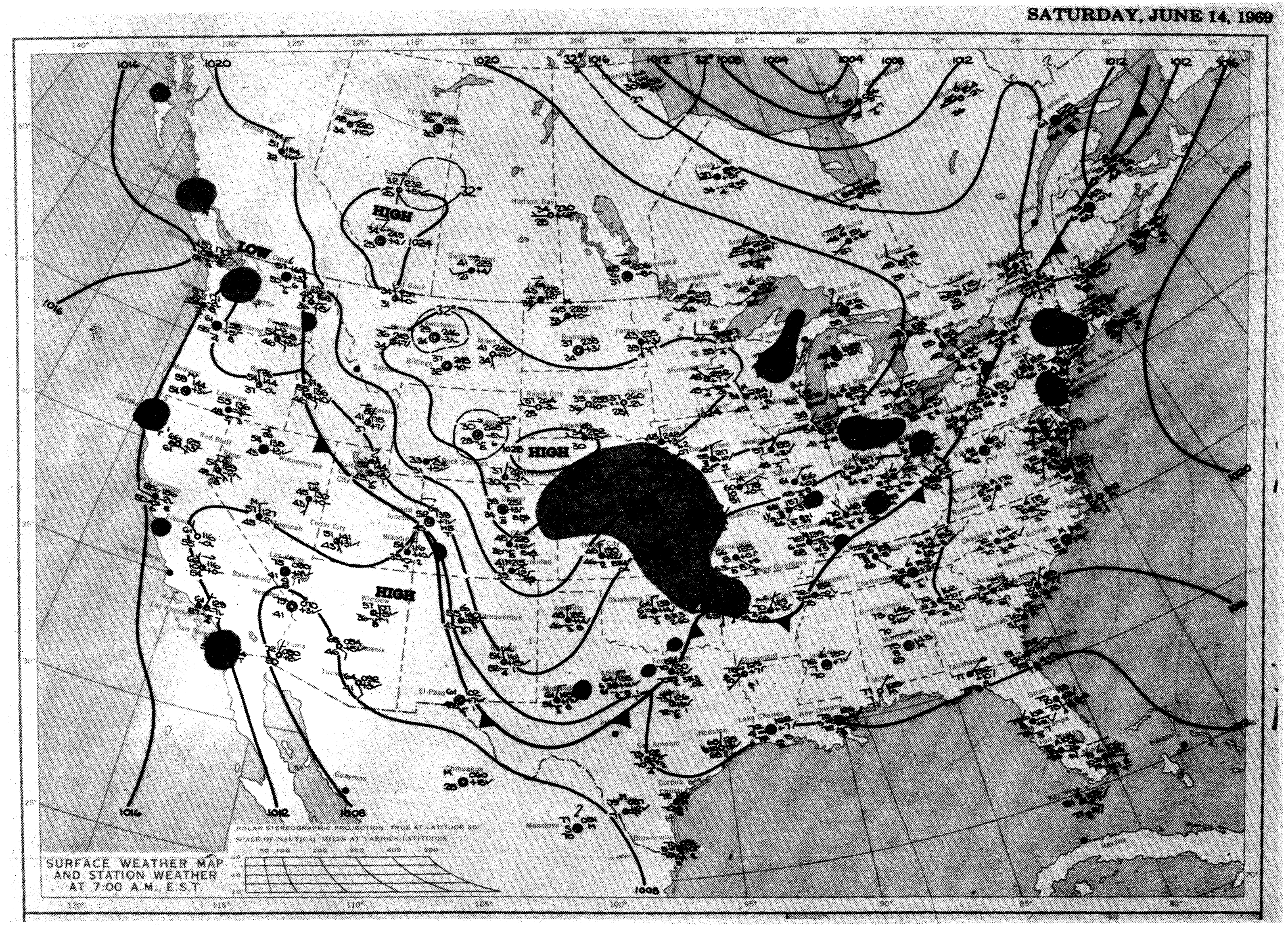
station closed down at 1815, and there was no action on the 13th. Discussions of the procedure for shutdown of the field operation were begun.

14 June 1969

There was no expectation, and indeed, no development, of weather suitable for the tracer work on convective storms on this date (Fig. 27a, b). At dinner time, however, a steady light rain began and continued for several hours. The base station was therefore activated for the collection of sequential samples, which was continued until 2305. Collections were made for radioactivity and pollen analysis (our procedure from former years), and for lead (Pb) analysis by University of Michigan people, for O-18 and D (deuterium) analysis by Argonne Laboratory personnel, and for trace metals analysis by ISWS.

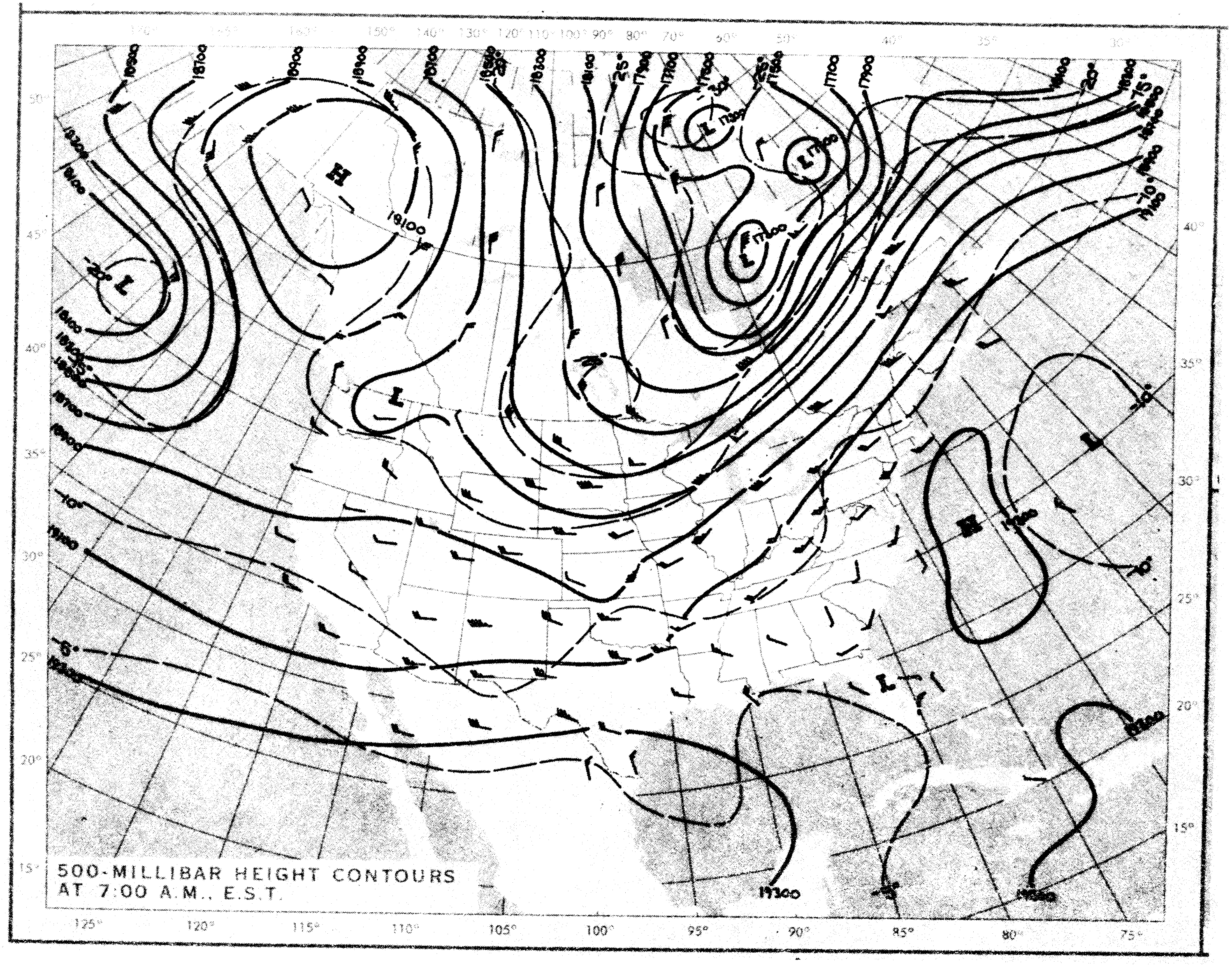
In addition, the network samples were gathered and divided for similar analyses. Although these samples do not represent the accomplishment of our stated objective, they do provide an unprecedented set of data which will be evaluated and examined with interest.

There were no further rain-collecting operations. Another type of experiment designed to measure the dry-fallout contribution of trace materials to our open samplers was conducted in the period of 6-12 June.



(a) Surface map.

Figure 27. Weather maps, 0700 CDT, for 14 June, 1969.



(b) 500 mb map.

Figure 27. Concluded.

E. Data acquired

As pointed out above, a comprehensive record of data is routinely recorded on magnetic tape at the University of Michigan base station. This includes verbal comments and audible radio communications with the aircraft and mobile units in one AM channel, event-type observations (tipping-bucket, 1/60 mi. of wind, bottle-change signals, start and stop signals) multiplexed by means of audio-frequency into a second AM channel, raindrop-size distributions in one FM channel, and continuous wind direction in a second FM channel, all synchronized by means of WWV time signals (in one of the AM channels). These data are reduced, translated and stored on IBM-compatible tape by means of the hybrid A-D computer facility of The University of Michigan. They are not printed out here.

Additional written logs of data are maintained in the field, and others are constructed as samples are gathered, treated, divided and analyzed.

Table 1 is a summary of the samples collected in May-June 1969. The Michigan analyses consist of (a) indium measurement for tracer experiments and for natural background determinations, (b) β-radioactivity for some large samples collected sequentially at the base station, and (c) determinations of Pb content. Table 2 gives the results so far obtained in the indium measurements of rain samples. Table 3 gives the indium analysis results for dry fallout samples. These represent an attempt to assess the rate at which our network samplers acquire indium contamination by simply collecting natural dust fall. There appears a nearly linear relationship with time of exposure at a rate of about 1.1 ng per day. Table 4 presents our β-radioactivity results for sequential series of samples taken on 1 and 14 June. Work continues on analysis of the remaining samples.

TABLE 1
Summary of Samples Collected
in May-June, 1969, at Clinton, Illinois

Data 1969	Type of Sample	Number of Samples	Distribution of Samples*
25 May	Network, scat. $\dot{\nabla}$	3	M
29 May	Network, tracer In	26	M
	Network, dry	15	M, I.
	Station, Dry	2	M, I.
1 June	Network, rain	29	M, I.
	Station, sequential	8	M
4 June	Network, rain	4, (15)	M, (I)
14 June	Network, rain	58	M, I,
	Station, sequential	21	M, I, A.
29 May	Station, rotobar	4	M
31 May	Station, rotobar	1	M
1 June	Station, rotobar	2	M
7 June	Station, rotobar	2	M
8 June	Station, rotobar	1	M
9 June	Station, rotobar	1	M
11 June	Station, rotobar	11	M
12 June	Station, rotobar	10	M
12 June	Station, Andersen	7 sets of 6 each	M
6-12 June	Station, Dry fallout	8	M, I

* M: The University of Michigan, Meteorological Laboratory, Professor A. N. Dingle

I: Illinois State Water Survey, Mr. Wayne Bradley

TABLE 2

Results of Indium Analyses for Network Samples collected at Clinton, Illinois, 1969

Sample No.	Aliquot	Water Amount ml	Total Indium ng	Indium Conc. ng/l	Half-life min.
	(a) For Rain of 25 May 1969				
NW-3		~850			
NE-14		~600			
RG-118		~900	0.6	----	55.4
	(b) For Rain of 29 May 1969				
RG-89	A	650	5.2	8.00	60.5
	B	707	4.4	6.22	60.5
	C	659	5.7	8.65	58.3
RG-146		798	4.5	5.64	58.3
RG-147	A	810.5			
	B	236.5	9.6	40.59	63.2
RG-148		430			61.9
149		56	2.8	50.00	68.4
161		294	15.0	51.02	61.2
188		151.2	1.7	11.24	63.3
192		341.2	4.0	11.72	77.0
145		183	10.6	57.92	96.5
163		236	1.7	7.20	61.9
159		473			
SE-1		554.5	5.5	9.92	58.3
2		517.7	19.4	37.47	61.2
3		170.6	2.9	17.00	59.7
6		171.7	3.2	18.64	59.7
21		503	5.8	11.53	60.5
22		616	5.4	8.77	57.6
SW-3		41.0	5.6	136.6	60.5
4		100	3.05	30.50	
5		302.3	6.8	22.50	76.0
NE-14					
M-1	A	705	40.0	56.74	64.0
	B	758	60.0	79.16	64.8
M-2		524	26.0	49.63	
3		820	10.1	12.31	
4		508	3.8	7.48	
5		314	9.2	29.44	

Table 2 - continued

(c) For Rain of 1 June 1969

RG-103		583.1			
104		492.5	6.6		60.5
105		693.2			
115		708.5			
116		737.1	4.7		58.3
117		427.5	2.0	4.68	61.2
118		746.8	6.3	8.44	60.5
119	A	579.8			
	B	689.3			
128		707.8			
129		813.0			
130	A	657.4	5.0	7.61	61.9
	B	619.5	4.5	7.26	60.5
131		749.1			
132		506.2	5.2		56.9
135		370.8			
142		890.7	6.8		62.6
143	A	847.9	4.0		54.7
	B	606.5			
144	A	795.3	3.4		59.0
	B	299.8			
145		755.7			
150		202.8	3.1		56.8
156		350.4			
157	A	845.0			
	B	239.5	2.6		58.7
158		750.7	7.4	9.86	56.2
159		590.7	3.7	6.26	59.0
160		331.0	2.2	6.65	61.2
163		307.8			
170	A	815.9	5.15	6.31	
	B	744.9	6.6	8.86	58.3
	C	513.0	5.2	10.14	59.0
171		673.1			
172		569.1	4.2	7.38	56.2

(d) For Rain of 4 June 1969

RG-144		827.2	3.3	3.99	58.3
(145) (159)	------------	832.0	2.1		57.6
SW-14		812.2	3.0	3.69	64.0
(19) (26)	------------	†675.5	4.5		64.0

† leaky funnel, some water lost in filtering.

