Hydrologic and Hydrochemical Observations within Beverly Swamp

HYDROLOGIC AND HYDROCHEMICAL OBSERVATIONS
OF BOTH
STREAM AND GROUNDWATER WITHIN BEVERLY SWAMP

by

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A Research Paper

Submitted to the Department of Geography

in Partial Fulfilment of the Requirements

for the Degree

Bachelor of Arts

McMaster University

April 1976

BACHELOR OF ARTS (1976)
(Geography)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Hydrologic and Hydrochemical Observations of Both Stream and Groundwater within Beverly Swamp

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NUMBER OF PAGES:

ABSTRACT: In 1975, field observations were made in Beverly Swamp to determine the impact of the construction of a Hydro powerline on the groundwater and stream flow regime of the Swamp. Results indicate significant differences between the forested areas and the forest clearings in terms of their hydrologic and hydrochemical characteristics.

Acknowledgments

A special thanks and word of appreciation is in order for the assistance of some people in undertaking this research project.

I wish to express appreciation to both the National Research Council and Ontario Hydro for their financial aid to the project. I would also like to thank Dr.M.K. Woo for his unfailing advice during the research and composition of this paper. Special thanks to Tim Marta and John Smith Sr. for their support in the field and to Michael McKie and Cathy Martin for their help in producing the contour maps. Finally, thanks to Brenda Fukumoto for her help in typing this paper.

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I INTRODUCTION

I-1 Object of Study

There are many basin studies concerning the impact of forest cuttings on water chemistry (Fredrikson, 1971; Brown and Krygier, 1970; Hornbeck et al., 1970; Gessel and Cole, 1965). These studies are primarily concerned with forested basins having much drier conditions than those afforded by the presence of a swamp. Other researchers working in swamp environments (Moore and Bellamy, 1974; Heikurainen, 1967; Waksman and Stevens, 1929) did not consider the groundwater hydrochemistry as related to forest clearing. The objective of this study is:

1. to examine the hydrologic and hydrochemical characteristics of a southern Ontario swamp, and
2. to determine the effects of forest clearing on the hydrologic and hydrochemical regimes of the swamp.

I-2 Field observations and instrumentation

In 1975, the construction of towers supporting transmission lines across Beverly Swamp offered opportunities to study the effects of forest clearing along the Ontario Hydro right-of-way. Field data were collected at several sites in and around the Beverly Swamp area (figure I-1).

Water level records - Weekly readings of staff gauges (figure I-2) were made at three locations within the Swamp,

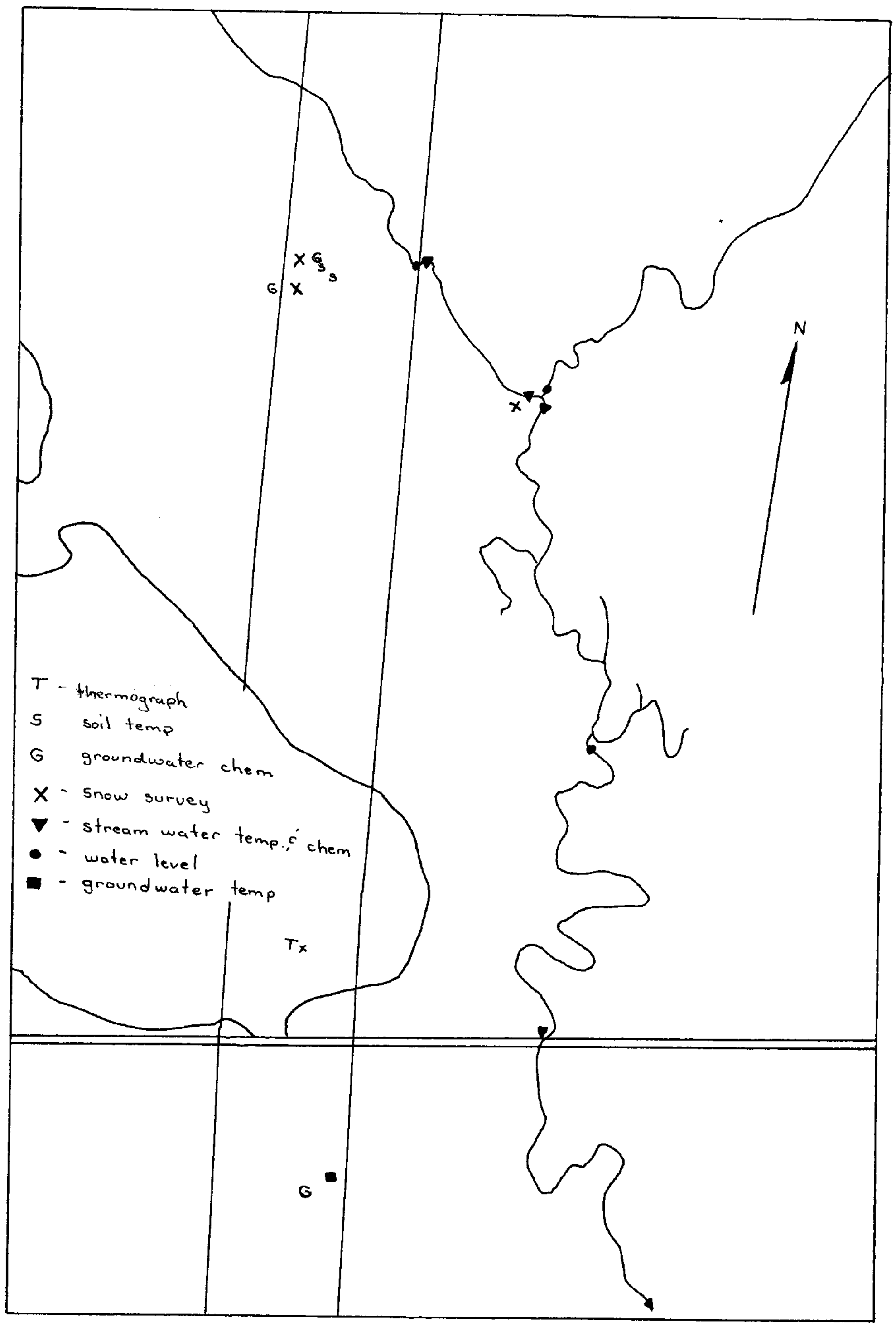


Figure I-1 Locational map showing data collection sites in and around Beverly Swamp while continuous discharge records were maintained by the Water Survey of Canada at Westover. Groundwater levels were obtained at three sites within the Swamp (figure I-1, utilizing a floatation device (figure I-3, I-4). At one site in the southern portion of the Swamp, groundwater level was continuously monitored by an Ott Water Level Recorder (figure I-5).

Water chemistry - Water samples were obtained at weekly intervals and analyzed for pH, alkalinity and water hardness. pH was measured in the field by a Metrohm portable electric pH meter (figure I-7). Alkalinity was measured within several hours after samples were brought back to the laboratory. Its determination was made through the titration of 0.01N hydrochloric acid into a 25 ml. water sample and the rate of pH decrease observed. The volume of acid and end point of titration were noted and alkalinity was obtained through the use of a computer program (Wigley, 1972). Calcium and total hardness were obtained by the ethylenediaminetetra-acetic acid (EDTA) titration method, using a kit available from the British Drug House.

Water, soil and air temperature - Water temperature was measured at points where water samples were collected for chemical analysis, using a portable salinity - conductivity - temperature meter manufactured by the Yellow Springs Instrument Company (figure I-6). Soil temperature was obtained in a forest opening and underneath the forest canopy, in the northern portion of the Swamp (figure I-1) by means of thermister discs embedded at depths of 1, 5, 10, 25, 50 and 100 cm. beneath the soil surface. Electrical resistance, which is directly proportional to temperature, was measured with a BRI Resistance Bridge manufactured by J. J. Lloyd Instruments Limited (figure I-7). Air temperature was recorded by a hygrothermograph, Model #H-311; constructed by Weather Measure Corporation in an open site above a small quarry (figure I-8).

Precipitation - Four snow survey sites (figure I-1) were established to measure the amount of snow on the ground and weekly snow accumulation, where weekly accumulation was obtained by noting the depths and weights of snow above several snow-boards with a surface area of one square foot (figure I-9). A tipping-bucket rain gauge, Model P-52. manufactured by Weather Measurement Corporation was positioned alongside the thermograph in the open site. Non-recording rain gauges were strung across two locations at the North test site and at the Control site to study the spatial variation in rainfall in disturbed and undisturbed wooded environments.

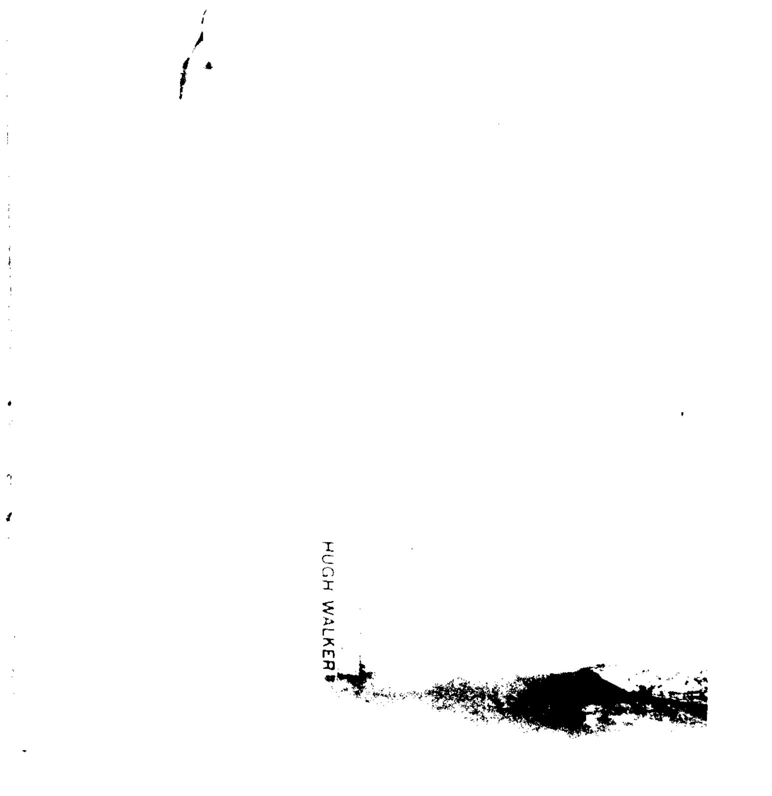


Figure I-2 Staff gauge during winter freeze-up

Figure I-3 Groundwater pipe and floatation device

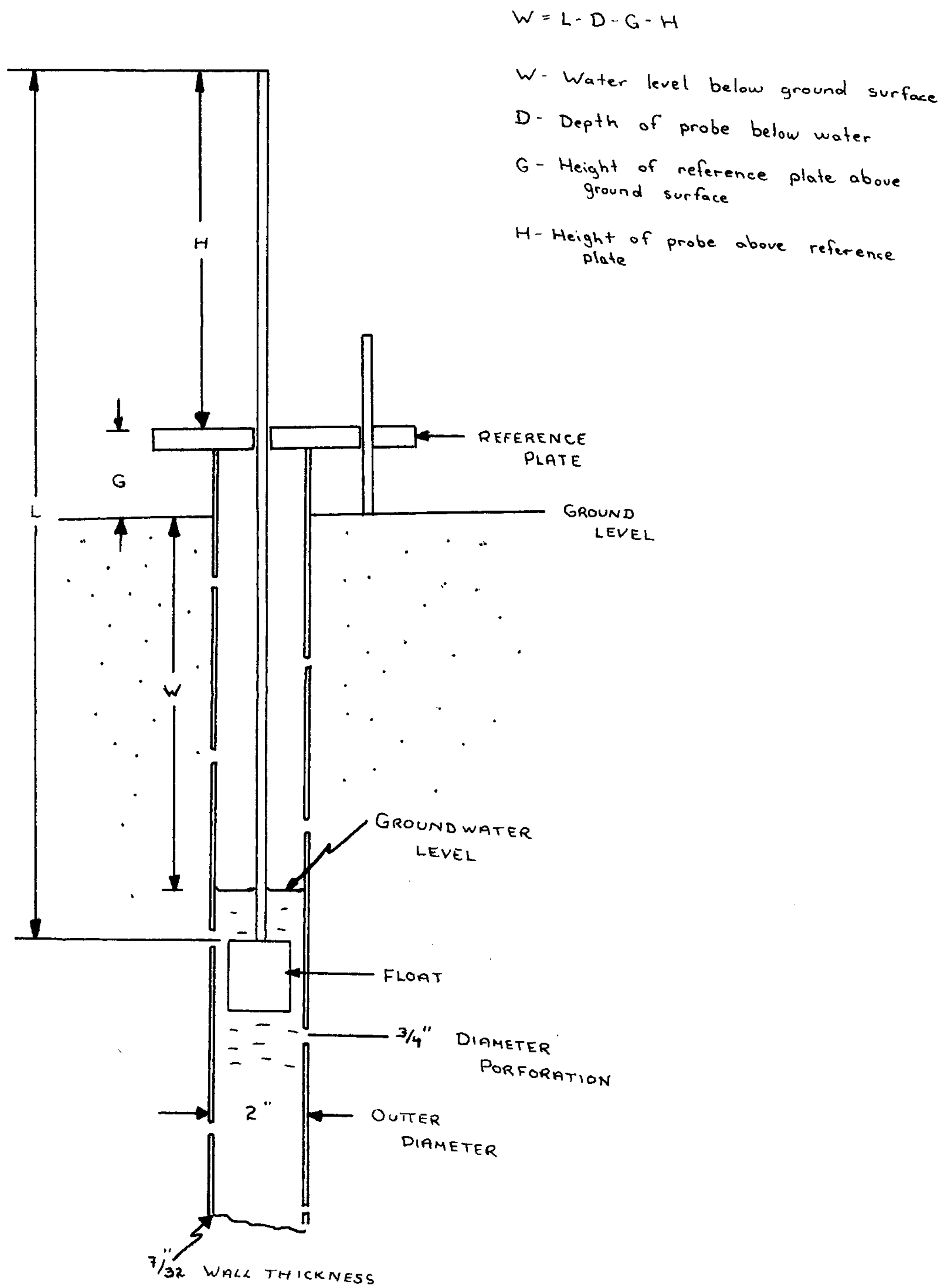


Figure I-4 Method used to obtain groundwater levels

Figure I-5 Ott Water level recorder (groundwater)

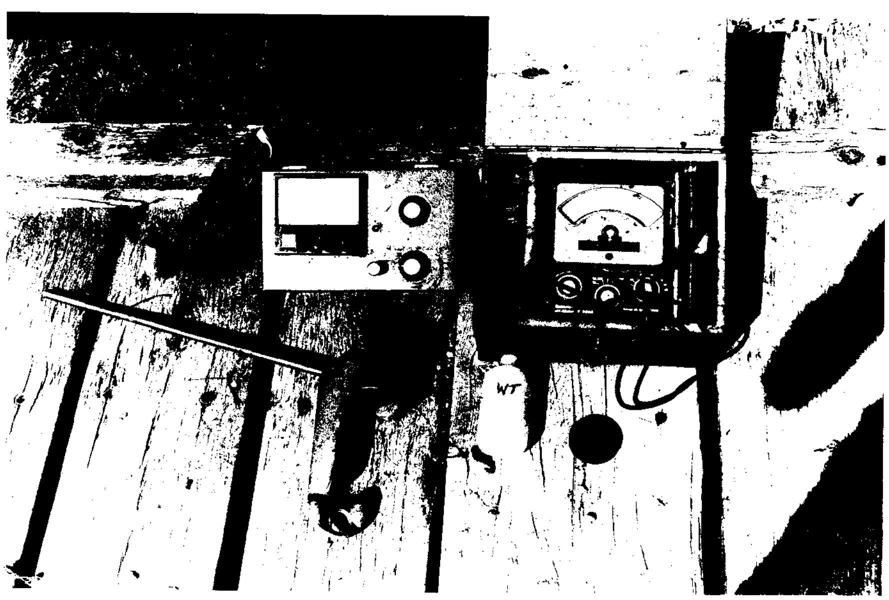


Figure I-6
YSI salinity-temperature-conductivity meter (upper left), Metrohm portable pH meter (right), sample bottle and DH-48 suspended sediment sampler (lower left)

Figure I-7 Resistance bridge and thermister rod

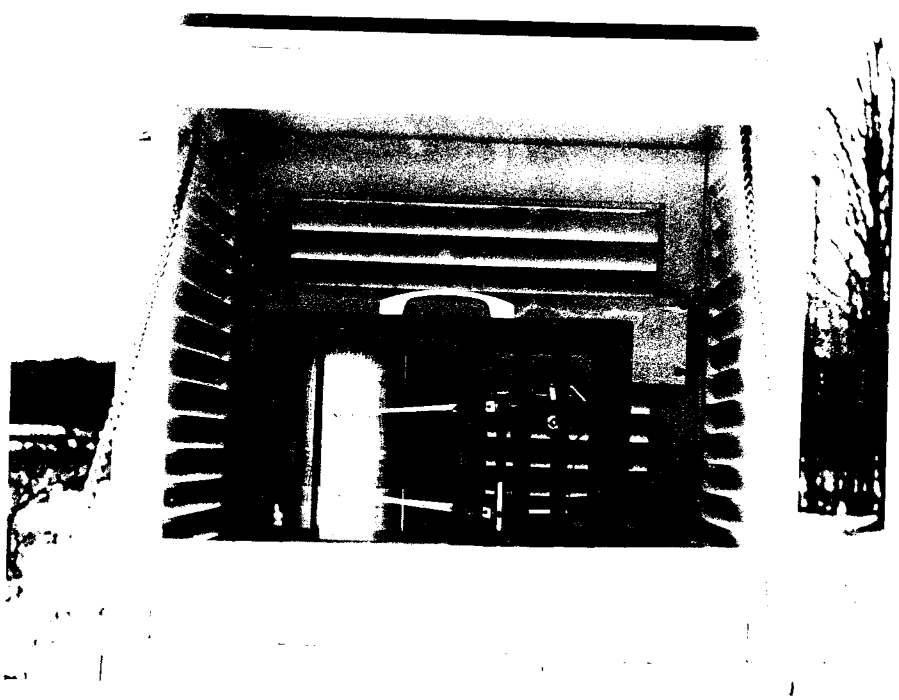


Figure I-8 Hygrothermograph housed in a Stevenson's screen

Figure I-9 A typical snow survey site showing a snow stake and snowboard

II - STUDY AREA

II-1 Drainage Basin

Spencer Creek Basin occupies the northwestern portion of the Region Municipality of Hamilton Wentworth (figure II-1). The present study concerns a part of the basin above the Westover gauging station (43° 21' 07" N, 80° 4' 51" W; elevation 260 m. above sea level). This study includes an area of 63.4 km^2 of which 8.4 km^2 is covered by Beverly Swamp.

II-2 Geology

Spencer Creek Basin lies above the Niagara Escarpment and is underlain by Silurian formations which rest unconformably upon Precambrian rock of igneous and metamorphic origins. The Palaeozoic beds dip gently southwestwards (5.3 m/km) to form a cuesta (figure II-2). A typical description of the bedrock in the Beverly Swamp area is afforded by a borehole record from Beverly Township (Caley, 1940), table II-1).

The entire area was glaciated, resulting in a variable thickness of drift deposits. This drift controls the topography to the extent that the present landscape does not express the structural trends of the underlying rocks (Karrow 1974, 1963; Straw, 1968; Chapman and Putman, 1966). A large portion of the study area is

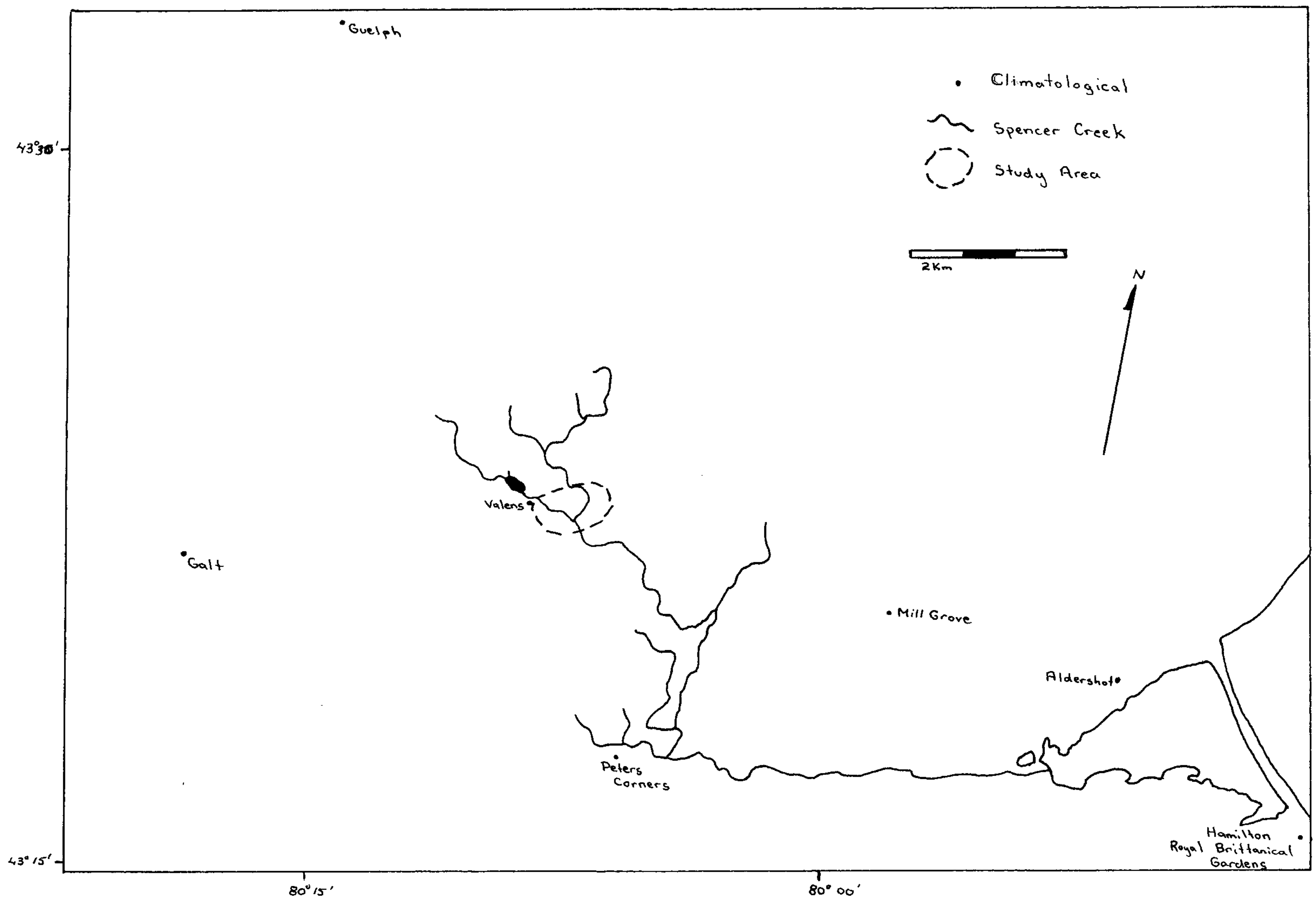


Figure II-1 Location map of Spencer Creek basin

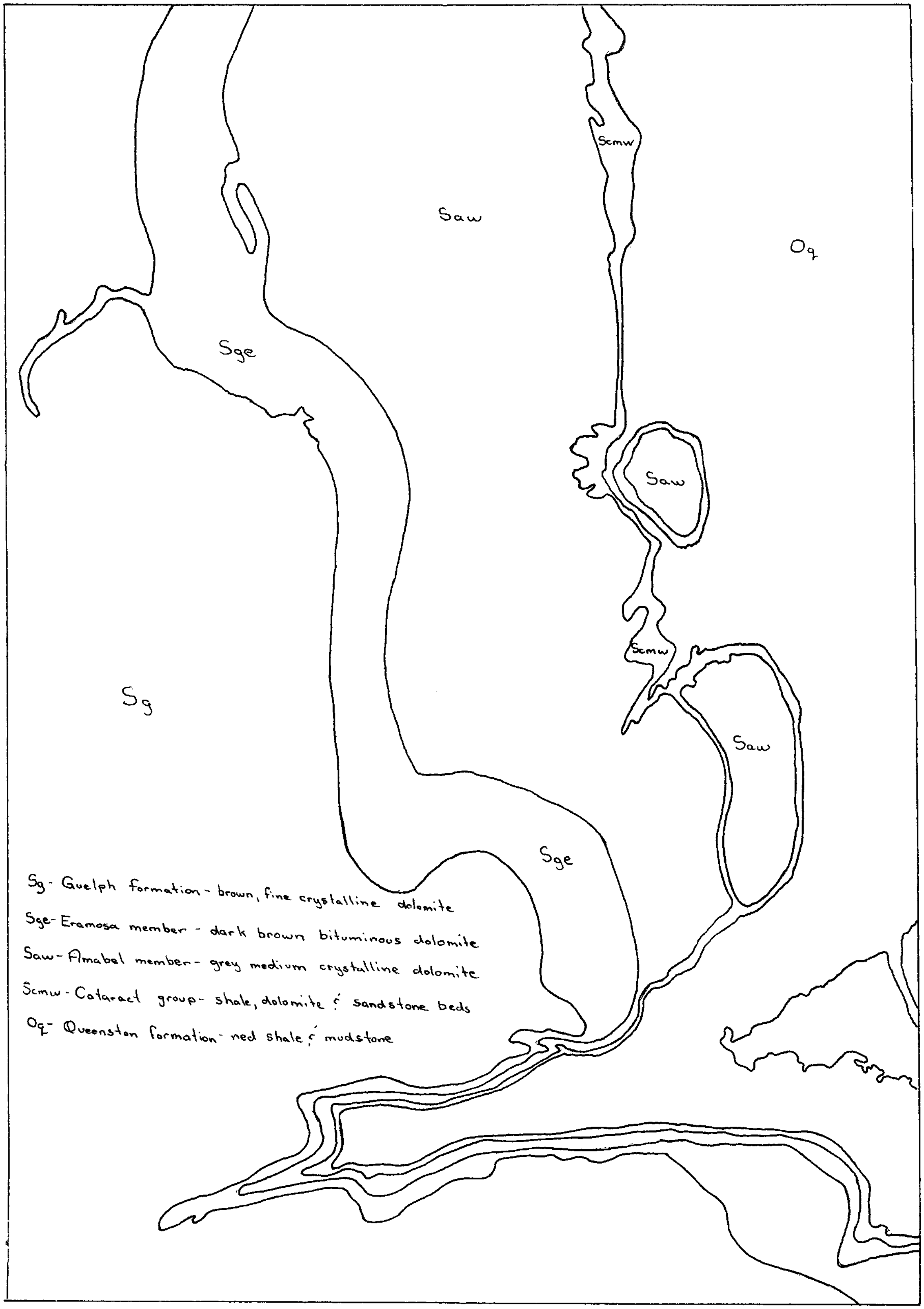


Figure II-2 Geology of Southeastern Ontario

Table II-1

Borehole record from Beverly Township

Depth	Lithology
0 - 30.5 m.	Brownish grey, finely granular dolomite (Guelph Formation)
30.5 - 42.7 m.	Dark Brownish grey, finely crystalline dolomite with black bituminous parting (Lockport, Eramosa Formation)
42.7 - 48.8 m.	Light grey, crystalline dolomite (Lockport Formation)
48.8 - 59.4 m.	Light grey to white, coarsely crystalline dolomite (Lockport Formation)

covered by the Wentworth Till which is described by Karrow (1963), "as a thin sheet of till lying as a veneer over older deposits..., which are generally outwash and spillway gravels." Locally, the till vanishes to reveal bedrock outcrops of the Guelph formation. A thin till cover combined with the outcropping of gently dipping dolomite beds, present a comparatively flat landscape, interrupted by the occurrence of moraines and drumlins with a relative relief of approximately 100 m. Drumlins associated with the Wentworth Till orientate ESE - WNW, while the moraines (Galt and Moffat) trend NE - SW (figures II-3, II-4). The occurrence of moraines produces rolling and hummocky terrain north and west of Beverly Swamp.

During the retreat of the ice sheet, glacier-dammed lakes were created, covering a large portion of the Spencer Creek Basin. Wave-cut terraces in the drumlins and adjoining gravel spits occur at 253, 266.7 and 282 m. above sea level. Horton (1961) suggested that these terraces were at two former lake levels: created either by maximum water level and a stable period in the retreat of Lake Warren, or the upper levels of Lake Whittlsey and Warren respectively.