TABLE 3

Results of Indium Analyses for Dry Fallout collected at Clinton, Illinois, 1969

Sample No.	Duration of exposure Hr:Min	Indium Amount ng	Half-life min.
	(a) For exposure period of 29 May rain samplers		
RG-134		2.2	71.2
135		1.0	63.3
150		1.5	69.1
160			
162			
SE-4		2.1	76.0
8		4.8	58.3
9		3.4	59.7
10		2.2	65.5
12		4.5	59.0
14			
16		1.3	70.5
19		3.3	64.0
M-24			
25			
O-1	56:00		
O-2	10:00		
	(b) For exposure periods ending 0900 on 14 June		
DF-2	120:30	5.5	72.0
3	96:30	4.3	62.6
4	72:30	3.2	64.8
5	66:30	3.3	61.9
6	60:10		
7	48:40		
8	38:30		

Results of β-radioactivity measurements on sequential samples
1 and 14 June, 1969

Sample No.	Time CDT Start	End	Water Amount mb	β-count pCi	β-conc. pCi/ℓ.*
(a) 1 June 1969					
1	0943:00	1002:00	580	107.7	483
2	1040:45	1049:30	2190	253.5	329
3	1049:30	1056:12	2180	138.9	175
4	1056:12	1101:00	2280	118.5	142
5	1101:00	1104:50	2230	115.1	138
6	1104:50	1108:50	2080	99.1	122
7	1108:50		510	22.7	127
(b) 14 June 1969					
1	1953:00	2003:00	1000	39.3	99
2	2003:00	2019:00	970	37.8	98
3	2019:00	2039:00	970	37.8	99
4	2039:00	2051:00	940	32.5	87
5	2051:00	2106:00	1040	47.2	115
6	2106:00	2121:00	960	45.8	121
7	2121:00	2129:00	1880	156.1	189
8	2129:00	2132:20	2080	109.9	184
9	2132:20	2135:10	1520	114.2	221
10	2135:10	2139:00	1300	67.8	134
11	2139:00	2145:00	1000	51.2	129
12	2145:00	2154:55	980	51.4	144
13	2154:55	2203:00	1070	52.3	124
14	2203:00	2210:00	1380	65.2	122
15	2210:00	2215:00	1120	35.7	80
16	2215:00	2224:00	1120	27.4	62
17	2224:00	2229:45	1490	41.4	73
18	2229:45	2234:00	1120	25.3	57
19	2234:00	2238:00	1300	10.4	20
20	2238:00	2250:15	1580	29.2	47
21	2250:15	2305:00	1400	26.2	47

* Corrected for self-absorption of sample and established efficiency of counter.

II. Laboratory Activities

Four distinct areas of laboratory work have been pursued, (1) the routines, formerly established, of measuring β-radioactivity, determining pollen concentrations, and reducing the ancillary data to graphic presentations, (2) a set of experiments and measurements designed to determine the particle sizes generated by the pyrotechnic flares under flying-speed ventilation, (3) a continuous program on the neutron activation measurement of indium, and (4) calibrations of the photoelectric raindrop-size spectrometer.

1. Routine measurements and data reduction

The β-radioactivity determinations were made as before using facilities of the School of Public Health, Department of Environmental Health, to evaporate the water samples to dryness, and measure β-radioactivity in the low-background beta-counter. The residue from these samples was then resuspended and processed chemically using palynologic procedures and microscopic identification and counting of pollens. These procedures were done by one part time assistant in research, Mr. Yean Lee, under the guidance of cognizant staff members of the Environmental Health and Botany Departments.

The data reduction job has been greatly reduced by our 4-channel tape recording system (see Report No. COO-1407-15). A certain amount of troubleshooting, with the aid of our electronic consultants, has been necessary, but the procedure of counting events and/or determining their relationships in time by means of the hybrid analog-digital computer facility of the Department of Meteorology and Oceanography is now quite straightforward. Using this system, all data on wind speed and direction, rainfall intensity (from tipping bucket events), times of bottle changes (in sequential sampling at the base station), verbal observations and remarks during the operation, rain drop-size distributions, and WWV time signals, are recorded as the respective events occur, on one tape. The analog-digital conversions are made, and the results are assembled in suitable format on computer tape for future research use, and are printed out as desired. Coordination of these data with various sample analyses is done manually and presented graphically as before (see below). During the year just past, a great deal of earlier data (from 1967 and 1968 cases in Oklahoma) as well as that from 1969 in Illinois have been processed. The drop-size data have been withheld pending a new calibration, which was done this year (see below). We are currently working on the mode of presentation of these data, and on the incorporation of this basic information into our interpretations of the rain scavenging processes.

Results of these efforts are given below, without further comment at this time, Figures 28 through 31, the

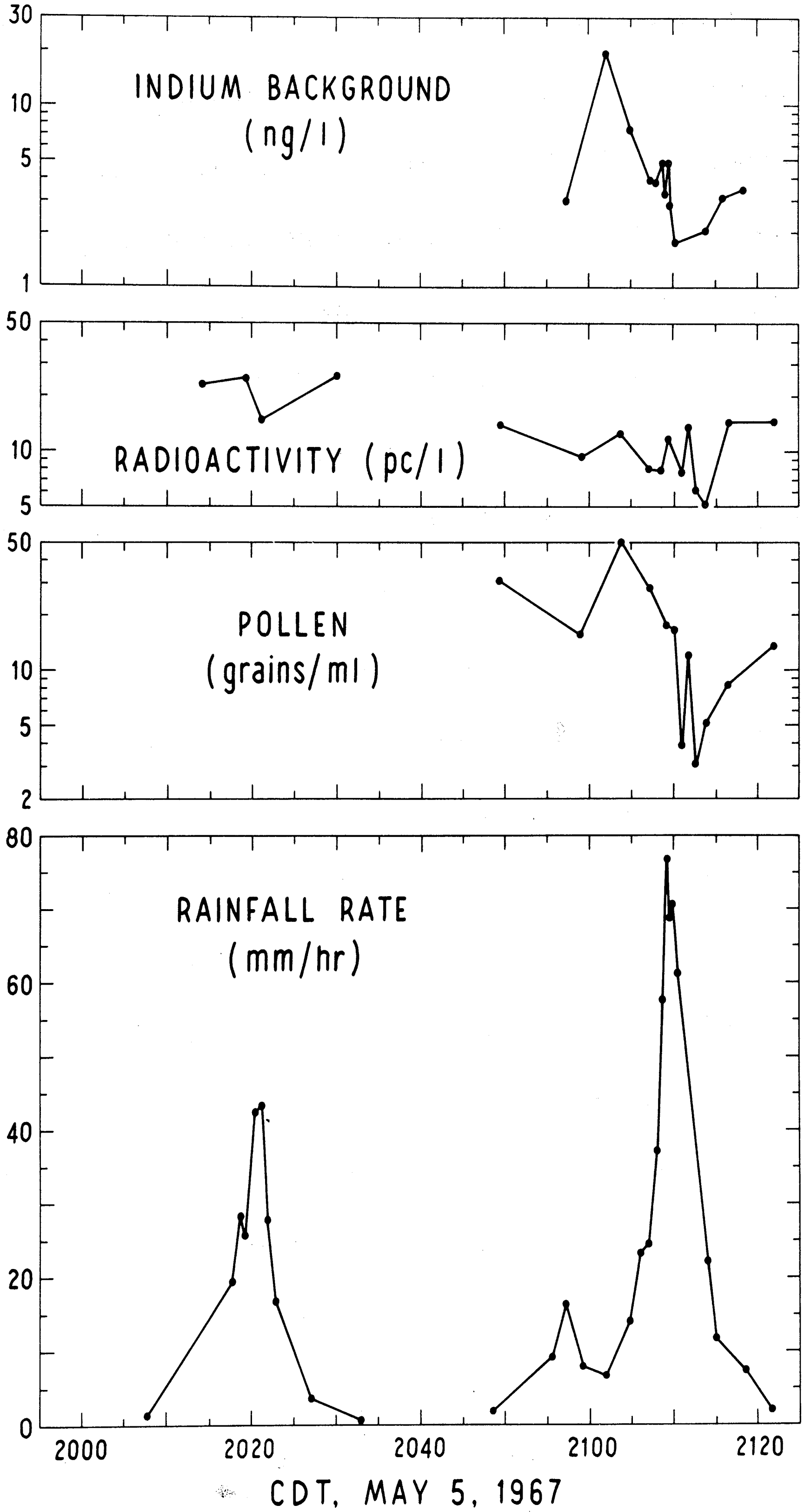


Figure 28. Rainfall rates, pollen and radioactivity concentrations, and indium content for rain samples collected on 5 May, 1967, at Chickasha, Oklahoma.

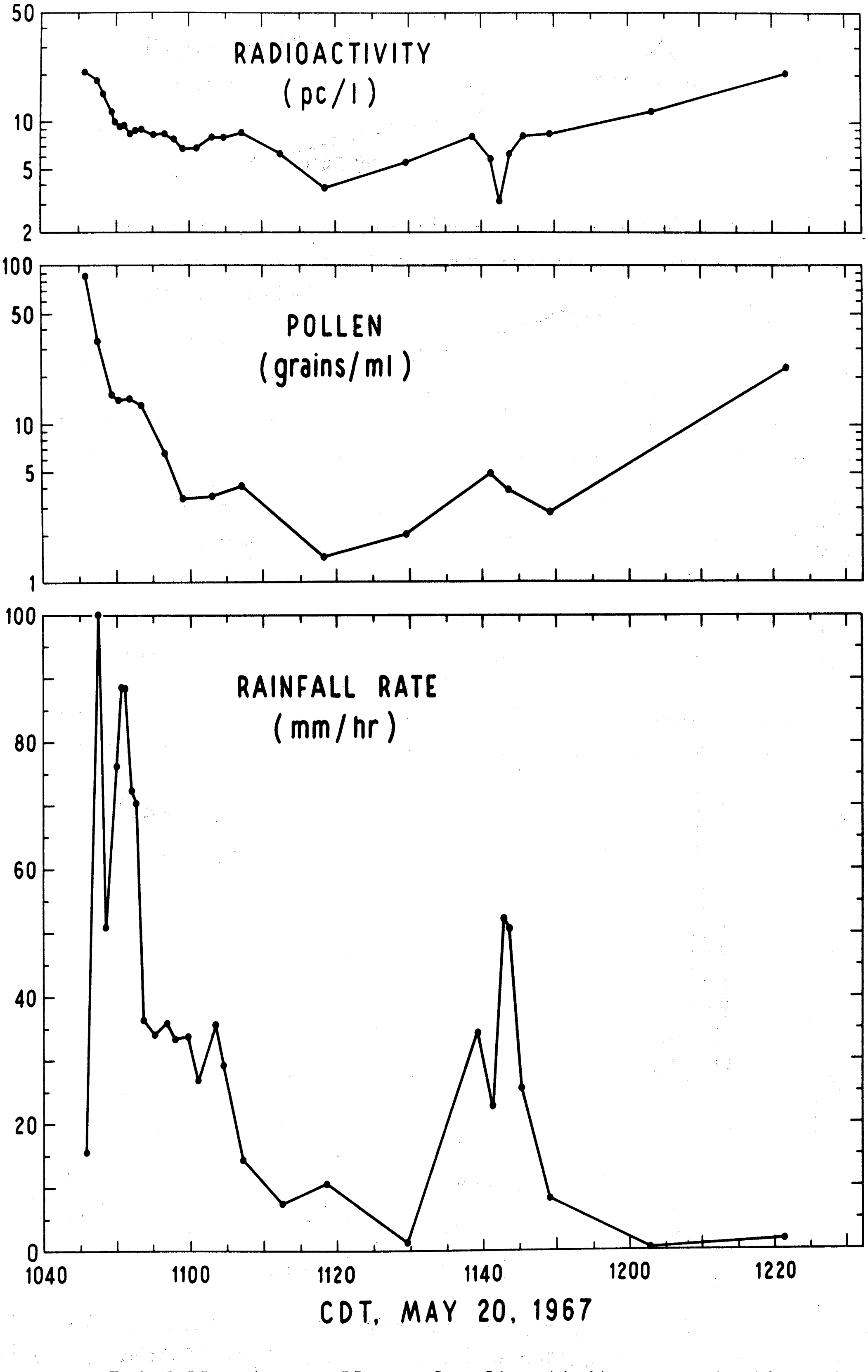


Figure 29. Rainfall rates, pollen and radioactivity concentrations for rain samples collected on 20 May, 1967, at Chickasha, Oklahoma.

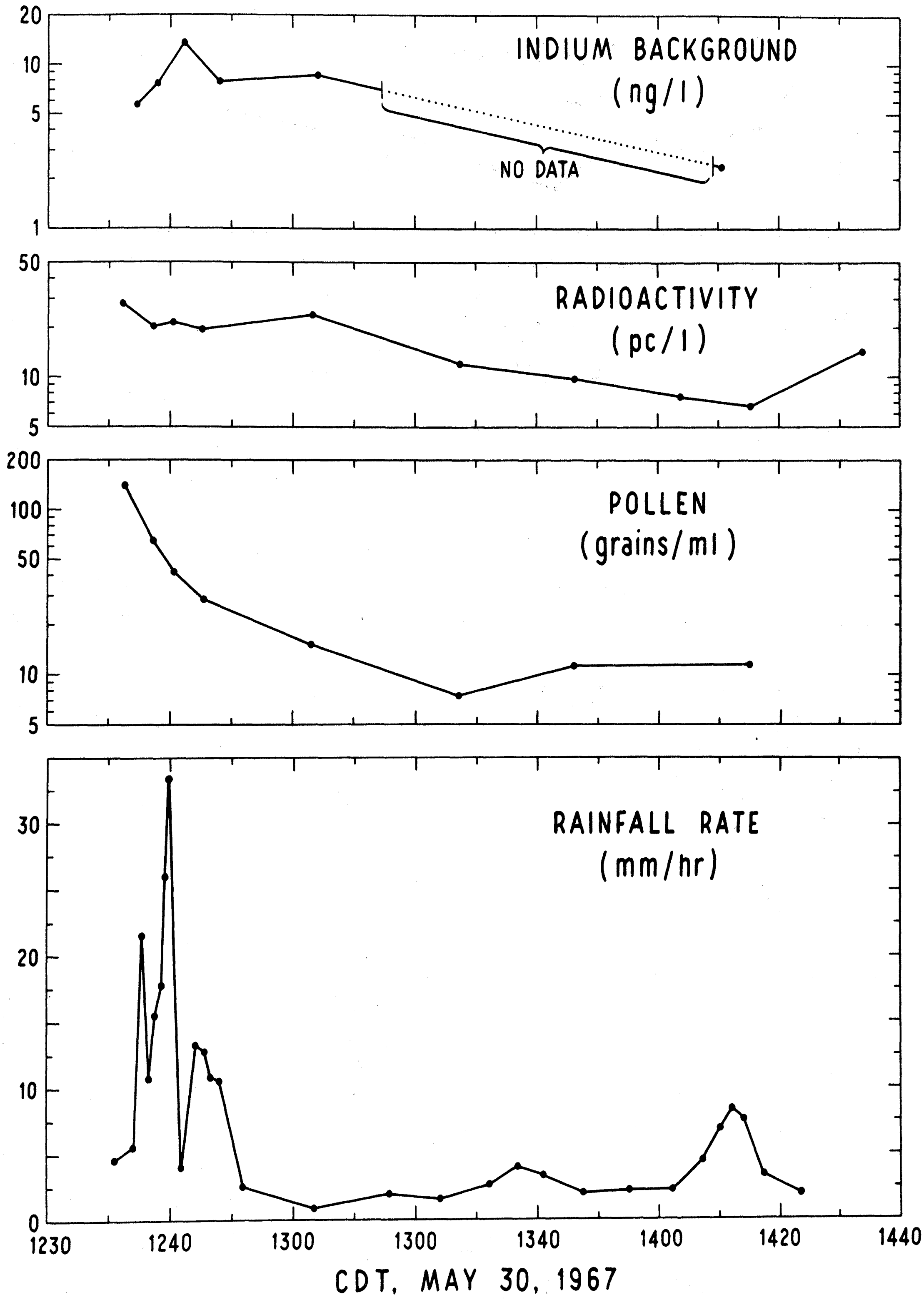


Figure 30. Rainfall rates, pollen and radioactivity concentrations, and indium content for rain samples collected on 30 May, 1967, at Chickasha, Oklahoma.

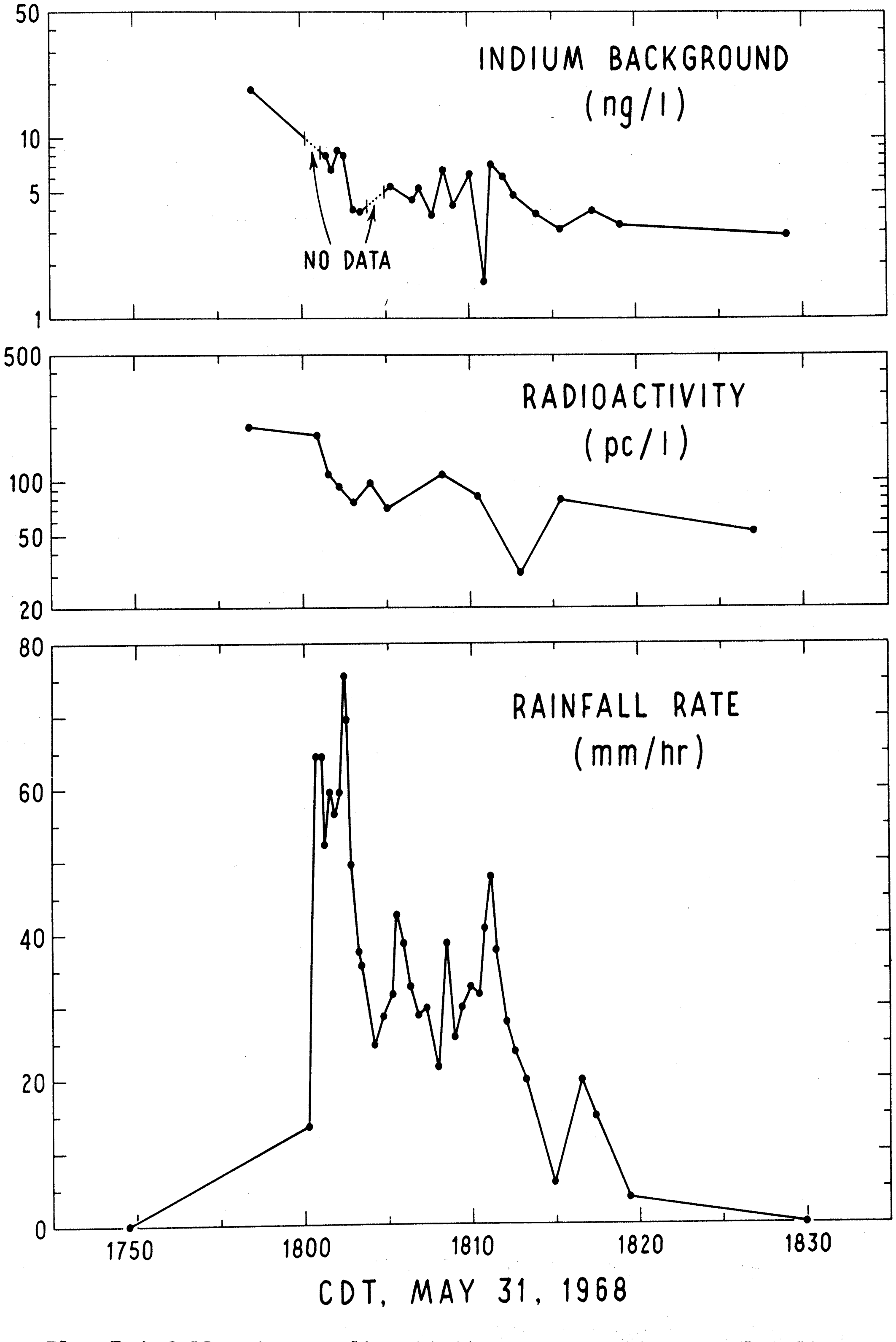


Figure 31. Rainfall rates, radioactivity concentrations, and indium content for rain samples collected on 31 May, 1968, at Chickasha, Oklahoma.

legends of which are self-explanatory.

2. Particle-size measurements

A proper interpretation of the results of our tracer experiments depends heavily upon our knowledge of the size spectrum of the tracer-bearing particles.

Three different approaches to particle-size determination have been used. The first was to turn to the established particle laboratory at the University of Minnesota, mainly because of our need to know the particle size spectrum down to $r = 0.01\mu$ or smaller, and because of the technical difficulty of making such measurements.

A summary of the results of the measurements done under Professor Liu's direction is given in Figure 32, and Figure 33 is an electron micrograph of characteristic particles. But Figure 34 is another electron micrograph which indicates special requirements of the system under study. The flare material, burned in a simple laboratory combustion chamber, forms a highly concentrated vapor which condenses and agglomerates very rapidly. The first few milliseconds after ignition determine the particle size distribution, and subsequent agglomeration processes form the chains shown in Figure 34, these depending upon the concentration of the smoke plume. It therefore is evident that the ventilation situation of the burning flares in field conditions must be simulated as well