Beverly Swamp is a remnant of the former glacial lakes. Recent drilling by Ontario Hydro enables the

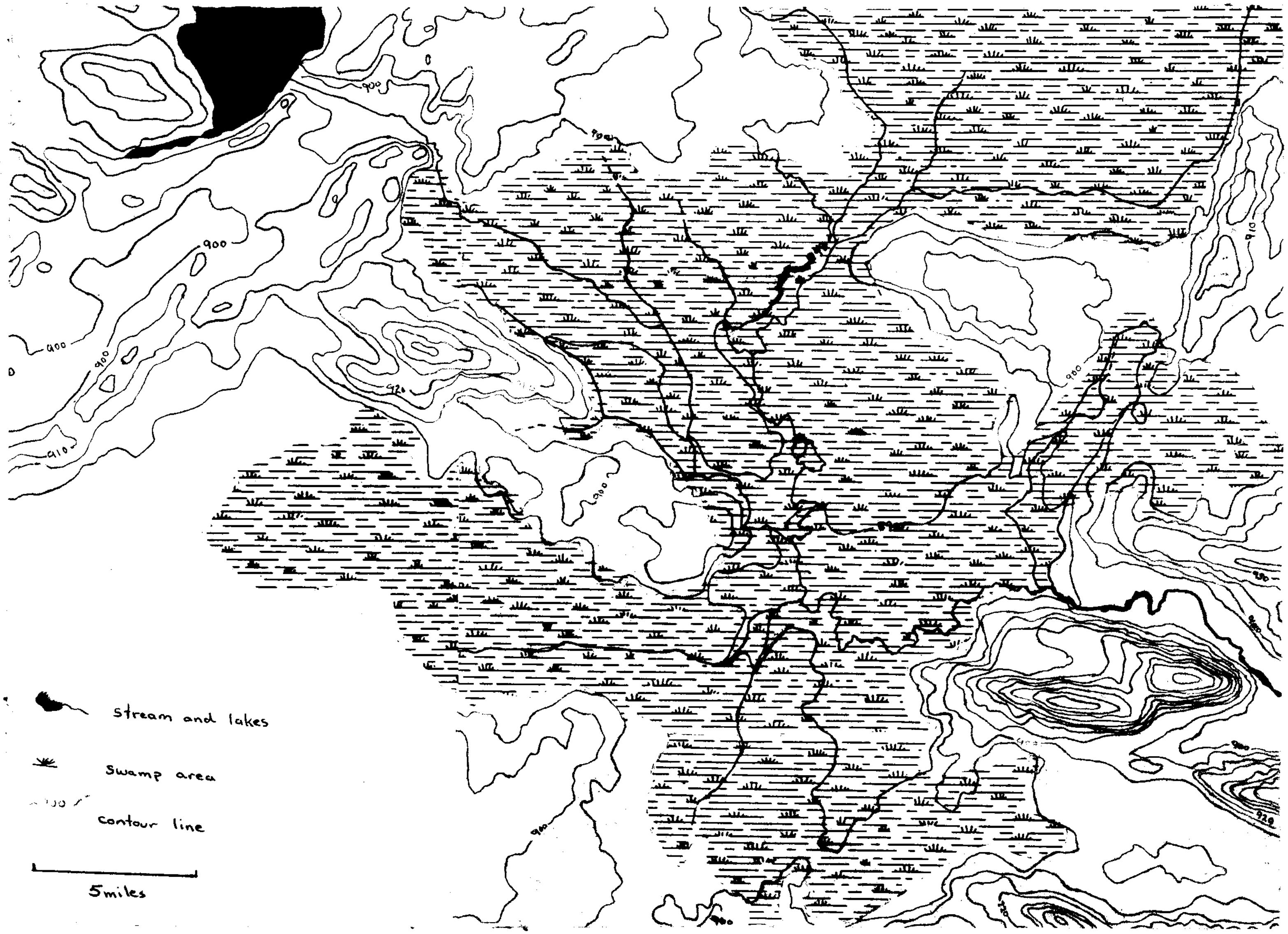


Figure II-3 Topography of Beverly Swamp

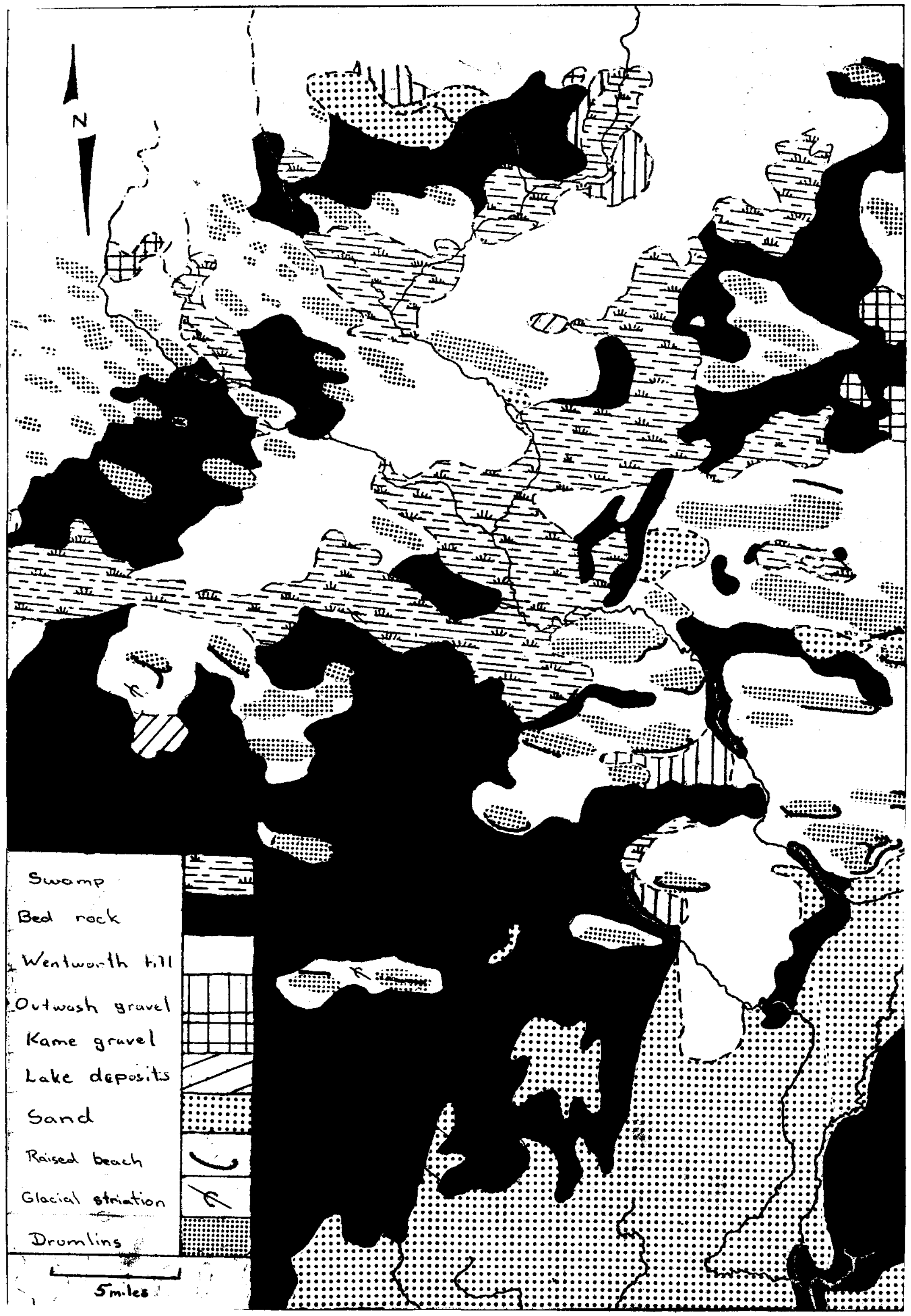


Figure II-4 Pleistocene geology of Upper Spencer Creek construction of two profiles across the Swamp (figures II-5, II-6). The profiles show two bedrock depressions of widely differing sedimentary characteristics, with the southern depression attaining a greater depth. Stratigraphically, the records show three phases in Swamp deposition:

1. the bottom layer fines upwards showing both glacial and lacustrine retreats.
2. a series of layers coarsening upwards (in the most southerly depression only) may have resulted from a transgression during glacial retreat.
3. the upper and most recent deposits consist of layers of organic muck[1], gyttja[2] and marl[3].

II-3 Vegetation

According to Halliday's (1937) classification, Spencer Creek Basin falls within the Great Lakes - St. Lawrence Forest Region, Huron - Ontario section. The prevailing vegetation type is broad-leaved. Sugar maple and beech comprise approximately three quarters of the forests; with some intrusion by black walnut, sycamore, black oak and in swampy areas, black elm and white cedar. A regionalized method of categorization was introduced by the Department of Regional Economic Expansion (1971) to include forestry growth potential (figure II-7).

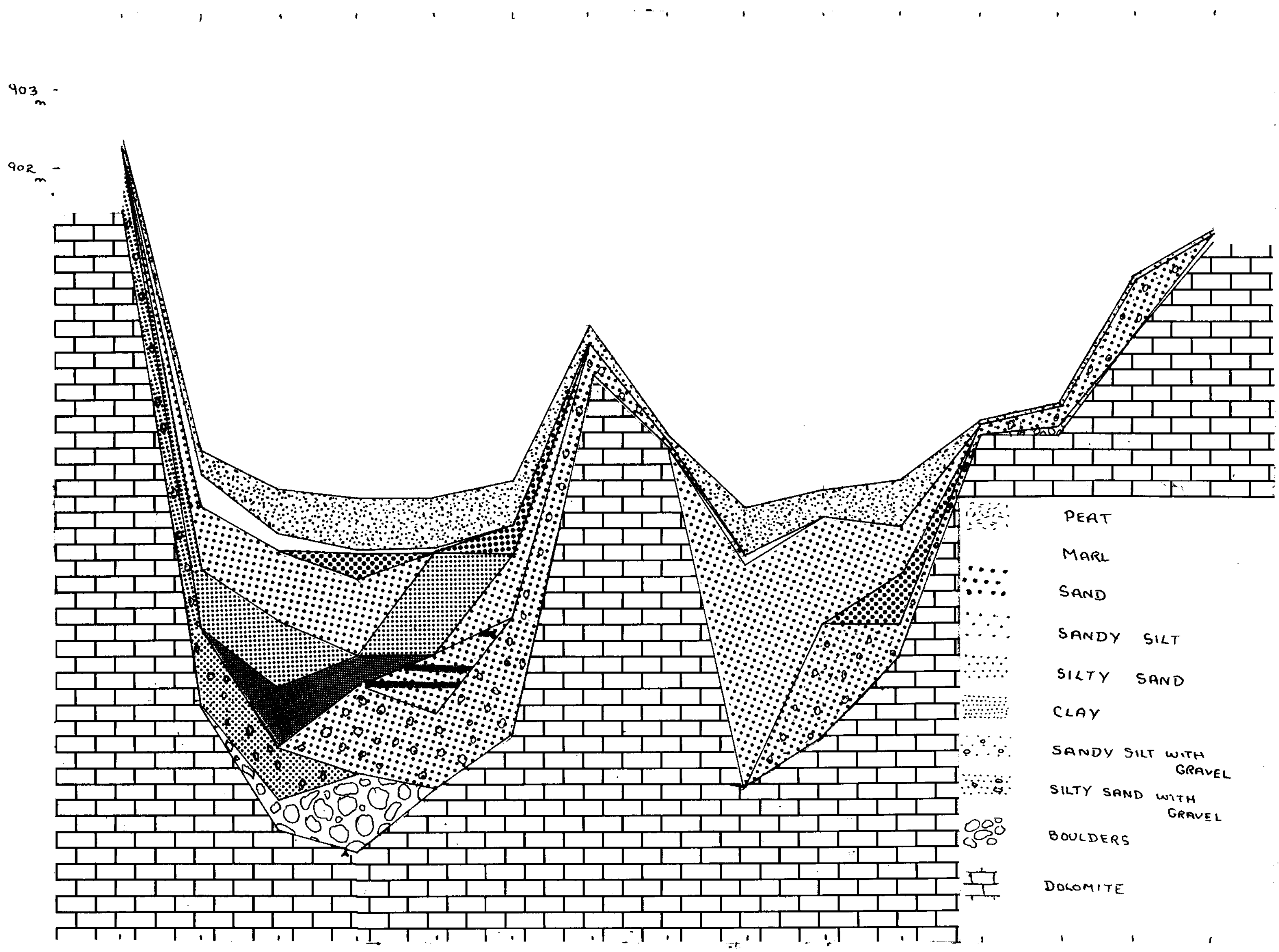


Figure II-5 Profile of superficial deposits across Beverly Swamp based on the Ontario Hydro drill-hole records — western profile

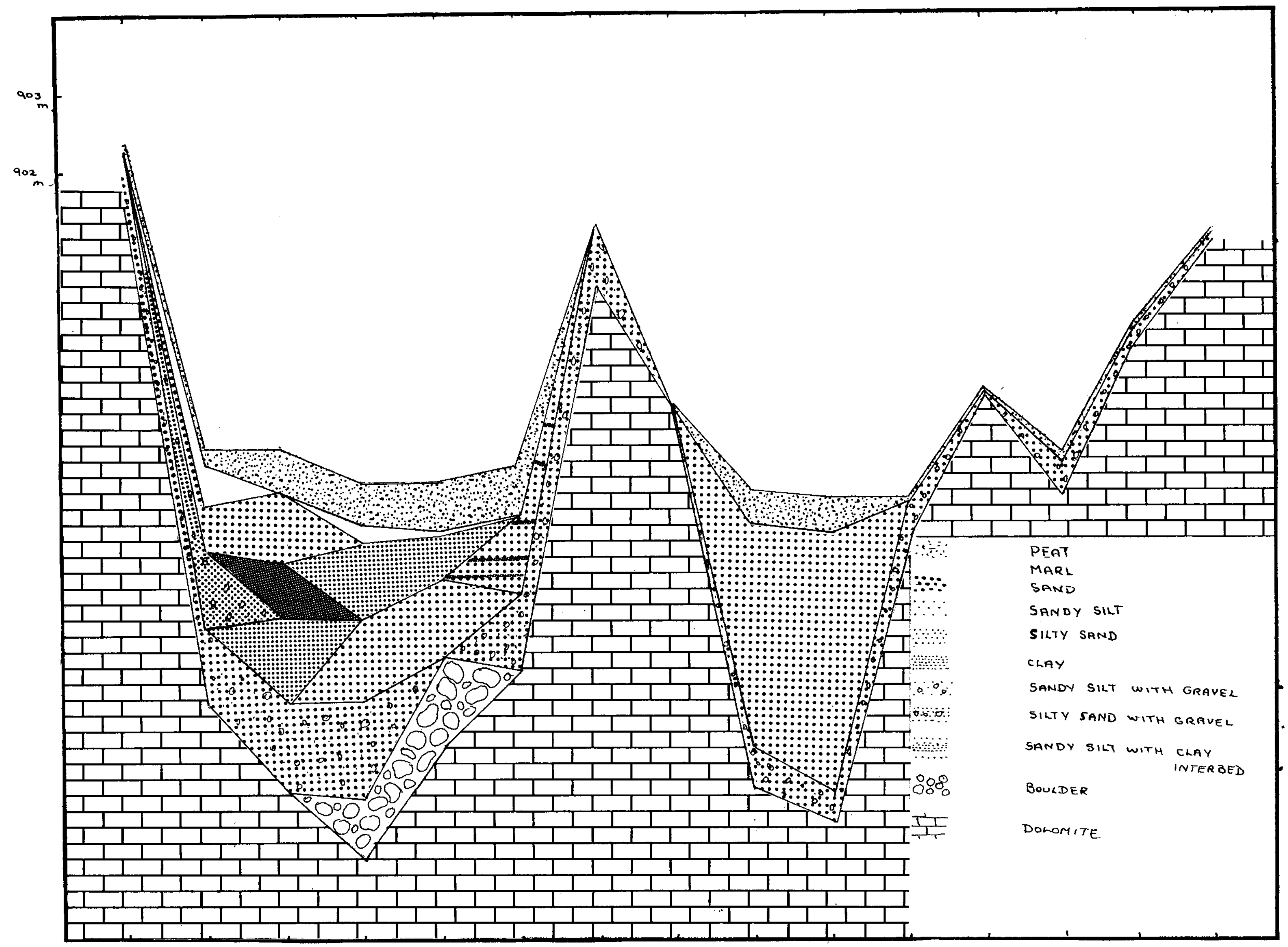
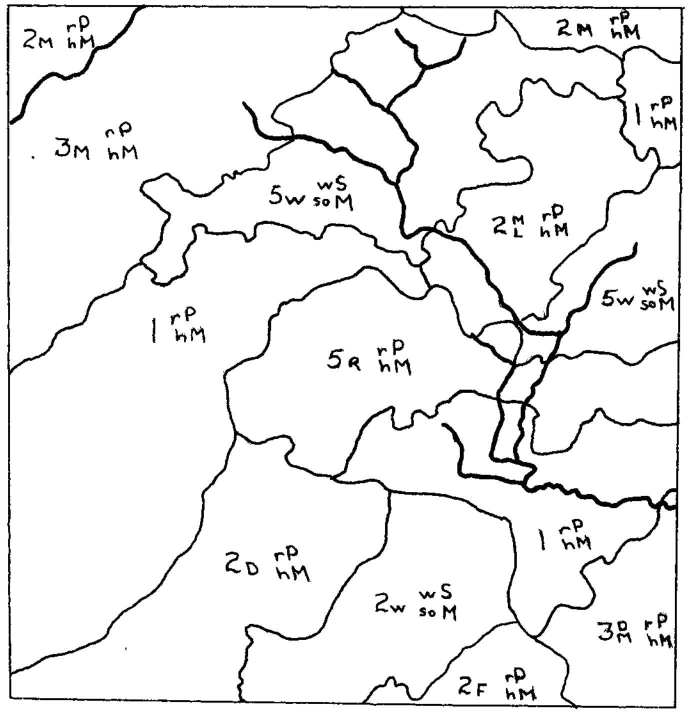


Figure II-6 Profile of superficial deposits across Beverly Swamp based on the Ontario Hydro drill-hole records — eastern profile



1 - Land having no important limitation to the growth of commercial forest
2 - Lands having slight limitations to the growth of commercial forest
3 - Lands having moderate limitations to the growth of commercial forest
4 - Lands having slightly severe limitations to the growth of commercial forest
5 - Lands having severe limitations to the growth of commercial forest

Limitations

D - physical restrictions to rooting dry dense consolidated layers
F - low fertility
M - soil moisture deficiency
R - restrictions to rooting by bedrock
W - soil moisture surplus

Indicator species

rP - red Pine
wS - white Spruce
hM - hard Maple
soM - soft Maple

5 km

Figure II-7 Forest map of the Beverly Swamp area showing major tree types and soil deficiencies

The Swamp displays localized changes in vegetation. Coniferous trees dominate the northern portion while deciduous trees are more abundant in the south. The effects of vegetation differences on the groundwater regime will be discussed in section V-4 to V-6.

II-4 Climate

Figure II-8 shows the monthly precipitation, mean monthly maximum and minimum temperatures of six climatological stations in and around the study area. In an attempt to discern any spatial and temporal anomalies, the monthly means for the entire region were calculated by:

$$\bar{X} = \frac{1}{6}\sum_{i=1}^{6} X_i \qquad \text{(II-1)}$$

where $\bar{X}$ is the regional mean, and X_i is the monthly data from station i. Deviations from the overall monthly mean (D_i) were calculated by:

$$D_i = X_i - \bar{X} \qquad \text{(II-2)}$$

Nine to eleven years of monthly data from six stations were compiled in an attempt to distinguish a station representative of the study area. Tables II-2 to II-4 show the deviation of individual station data from the monthly regional means. Precipitation values were checked for anomalies, where an anomaly was arbitrarily set at $|D_i| \geq 10$mm. In the case of temperature, the fluctuations

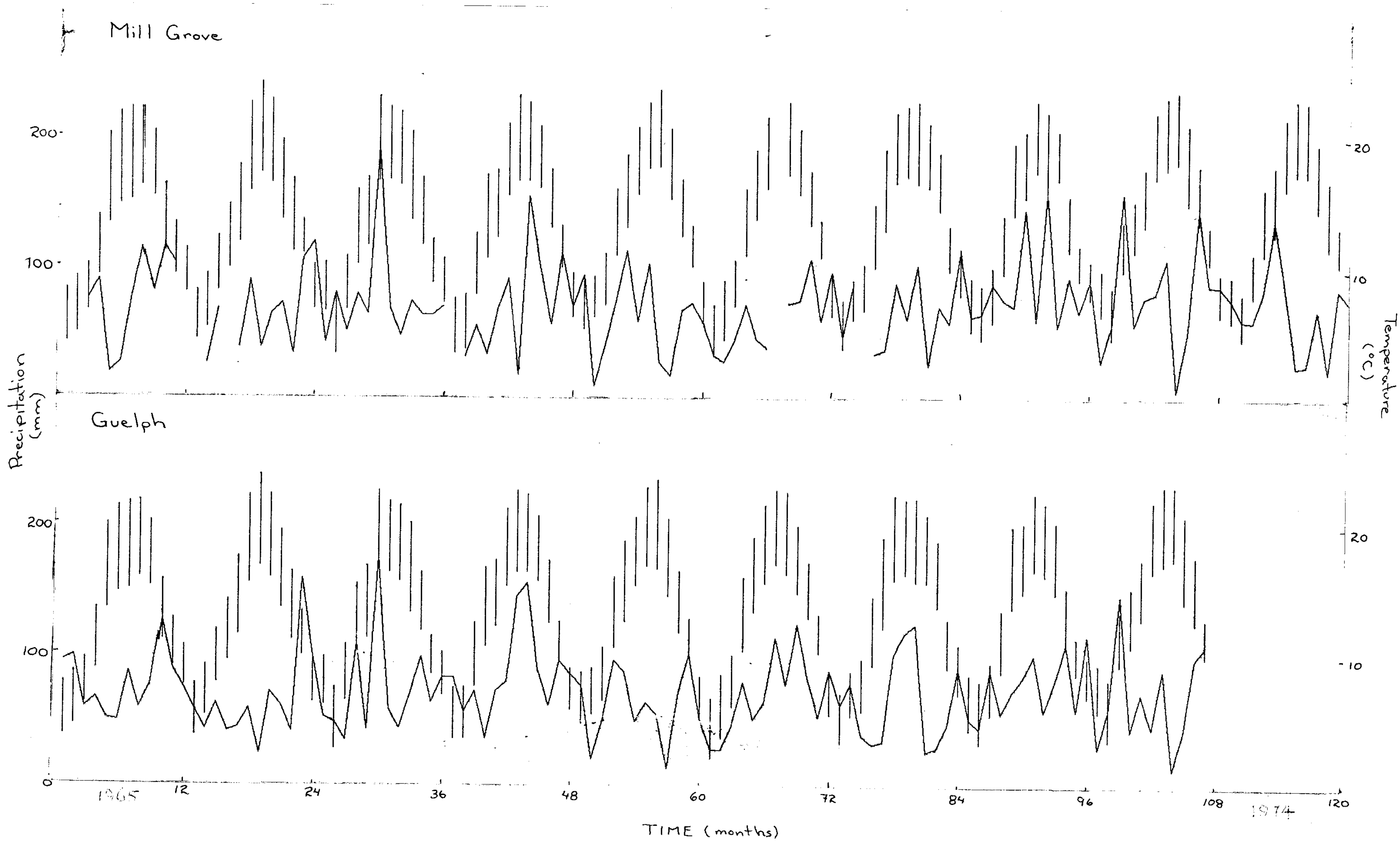
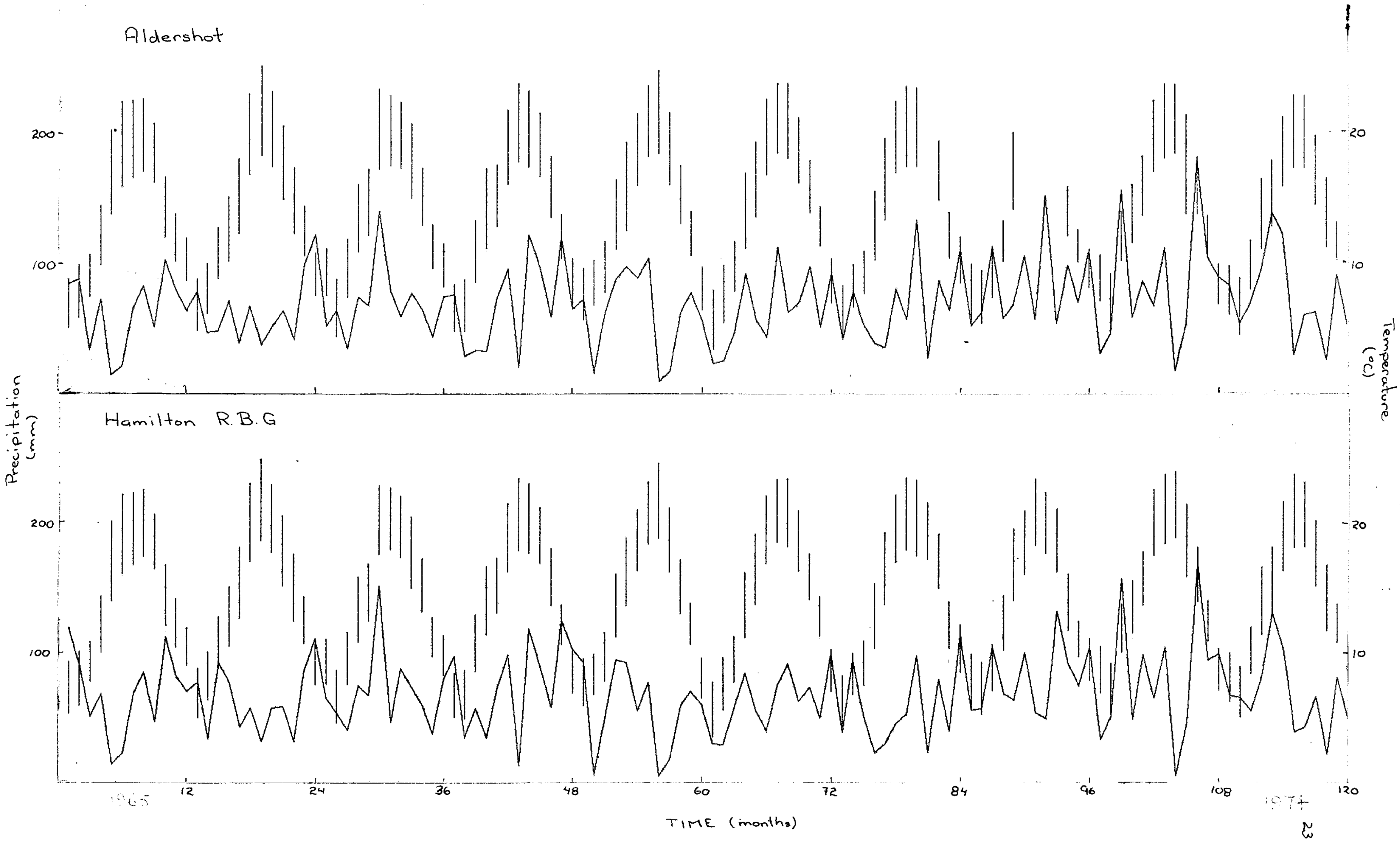


Figure II-8 Graphs showing monthly precipitation and monthly maximum and minimum temperatures for stations in the vicinity of Beverly Swamp


Aldershot
Hamilton R.B.G
Precipitation (mm)
Temperature (°C)
200
100
20
10
12
24
36
48
60
72
84
96
108
120
TIME (months)
1965
1974