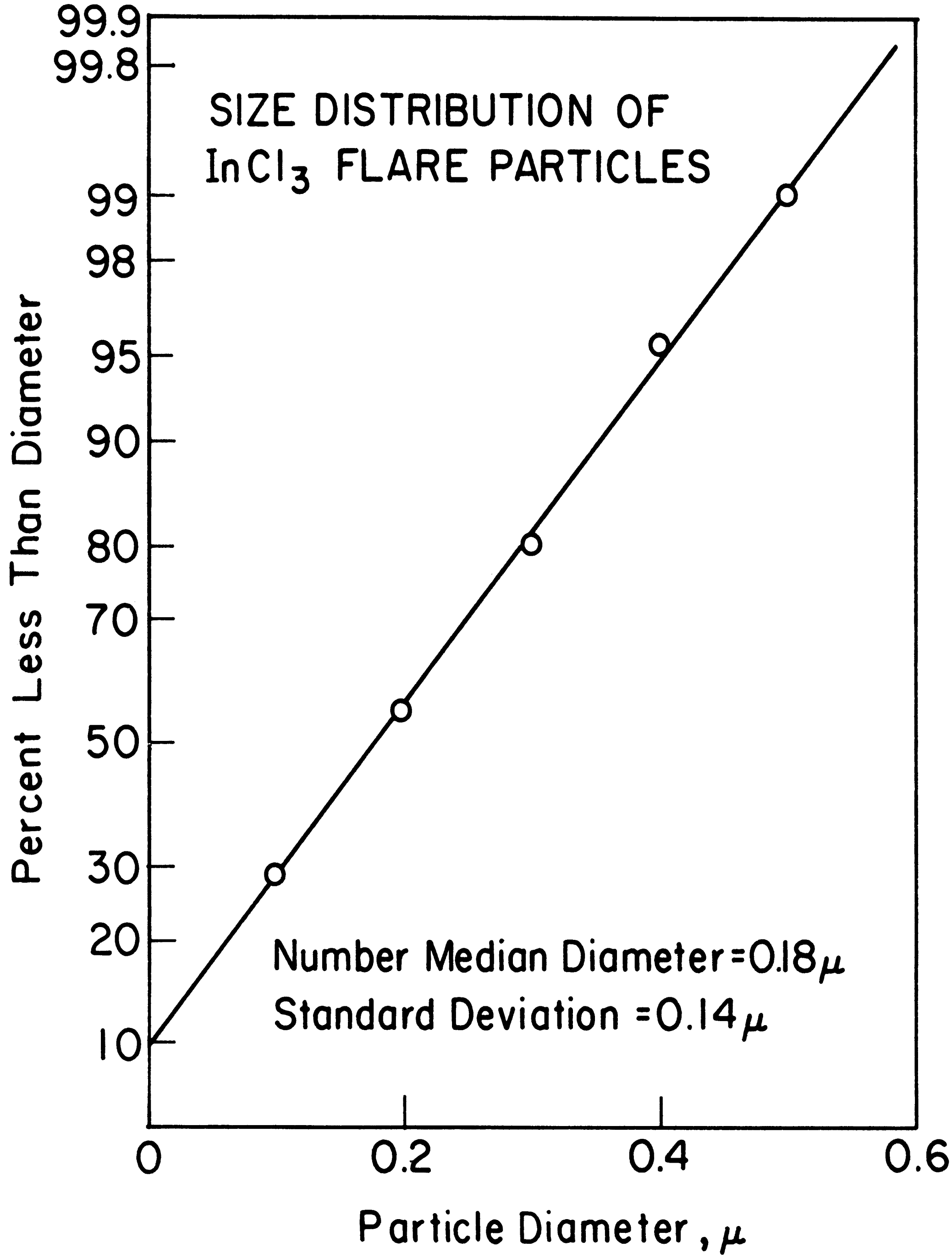


Figure 32. Summary of results of particle-size measurements in smoke from indium flare material burned in a combustion chamber, diluted, and sampled.

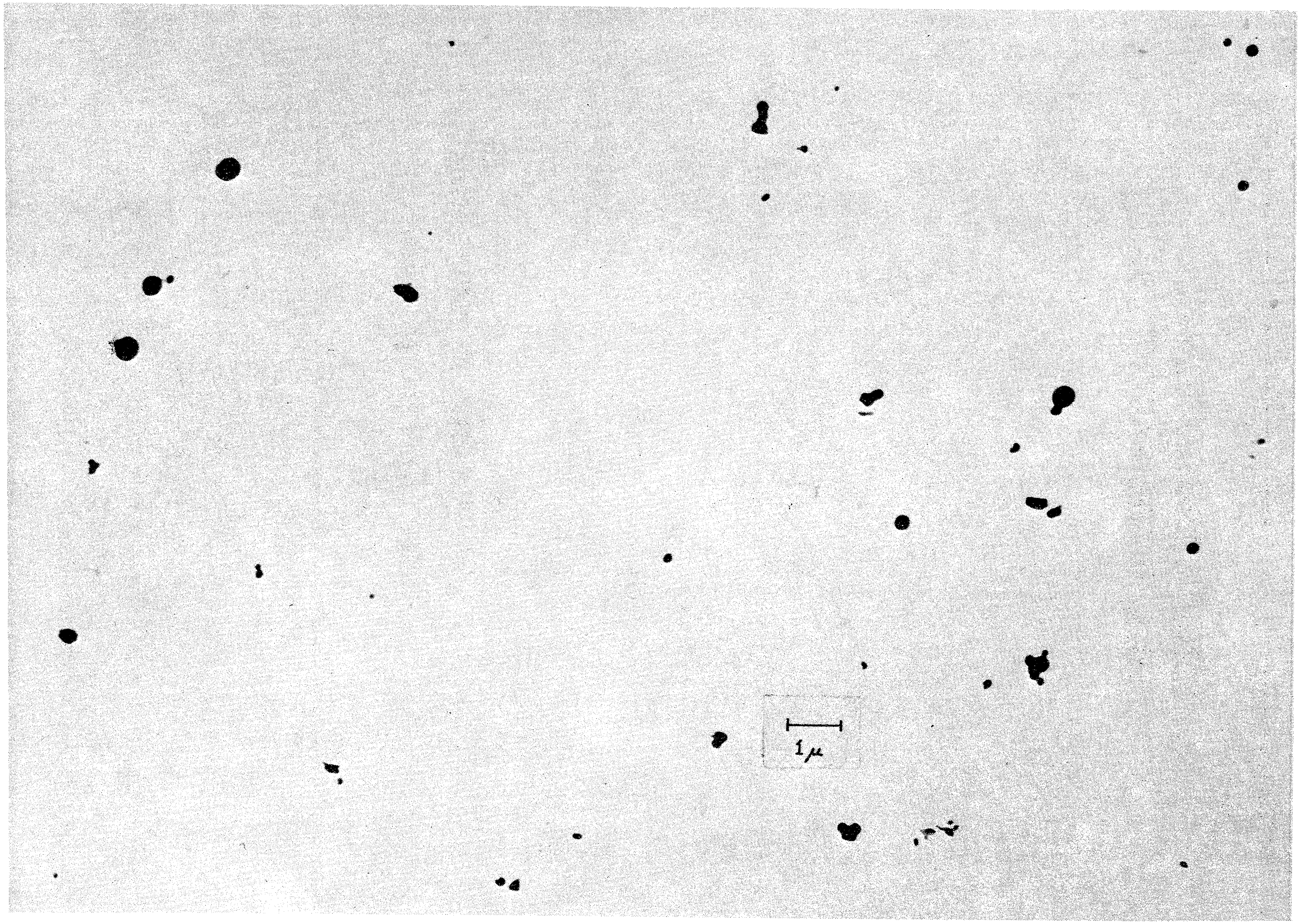


Figure 33. Typical photograph of particles counted to construct Figure 32.

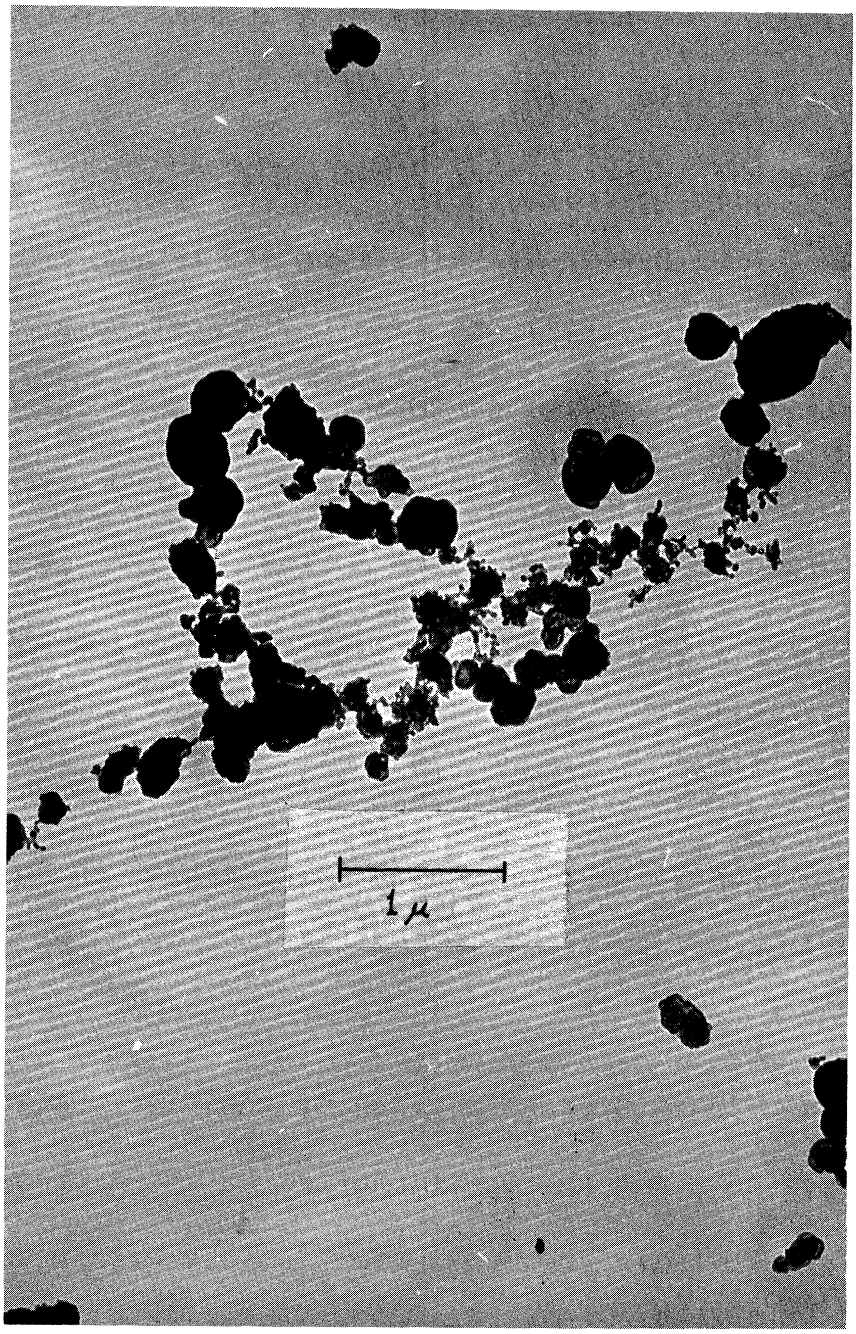


Figure 34. Aggregates formed in smoke from indium flare material burned with very little ventilation.

as possible. The normal air speed of 120 mph is equivalent to 5.4 cm per millisec., an important factor in determining the particle sizes in the tracer plume.

Our second approach, therefore, was to duplicate the field situation quite literally by sampling the flare plume laid by one aircraft by means of equipment aboard a pursuing aircraft. To sample the plume at all adequately, the experiment had to be performed in relatively smooth clear air, so in this respect, the turbulence of the convective storm indraft could not feasibly be simulated.

The flare-carrying aircraft is shown in Figure 35 with flares in place, and the sampling aircraft is shown in Figure 36. Sampling instruments in the C-45 are shown in Figures 37 and 38.

Figure 39 is a cross-section of the electrostatic sampler, and Figure 40 gives the configuration of the microscope slides in the precipitating region. These slides were previously coated with a carbon film which served as the sampling surface, and which could be floated off the slide, carrying the sample particles, and picked up on electron microscope grids for examination and photographing. In this manner, five grids were taken along the center line of each of the sampling slides, being designated 5-1, 5-2, 5-3...5-5; 4-1...4-5; 3-1...etc., progressing from the upstream edge (Figure 40) to the downstream edge of the sampling area. Photographs of the electron

Figure 35. The Piper Aztec airplane of Weather Service, Inc., used to place indium tracer; flares in place under inspection by Messrs. James Fairobent, left, and David Curtin, right, of The University of Michigan research team.