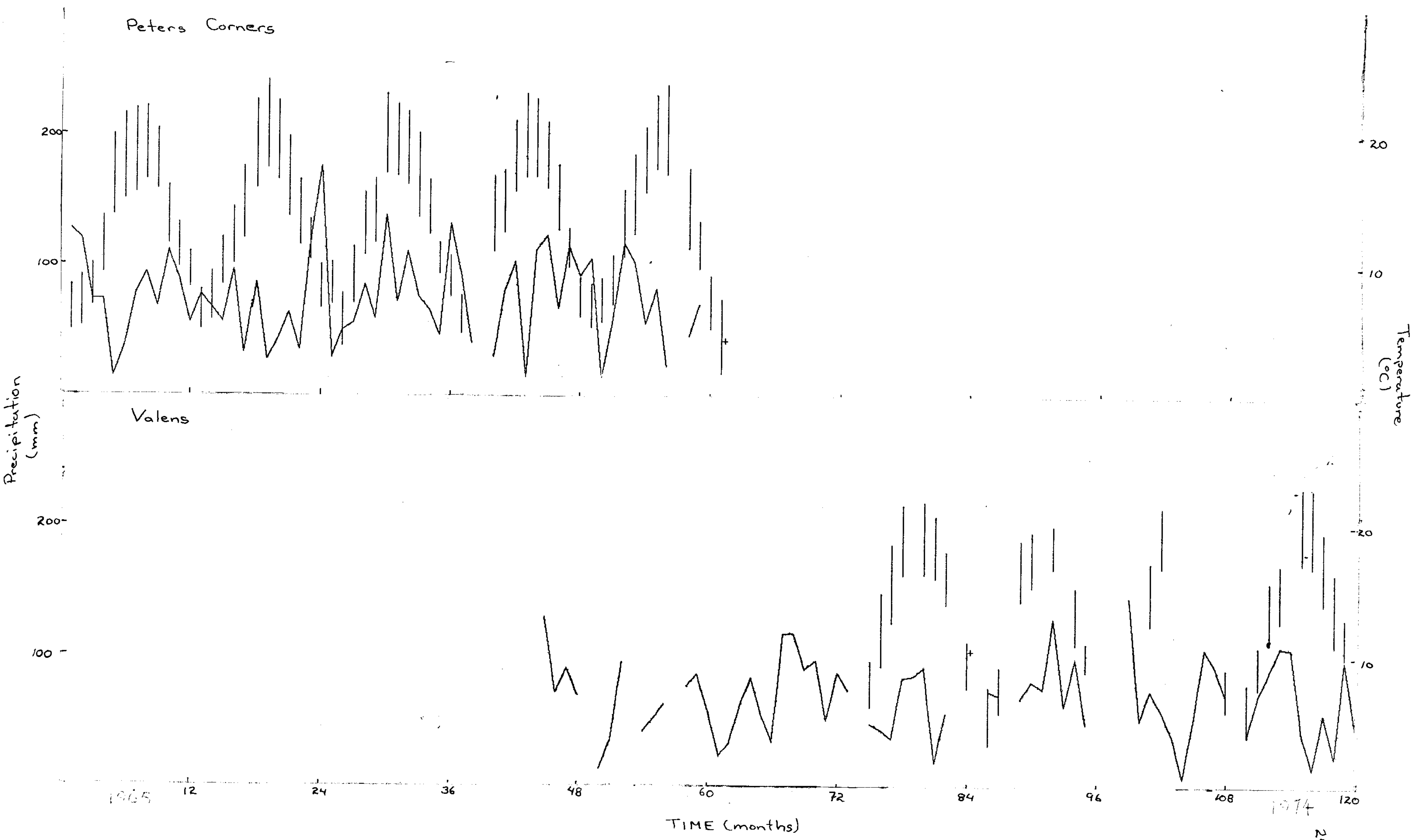

Peters Corners
Valens
Precipitation (mm)
200
100
Temperature (°C)
20
10
-20
TIME (months)
12
24
36
48
60
72
84
96
108
120
1965
1974

Table II-2

Mean monthly precipitation values for locations in and around Beverly Swamp

	Guelph	Aldershot	Hamilton RBG	Millgrove	Peters Corners	Galt Osmond	Valens	Mean
Jan.	59.69/9	71.37/11	67.06/11	55.88/8	78.49/6	58.93/9	53.34/3	63.54
Feb.	53.09/9	59.69/11	54.36/11	54.61/9	58.42/5	46.99/9	46.48/5	53.38
Mar.	67.06/9	68.58/11	73.91/11	72.69/10	61.72/4	66.55/9	70.36/7	68.69
Apr.	62.48/9	63.75/11	63.75/11	69.77/10	80.52/5	68.58/9	71.12/6	67.85
May	58.67/9	69.60/11	67.82/11	65.02/11	58.17/5	69.85/9	71.63/6	65.85
Jun.	78.74/9	78.74/10	73.36/10	89.66/10	84.33/5	105.66/8	68.07/6	82.65
Jul.	88.90/9	61.47/10	56.13/10	57.15/9	55.37/5	60.20/9	68.33/6	63.94
Aug.	73.41/9	77.22/10	72.14/10	77.22/10	71.37/5	73.15/9	70.61/6	73.59
Sep.	65.02/9	56.90/10	53.59/10	61.98/10	66.29/4	60.45/9	67.82/6	61.72
Oct.	80.01/9	77.72/10	76.20/10	77.22/10	65.28/5	71.12/9	75.69/7	74.75
Nov.	86.36/9	79.50/10	74.17/10	81.28/10	87.83/5	74.68/9	77.72/6	80.22
Dec.	86.11/8	86.11/10	88.90/10	86.61/9	114.05/4	90.93/9	71.37/6	89.15
Total	859.54	850.65	821.39	844.04	881.89	847.09	812.54	845.33

Precipitation in mm./ number of years data
RBG = Royal Botanical Gardens

Table II-2

Deviation of Precipitation from the regional mean

	Guelph	Aldershot	Hamilton RBG	Millgrove	Peters Corners	Galt Osmond	Valens
Jan	-3.85	+7.83	+3.52	-7.66	+14.49*	+4.61	-10.20*
Feb	-0.29	+6.31	+0.98	+1.23	+5.04	-6.39	-6.90
Mar	-1.63	-0.11	+5.22	+3.95	-6.97	-2.14	+1.67
Apr	-5.37	-4.11	-4.11	-3.08	+12.67*	+0.73	+3.27
May	-7.18	+3.75	+1.97	-0.83	- 7.68	+4.00	+5.78
Jun	-3.91	-3.91	-9.29	+7.01	+1.68	+23.01*	-14.58*
Jul	+24.96*	-2.47	-7.81	-6.79	-8.57	-3.74	+4.39
Aug	-0.18	+3.63	-1.45	+3.63	-2.22	-0.44	-2.98
Sep	+3.30	-4.82	-8.13	+0.26	+4.57	-1.27	+6.10
Oct	+5.26	+2.97	+1.45	+2.47	-9.47	-3.63	+0.94
Nov	+6.14	-0.72	-6.05	+1.06	+7.66	-5.54	-2.72
Dec	-3.04	-3.04	-0.25	-2.54	+24.90*	+1.78	-17.78*
$\frac{\Sigma}{12}$	+1.19	+0.44	-2.00	-0.11	+3.01	+0.92	-2.75

* anomalies

Table II-3

Mean Minimum Temperatures for Locations in and around Beverly Swamp

	Guelph	Aldershot	Hamilton RBG	Peters Corners	Millgrove	Valens
January	-11.5/9	-8.9/11	-8.6/11	-10.3/6	-9.9/11	-7.8/1
February	-11.5/9	-8.7/11	-8.4/11	-9.7/4	-10.1/11	-11.0/3
March	-6.3/9	-4.0/11	-3.8/11	-5.2/11	-5.2/11	-6.9/4
April	-0.2/9	1.5/11	1.5/11	0.8/5	0.7/11	-0.3/3
May	5.3/9	6.6/11	7.8/11	4.7/5	6.2/11	6.7/5
June	11.3/9	13.2/9	13.3/10	11.8/5	12.0/10	12.1/4
July	13.1/9	15.6/9	16.1/10	13.7/5	13.9/9	14.7/3
August	12.6/9	15.5/9	15.8/10	13.2/5	13.8/10	13.3/3
September	10.3/9	11.4/8	12.1/10	9.6/4	10.3/10	9.8/4
October	4.2/9	6.0/10	6.2/10	3.9/5	4.8/10	4.4/4
November	-1.0/9	0.9/10	1.0/10	-0.3/5	0.0/10	-0.8/3
December	-7.0/8	-4.7/10	-4.6/10	-6.4/5	-5.8/10	-6.0/3

temperature in ^{o}C/ number of years data

RBG = Royal Botanical Gardens

Table II-3

Deviation from mean regional minimum

	Mean	Guelph	Aldershot	Hamilton RBG	Peters Corners	Millgrove	Valens
January	-9.5	-2.0	+0.6	+0.9	-0.8	-0.4	+1.7
February	-9.9	-1.6	+0.8	+1.5	+0.2	-0.2	-1.1
March	-5.2	-1.1	+1.2	+1.4	0	0	-1.7
April	0.6	-0.8	+0.9	+0.9	+0.2	+0.1	-0.9
May	+6.2	-1.1	+0.4	+1.6	-1.5	0	+0.5
June	+12.3	-1.0	+0.9	+1.0	+0.5	-0.3	-0.2
July	+14.5	-1.4	+1.1	+1.6	+0.8	-0.6	+0.2
August	+14.1	-1.5	+1.4	+1.7	+0.9	-0.3	-0.8
September	+10.6	-0.3	+0.8	+1.5	-1.0	-0.3	-0.8
October	+4.9	-0.7	+1.1	+1.3	-1.0	-0.1	-0.5
November	0	-1.0	+0.9	+1.0	-0.3	0	-0.8
December	-5.7	-1.3	+1.0	+1.1	-0.7	-0.1	-0.3
Σ		-13.8	+11.1	+15.5	-2.7	-2.2	-4.7
General Deviation $\frac{\Sigma}{12}$		-1.15	+0.93	+1.29	-0.23	-0.18	-0.39

RBG = Royal Botanical Gardens

Table II-4

Mean maximum temperatures for locations in and around Beverly Swamp

	Guelph	Aldershot	Hamilton RBG	Peters Corners	Millgrove	Valens
January	25.6/9	30.1/11	30.4/11	28.2/6	27.8/11	31.8/1
February	26.4/9	30.4/11	30.5/11	27.5/5	27.8/11	25.6/3
March	35.4/9	37.8/11	36.5/11	36.1/4	36.4/11	33.9/5
April	50.3/9	49.4/11	51.8/11	51.0/5	51.1/11	49.2/4
May	62.6/9	60.6/11	63.4/11	60.8/5	59.5/11	62.6/5
June	73.9/9	76.7/9	75.1/10	79.6/5	74.1/10	71.0/3
July	77.4/9	80.7/9	80.3/10	78.6/5	78.5/9	78.8/1
August	76.6/9	80.5/9	79.3/10	77.4/5	77.9/10	77.3/3
September	69.4/9	71.7/8	71.3/10	69.3/4	69.9/10	68.3/3
October	58.2/9	53.3/10	58.9/10	56.8/5	57.5/10	55.7/3
November	41.5/9	45.4/10	45.5/10	42.8/5	43.2/10	39.3/2
December	31.2/8	35.4/10	35.4/10	32.3/5	33.0/10	32.6/3

Mean monthly temperature/Number of years data
RBG = Royal Botanical Gardens

Table II-4

Deviation from mean regional maximum

	Mean	Guelph	Aldershot	Hamilton RBG	Peters Corners	Millgrove	Valens
January	29.0	-3.4	+1.1	+1.4	-0.8	-1.2	+2.8
February	28.0	-1.6	+2.4	+2.5	-0.5	-0.2	-2.4
March	36.0	-0.6	+1.4	+0.5	+0.1	+0.4	-2.1
April	50.5	-0.2	-1.1	+1.3	+1.0	+1.1	-0.8
May	61.6	+1.0	-1.0	+1.8	-0.8	-2.1	+1.0
June	74.2	-0.3	+2.5	+0.9	+0.4	-0.1	-3.2
July	79.1	-1.7	+1.6	+1.3	-0.5	-0.6	-0.3
August	78.2	-1.8	+2.3	+1.1	-0.8	-0.3	-0.9
September	70.0	-0.6	+1.7	+1.3	-0.7	-0.1	-1.7
October	56.7	+1.5	-3.4	-2.2	-0.1	+0.8	-1.0
November	43.0	-1.5	+2.4	+2.5	-0.2	+0.2	-3.7
December	33.2	-2.0	+2.2	+2.2	-1.0	-0.2	-0.8
Σ		-5.9	+6.9	+10.3	-2.2	-1.4	-4.2
General Deviation $\frac{\Sigma}{12}$		-0.49	+0.58	+0.86	-0.18	-0.12	-0.35

RBG = Royal Botanical Gardens

from the regional mean and their consistency were noted.

In general, mean and annual precipitation (Table II-2) increases from south to north; but in the cases of Guelph and Galt Osmond the yearly values are controlled by the presence of single anomalous values. Without these values their means change from positive to negative, shifting the trend to an increase (at a smaller rate than above) to the northeast. The occurrence of several anomalous values in the records of Peters Corners and Valens suggests that the data from these stations are of low reliability.

Spatial trends can be observed for both maximum and minimum temperatures using the mean monthly deviations from the regional mean values (Tables II-3, II-4). There is an apparent temperature decrease to the northwest and may be attributed to an increasing distance of the stations from Lake Ontario, hence its moderating effect on temperature. Observations of individual stations show that their deviations from the regional mean were consistent (all temperatures were either greater than or less than the regional means), except Valens which displays large fluctuations from month to month again, suggesting that data from Valens is likely to be unreliable.

Notes

[1] Organic muck - Presant, Wickland and Matthews (1965) state that, "mucks and poorly drained soils where twelve inches or more of organic material have accumulated and are closely associated with terminal moraines and drumlins. The surface material in muck deposits consist of black, friable, well decomposed organic debris...derived primarily from herbaceous plants and tree leaves." Decomposition decreases with depth.

[2] Gyttja - according to Karrow (1963), is black organic mud having higher hydrocarbon content than peat.

[3] Marl - limey mud which underlies organic debris.

III - Water Balance of Upper Spencer Creek

III-1 Water Balance Equation

The hydrologic cycle is a concept which considers the processes of motion, loss and recharge of the earth's waters (Gray, 1973). For a drainage basin, this cycle can be divided into five principal parts by the water balance equation:

$$I + P - E - O = \frac{\Delta s}{\Delta t} \qquad \text{(III-1)}$$

where I = inflow of the basin

P = precipitation

E = evaporation

O = outflow of water from the basin

$\frac{\Delta s}{\Delta t}$ = change in storage in the basin

Using various components of the water balance equation an attempt will be made to understand their magnitudes and characteristics as applied to Spencer Creek.

III-2 Precipitation - Rainfall

Mean annual precipitation of Upper Spencer Creek Basin is 844 mm. as indicated by the records of Millgrove. The bulk of the precipitation comes in June and from October to December. Precipitation occurs mainly as rain and snowfall. In 1975, precipitation in the form of rainfall was gauged in an open and a wooded environment, to observe the influence of interception on the amount of rain received at the ground surface (figure III-1). Interception loss was obtained as:

$$I = P_o - P_c \qquad \text{(III-1)}$$

where P_o = rainfall received at ground level in open area (figure III-2)

P_c = rainfall received over a comparable time under the forest canopy

I = interception

Between April 1 and November 1, total rainfall in the open site was 636 mm. Based on weekly records, interception within this period was calculated to be 13 percent, at a densely wooded site dominated by cedar. Existing literature on rainfall interception suggests that it is dependent on tree type (Eidmann, 1954), age of vegetation (Delf et al, 1958) and the amount of incoming precipitation (Penman, 1963). Compared to results obtained in other studies, the values are comparable to Delf et al and Penman but slightly lower than Eidmann.

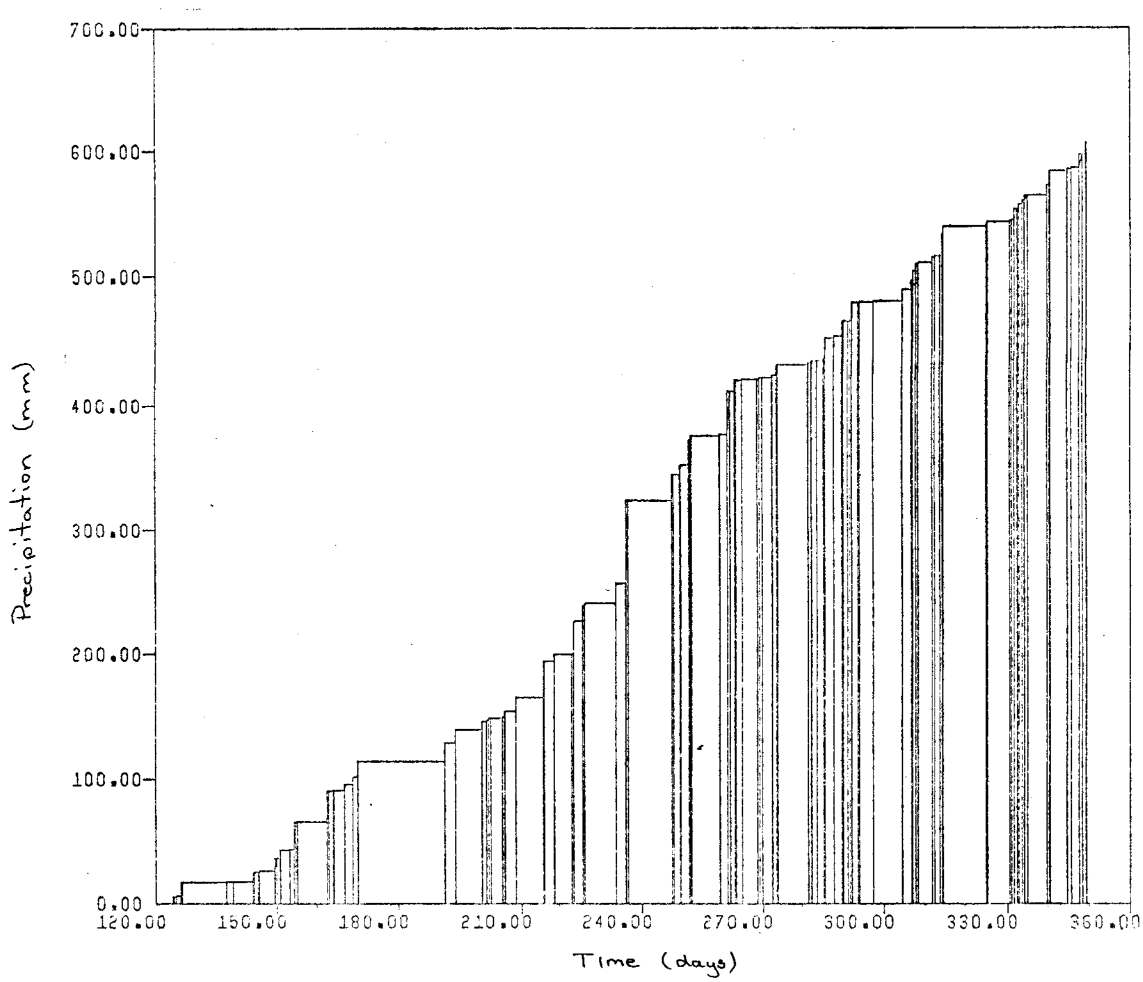
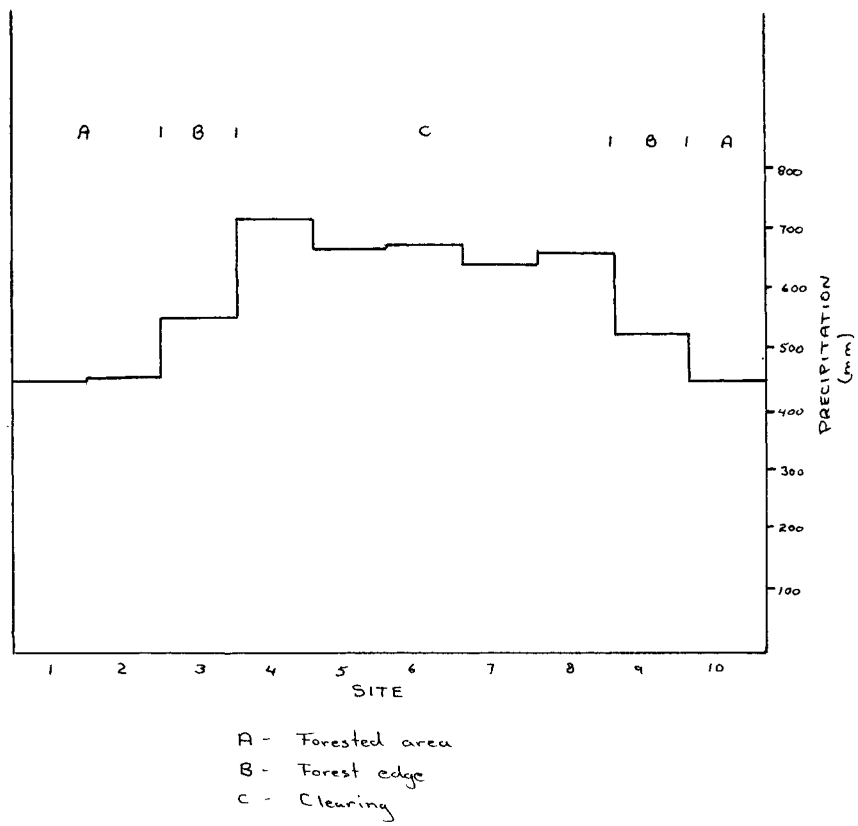


Figure III. 1 Cumulative rainfall for an open site in Beverly Swamp April 1 - November 1, 1975



Total precipitation across clearing

Figure III-2 Interception

Table III-1

Snow Survey Data - Depth, Winter 1974-75

	Open		S. of Tower		Tower		Confluence		Centre of Opening
	New	Net	New	Net	New	Net	Net	New	
03 Dec. 1974	10.3	10.3	10.2	10.2	9.3	9.3	9.7	9.7	10.2
11 Dec. 1974	4.6	8.9	4.1	10.3	3.7	10.2	3.8	8.1	8.9
22 Dec. 1974	6.5	7.9	8.0	13.6	6.3	13.8	8.1	13.8	17.2
30 Dec. 1974	0	0	2.2	13.1	1.9	12.2	1.9	11.4	17.8
06 Jan. 1975	7.5	7.3	7.1	18.5	6.4	16.9	-	-	22.9
19 Jan. 1975	6.7	6.7	5.7	12.8	4.6	12.8	6.2	8.7	18.4
26 Jan. 1975	0.2	3.9	0.6	10.0	0.5	12.4	0.3	7.9	18.4
02 Feb. 1975	0	0.4	0.14	9.0	0.1	9.8	0.1	5.1	9.5
09 Feb. 1975	6.4	8.7	5.3	13.7	5.4	13.6	7.2	10.1	24.1
16 Feb. 1975	7.7	15.1	8.2	19.1	7.5	19.8	8.5	17.3	30.5
23 Feb. 1975	0	1.8	-	11.9	-	16.2	-	9.5	18.4
02 Mar. 1975	4.6	4.6	8.9	19.0	7.9	17.9	9.3	12.8	27.3
09 Mar. 1975	12.1	16.1	10.0	21.3	9.3	25.2	-	-	12.1
16 Mar. 1975	0.60	11.1	1.1	18.1	2.0	21.8	0.51	12.8	16.5
23 Mar. 1975	0	0	0	9.3	0	10.5	0	5.9	6.4
06 Apr. 1975	4.0	4.0	8.8	14.9	9.6	19.5	7.0	10.6	11.4
13 Apr. 1975	0	0	0	5.17	0	13.0	0	5.82	2.5

Depth in cm.

Table III-1

Snow Survey Data - Water Equivalent, Winter 1974-75

	Open		S. of Tower		Tower		Confluence		Centre of Opening
	New	Net	New	Net	New	Net	Net	New	
03 Dec. 1974	1.50	1.50	1.39	1.39	1.40	1.40	1.28	1.28	10.2
11 Dec. 1974	0.31	1.28	0.27	1.18	0.28	1.53	0.31	1.32	8.9
22 Dec. 1974	0.74	0.87	0.86	2.88	0.74	3.15	0.87	2.71	17.2
30 Dec. 1974	0	0	0.36	2.79	0.37	2.66	0.42	2.67	17.8
06 Jan. 1975	0.95	1.16	0.96	4.79	0.90	4.77	-	-	22.9
19 Jan. 1975	0.88	0.88	0.67	3.12	0.64	3.37	0.75	3.21	18.4
26 Jan. 1975	0.08	1.19	0.15	3.65	0.14	3.99	0.11	2.63	18.4
02 Feb. 1975	0	0.12	0.03	2.36	0.03	2.46	0.03	1.59	9.5
09 Feb. 1975	0.69	1.54	0.60	2.90	0.61	2.84	0.76	4.63	24.1
16 Feb. 1975	1.03	1.99	0.84	3.10	0.76	3.48	0.98	2.99	30.5
23 Feb. 1975	0	0.45	-	4.52	-	5.88	-	3.30	18.4
02 Mar. 1975	0.67	0.67	0.95	5.83	0.85	5.01	1.10	5.0	27.3
09 Mar. 1975	1.73	2.96	1.86	4.12	1.74	6.22	-	-	12.1
16 Mar. 1975	0.26	2.74	0.44	5.09	0.47	4.84	0.16	4.28	16.5
23 Mar. 1975	0	0	0	2.17	0	3.01	0	2.74	6.4
06 Apr. 1975	1.16	1.16	2.38	5.97	2.43	6.70	1.48	5.89	11.4
13 Apr. 1975	0	0	0	2.48	0	5.16	0	2.69	2.5

Water Equivalent in cm.

III-3 Snow Storage

Snow and ice constitute a major storage in the water balance of Spencer Creek. Snow measurements were taken at four locations in and around Beverly Swamp in an attempt to determine the environmental effects on snow distribution and storage (figure III-3, I-1). These sites include an open field location, two sites within a dense cedar wood and a site in a predominantly broad-leaf wood.

The open site experienced intense snow drifting and frequent occurrence of melt events throughout the winter of 1975, sometimes resulting in a complete disappearance of the snow pack in mid-winter (table III-1, figure III-4). The sites under a forest canopy were protected from wind and from intense solar radiation, and a continuous snow pack was maintained during winter. Sites located within the cedar wood normally have a larger amount of snow on the ground than the broad leaf forest site, because the later site afforded a lesser amount of shade and protection from the wind. An opening inside the cedar wood accumulated more snow than all other sites during January, but was subjected to rapid melt in March (figure III-4).

III-4 Regime of Spencer Creek

A more complete compilation of climatological data for the study area was made in 1975 to enable a detailed comparison with the Westover discharge for the same year.