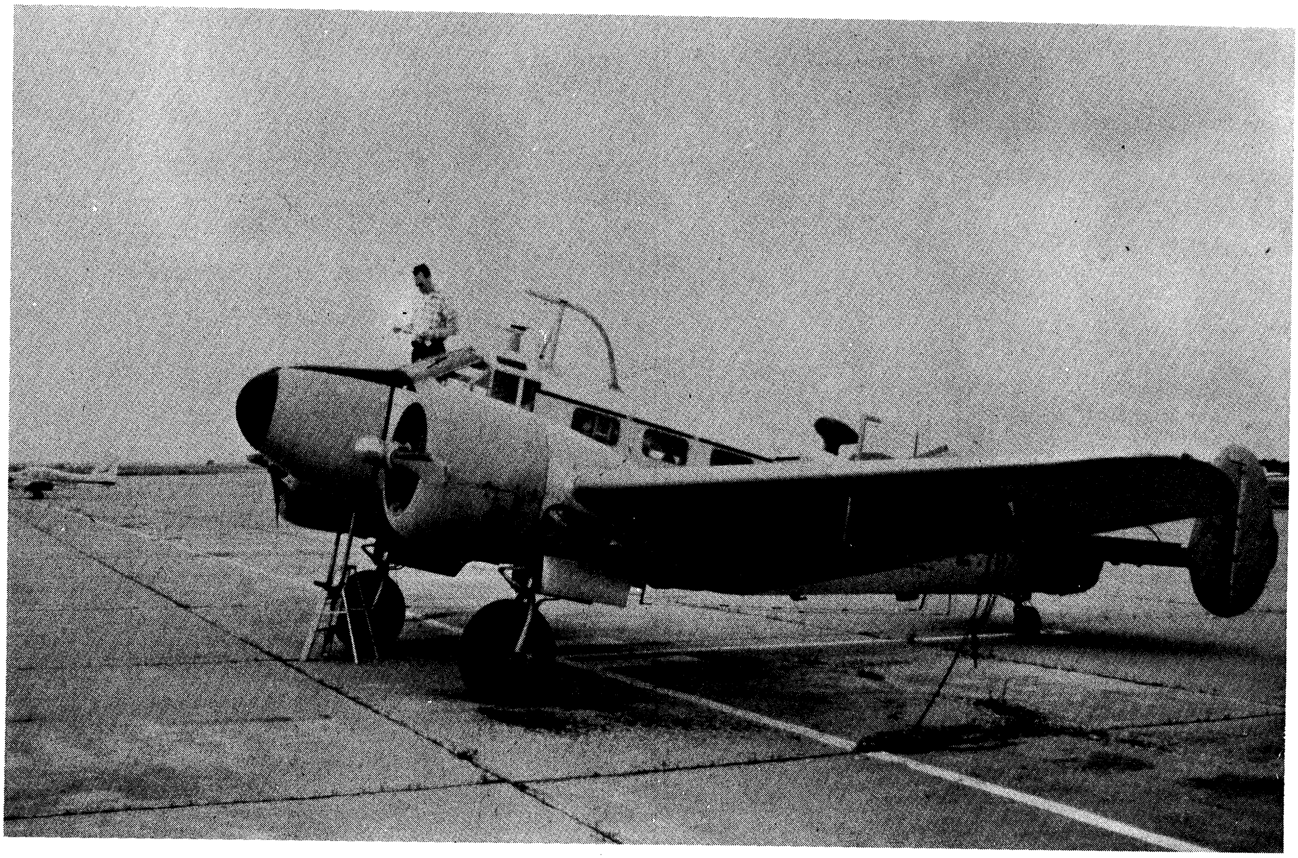


Figure 36. The University of Illinois C-45 airplane used for in-flight sampling of the indium flare plume. Pilot Milton Craig stands left and beyond the air sample intake which rises 2 ft. above the forward cabin roof.

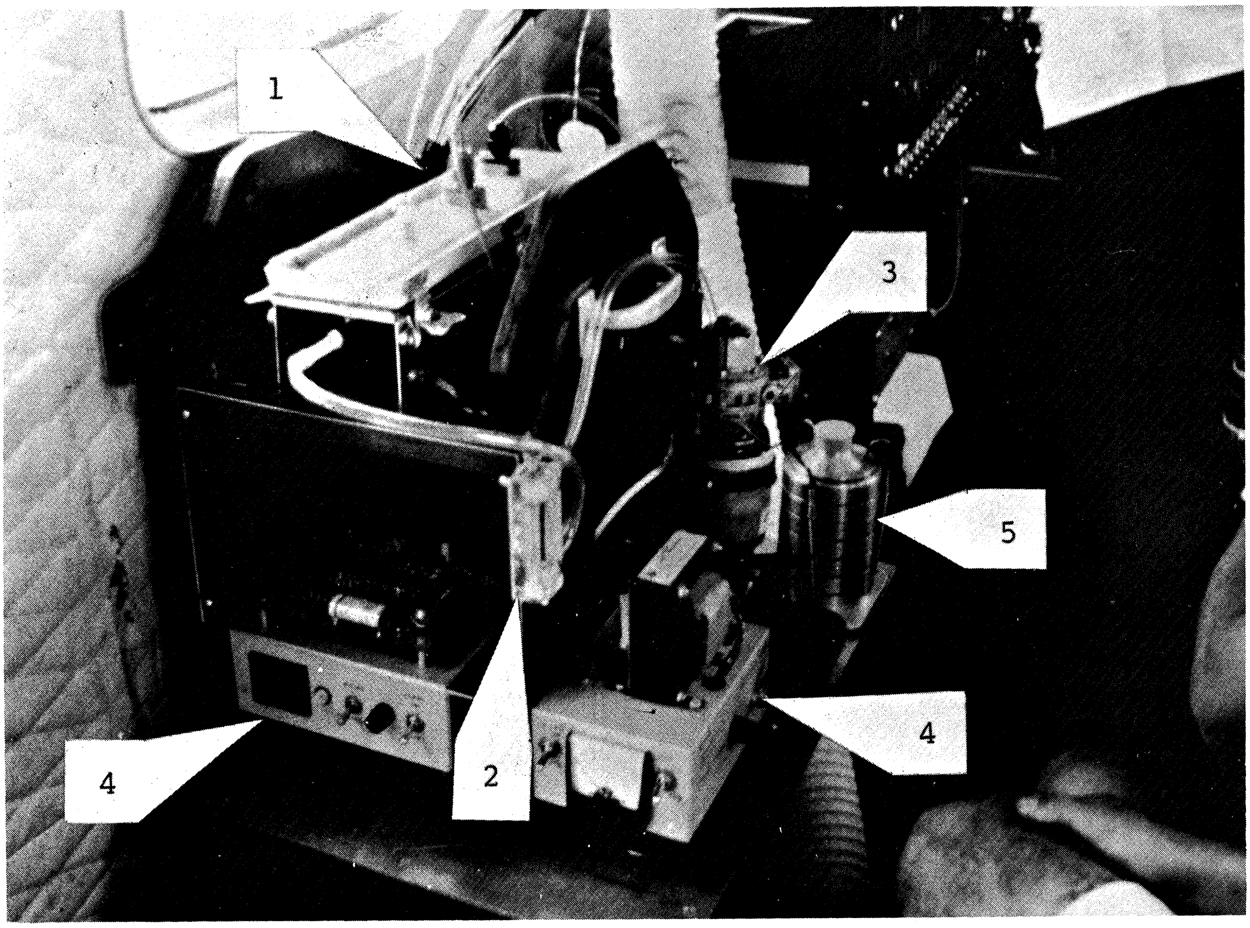


Figure 37. Sampling assembly in the C-45 airplane: (1) Whitby-Liu electrostatic sampler; (2) air flow meter; (3) pump; (4) power supplies; (5) Andersen sampler.

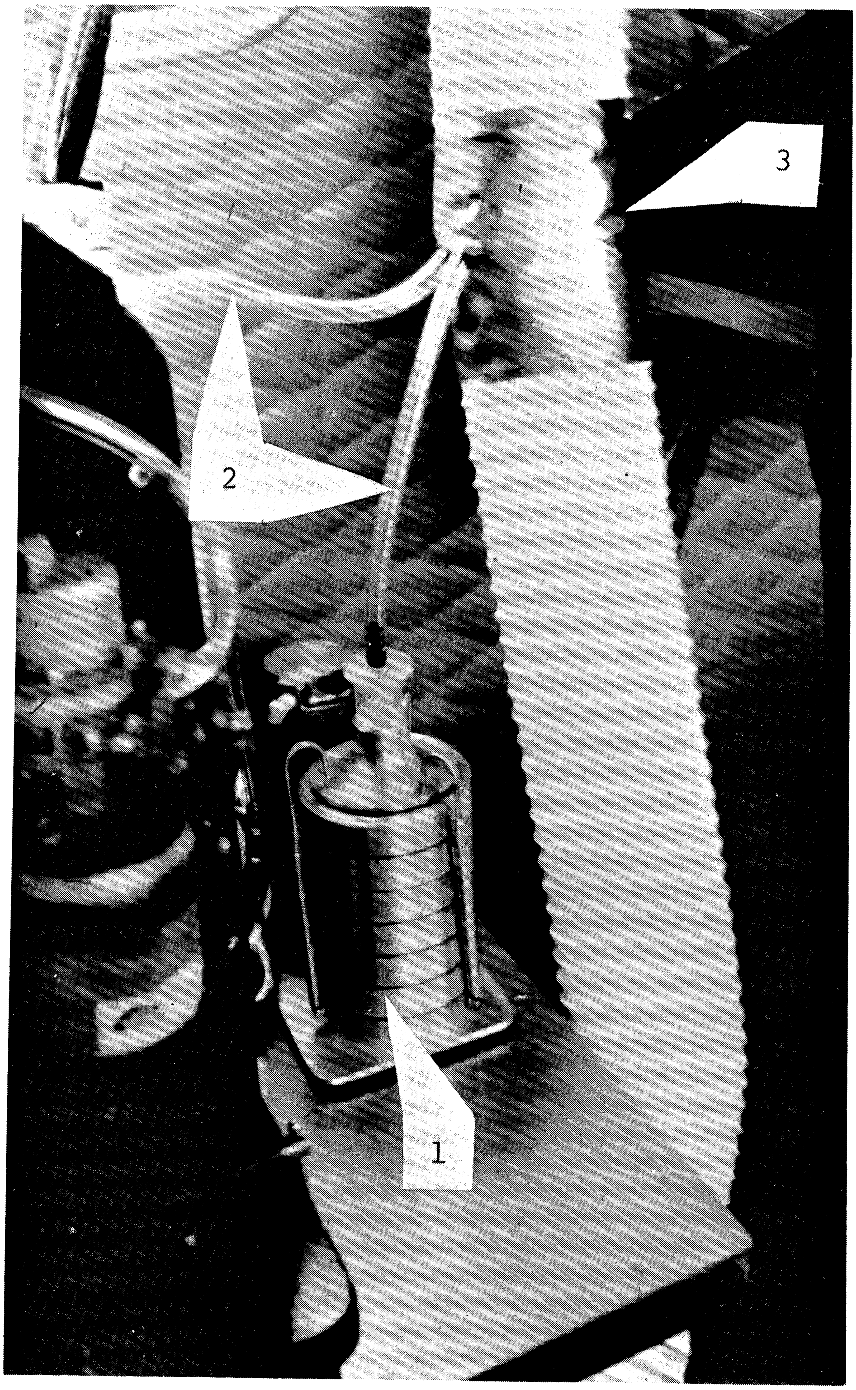


Figure 38. Sampling assembly in C-45 airplane: (1) Andersen impactor sampler; (2) tubes from isokinetic nozzles to samplers; (3) air intake conduit.

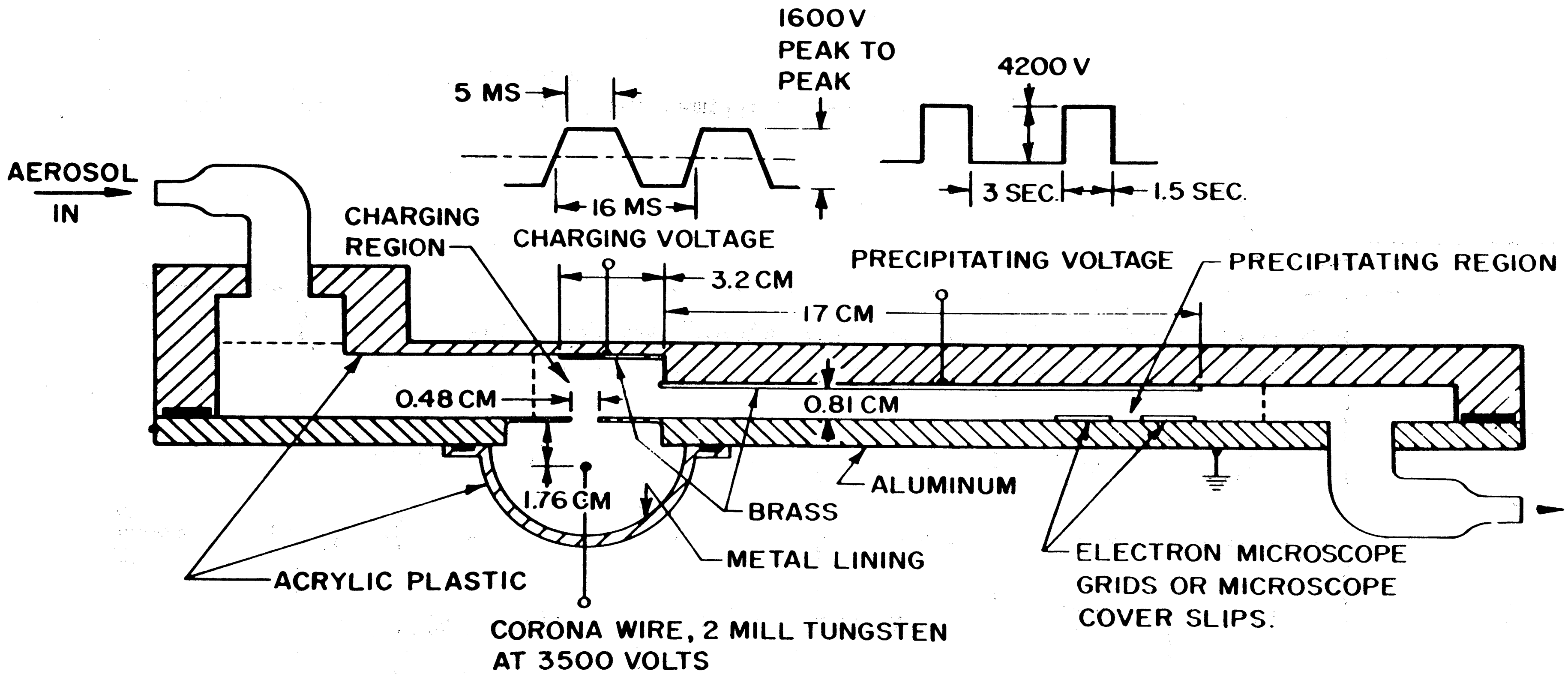


Figure 39. Cross-section of the electrostatic sampler showing dimensional and electric details.