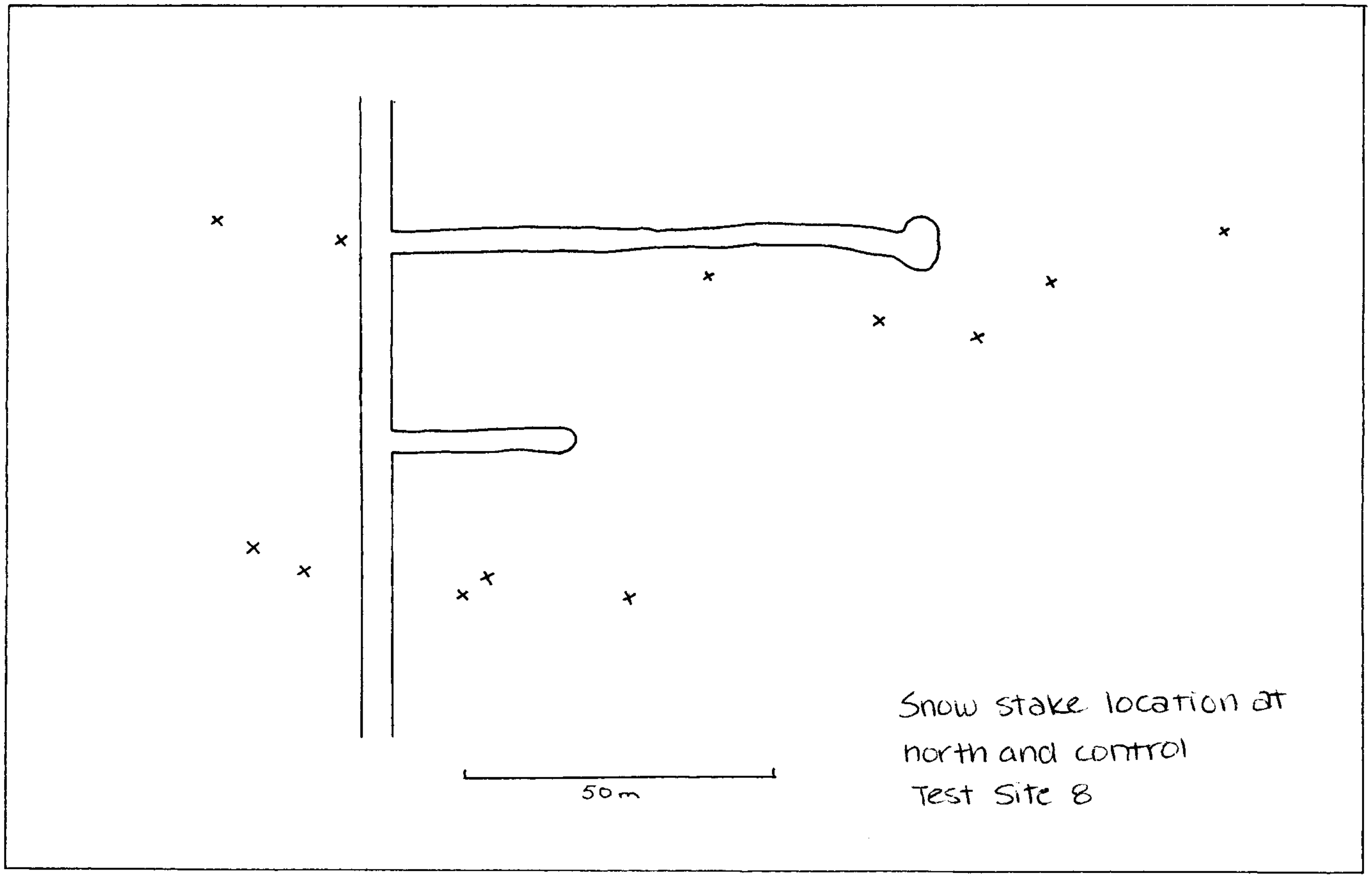
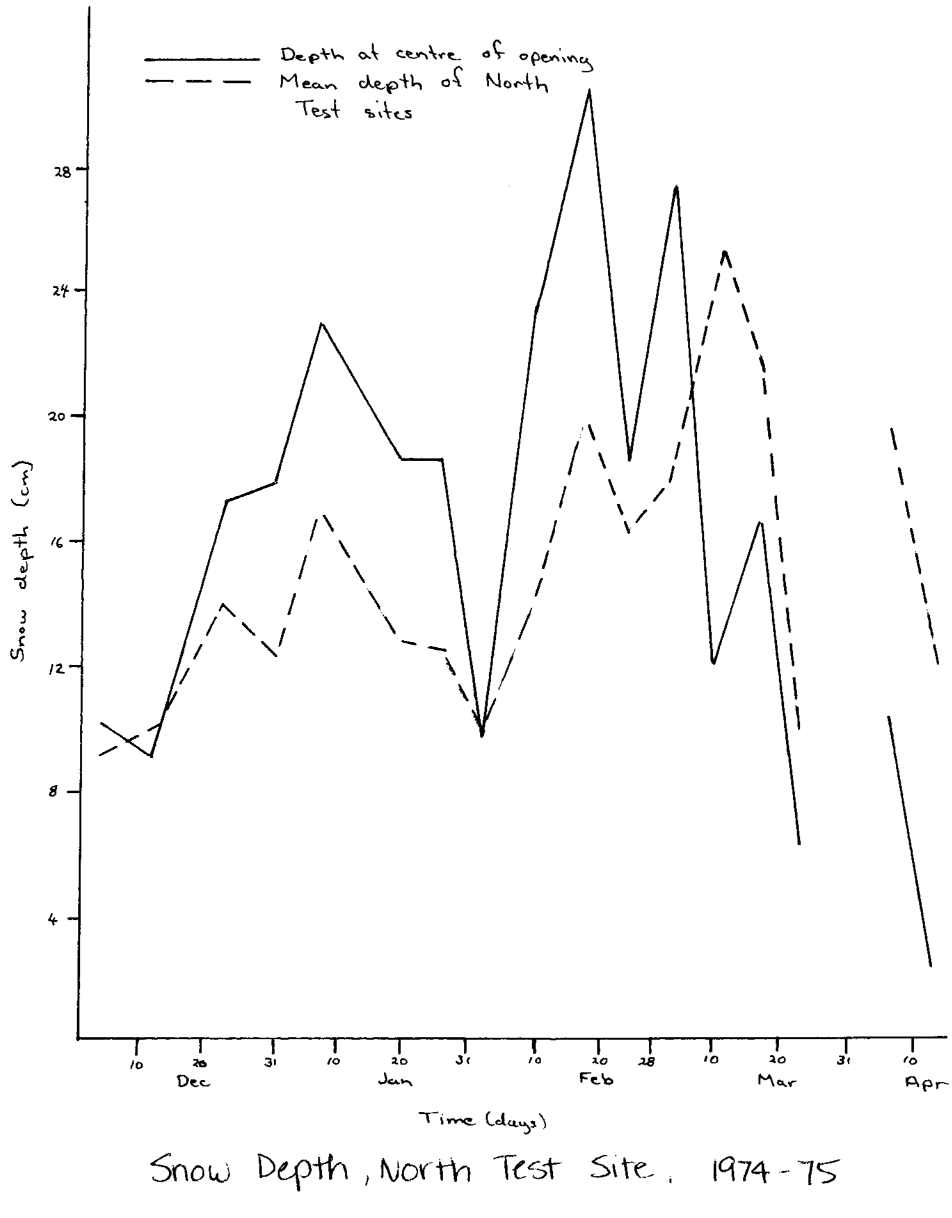
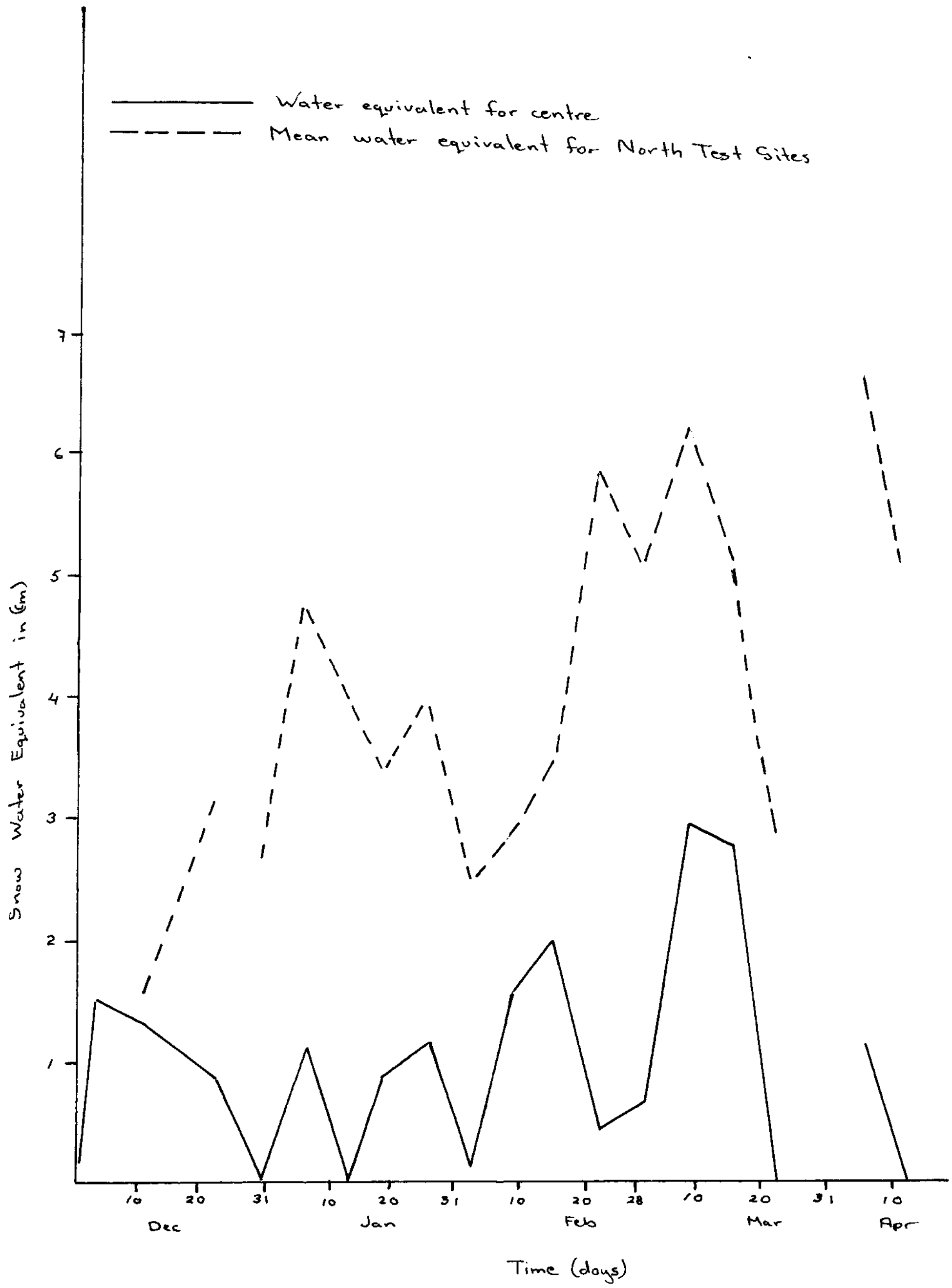


Figure III-3 Locational map of snow survey sites in Beverly Swamp



Snow Depth, North Test Site, 1974-75

Figure III-4 Snow Depth and Water Equivalent for three snow survey sites in Beverly Swamp



Snow Water Equivalent, North Test Sire 1974-75

Figure III-4

This information will then be extrapolated back, in an attempt to discuss past hydrographs from the same station.

The most prominent feature of the hydrograph from Westover station is the high fluctuations resulting from periodic melting of snow and ice. The magnitude and timing of discharge peaks is dependent upon four variables associated with winter storage. These are: the number and duration of thaw periods (figure III-5); winter precipitation characteristics (type and quantity);winter temperature and related ice thickness (frequency of melt periods during winter months); topographical and vegetational characteristics (slope orientation and the amount of vegetation cover to provide shade which retards the ablation of the pack (Hilbert, 1967; Molchanov, 1963).

Further regulation of stream flow was due to the operation of Valens Reservoir. A release of water in spring intensifies the spring discharge peaks, but the maintenance of a high water level in the Reservoir during the summer restricts flow into the western tributary of Spencer Creek. This restriction compounds the effect of increasing evapotranspiration and the stream then tends to be influent. Discharge continues to drop until a minimum is attained between late June and early July, after which there is a slow increase. This period is frequently interrupted by precipitation events (figure III-6) creating

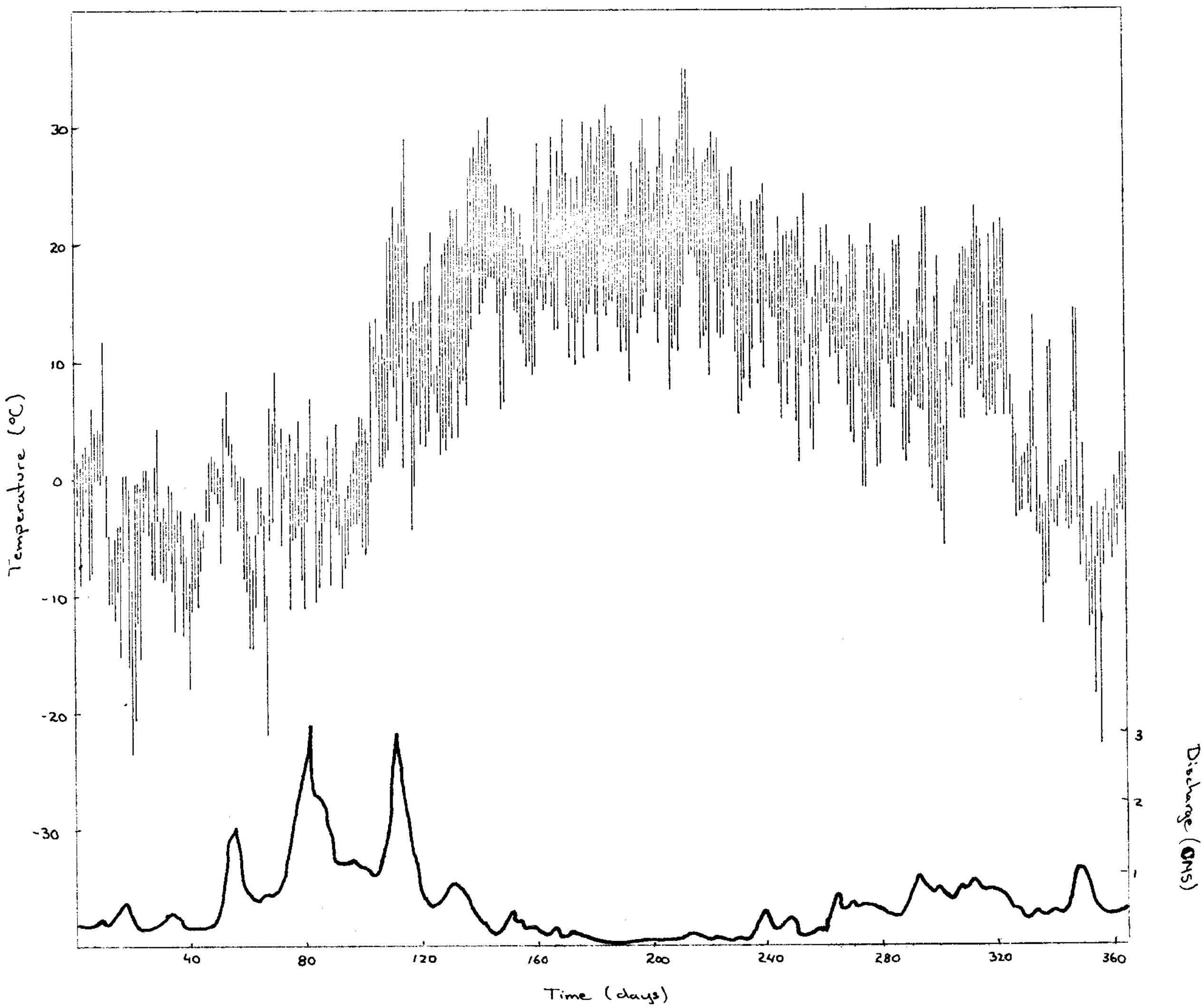


Figure III-5 Temperature of open site as compared with discharge for Westover 1975

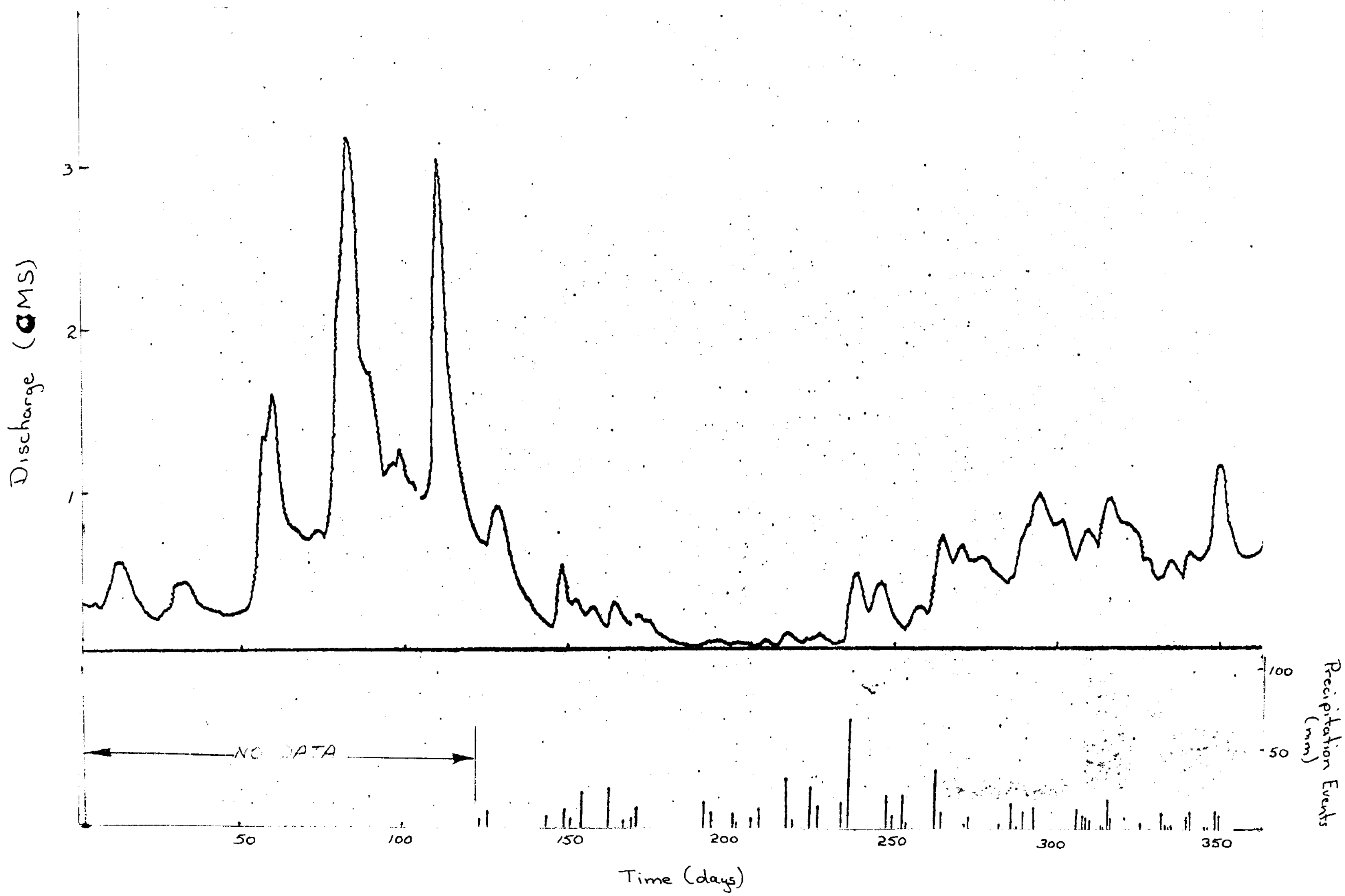


Figure III-6 Rainfall at the open site as compared with discharge for Westover 1975 sharp peaks in the hydrograph.

Increase in discharge occurs in late September corresponding with: a reduction in evaporation; release of water from Valens Reservoir and increase precipitation. A slight drop in discharge occurs during winter with the flow being slightly higher than summer.

Only a partial record for 1971 discharge exists (figure III-7). It exhibits the longest continual dry spell of the years investigated, which indicates a minimum precipitation input, with concurrent high temperatures. For 1972 (figure III-8) a single, large flood peak occurred resulting from rapid and intense melt of snow storage in spring. Moderately large precipitation events continued throughout the year preventing the occurrence of extremely drought conditions. In 1973 (figure III-9), a mild winter punctuated by melt periods, led to the occurrence of several smaller peaks and in the following year (figure III-10), four distinct peaks can be attributed to mid-winter thaw events.

III-5 Evapo-transpiration

Evapo-transpiration was not measured, but an indirect method of estimation can be utilized based upon the water balance equation:

$$E = P - Q + \frac{\Delta s}{\Delta t} \qquad \text{(III-3)}$$

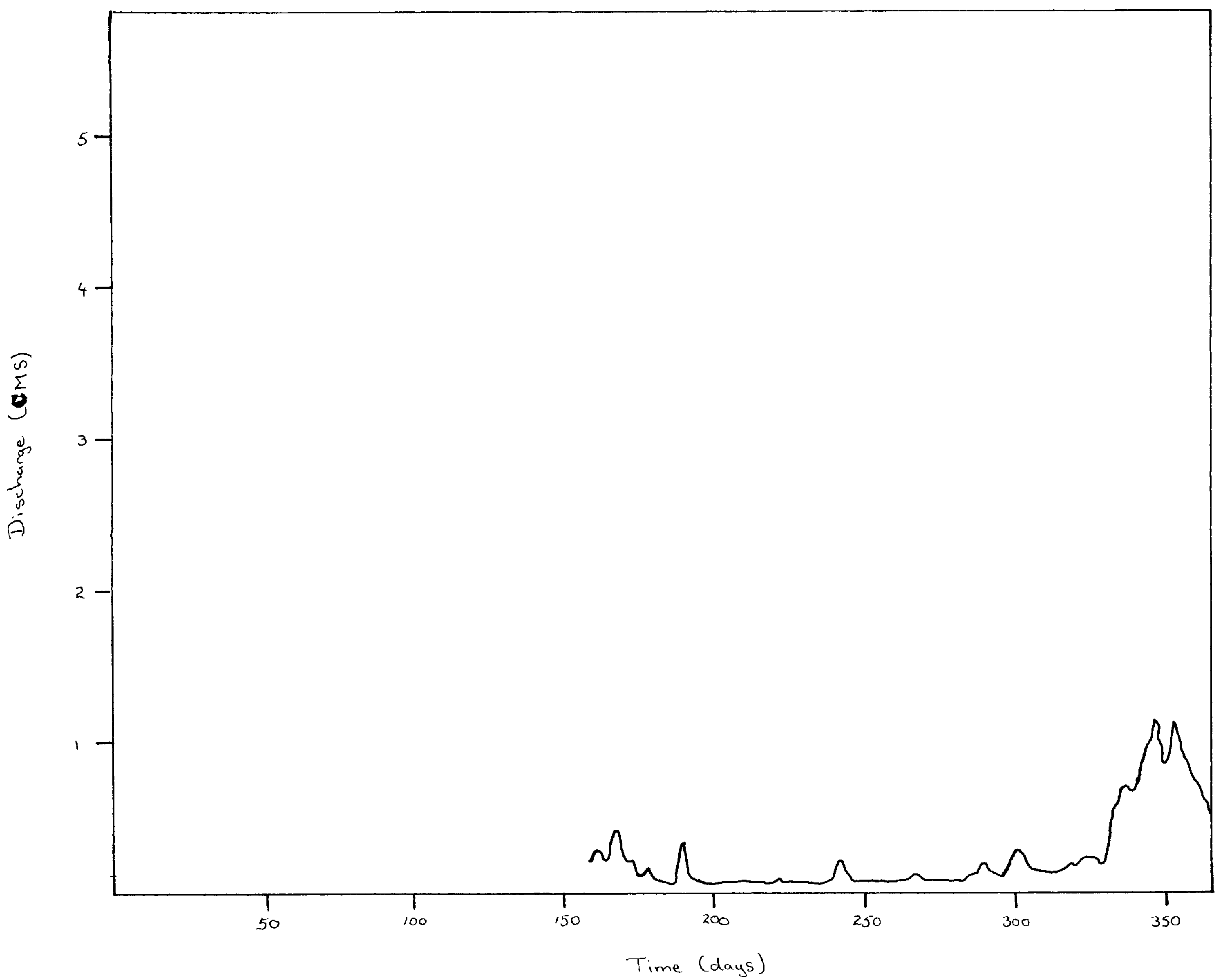


Figure III-7 Discharge of Spencer Creek at Westover 1971

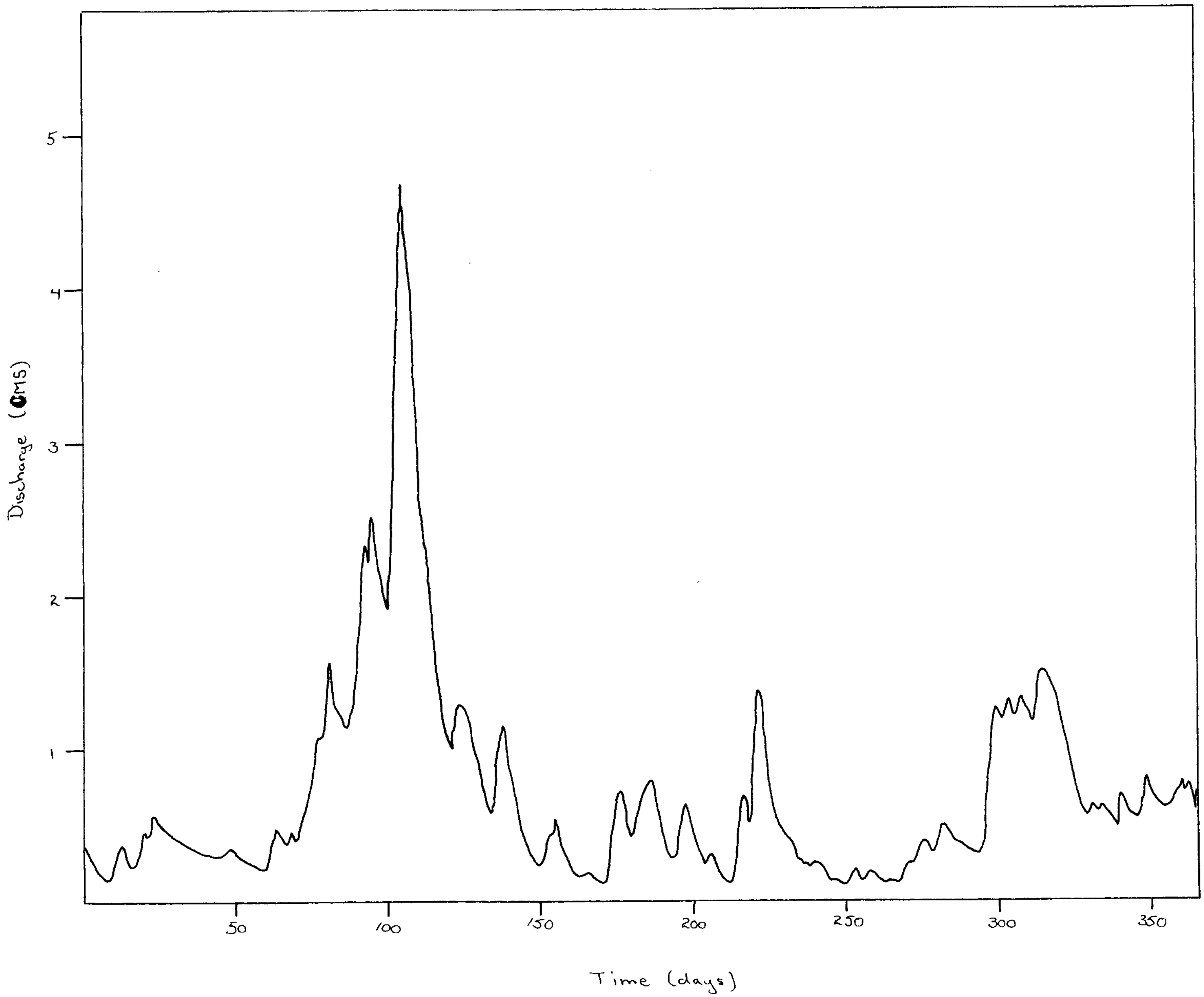


Figure III-8 Discharge of Spencer Creek at Westover 1972

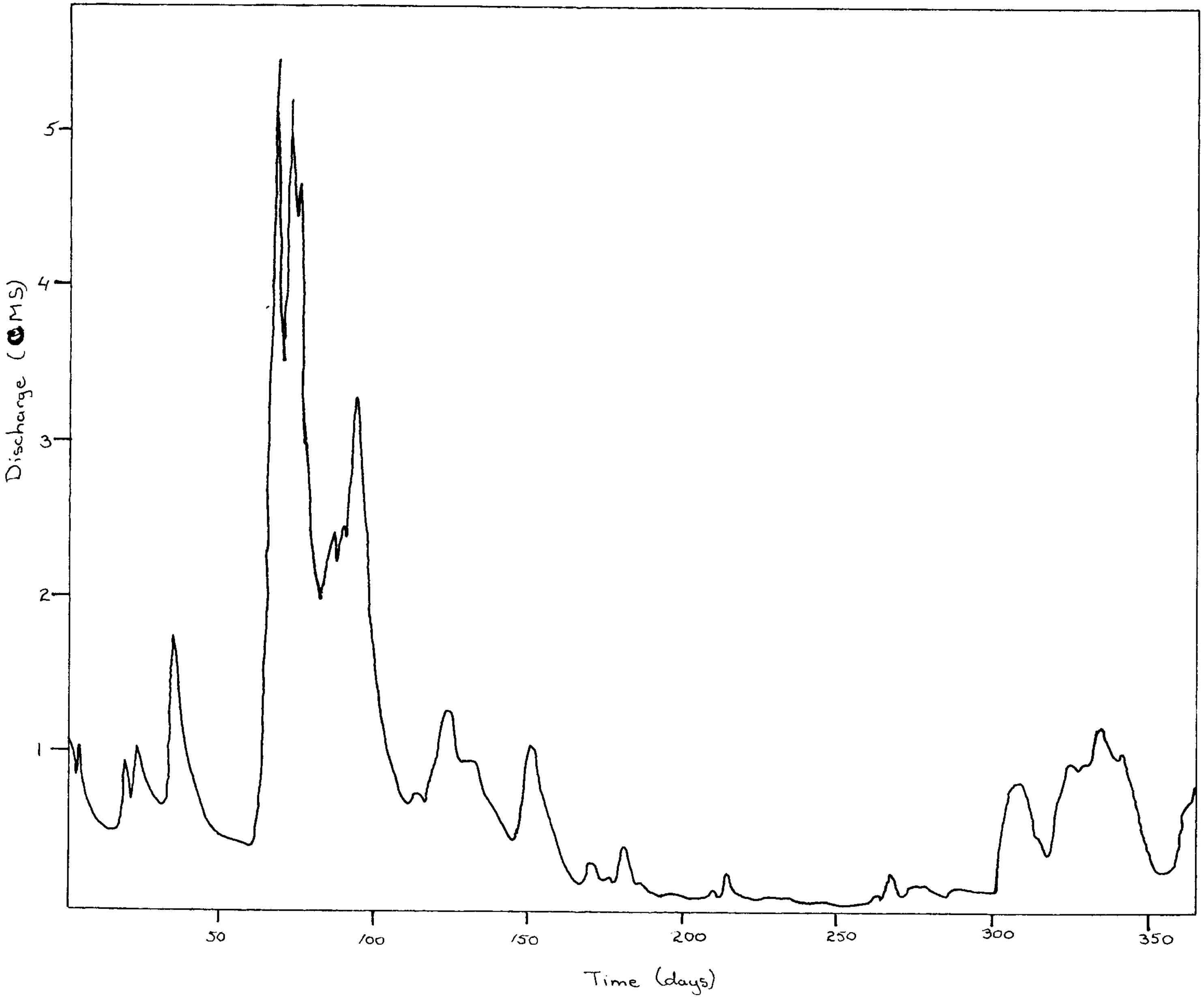


Figure III-9 Discharge of Spencer Creek at Westover 1973

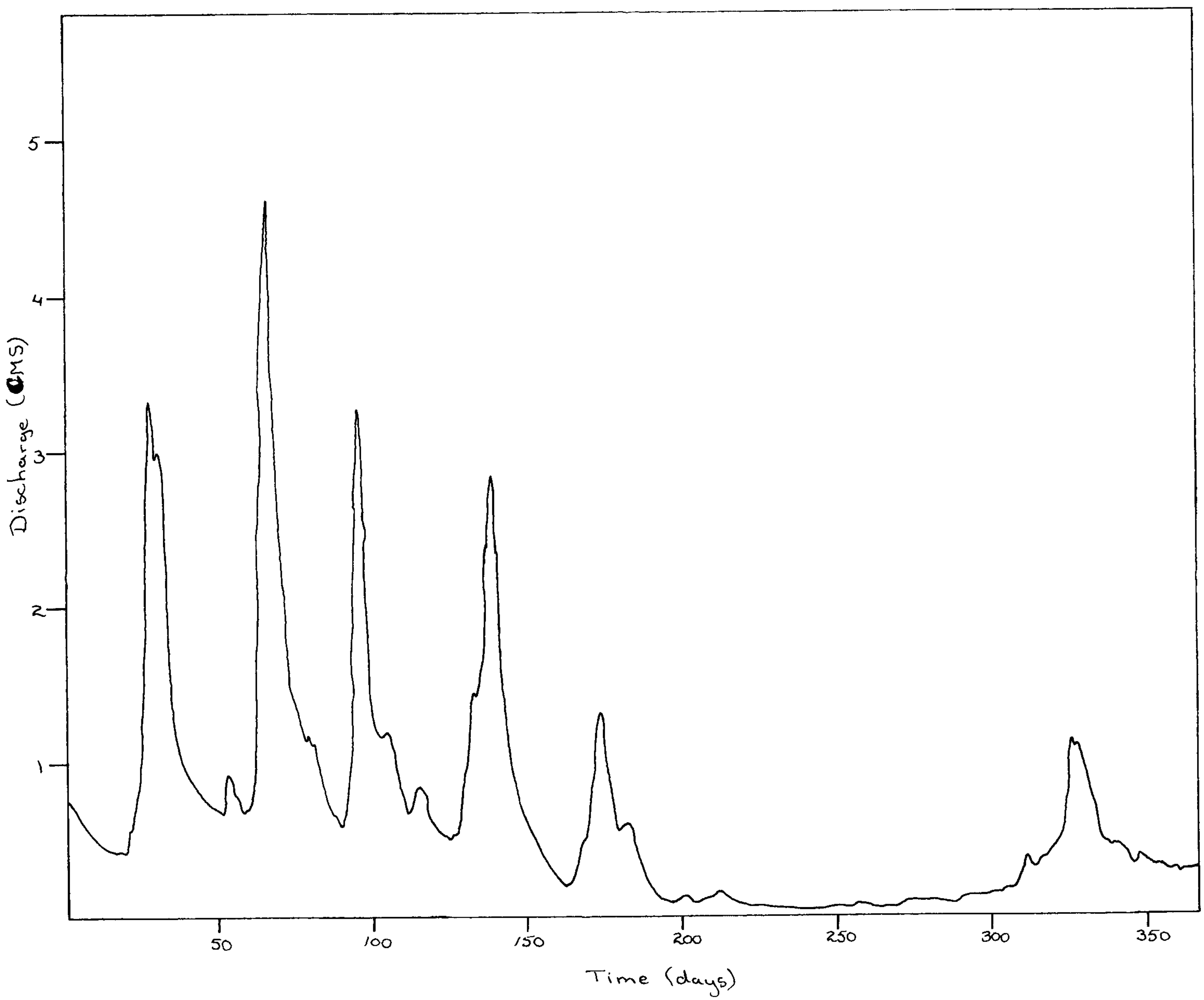


Figure III-10 Discharge of Spencer Creek at Westover 1974

where E = evapo-transpiration

P = precipitation

Q = discharge

$\frac{\Delta s}{\Delta t}$ = the change of storage within the basin

Over a period of several years, $\frac{\Delta s}{\Delta t}$ approaches zero and evapo-transpiration can be obtained as the difference between cumulative P and cumulative Q. For this analysis, a double mass curve technique was employed.

Based on the analysis of precipitation data (section II-4) the record from Millgrove was considered to be representative of the basin. For discharge, Westover was selected because it is located not far downstream from Beverly Swamp. The discharge records were converted into mm. units with the cumulative precipitation and discharge data plotted as figure III-11. A difference between cumulative precipitation and cumulative discharge over a period of four years shows the total loss via evapo-transpiration.

Evapo-transpiration for wooded areas such as Beverly Swamp, are not constant but alter due to aging, Molchanov (1963;figure III-12). This alteration entails an increase in evapo-transpiration rates when the age of the forest averages between 30 and 60 years, after which evaporation rates tend to decrease. Beverly Swamp experiences a rapid

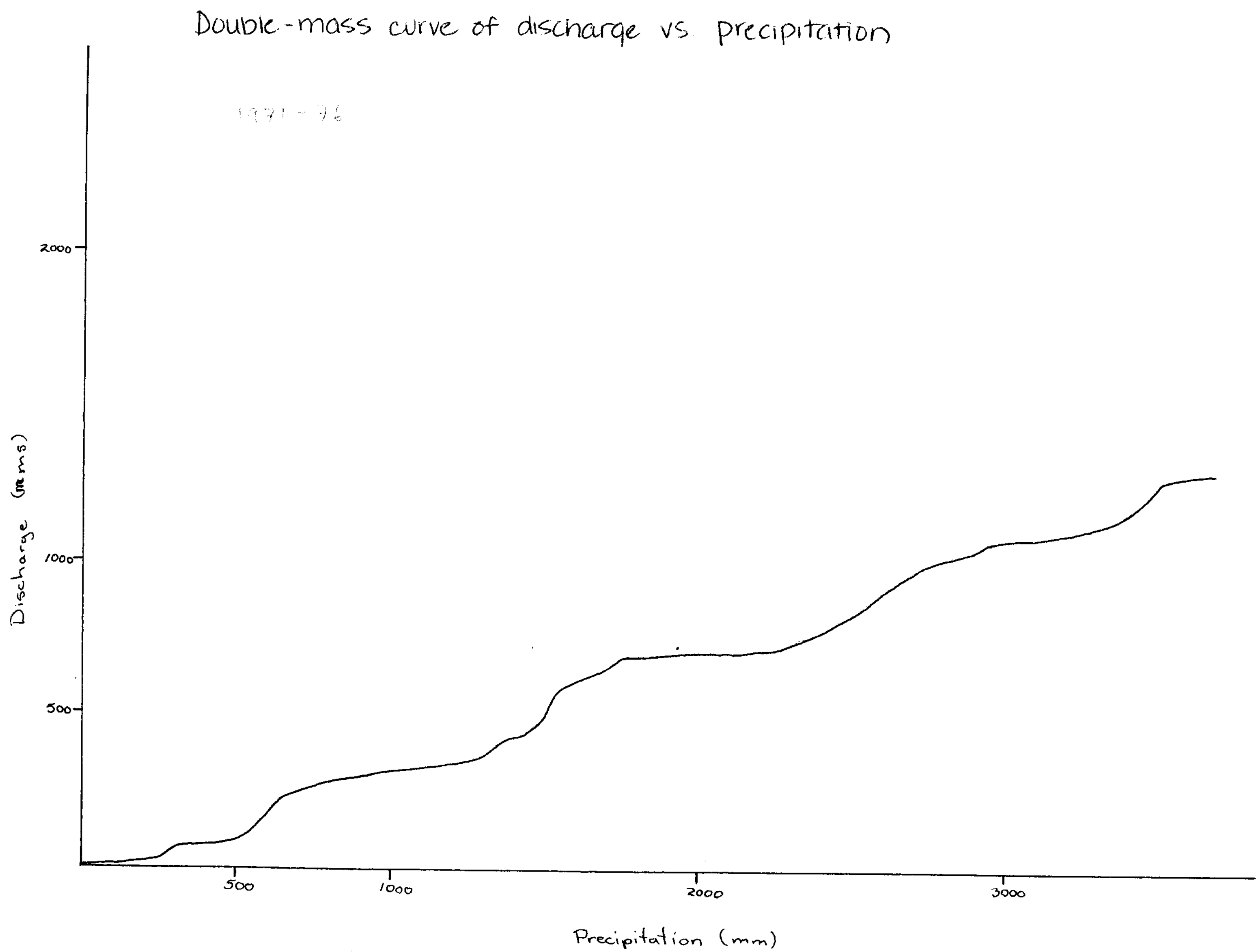


Figure III-11 Double-mass curve showing cumulative discharge at Westover and cumulative precipitation at Hillgrove between July 1971 to June 1975

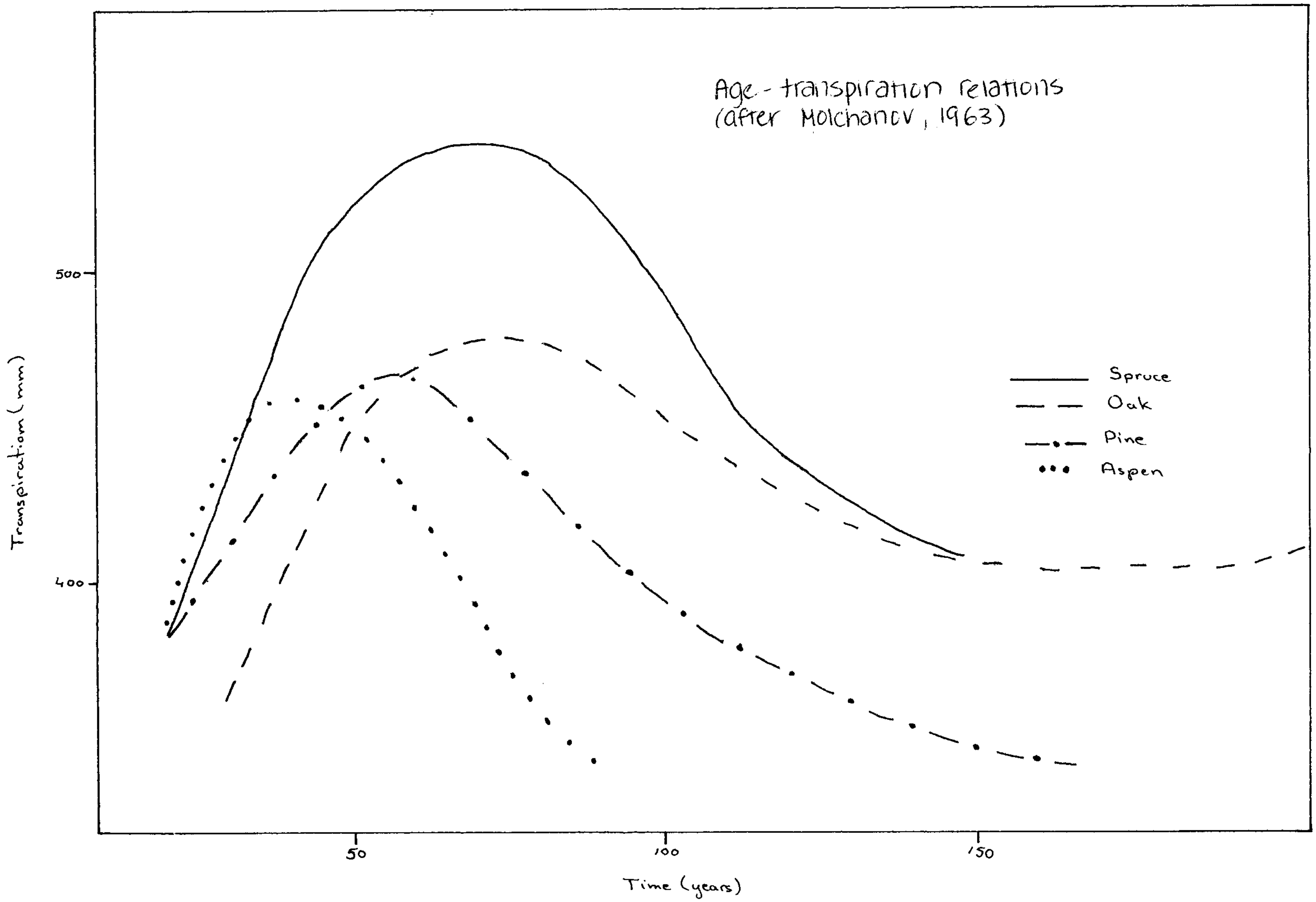


Figure III-12 Relationship between evapo-transpiration and vegetation age based on Molchanov vegetation turnover which should maintain a high evapo-transpiration level.

According to the double mass curve, evaporation accounts for 65 percent of total precipitation. This value is comparable to other swamp environments. For example, Romanov (1968) in his study of High moor bog evapo-transpiration obtained values between 65 and 70 percent, while Linacre et al (1970) found similar values for an Australian swamp.

III-6 Spatial variation of discharge at Beverly Swamp

The Beverly Swamp section of Spencer Creek Basin was studied intensively in 1975 because of its importance as a major storage area for Spencer Creek, a point which has been emphasized by the Spencer Creek Conservation Authority (1968). Information on outflow from the Swamp was available at Westover from the Water Survey of Canada (section III-4), while inflow from Valens Reservoir, down the western tributary, was regulated by the Conservation Authority. Weekly changes of discharge within the Swamp were measured at three sites for this project (figure I-1).

Operation of Valens Reservoir requires a substantial quantity of water to be stored between June 1, and October 1 for recreational and agricultural usages. Due to this control, the western tributary was usually dry throughout

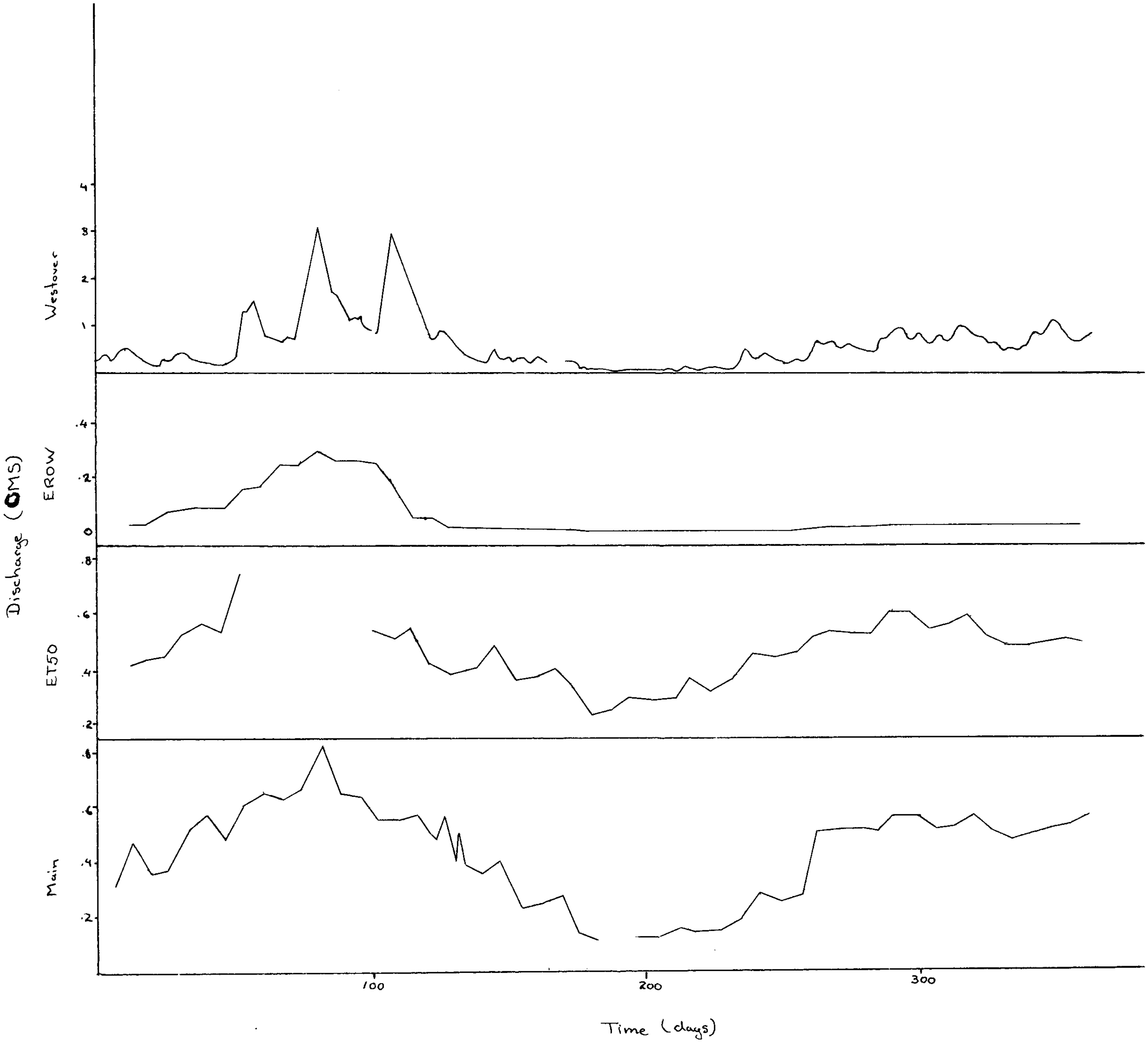


Figure III·13 Discharge of Spencer creek and its tributaries summer (section III-4), though the eastern tributary continued to flow, thus helping to maintain low flow at Westover (figure III-13). Further climatological controls on the hydrographs have been discussed in section III-4 with reference to Westover; these effects can be extrapolated over the entire basin.

A comparison of the hydrographs of the tributaries and the main channel in the swamp indicates a loss of water as the stream flows through the Swamp. This is due to the high infiltration rate of peat and the ability of the Swamp soil to retain water (Moore and Bellamy, 1974; Radforth, 1969). The Creek entering the Swamp will then tend to be influent during the dry period. A comparison of discharge data on four occasions seems to support this hypothesis (table III-1). It is further hypothesized that surface drainage in the Swamp re-enters the Creek as it exits from the Swamp. This is indicated by an increase in discharge between the Main swamp station and that of Westover.

Table III-2

Discharge measurements at four sites along Spencer Creek within and below Beverly Swamp

Date	Discharge $\left(\frac{m^3}{s}\right)$		
	Sum of Eastern and Western tributaries at confluence	Main	Westover
June 18, 1975	.43	.28	.317
June 27, 1975	.29	.135	.113
July 17, 1975	.32	.128	.271
October 18, 1975	.67	.68	.771

IV - Hydrochemistry of Upper Spencer Creek Basin

IV-1 Carbonate Solution Processes

Interactions between the hydrologic cycle and geochemical conditions modify the chemical properties of water in the drainage basin (Stumm and Morgan, 1970). In carbonate terrains the dissolution of calcium carbonate accounts for the majority of solutional activities. Following is a review on the carbonate solutional process.

The dissolution of calcium carbonate may be represented as:

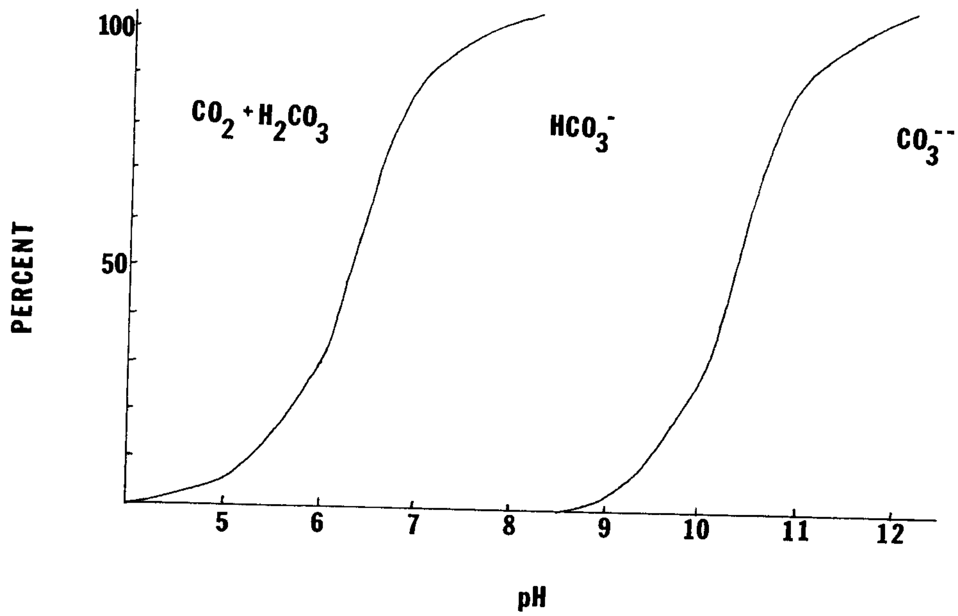
$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-} \qquad \text{(IV-1)}$$

However, CO_3^{2-} is unstable within the range of pH values experienced in most natural waters (figure IV-1). Within pH values ranging from 7 to 9, a more stable ion is the bicarbonate, HCO_3^- (which accounts for the majority of dissolved carbonate species, Drake 1974). The solutional reactions which concern carbonate minerals are:

$$H_2O \rightleftharpoons H^+ + OH^- \qquad \text{(IV-2)}$$

$$CaCO_3 + H^+ \rightleftharpoons Ca^{2+} + HCO_3^- \qquad \text{(IV-3)}$$

Any acid present in natural aquatic environments will dissociate to produce H^+ ions. These ions associate with the CO_3^{2-} ion produced through the dissociation of



Properties of CO_2, HCO_3^- and CO_3^{--} as related to pH (after Hutchinson, 1957)

Figure IV-1 Carbonate stability as related to pH changes

Table IV-1

Bogli's four solution phases for limestone

Phase	Occurrence
1	-dissociation of $CaCO_3$ with Ca^{2+} and CO_3^{2-} ions lost to the water (equation IV-1)
2 + 3	-H^+ ions act upon CO_3^{2-} (equation IV-3). A portion of CO_2 dissolved in water forms a weak carbonic acid with its subsequent dissociation of H^+ ions to associate with CO_3^{2-} ions formed in phase 1 (equation IV-4). This removes CO_3^{2-} from solution allowing further solution of limestone
4	-water saturated in phases 2 and 3 and in equilibrium with the H^+ activity in the water allows further diffusion of CO_2 into the water. Thus if a continual water/air interface is maintained the cycle of solution continues

carbonate minerals. Carbonate solution is therefore pH dependent. Since water in contact with the atmosphere reacts with carbon dioxide to produce carbonic acid:

$$H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \qquad (IV-4)$$

it is possible to sum equations IV-3 and IV-4 to yield:

$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca^{2+} + 2HCO_3^- \qquad (IV-5)$$

These relationships are best shown by Roques' (1968) diagram based on the Mass Transfer Theory (figure IV-2).

Bogli (1960) discussed and related the different phases in the solution of calcium carbonate to stages in the solution of limestone. He described the solution of limestone as the result of four phases (figure IV-3, table IV-1).