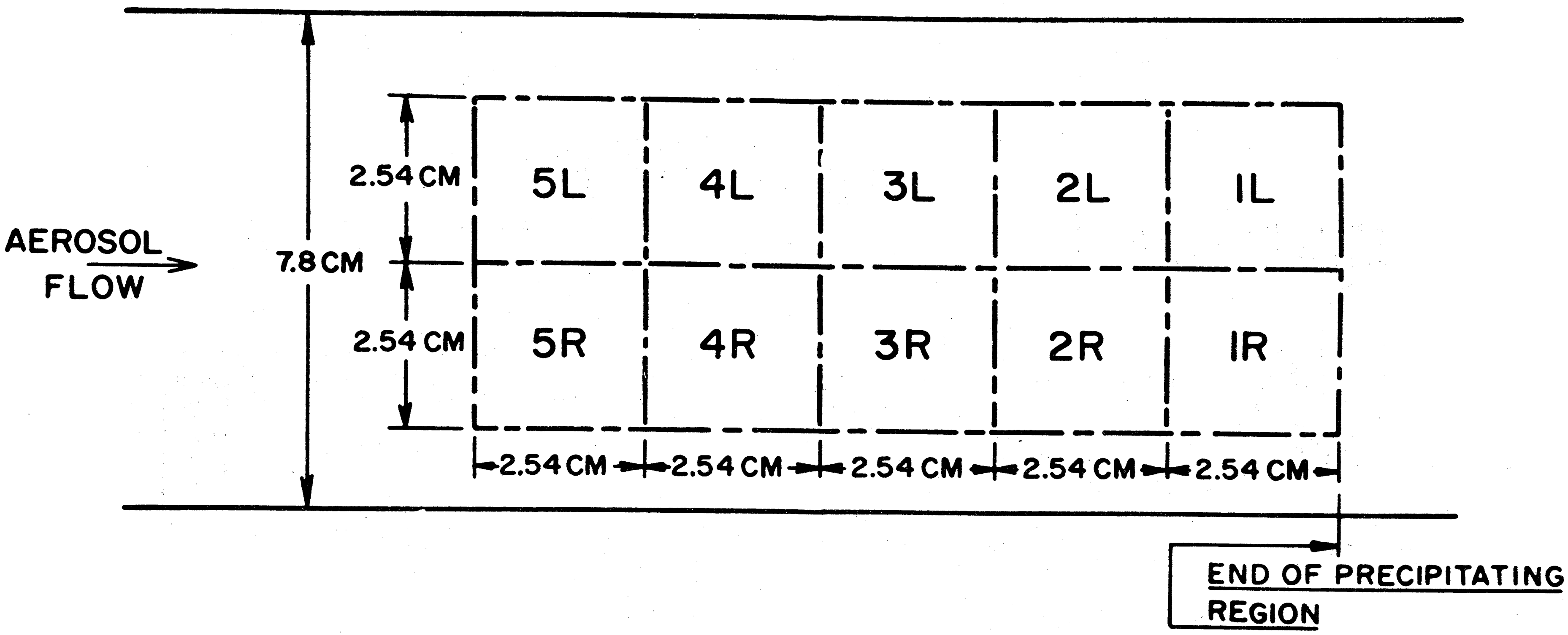


Figure 40. Configuration of the sampling slides in the precipitating region of the electrostatic sampler.

microscope images at 5,000 X, 7,250 X and 21,000 X magnifications were made, choosing typical areas. Figure 41 shows typical photographs at the magnification of 5000 X. Obviously special questions of interpretation arise, as for example in Figure 41 d, a large flake-like particle, standing well above the sampling surface (note shadow), is obviously difficult to measure in any meaningfull way, and appears not to be a product of condensation or coagulation from the vapor and/or smoke. In Figure 41 e, a large particle (1.6μ in longest dimension) appears to have no shadow, and lies in the center of a halo of much smaller particles having definite shadows. Although the shadowing technique was used to distinguish sample particles from dust acquired later, and to indicate places from which sample particles had been removed or vaporized, it is difficult to interpret this photograph by those guidelines.

Particle size measurements from 82 such photographs were made. The counts were normalized for 30 pictures under each magnification and to a standard viewing area of 13.6 X 17.74μ. Inasmuch as 55 pictures are required to cover completely one grid square at 5000 X magnification, the total area represented in our counts is very small.

To examine for changes of sampling rate along the flow path, grids from slides 5, 3 and 1 were counted and summarized for each slide. The results are presented in Figure 42 in which a constant mass distribution curve is drawn as a criterion

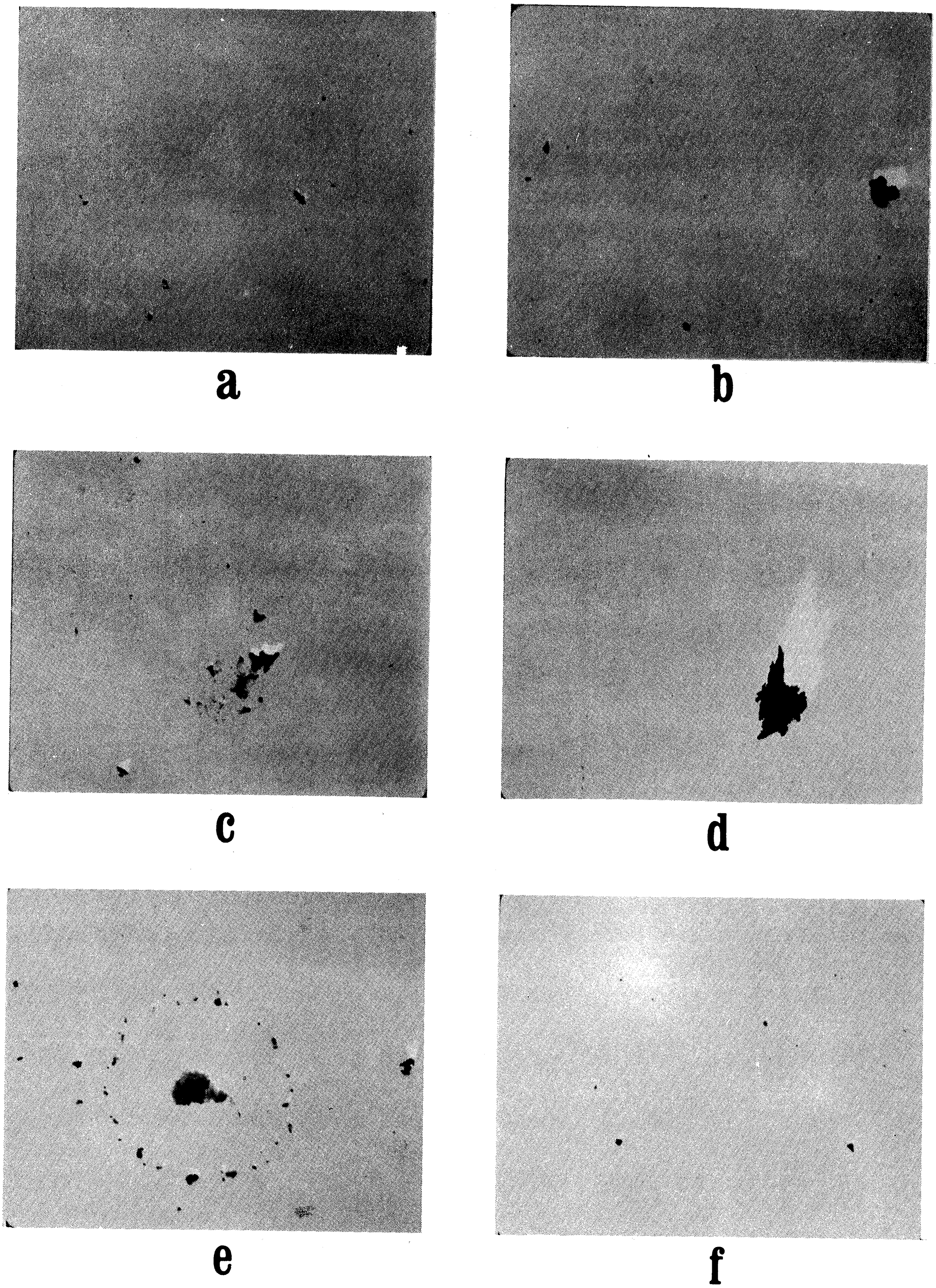


Figure 41. Typical electron photo-micrographs of particles collected using the electrostatic sampler. Magnification 5,000 X. See text for discussion.

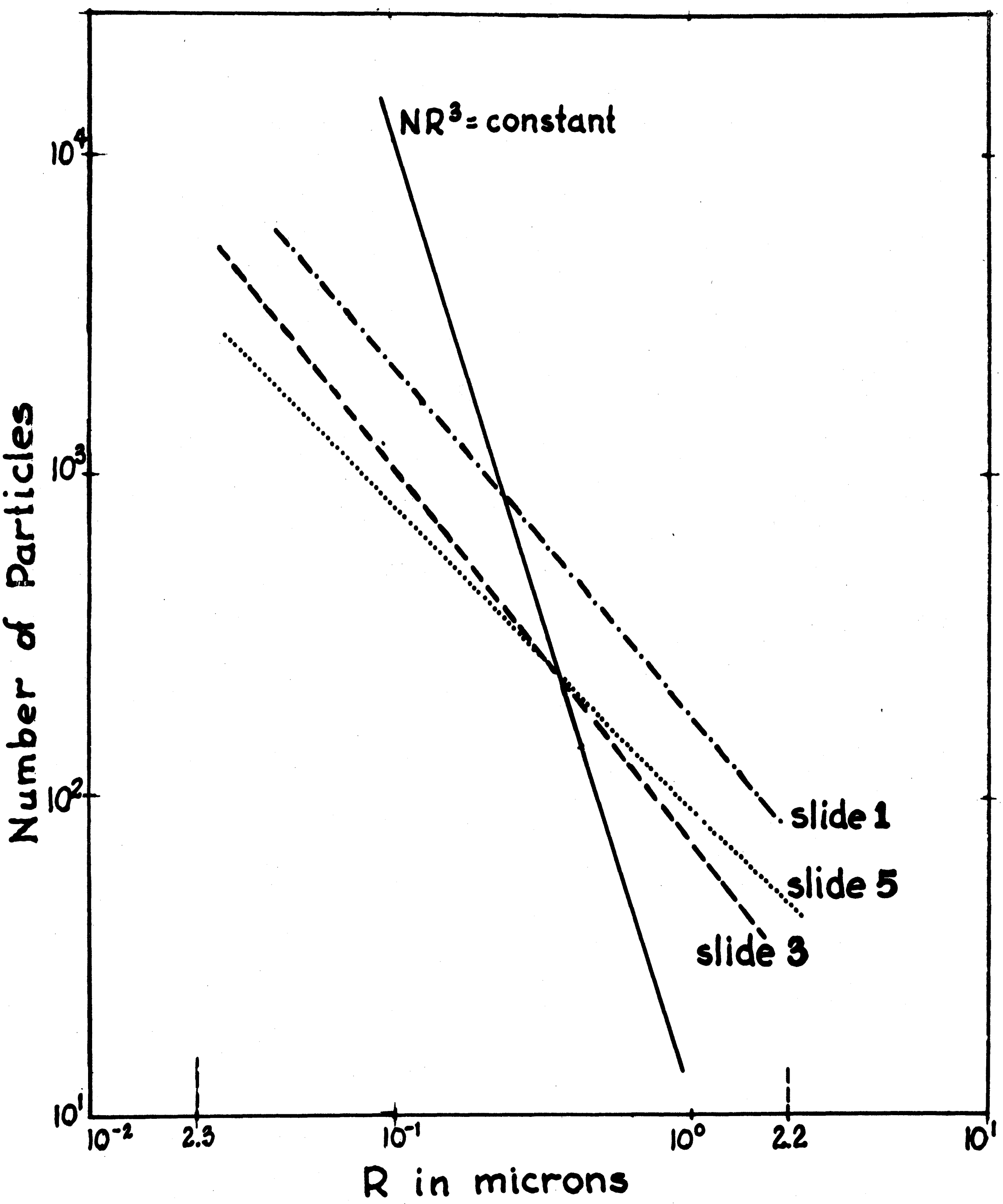


Figure 42. Nominal particle-size distributions for slides 1, 3, and 5 (Fig. 40) as determined from electron photomicrographs and drawn by eye through the data points.