Determination of the concentration of these various ions in solution is facilitated by the Law of Mass Action (Stumm and Morgan, 1970; Drake, 1974):

$$aA + bB \rightleftharpoons cC + dD \qquad (IV-6)$$

where the lower case letters indicate numeric proportion and the upper case indicates the subject. This equation can be transferred such that an equilibrium constant (K) is obtained:

Solubility of $CaCO_3$ (after Roqués)

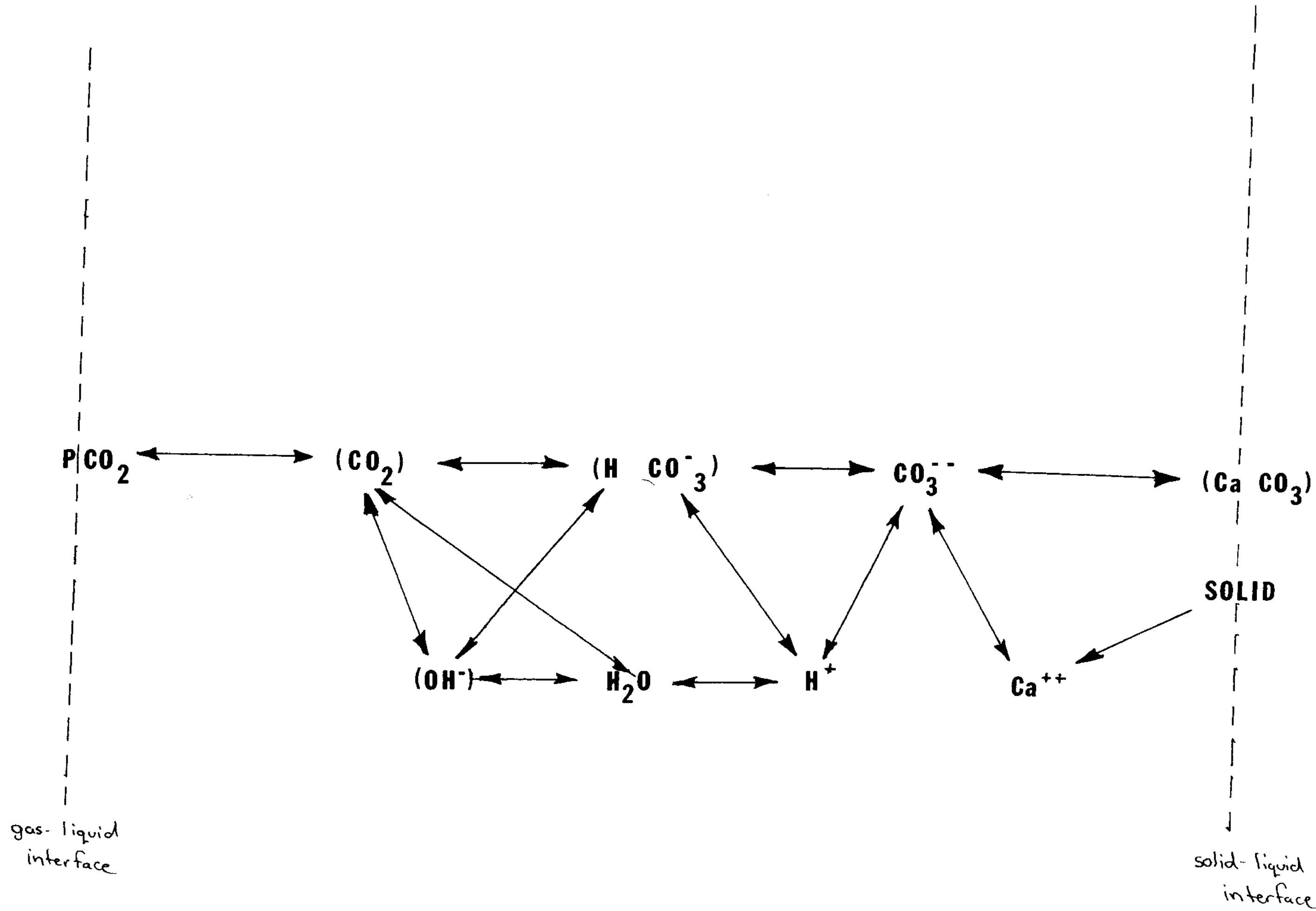
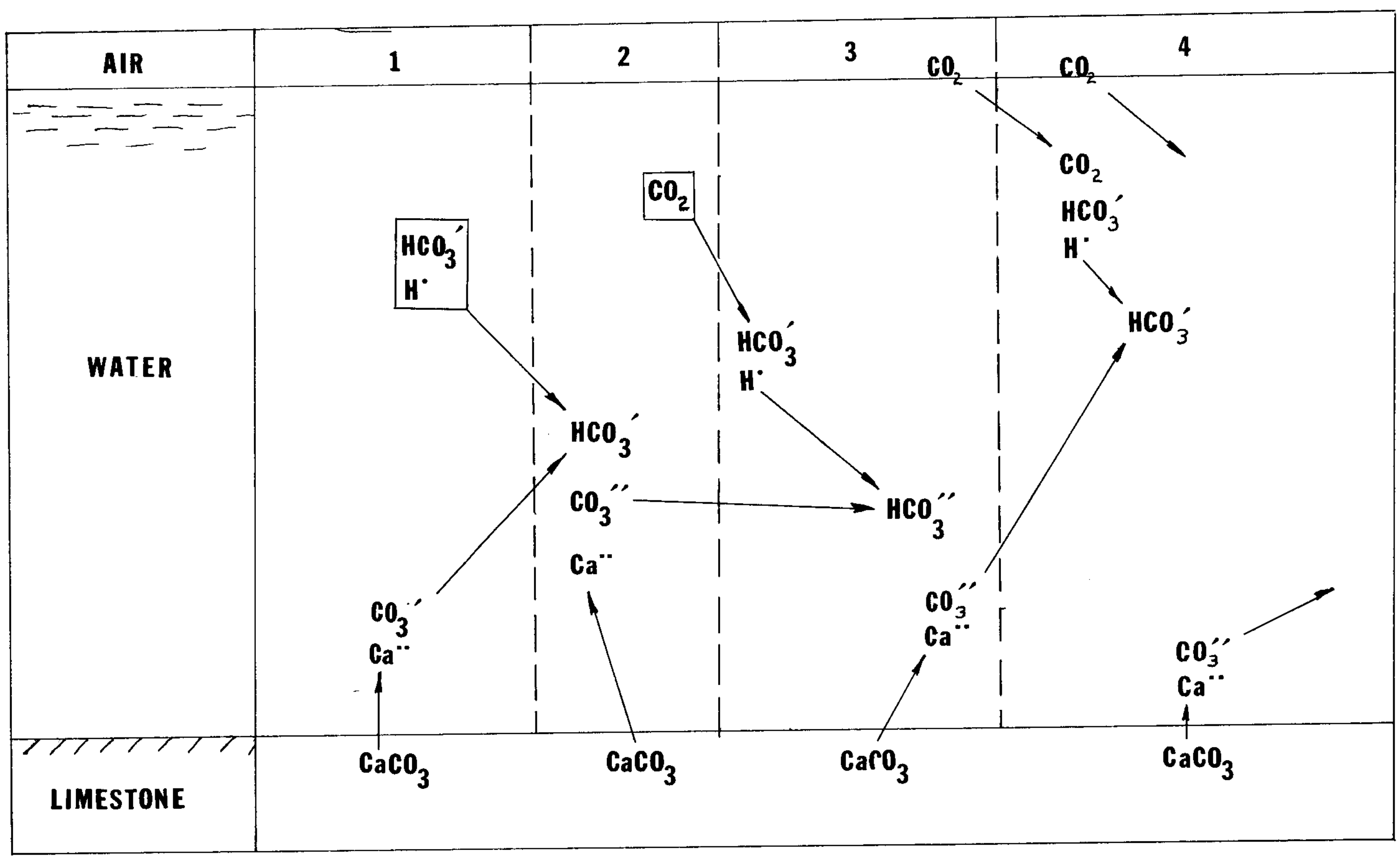


Figure IV-2 Diagram based on Mass Transfer Theory (Roqués)



Scheme of limestone solution (after Bögli, 1960)

Figure IV-3 Bögli's stages in solution of limestone

$$\frac{[C]^c\,[D]^d}{[A]^a\,[B]^b} = K \qquad (IV-7)$$

where [ ] is the activity of the enclosed species. If equilibrium is in effect there is a continual flow of ions between substances; A and B to C and D, without further production of either. A constant concentration of component substances in the solution reactions of carbonates makes the consideration that thermodynamic equilibrium state important and useful (Drake, 1974).

If the activities of a substance involved in a particular reaction are known, an ion - activity product (K_{iap}) can be obtained for equation IV-7. Generally, $K_{iap} \neq K$:

if $K_{iap} < K$ the reaction will proceed in sum to the right of the equation

$K_{iap} > K$ to the left of the equation (equations IV-7, 8)

Therefore, if

$$K_{iap} < \frac{[Ca^{2+}]\,[CO_3^{2-}]}{[CaCO_3]} \qquad (IV-8)$$

dissolution of calcite will occur and conversely if K_{iap} is larger, calcite will be formed (this is used to determine saturation state). Saturation indices (or saturation state) can be computed through a measurement of pH, Ca^{2+}, Mg^{2+}, HCO_3^- and temperature (Langmuir, 1971;

Wigley, 1971).

For calcite, $SI_c = \log\left\{\left(\left[Ca^{2+}\right]\left[HCO_3^-\right]K_2/\left[H^+\right]\right)/K_s\right\}$ (IV-9)

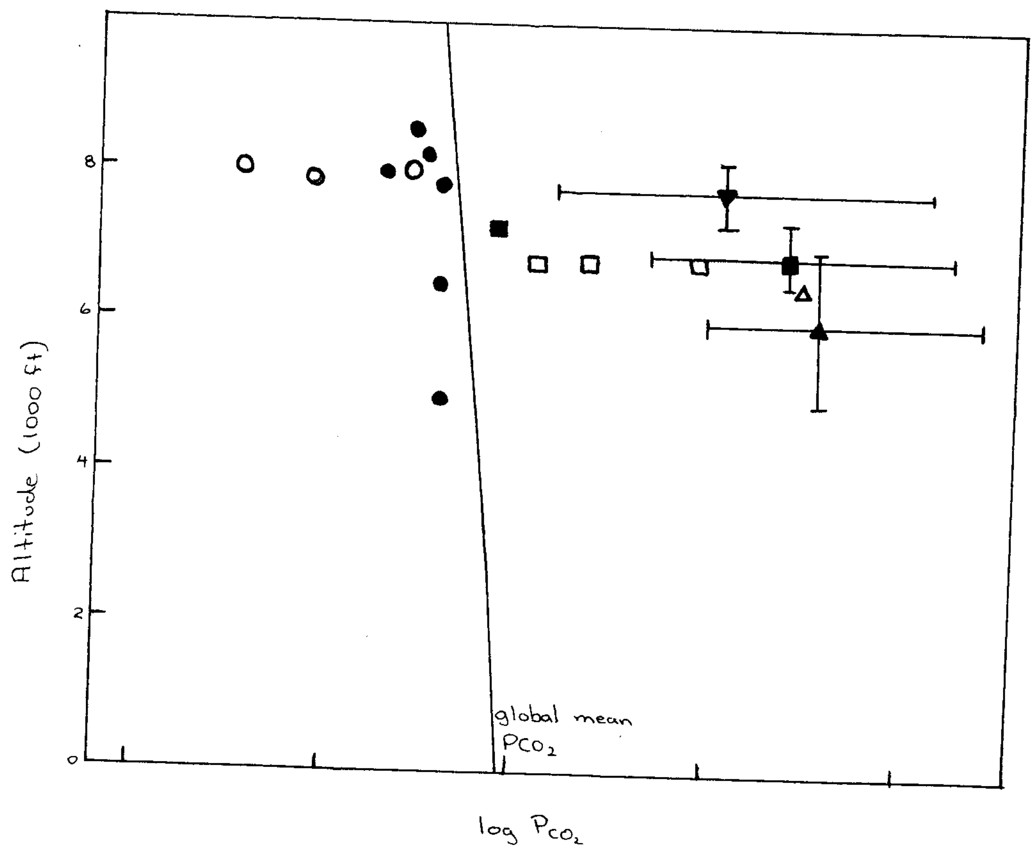
For dolomite,

$$SI_d = \log\left\{\left(\left[Ca^{2+}\right]\left[Mg^{2+}\right]\left[HCO_3^-\right]K_2^2/\left[H^+\right]^2\right)/K_d\right\} \quad (IV\text{-}10)$$

where K_2, K_s and K_d are dissolution constants for H_2CO_3, calcite and dolomite respectively.

Carbonate solutional process is dependent upon environmental controls. The major control over the solution of carbonate rock is the solubility of CO_2 in water, which is inversely related to temperature. Sweeting (1973) described two types of solubility: anaerobic; where water comes into initial equilibrium with the air but the absorption of CO_2 ends when calcium carbonate solution occurs; equilibrium; where the water is in contact with a continuous supply of air during solution. Calcium carbonate solubility under anaerobic conditions is 14 ppm. and 74 ppm. at 10°C for conditions of equilibrium, yet field observations can exhibit values of 200 - 300 ppm.

Explanation of this phenomena lies in the partial pressure of carbon dioxide (PCO_2) in the soil, which far exceeds the atmospheric PCO_2. An increase in PCO_2 is directly related to vegetation and microbiological activity (Lickens et al, 1967; Ford, 1971), figure IV-4. Seasonal fluxes in carbonate solution reflects an increase



Dependence of PCO_2 on altitude and changes in vegetation (after Ford)

Figure IV-4 Relationship of PCO_2 to altitude and biotic environment (Ford) in CO_2 production through increased biotic activity in late spring and summer (Sweeting 1973; Shuster and White, 1971). Drake (1974) suggested that mixtures of ground and surface waters are more intense during the drier years when the contribution of CO_2 to the streams via baseflow is highest.

Temperature affects the solubility constant, K (Drake, 1974). There is also a direct relationship between PCO_2 and temperature (Drake and Wigley, 1975; Harmon et. al., 1972; Weyl, 1954).

Discharge is as influential as CO_2 solubility in determining the concentration of dissolved carbonates in water. Most authors suggest an inverse relationship between discharge and total dissolved load (Crisp, 1966; Livingston, 1963; Gorham, 1956).

IV-2 Basin denudation

Determination of denudation rates for a basin necessitates the monitoring of both suspended and dissolved load in the stream. Spencer Creek is characterized by a low percentage of suspended material which is composed almost entirely of organic matter (figure IV-5). A meagre amount of clastic material is usually present at the beginning of the spring flood season. Unlike most suspended load vs. discharge relationships which exhibit peak concentrations during flood (Livingston, 1963;

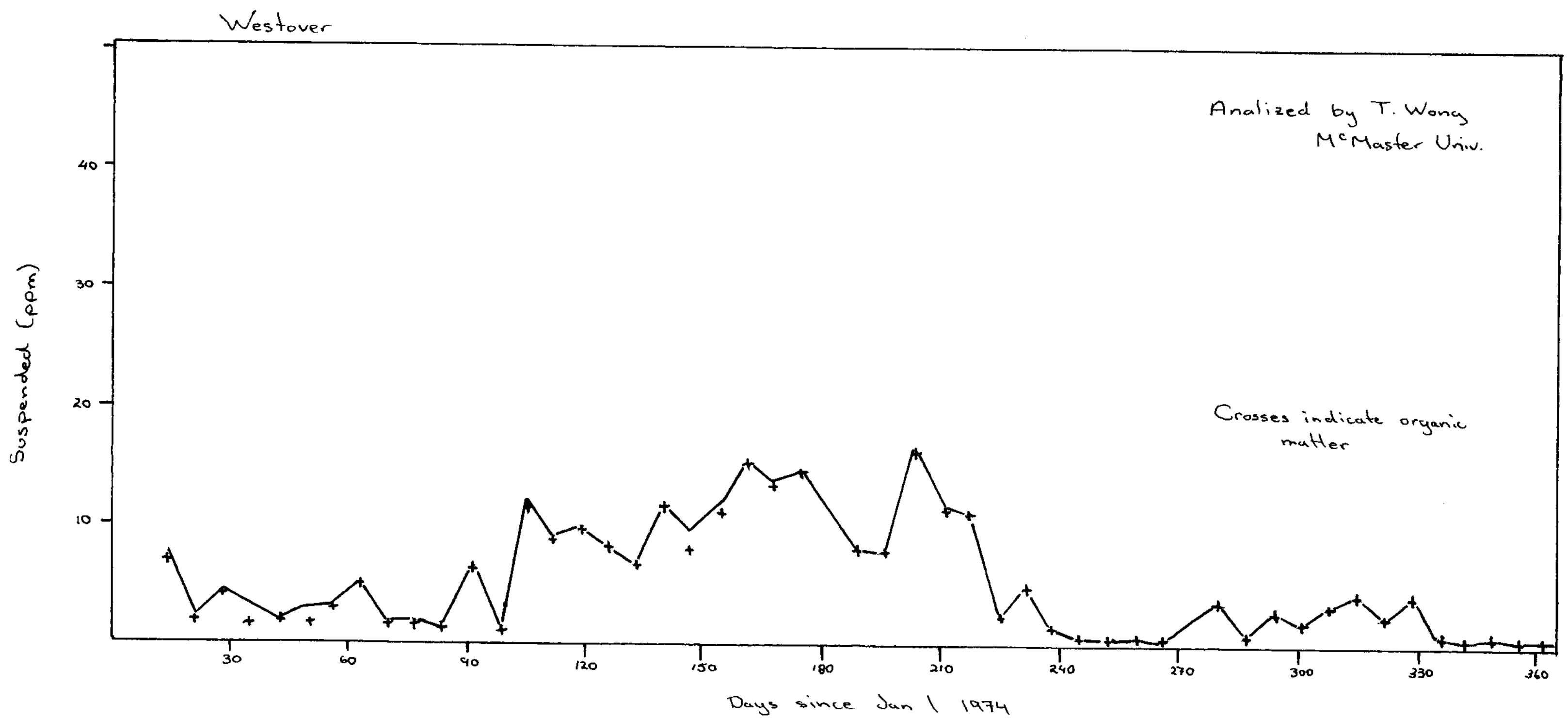


Figure IV-5 Relationship of clastics to total suspended load, Westover 1974 (Wong)

Table IV-2

Dependence of K on temperature and PCO_2

Temperature (°C)	0.033% PCO_2	0.44% PCO_2
0	96	106
5	86	94
10	75	83
15	67	74
20	59	65
25	54	59
29	49	54

Morisawa, 1968), the highest load for Spencer Creek occur in summer, corresponding to increasing biotic activities. Figure IV-6 shows the general trend in the concentration of suspended load down the basin.

Dissolved load concentrations are inversely related to discharge (section IV-1). Corbel (1959) was one of the first investigators to establish an empirical method to determine the rule of denudation.

$$X = \frac{4ET}{100} \qquad \text{(IV-11)}$$

where E = runoff in decimeters

T = average $CaCO_3$ concentration in ppm.

X = the value of limestone solution in m^3/year/km^2 or mm. per 1000 years.

His formula was thought to be in error by Williams (1963), who assumed the specific gravity of limestone to be 2.72 rather than 2.5 as postulated by Corbel, and no allowance was made by Corbel for the occurrence of other rock types within the study area. Williams working in Ireland produced another formula:

$$X = \frac{E\ (T_c + T_m)\ n}{10s} \qquad \text{(IV-12)}$$

where E = total runoff in decimeters

T_c = mean $CaCO_3$ content in ppm.

Trend in suspended load down stream

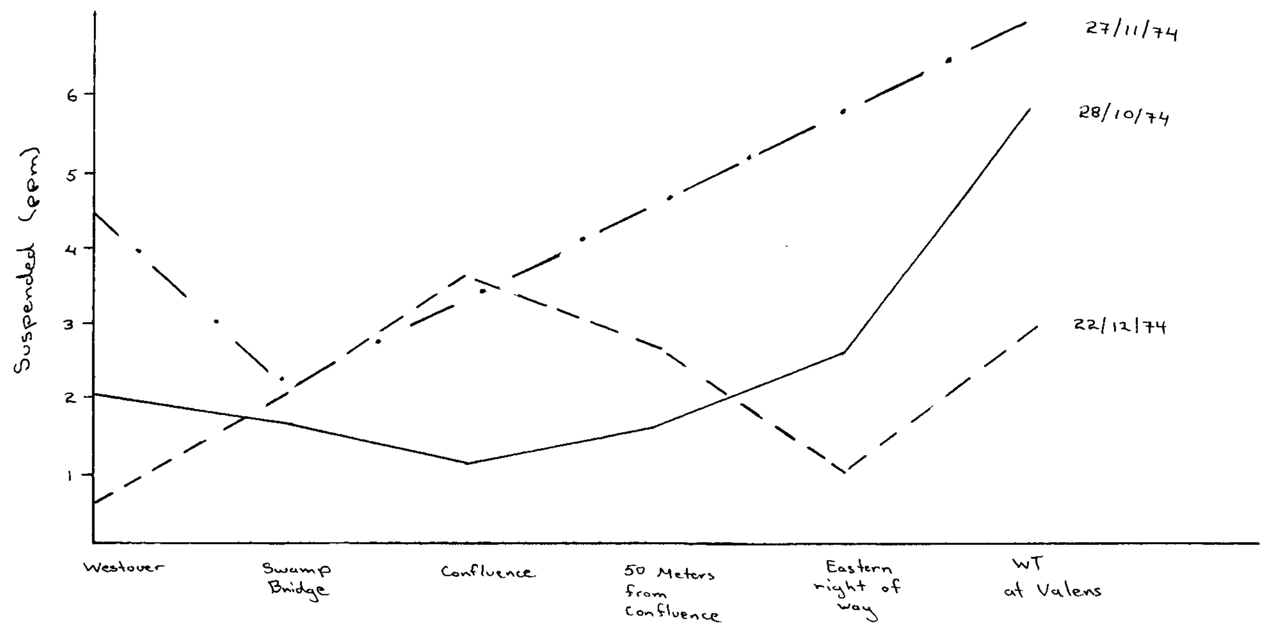


Figure IV-6 Change in suspended load down the basin where n = fraction of basin in limestone

T_m = $MgCO_3$ content in ppm.

S = specific gravity of limestone

X = limestone removed through solution in m^3/year/km^2 or mm./1000 years

Equations IV-11 and IV-12 do not allow for variations in discharge and in solute concentration during the year. For this study, the author computes the limestone solution rate by:

$$X = \sum_{i=1}^{m} \frac{Q_i C_i}{S\ 10^6}\ n \qquad \text{(IV-13)}$$

where Q = discharge in m^3/p

p = length of sampling period

C_i = mean concentration of water hardness in ppm./p

n = fraction of basin in limestone

S = density of limestone; 2.5

m = total number of sampling period

Applying all three methods to Spencer Creek, it was found that all three equations for basin denudation produced comparable results (Table IV-3).

Comparison of suspended and dissolved loads for 1974 (figure IV-5, IV-7) shows that the former was negligible and it was therefore not measured during the

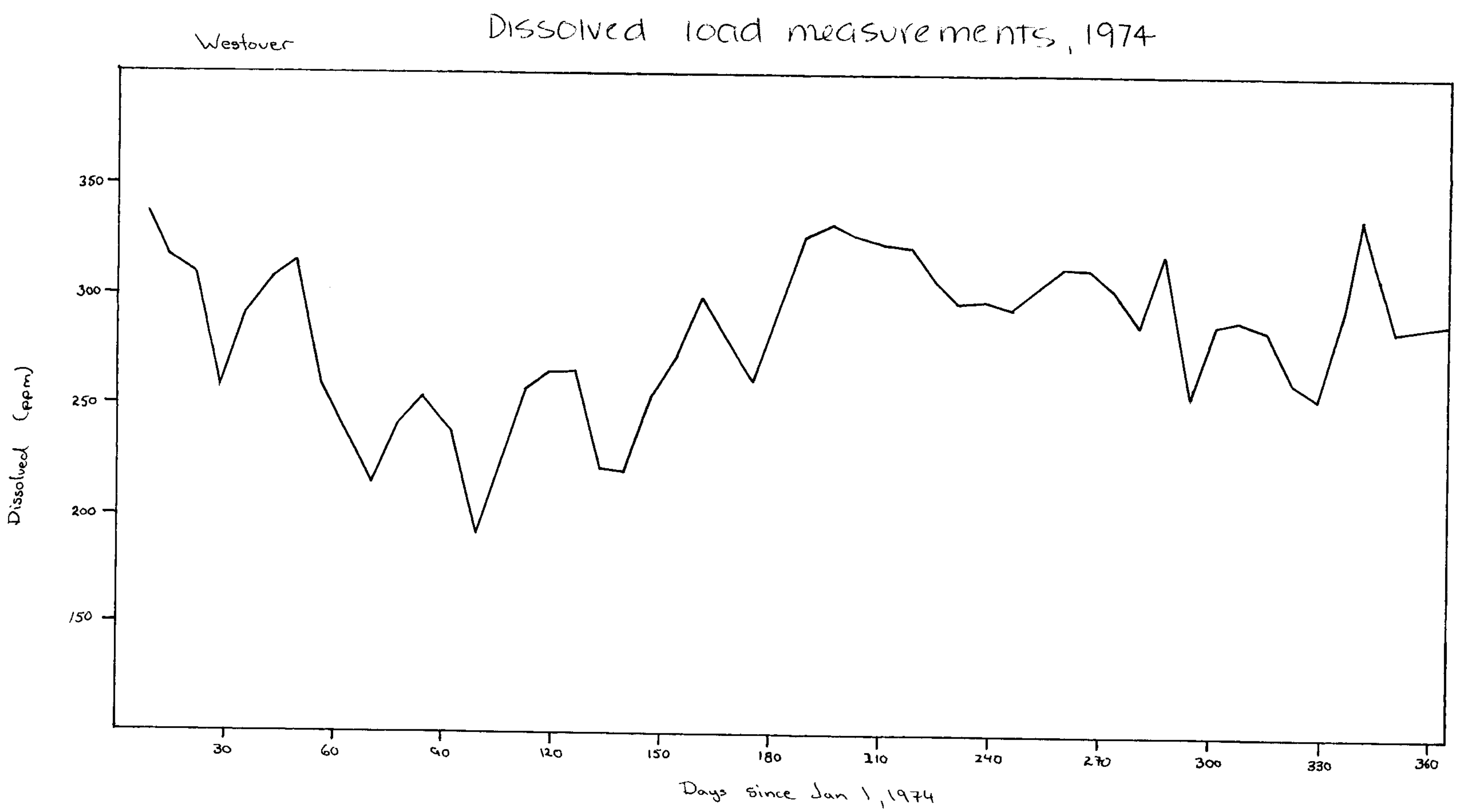
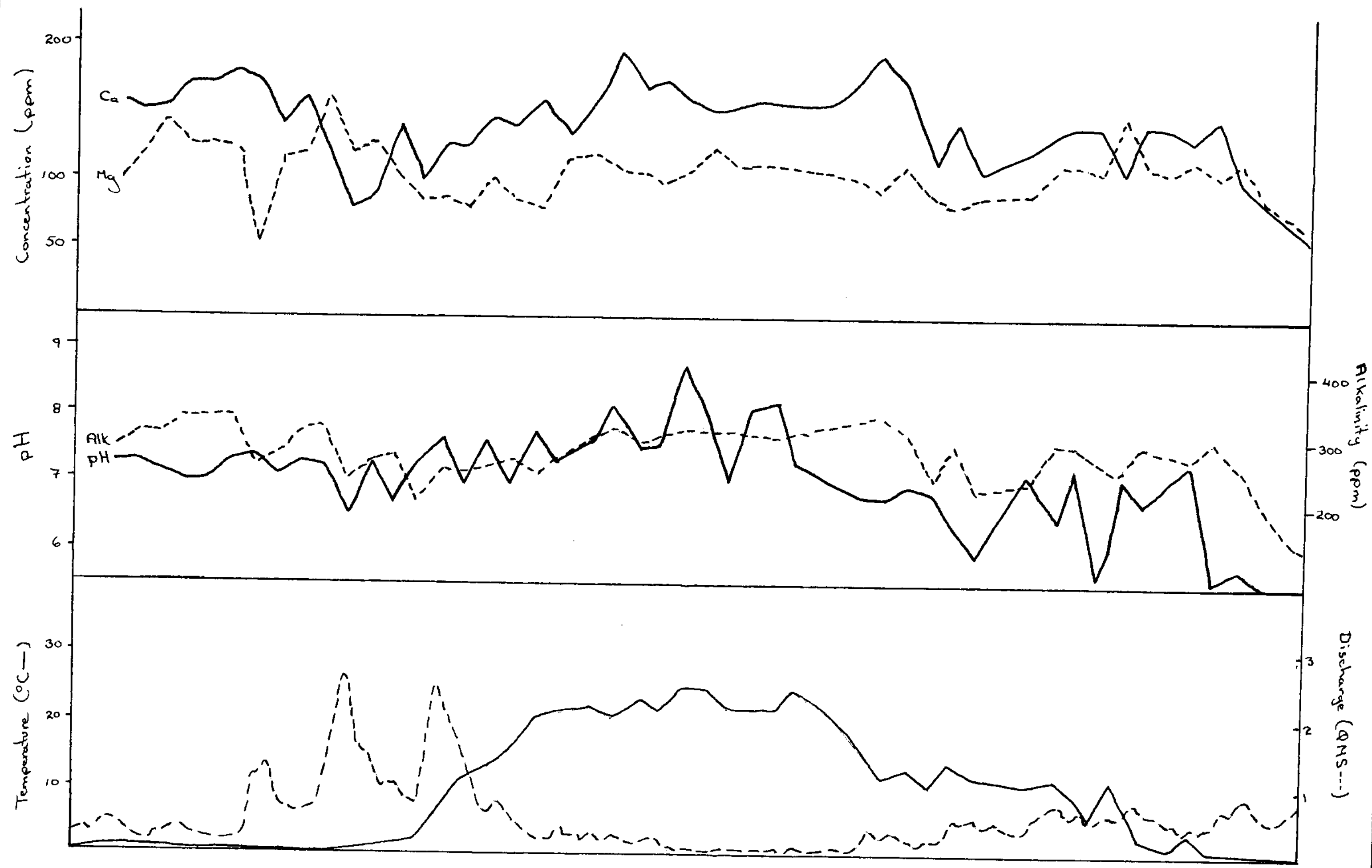


Figure IV-7 Total hardness concentration at Westover, 1974 (Woo)



Seasonal variations in water chemistry at Westover 1975

Figure IV-8 Change in hydrochemistry at Westover, 1975 over time

Table IV-3

Computed denudation rates (m^3/year/km^2)

for the upper Spencer Creek basin

Year	Corbel (1959)	Williams (1963)	present study
1974	2339.4	2150.2	2448.2
1975	1794.6	1782.4	1722.8

For Spencer Creek,

$n = 1.0$	$n = 1.0$	$n = 1.0$
$T = 293.0$ (1974)	$T_m + T_c = 293.0$ (1974)	w_i = section III-6
258.8 (1975)	258.8 (1975)	C_i = section IV-3
$E = 2.80$ (1974)	$E = 2.80$ (1974)	
2.95 (1975)	2.95 (1975)	

1975 field season.

IV-3 Comparison of Chemical Components

During 1975, bi-weekly measurements of water temperature, pH, alkalinity, calcium and magnesium carbonate were carried out at ten sites along Spencer Creek (figure I-1). Temporal (figure IV- 8) and spatial (figure IV- 9, IV-15) characteristics were graphed.

Weekly measurements from Westover gauging station were used to show the temporal pattern. Due to the seasonality effect, there was an inverse relationship between discharge and water temperature. Water temperature for Spencer Creek remained at 0°C during the first few months of the year and did not begin to rise until early April, when the last major flood peak occurred. Water temperature rose to 20°C at the beginning of June, and this high value was maintained for most of the low flow period. However, a steady drop began in August, accompanied by an increase in discharge. By this time fluctuations were due to individual rain events. Towards the end of November, water temperature dropped to 0°C.

pH exhibited an annual pattern, with large fluctuations occurring between sampling periods. Higher pH in summer was accompanied by a drop in discharge. In autumn and winter lower values prevailed.

Spencer Creek showed a high concentration of calcium

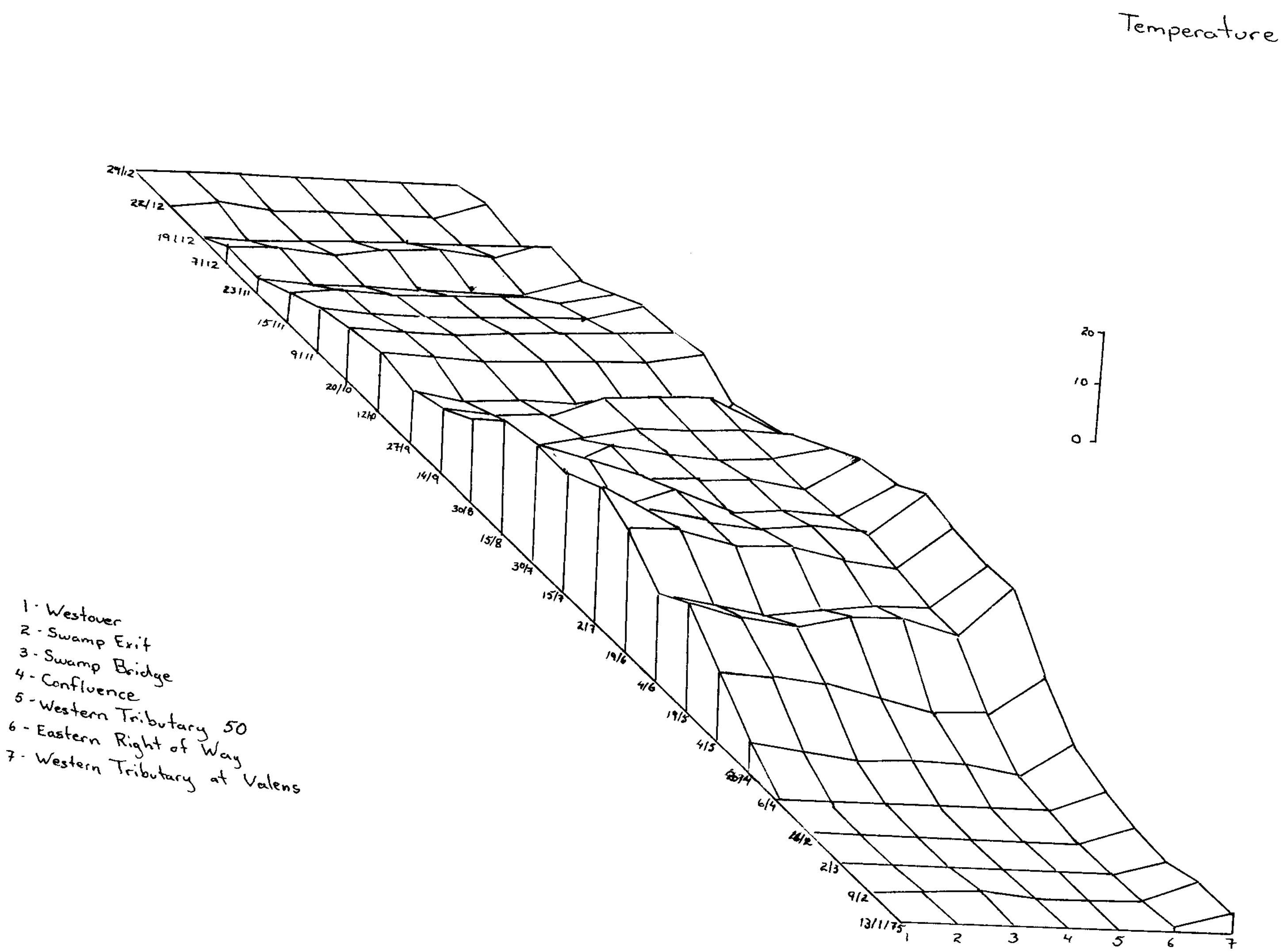


Figure IV-9 Exhibit both spatial and temporal changes in temperature for 1975

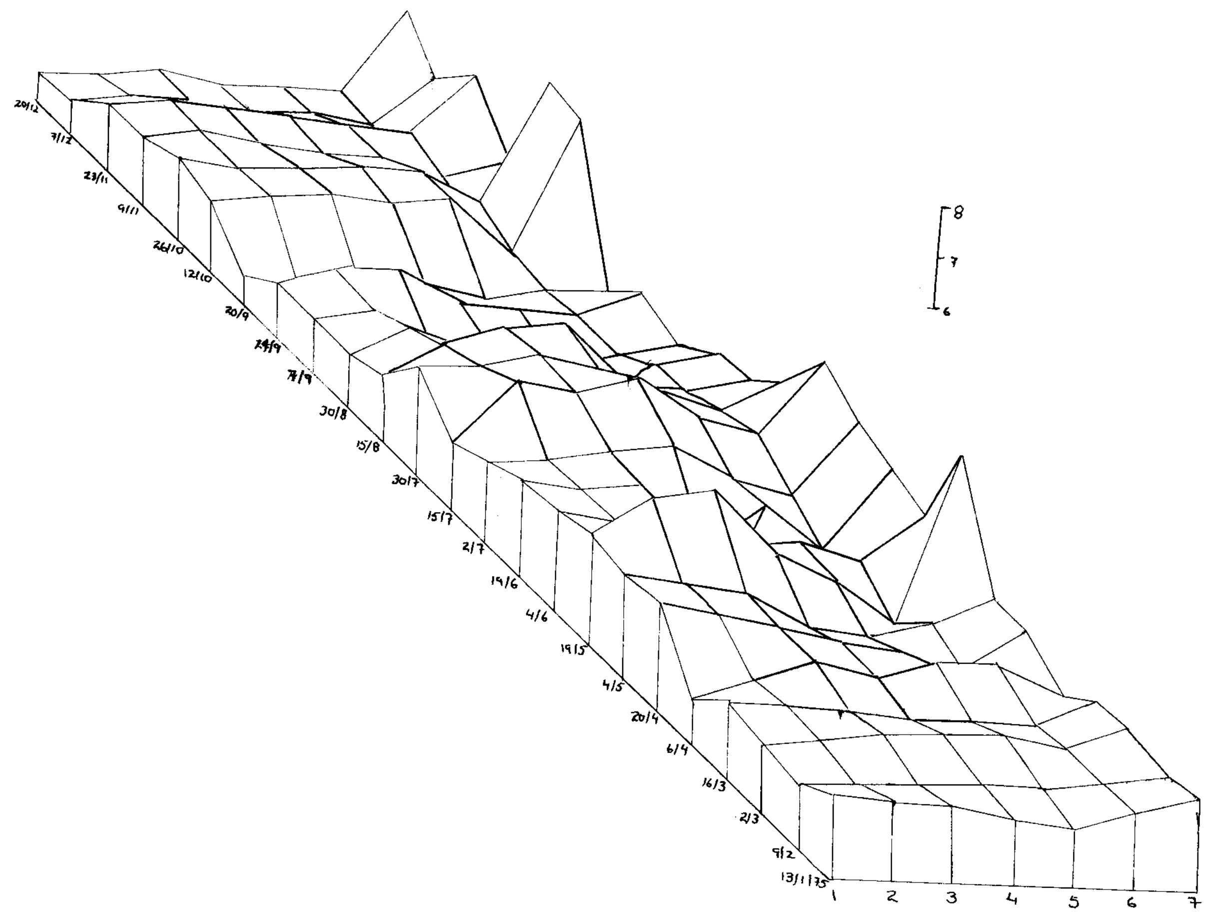


Figure IV-10 Exhibit both spatial and temporal changes in pH for 1975

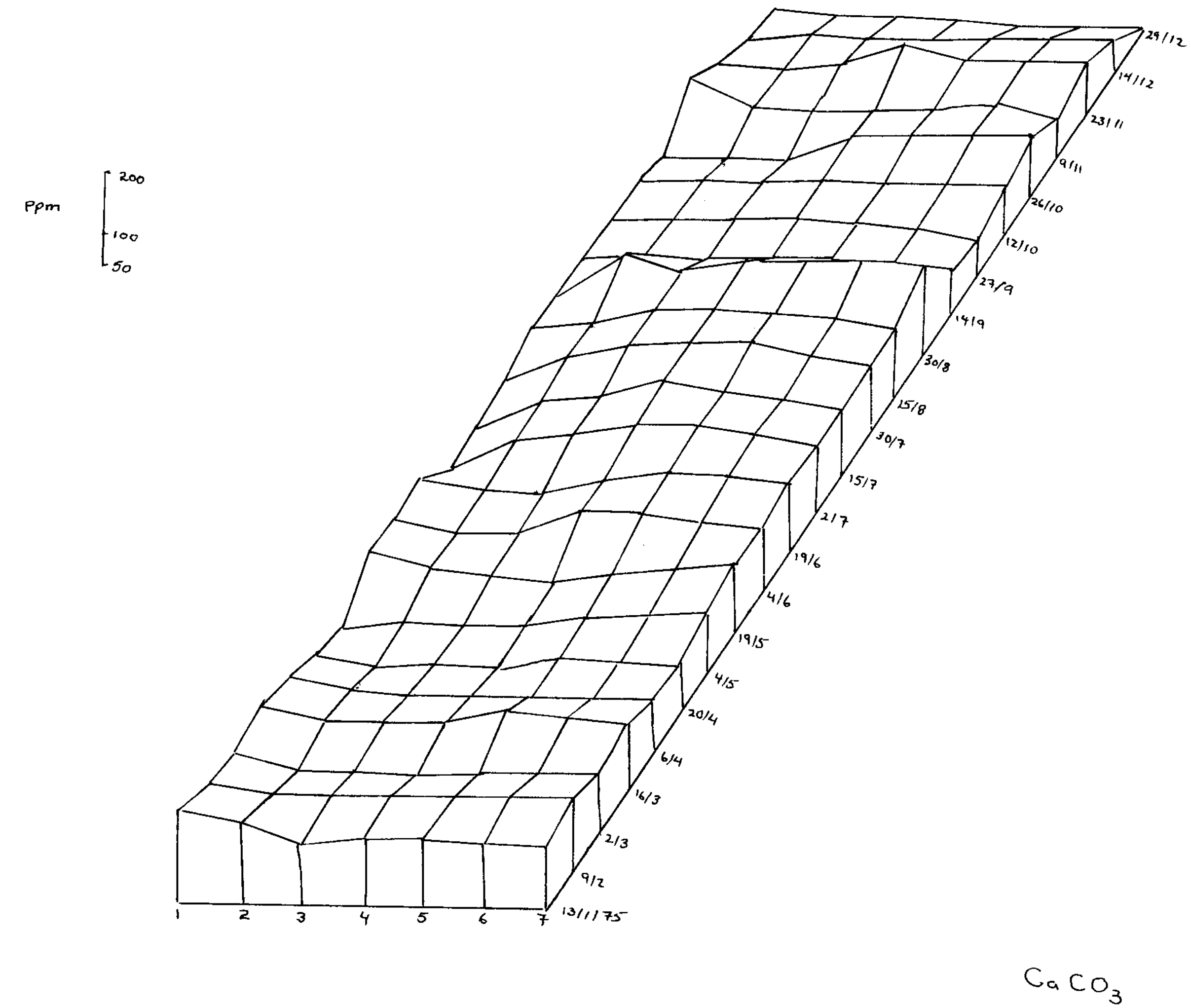


Figure IV·11 Exhibit both spatial and temporal changes in $CaCO_3$ for 1975

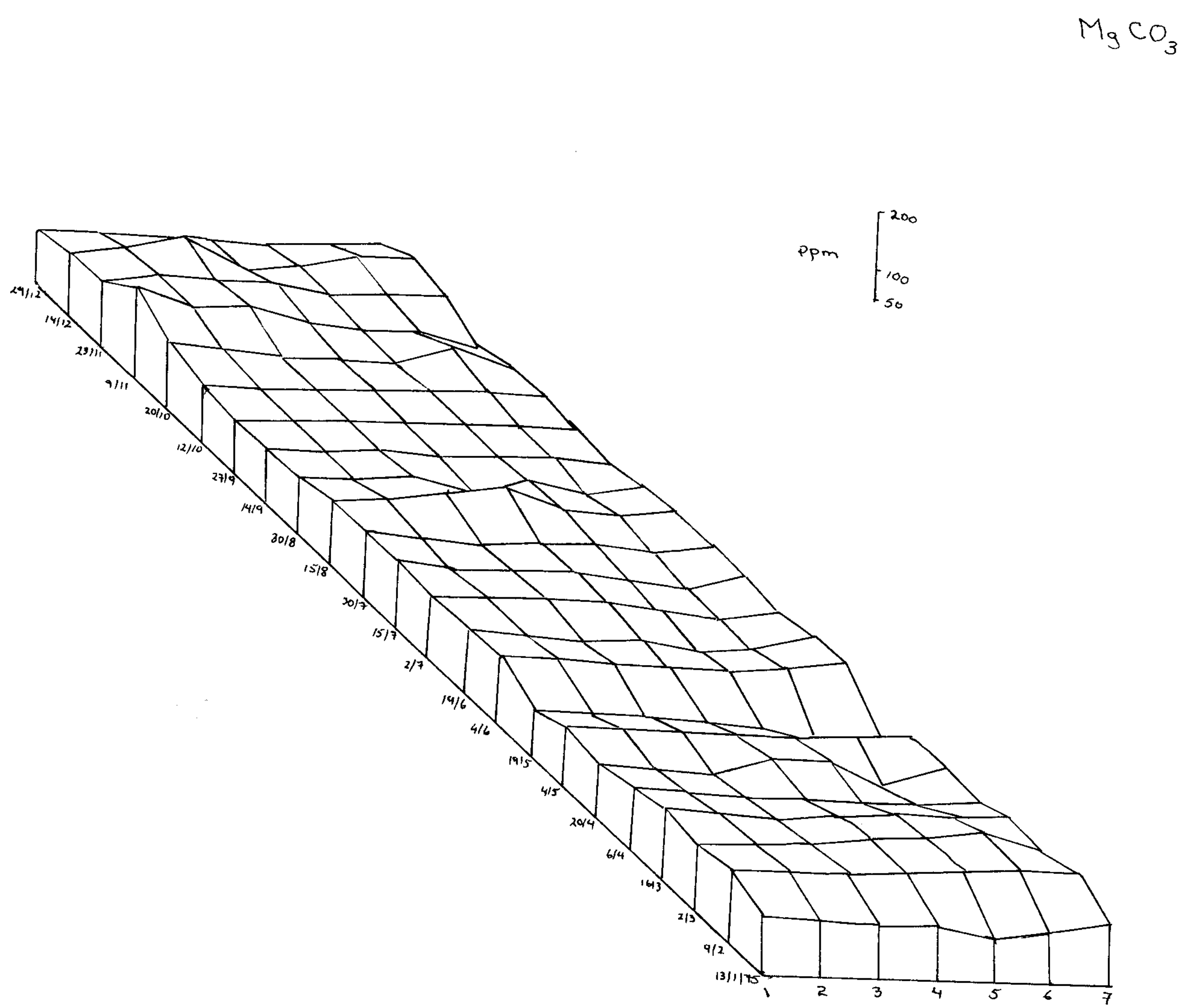


Figure IV-12 Exhibit spatial and temporal changes in $MgCO_3$ for 1975

Alkalinity

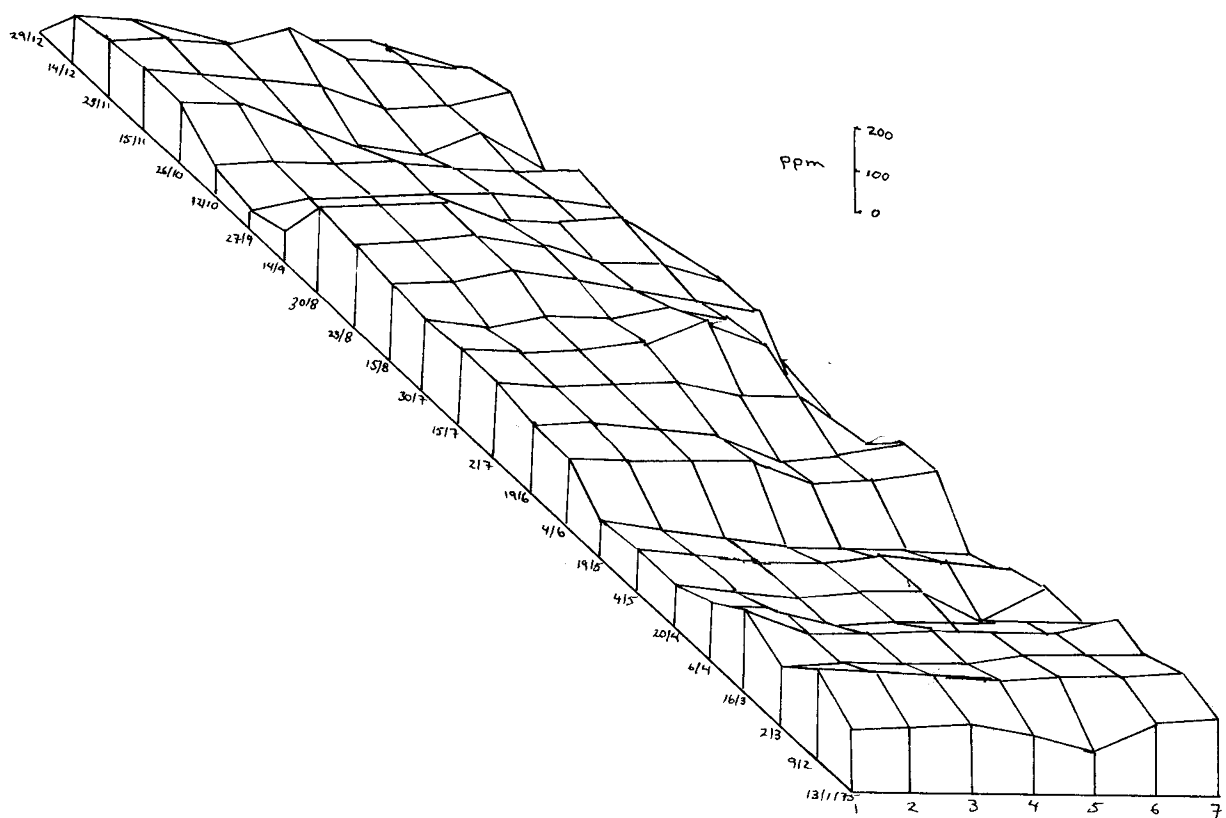


Figure IV-13 Exhibit spatial and temporal changes in Alkalinity for 1975

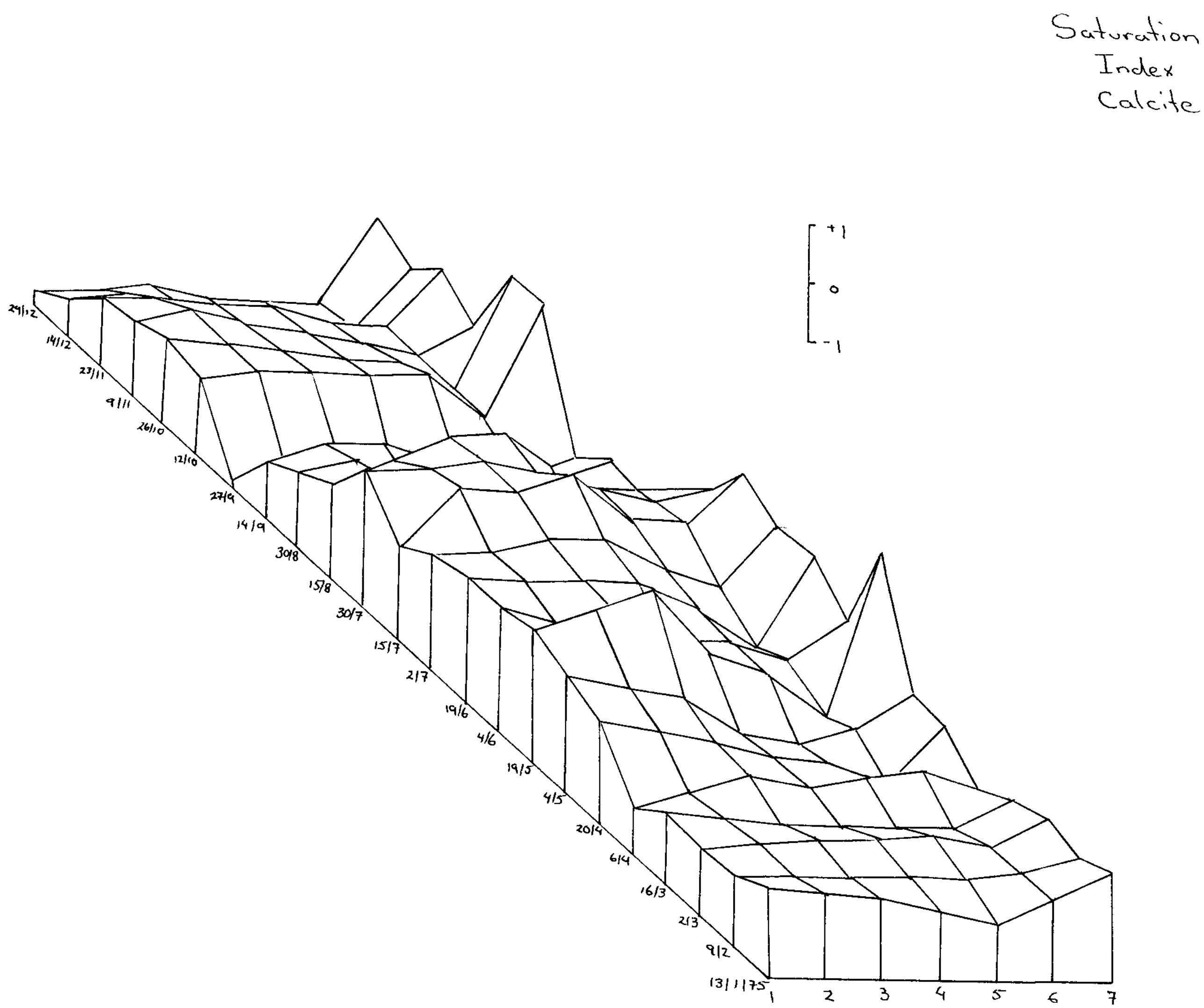


Figure IV-14 Exhibit spatial and temporal changes in the Saturation Index - calcite for 1975

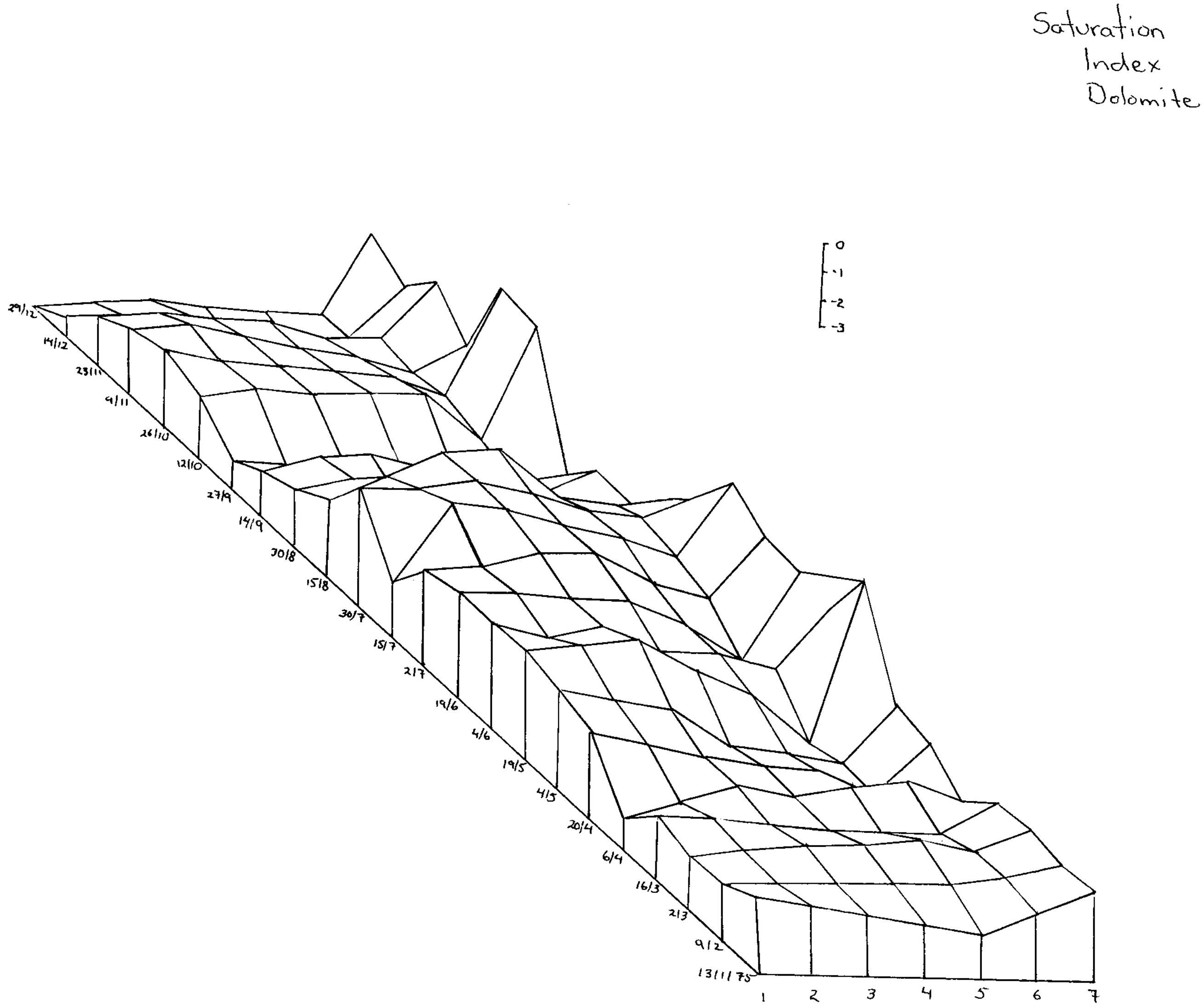


Figure IV-15 Exhibit spatial and temporal changes in the Saturation Index - dolomite for 1975 and magnesium hardness as well as alkalinity. The relatively high concentrations are due to the presence of limestone and dolomite bedrocks and high CO_2 production by biotic action particularly during the summer months.

To determine the effects of Beverly Swamp on the hydrochemical characteristics of the basin, a series of sampling sites were selected along Spencer Creek above, within and below the Swamp. Downstream variations of water temperature is shown in figure IV-9. Water released from Valens reservoir had a temperature of about $4^{o}C$, but was considerably higher in the summer. Once the stream enters the Swamp, temperature decreases as more shade was afforded by vegetation. On leaving the Swamp, a gradual increase in temperature was noticeable in the summer months.

Water entered the Swamp with a pH of between 7 and 9 due to the proximity of carbonate rock to the surface. Groundwater within the Swamp had pH values of 5.5 to 7.5 because of abundant vegetation and organic matter. The mixing of stream water with water from the phreatic and vadose zones reduced the pH of the stream. On leaving the Swamp, pH rose again. In summer, higher pH values were observed above and below the Swamp, and can be attributed to the increase of CO_2 solubility in warm water (see figure IV-10).

There was no systematic variation of magnesium, calcium and alkalinity over the basin (figure IV-11, IV-13). Both magnesium and calcium have isolated highs and lows but these are not confined to any specific station or stations. Alkalinity graph shows greater relief but again no definite pattern arises.