The counted particles range through two orders of magnitude in radius, from 2.3×10^{-2} to $2.2 \times 10^{0}\mu$. Although slight differences between the slides appear, it is questionable whether they are significant. Whitby and Clark (1966) point out that particles larger than $5 \times 10^{-2}\mu$ are multiply charged in an apparatus of this type, and that therefore a minimum in the electrical mobility of the particles may occur in the size range $r = 0.2\mu$ (for strong field charging) to 3μ (for diffusion charging). It is therefore not surprising that our data fail to show significant sorting or complete deposition with distance downstream.

The results are disappointing in that they indicate a relatively large proportion of the mass of plume material in the larger particles. For our immediate purpose, it would appear to be more advantageous to have the large fraction of the mass of tracer indium associated with the small particles. There is, however, some suggestion in the large particle shapes (e.g. Fig. 41 d) that they do not represent tracer-containing parts of the flare, but may rather be fragments of the flare wrapper, and may therefore not carry a proportionate mass of indium.

Unfortunately, the Andersen impactor did not function properly in the airplane sampling experiments. If it had, we should have derived from its samples a view of the indium distribution with respect to the particle size. Accordingly a new experiment was carried out to obtain this information.

Our third approach to the particle-size measurement problem was to do an experiment using the prop-wash from a standing airplane as a wind source. For this purpose we rented a single-engine airplane and placed it in an extensive area of 2 in.-high grass. At the time of the experiment the grass was moist from fresh snow showers. The plane was faced into the wind of 8-10 mph and the flare mount was set up to hold the flare 41 in. above the ground and 12 ft 6 in. behind the propeller. The Andersen sampler was set 14 ft. behind the flare at a height (at intake) of 23 in. With this configuration, the sampler was in the flare plume throughout the burning time. The air speed at the sampler was of the order of 90 to 100 mph.

A section of the Andersen sampler is shown in Figure 43. For the experiment, a seventh stage of impaction sampling was added. The particle-size calibration of this instrument is presented in terms of spherical particles of unit density and a flow rate of 28.3 ℓ per min (1 cfm). These data and the results are given in Table 5. The indium amounts were determined by neutron activation and β-counting. Half-life measurements are given as an indicator of the purity of the indium in the sample counted. Pure In-116m has a half-life of 54 min., and very small amounts of other materials such as Na-24, Mn-56, As-76, and Cl-38 can contribute β-radiation of various half-lifes, usually resulting in a β-decay-determined half-life

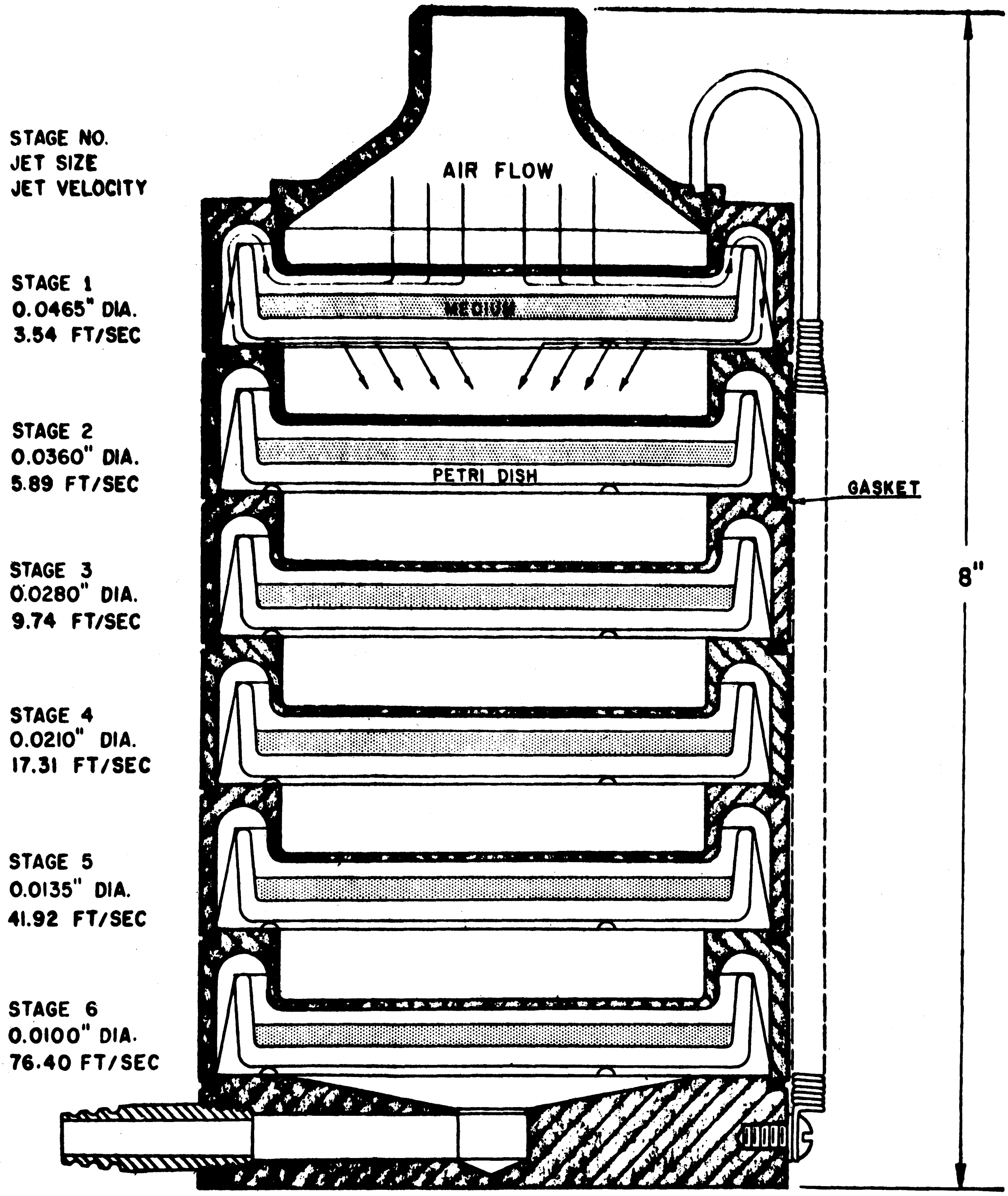


Figure 43. Six-stage Andersen impactor sampler. A perforated disk at each stage forms a pattern of jets which impinge upon a polyethylene collecting surface. The jets are progressively reduced in diameter, hence their velocity increases and the particles collected decrease in size toward the bottom stage.

TABLE 5

Results of Ground-Based Test, and Particle-Size Calibration of Andersen Sampler

Stage No.	Particle Size Range				Indium Data			
	95% r in u		50% r in u		β-cpm	Mass ng	Half Life, min	% of Total Mass
	lower	upper	lower	upper				
1	8.3	---	9.2	---	8.4×10^4	56	58	0.1
2	5.0	11.0	5.5	9.2	5.54×10^6	3,521	54	9.3
3	2.9	6.0	3.3	5.5	5.41×10^5	344	54	0.9
4	2.0	3.6	2.0	3.3	1.60×10^5	106	54	0.3
5	1.0	2.1	1.0	2.0	2.05×10^5	135	55	0.3
6	not known	1.1	up to 1.0		2.96×10^6	1,881	54	4.9
					2.82×10^6	1,792	55	
7	not known		not known		15.0×10^6	9,533	55	22.2
					12.7×10^6	8,090	55	
Filter	$<$0.1u	---	---	---	37.2×10^6	23,640	55	62.0
					36.1×10^6	22,940	55	
					45.6×10^6	28,980	55	

greater than 54 min.

The indium indeed appears to be distributed as a function of particle size, with amounts increasing toward the smallest particles (those collected by the filter). The peculiar secondary maximum for stage 2 is not at this point understood.

We conclude that this bimodal distribution needs both verification and interpretation. Inasmuch as the large proportion of the indium is found in the small particles on the filter, whereas the large proportion of total particle mass (as estimated from the electron photomicrographs) is in larger sizes, it appears that the indium is not associated with the smoke particle cloud in a mass proportional distribution. This may have to do with the distribution of temperature across the flare diameter as it burns, and with the production of special particles by the flare wrapper.

3. Neutron activation measurement of indium

In launching the pilot experiments to establish feasibility of indium as an atmospheric tracer in convective storm systems, it was reasonable and necessary to accept a certain amount of error in the indium analyses. This error is indicated to some extent by the range of β-decay half-life estimates that were derived from the counts of the activated samples. These varied upward to over 120 min in some cases (see Report No. C00-1407-20). The error of measurement is further indicated by (a) the difference between two measurements made on different aliquots of the same sample, and (b) the standard deviation of the rain sample indium background amounts.

Since 1 March 1969 the project has had the services of Dr. K.S. Bhatki, who is on leave from the Tata Institute of Fundamental Research, Bombay, India, as post-doctoral analytical radiochemist. Under Dr. Bhatki's guidance, the analytical procedures have been developed to the point that 88 per cent of current half-life measurements lie below 70 min, and different aliquots of the same sample show greatly improved reproducibility. (Tables 2 and 3, above).

These efforts have been prepared and accepted for publication by the Journal of Applied Meteorology (K.S. Bhatki and A.N. Dingle, The Measurement of Tracer Indium in Rain Samples, and, in more abbreviated form, by Radiochemical and Radioanalytical Letters (K.S. Bhatki and A.N. Dingle, Tracer Indium Determination in Rain Samples by Neutron Activation and Radiochemical Analysis), which should appear reasonably early in 1970.

In addition to the development of the analytical procedures, the production of data by analysis of collected rain samples has gone forward to near completion for the 1967, 1968, and 1969 collections. These results are given in Tables 2, 3, 6 and 7, and in Figures 28, 30, and 31.

4. Calibration of the raindrop-size spectrometer

Raindrop-size data have been recorded as part of our

TABLE 6

Results of Indium Analyses for Mobile Unit Samples collected near Tuttle, Oklahoma, 31 May 1968

Station No. (Sample)	Aliquot	Water ml	Indium ng	Indium conc ng/l	Half-life
201	A				
	B				
	C	974.1	3.20	3.3	64.0
	D	967.7	3.25	3.4	60.5
202	A	793.3	3.40	4.3	59.0
	B	857.9	3.10	3.6	57.6
	C	559.9	2.30	4.1	62.6
203	A	818.2	7.30	9.0	57.6
	B	901.9	6.75	7.5	60.0
	C	810.5	5.75	7.0	60.5
	D	836.9	5.75	6.9	62.6
204		598.8	0.70	1.2	70.5
205	A	501.2	8.85	17.6	
	B	517.3	9.00	17.4	
206	A	963.7	8.60	9.0	59.0
	B	821.8	6.60	8.0	59.0
	C	815.9	6.90	8.5	56.9
207	A	830.2	8.35	10.1	60.5
	B	936.9	6.60	7.1	60.5
	C	777.7			
	D	807.9			
208	A	762.0	10.45	13.7	60.5
	B	800.1	8.85	11.1	59.9
	C	761.4	9.30	12.2	59.9
	D	762.2	10.10	13.3	58.3
210	A	777.1	7.45	9.6	59.0
	B	739.2			
	C	889.7	8.85	9.9	60.5
	D	500.4	5.60	11.2	59.0

Table 6 con't.

Station No. (Sample)	Aliquot	Water ml	Indium ng	Indium conc ng/l	Half-life
211	A	806.0	6.60	8.2	60.5
	B	895.7	8.00	8.9	59.0
	C	830.5	6.65	8.0	56.8
	D	683.0	4.80	7.0	57.6
212	A	999.4	9.50	9.6	58.2
	B	972.4	7.50	7.7	60.5
	C	992.6			
	D	1008.1	9.60	9.5	56.9
	E	998.0			
	F	178.0	1.65	9.2	60.5
213	A	748.0	6.50	8.7	59.7
	B	645.9	6.20	9.6	56.8
	C	698.0	7.60	10.6	61.9
214	A	912.5	11.25	12.5	60.5
	B	820.4	13.85	16.9	57.6
	C	842.6	11.75	14.0	59.0
	D	907.8	10.05	11.7	58.3
216	A	809.3	10.10	12.5	61.0
	B	696.0	7.55	10.8	77.0
	C	715.2	9.60	13.4	59.7
	D	771.0	9.70	12.6	67.7
218	A	552.0	10.10	18.3	62.6
	B	574.4	11.20	19.5	60.5
219	A	876.1	10.80	12.3	57.6
	B	832.1	13.30	6.0	59.0
220		804.7	6.50	8.1	
101		281.9	9.40	33.3	
102		371.7	4.80	12.9	
103		214.6			
104		414.6			
106		339.9			
107		707.4			

Table 7

Results of Indium Analyses for sequential samples collected on 31 May 1968

Sample No.	TIME OF COLLECTION Duration, Min	Mean CDT h:m:s	Water ml	Indium ng	Indium conc. ng/1	Half life min.
(a) Michigan Base Station, Chickasha, Oklahoma						
1	6.26	17:57:14	960.1		15.7	61.01
2	0.77	18:01:45	987.6			
3	0.40	18:01:20	970.9		6.8	65.7
4	0.40	18:01:44	985.3		5.6	64.9
5	0.27	18:02:07	984.9		6.4	69.4
6	0.60	18:02:33	984.1		5.9	67.8
7	0.45	18:03:01	969.2		3.4	73.3
8	0.65	18:03:34	987.2		3.3	69.0
9	0.98	18:04:29	986.1			
10	0.65	18:05:12	989.4		6.6	69.4
11	0.48	18:05:46	1005.6		4.2	73.9
12	0.70	18:06:22	1006.4		3.9	74.7
13	0.72	18:07:04	1002.8		4.5	56.9
14	0.65	18:07:45	997.0		3.1	59.5
15	0.58	18:08:22	1013.1	4.9	4.8	
16	1.04	18:09:11	985.3	4.4	4.5	
17	0.70	18:10:03	975.5	5.4	5.5	
18	0.66	18:10:44	992.6	4.1	4.1	
19	0.52	18:11:19	991.1	5.1	5.3	
20	0.73	18:11:56	970.5	3.6	3.7	
21	0.92	18:12:46	977.1	4.3	4.4	
22	1.45	18:13:57	985.2	3.4	3.4	
23	1.95	18:15:37	968.4	2.6	2.7	
24	1.37	18:17:16	973.5	3.7	3.8	
25	2.15	18:19:04	991.8	3.0	3.0	
26	17.38	18:28:42	976.0	2.7	2.8	

Table 7 cont.

Sample No.	TIME OF COLLECTION Duration, Min	Mean CDT h:m	Water ml	Indium ng	Indium conc. ng/l	Half life min
(b) Michigan Mobile Unit # 2, east of Tuttle, Oklahoma						
M-1	5	18:17	898.5	19.1	21.3	
2	7	18:23	933.8	19.0	20.4	
3	4	18:29	907.3			
4	9	18:35	920.1	11.5	12.5	
5	11	18:45	926.0	10.8	12.2	
6	19	19:00	925.9			
7	7	19:13	932.4			

rain data since 1964. In the early stage this was reduced for selected time periods by manually measuring and counting pulses recorded by an oscillograph. Since the development of our magnetic tape recording system, the reduction of the records to drop size data has been transformed to an analog-digital computer process. Along with this transformation it has appeared important to recalibrate the instrument using the magnetic tape and computer-reduction techniques throughout the process.

The calibration requires that a few hundred water drops of uniform size be produced at several points throughout the raindrop-size spectrum, and that these be independently measured. At large drop-size, it is possible to obtain good measurements by collecting a few hundred drops in a vial and weighing to determine mean size, at the same time maintaining a check on the uniformity of size by means of one of the drop-stain techniques (drops on dyed filter paper, or on diazo paper, etc.). A difficulty enters this part of the calibration procedure because the large drops tend to pulsate as they fall, thus the optical signals received by the photometer of the spectrometer may vary substantially within a given drop-size category. Final calibration figures therefore depend mainly upon the statistics of the recorded pulses, because the actual size determination can be quite good.

At intermediate sizes, the weighing technique loses its value because the drop masses are very small, and catching and counting thousands is not feasible. The paper stain techniques become more reliable in the size range under 1 mm diameter, and can be checked by sampling the drop stream by catching a few at a time in oil for immediate measurement under a microscope. At these sizes the drop shape is only slightly affected by pulsations and the photoelectric signals are quite constant.

At small sizes, difficulty is encountered in generating uniform droplets for a long enough time period to obtain both the drop size data (by oil bath method) and the calibration pulse records.

A number of calibration experiments were conducted during July, 1969, and these have been introduced into the computing procedure for the reduction of the magnetic tape records compiled in the field.

III. Reporting and Publishing

1. Meetings attended and reports presented

13th Radar Meteorology Conference, 20-23 August, 1968, Montreal, Canada.

Attendance, conference with conferees, especially G. Vali of McGill University and J. Joss of Osservatorio Locarn-Monti, Switzerland.

<u>International Conference on Cloud Physics</u>, 26-30 August, 1968, Toronto, Canada.

Attendance and conferences with attendees, e.g., Dr. Philip Goldsmith, Meteorological Office, Bracknell, Berks., England; R. Engelmann, USAEC; G. Stout, Illinois State Water Survey; H.W. Georgii, Frankfurt, Germany; A. Gagin, Jerusalem, Isreal.

6th Severe Storms Conference, 8-10 April, 1969, Chicago, Illinois

Presentation of "Temporal variations of contamants in convective rains in relation to the processes of rain formation" by A.N. Dingle and D.F. Gatz. Discussion of various papers, and professional contacts.

50th Anniversity Meeting of the American Geophysical Union, 21-25 April, 1969, Washington, D.C.

Presentation of "Particle sizes produced by indium-emitting pyrotechnic flares" by G.W. Wambolt and A.N. Dingle.

IASPEI - IAGA General Scientific Assembly, 1-12 September, 1969, Madrid, Spain; Symposium on Atmospheric Electricity, 5-6 September.

Attendance and contacts with H. Dolezalek, ONR; H.W. Kasemir, NCAR; R.P. Muhleisen, Germany.

CACR Symposium on Atmospheric Trace Constituents and Atmospheric Circulation, 8-13 September, 1969, Heidelberg, Germany.

Presentation of "Contaminant Variations During Convective Rains and Their Interpretation: by A.N. Dingle and D.F. Gatz.

Participation in discussion, and renewed contacts with R. Reiter, Garmisch-Partenkirchen, Germany, W.N. Lablans, De Bilt, Netherlands; P.B. Storebø, Norway and numerous others.

7th International Conference on Condensation and Ice Nuclei, 18-24 September, 1969, Prague, Czechoslovakia, and Vienna, Austria.

Presentation of "Tracer Experiments in Convective Storms: *in situ* Research on Nucleation" by A.N. Dingle. Discussions and contacts with foreign scientists, particularly from Eastern Europe: V.G. Morachevsky, Russia; J. Podzimek, K. Spurny, F. Anzy, Czechoslovakia; L. Krastanov, Bulgaria; and numerous others.

2. Publications

COO-1407-20. Progress Report No. 4, Rain Scavenging Studies, by A.N. Dingle, August, 1968.

COO-1407-21. Progress Report No. 5, Rain Scavenging Studies, by A.N. Dingle, September, 1968.

COO-1407-22. Discussion of "Analysis of trace elements in air-borne particulates, by neutron activation and gamma-ray spectrometry" by J.R. Keane and E.M.R. Fisher, *Atmos. Envir.* *2*, 603-614, 1968, by A.N. Dingle. *Atmos. Envir.* *3*, 85-86, 1969.

COO-1407-23. Detection of indium as an atmospheric tracer by neutron activation, by D.F. Gatz, A.N. Dingle,

and J.W. Winchester, J. Applied Meteorol. 8, 229-235, April, 1969.

C00-1407-24. A pilot experiment using indium as tracer in a convective storm, by A.N. Dingle, D.F. Gatz, and J.W. Winchester. J. Applied Meteor. 8, 236-240, April, 1969.

C00-1407-25. Temporal variations of contaminants in convective rains in relation to the processes of rain formation, by A.N. Dingle and D.F. Gatz. Preprints of Papers presented at the Sixth Conference on Severe Local Storms, pp. 100-104, April, 1969. Published by the Amer. Meteorol. Soc., Boston, Mass.

C00-1407-26. Particle sizes produced by indium-emitting pyrotechnic flares, by G.W. Wambolt and A.N. Dingle. Trans. Amer. Geophys. Un. 50, 166, April, 1969. (Abstract).

C00-1407-27. Contaminant variations during convective rains and their interpretation, by A.N. Dingle and D.F. Gatz. Abstracts, CACR Symposium on Atmospheric Trace Constituents and Atmospheric Circulation, Heidelberg, Germany, September 8-13, 1969, p. J-8. (Abstract).

C00-1407-28. Tracer experiments in convective storms: *in situ* research on nucleation, by A.N. Dingle. Abstracts, 7th International Conference on Condensation and Ice Nuclei, Prague and Vienna, September 18-24, 1969. p. 11 (Abstract).

COO-1407-29. Tracer experiments in convective storms: *in situ* research on nucleation, by A.N. Dingle. *Proc. 7th International Conference on Condensation and Ice Nuclei*, September 18-24, 1969, Prague and Vienna, pp. 379-382.

COO-1407-30. The measurement of tracer indium in rain samples, by K.S. Bhatki and A.N. Dingle. *J. Applied Meteorol.*, accepted for publication early in 1970.

COO-1407-31. Trace substances in rain water: concentration variations during convective rains, and their interpretation, by D F Gatz and A.N. Dingle. Submitted to *Tellus*, 1 November 1969.

COO-1407-32. Tracer indium determination in rain samples by neutron activation and radiochemical analysis, by K.S. Bhatki and A.N. Dingle. Submitted to *Radiochemical and Radioanalytical Letters*, Budapest, Hungary, 13 November 1969.

IV. Personnel

1. Dr. Kasinath S. Bhatki, analytical radiochemist, on deputation leave from Tata Institute of Fundamental Research, Bombay, India.
2. Mr. Raymond E. Crabtree, electrical engineer, research engineer, part time.
3. Mr. Yean Lee, M.S., graduate student in meteorology,

research associate, part time.

4. Mr. R. Borys, undergraduate student in meteorology, assistant in research, hourly.

5. Mr. D. Curtin, undergraduate student in meteorology, assistant in research, hourly.

6. Mr. J Fairobent, undergraduate student in meteorology, assistant in research, hourly.

7. Mr. J. Goll, undergraduate student in meteorology, assistant in research, hourly.

8. Mr. S. Jermaine, undergraduate student in meteorology, assistant in research, hourly.

The anticipated personnel situation of the project is as follows:

Dr. Bhatki is scheduled to return to India in summer, 1970. There is some possibility that we can arrange to retain his services somewhat longer but negotiations for a replacement will be necessary sometime during 1970.

Mr. Crabtree will continue as our cognizant engineer in charge of maintaining smooth operation of all electronic equipment.

Mr. Lee will continue as research associate, part time, and graduate student associated with the project. In view of his current need to take a considerable course load in preparation for the Ph.D. qualifying examinations, his original contributions to the project work will be somewhat limited.

Mr. Duane Harding is expected to join the project as research associate, part time, and graduate student after 1 January 1970. He, too, is a new graduate student whose original contributions may be somewhat limited initially.

Messrs. Curtin, Fairobent, Goll and Jermaine will continue as assistants in research through the summer. Mr. Curtin will probably enter graduate school elsewhere for Fall, 1970, and Messrs. Jermaine and Goll expect to graduate in April, 1970, and go into military service or graduate school by Fall, 1970. Mr. Fairobent will continue as assistant in research to December 1970.