Saturation indices (SI_c and SI_d) indicate the saturation state of the water with respect to calcite and dolomite (equation IV-14, IV-15). Water entering the Swamp was supersaturated (figure IV-14, IV-15) but the degree of saturation was reduced as it entered the Swamp. Such effects of the Swamp on the saturation indices was conveyed downstream to the rest of the basin.

V - Hydrology and Hydrochemistry of Several Swamp Sites

V-1 Experimental Design

In 1975, observations were made in Beverly Swamp to study hydrologic and hydrochemical variations due to changing forest environment and forest cutting practice necessitated by Hydro powerline construction (figure IV-1, IV-2). An intensive study was carried out at three test sites (see figure I-1), with the following experimental design:

a) A control site was set up in the coniferous forest to provide a standard against which data from the other sites could be compared.

b) A proposed Hydro tower site, designated as north test site, occupied an existing forest opening, but otherwise resembled that of the Control site. Studies were carried out at this site to indicate any possible changes likely to be encountered after powerline construction.

c) South test site was located in a predominantly deciduous forest which was quite distinct from the vegetation of the Control site. Variations between these two sites were identified during the study period.

Figure V-1 Clearing right of way through Beverly Swamp

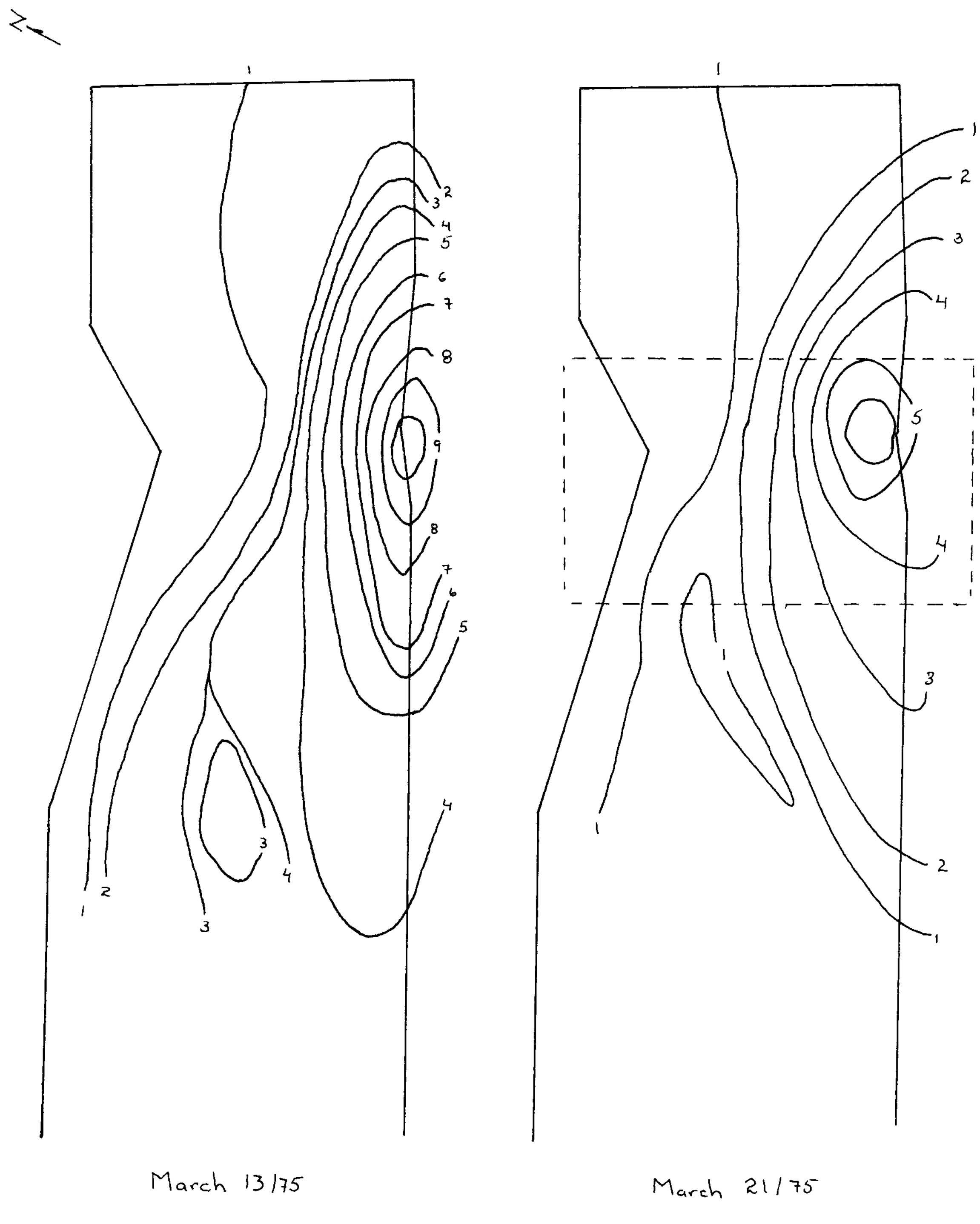
Figure V-2 Construction of hydro tower anchors in clearing

Six types of data were collected at approximately weekly intervals: snow distribution, rainfall, groundwater level readings, groundwater temperatures, soil temperatures and groundwater chemistry. Precipitation and soil temperature data were collected to detect the difference between open and forested areas, while the groundwater regime will be discussed in the context of changes in environment and cutting effects.

V-2 Precipitation

Study of precipitation took two forms: consideration of variations in the snow pack depth as related to the effects of interceptions, wind and shade; and rainfall as affected by interception. During the 1975 melt season an uneven distribution of snow in the forest clearing became apparent (figure V-3), and was characterized by greater depths along the southern border of the opening, and a shallower zone at the centre of the opening. A further study of this pattern was carried out during the winter of 1975-76 by placing a sampling grid across the opening and snow depths were measured at these sampling points.

Four weeks of data were compiled from January 9 to February 7 (figure V-4 to 8) at which time further cutting of the area was underway, thus changing the boundary between the forest and open zones. The dis-



- - - - Location of 1976 Intensive study on snow distribution
(depth in inches)

Figure V-3 Snow distribution in opening at the northern test site for two dates in 1975

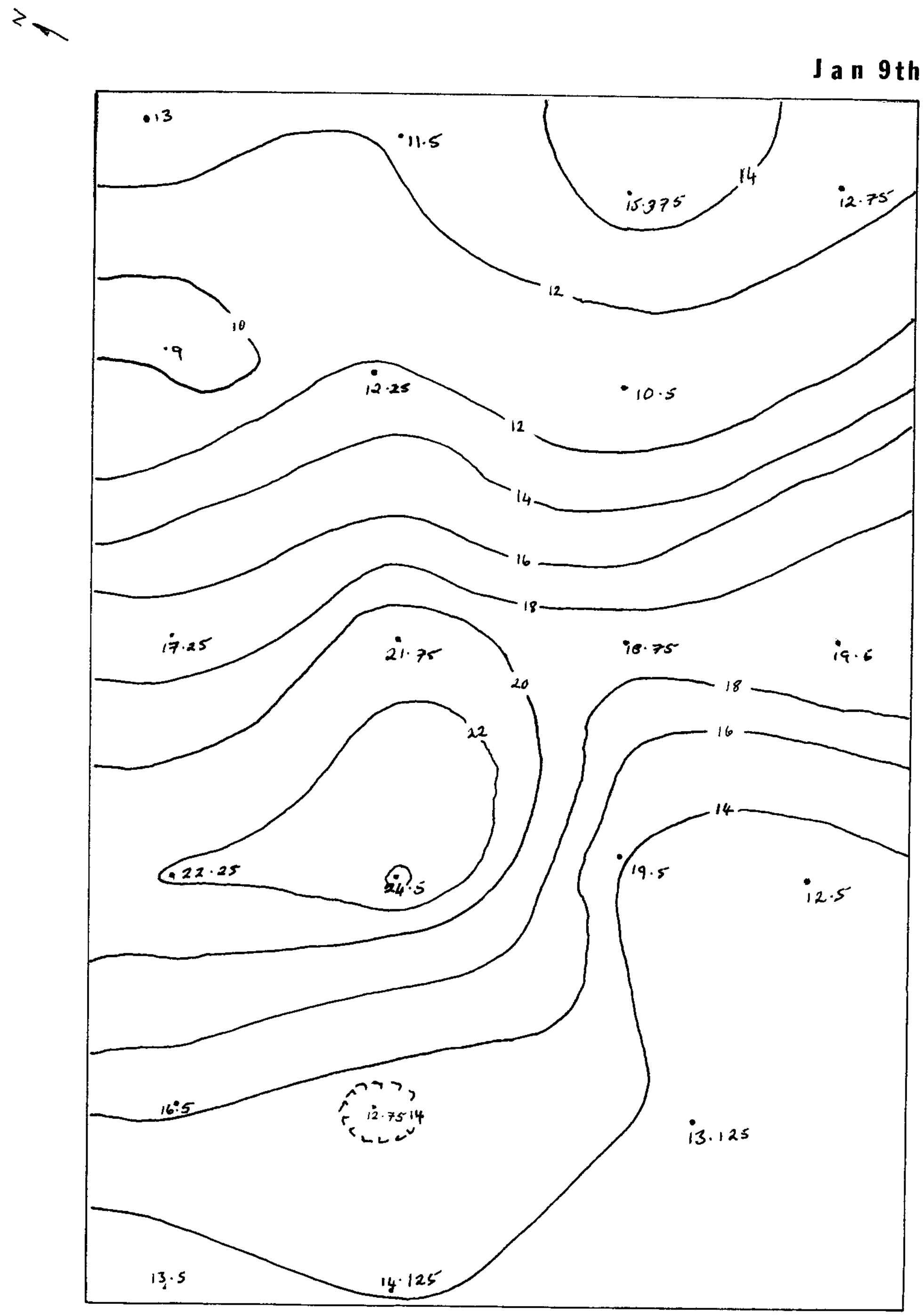


Figure V-4 Snow distribution in selected test area with opening in north test site for January 9, 1976

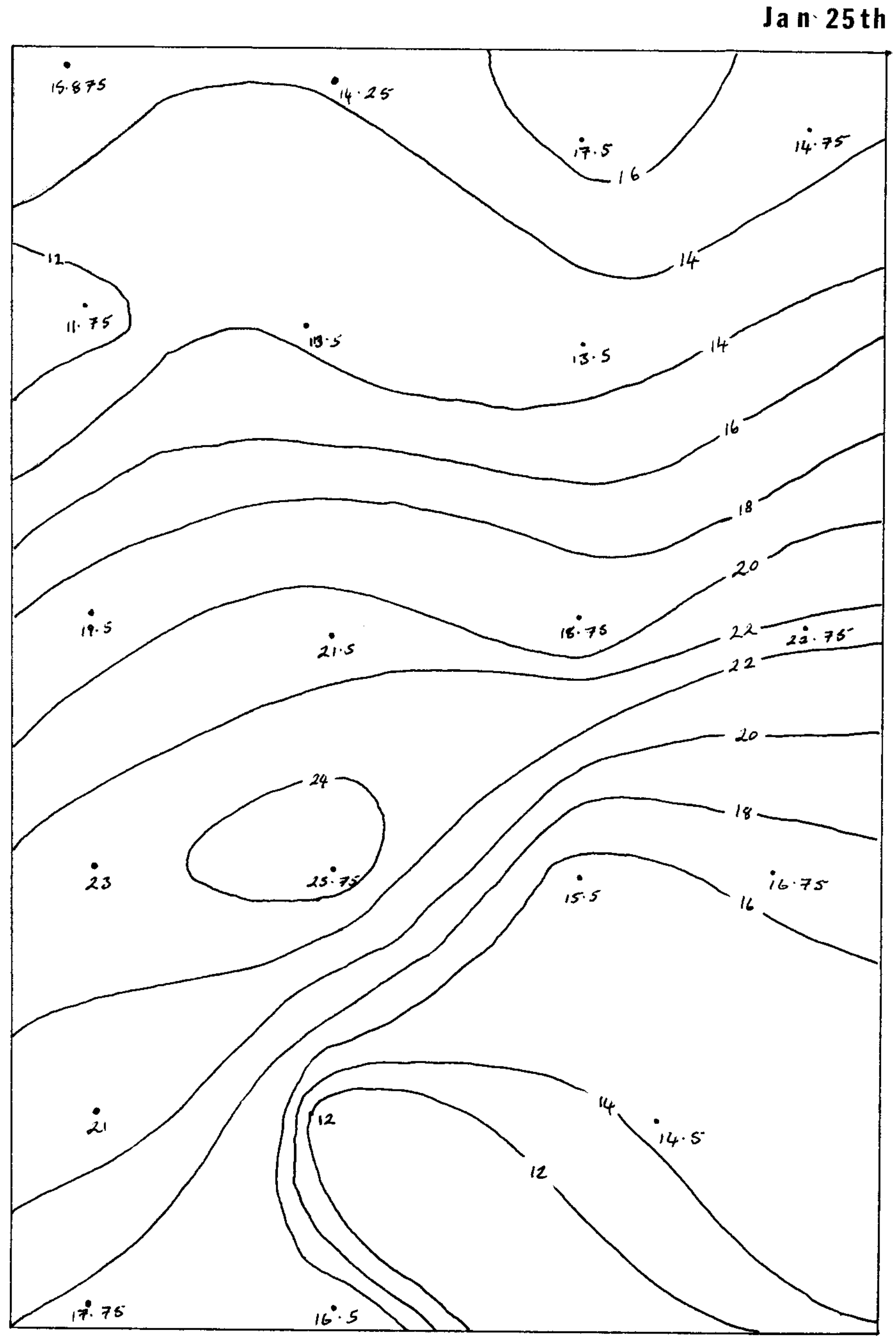


Figure V.5 Snow distribution in selected test area with opening in north test site for January 25, 1976

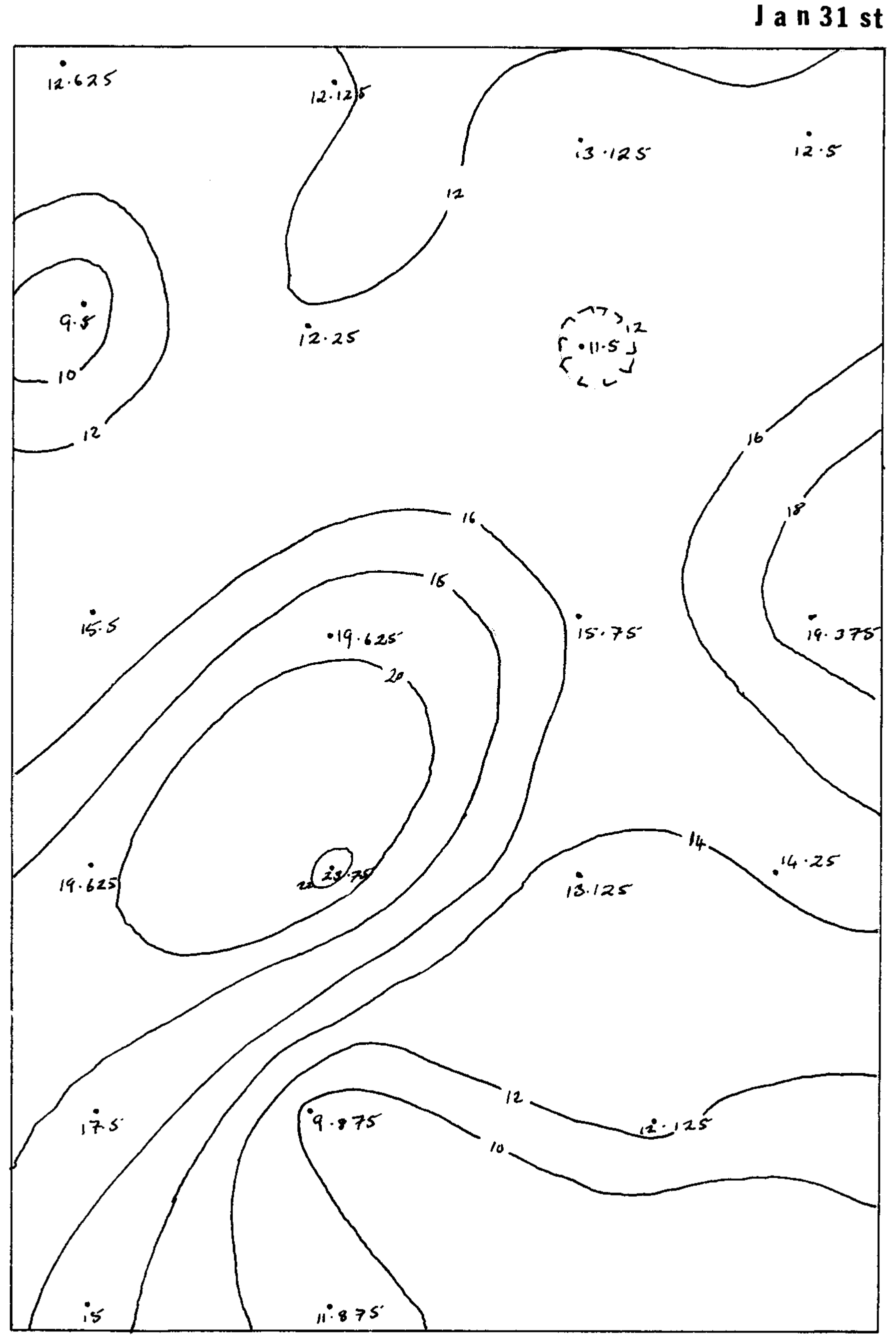


Figure V-6 Snow distribution in selected test area with opening in north test site for January 31, 1976

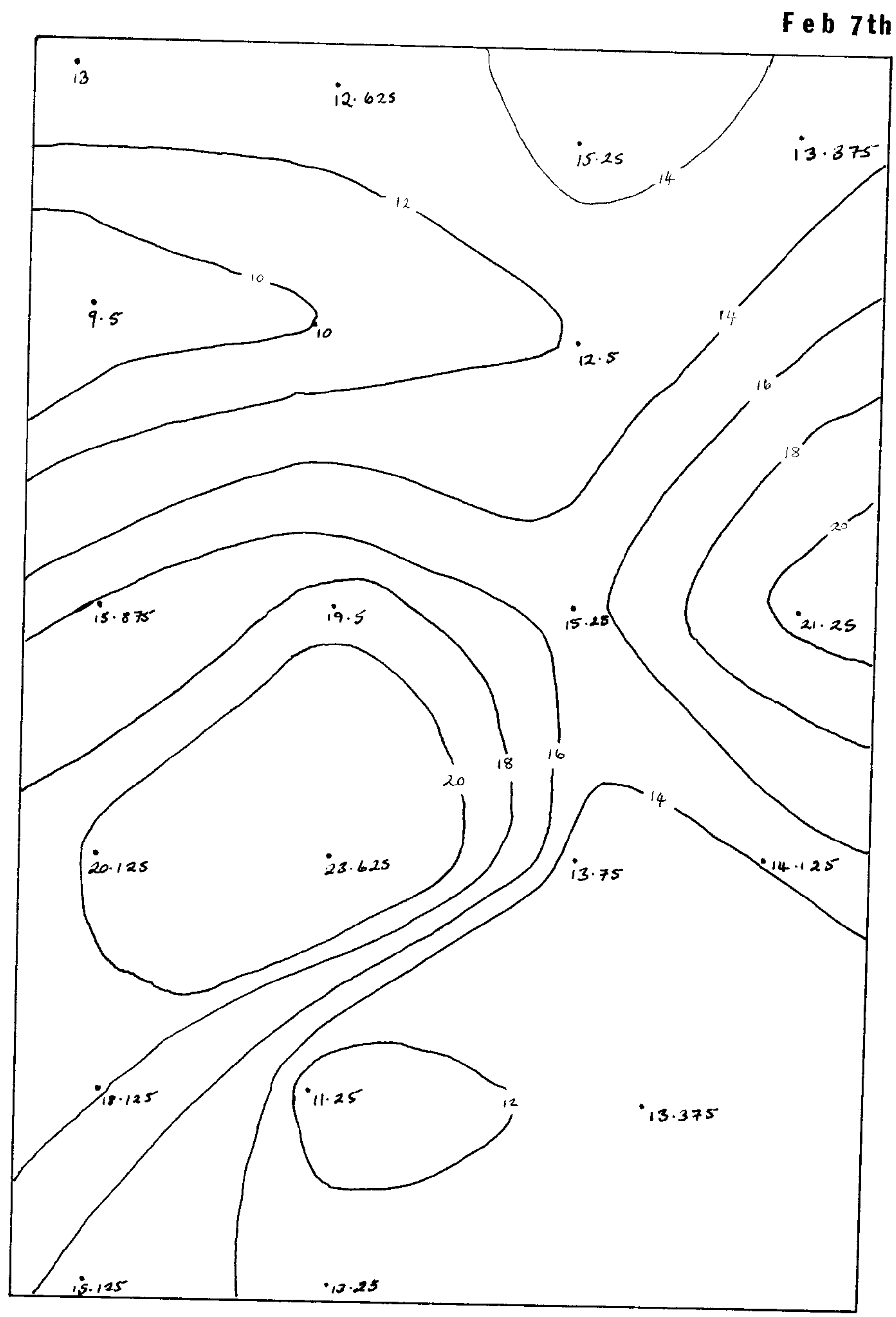


Figure V.7 Snow distribution in selected test area with opening in north test site for February 7, 1976

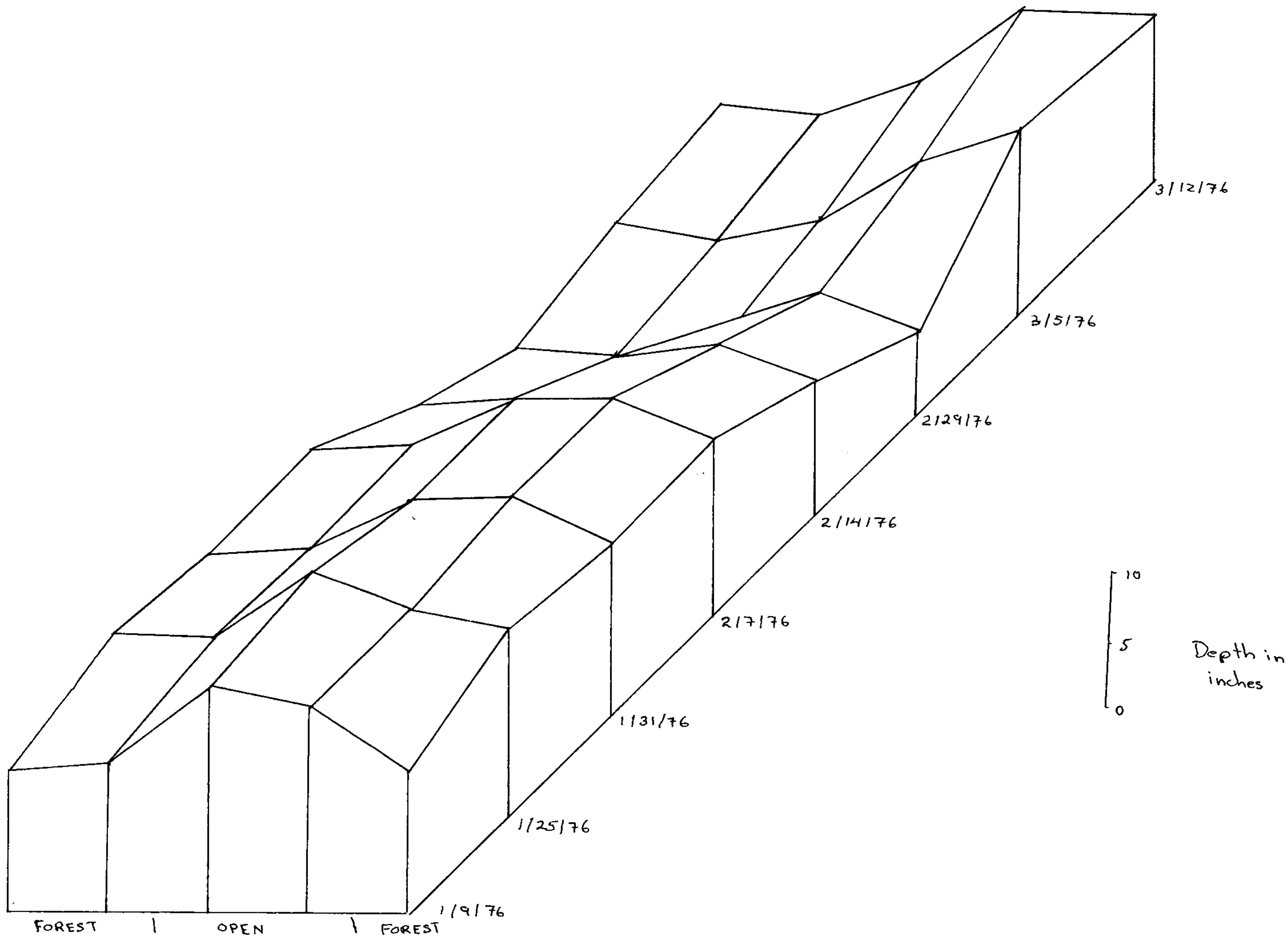
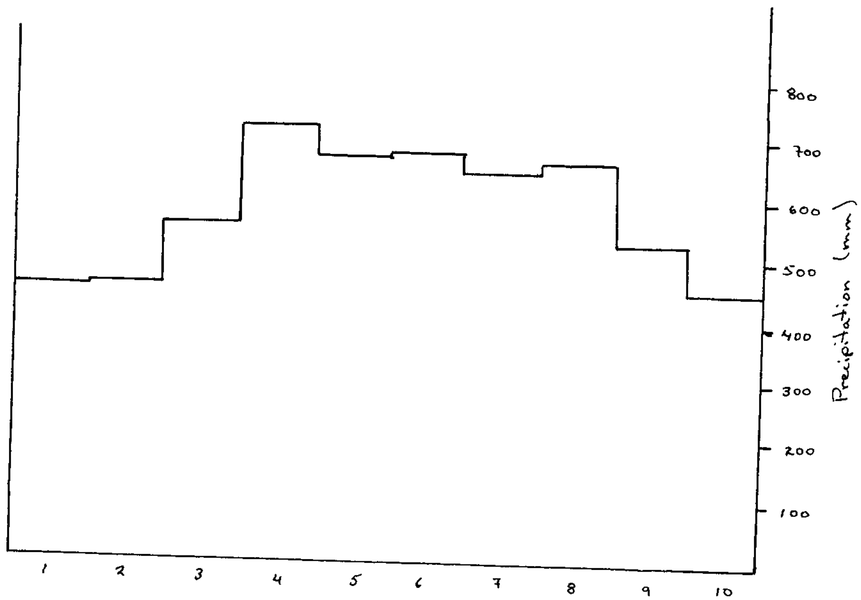


Figure V·8 Spatial temperal diagram exhibiting variations in snow distribution at groundwater test site



Total precipitation across clearing

Forest cover above individual gauges

Figure V-9 Total precipitation across clearing and the forest cover above individual gauges tribution of snow in both years were comparable, with a greater accumulation occurring in the open than under the forest canopy.

The most significant feature shown by the increased snow accumulation in the clearing was the decrease in depth downwind. These features have been observed in previous studies (Gary, 1974; Hoover and Leaf, 1967; Krecmer, 1966; Rothacher, 1965; Anderson and Gleason, 1959). Gary (1974) considered the differences between the opening and the forested area to be related to the back eddies from the prevailing winds, shade afforded by trees and the amount of solar energy penetrating the trees. Figure V-8 shows the prevailing wind direction for the winter period (SSW according to the Monthly Weather Records, 1975) and the shaded region, along the southern border. Snow distribution measurements (figure V-4, V-8) and environment variables conform to findings by Gray (1974) and Anderson and Gleason (1959).

Rainfall measurements at the North test site were made from the beginning of May to December 7, providing mean weekly values ranging from 0 to 60 mm. Individual rain gauges showed large variation (figure V-7), but the presence of the opening caused an abrupt increase in precipitation (Krecmer, 1966; Niederhof and Wilm, 1943). Both weekly and seasonal totals exhibited a reduction of rainfall in the wooded area where interception was high.

A further set of rain gauges were positioned west of the previous line at the end of August to verify the results obtained for the North test site; which they did. Rainfall at the control site, having the same vegetation characteristics as the North test site, was also measured after mid-July, with comparable values between the Control and the North test site.

V-3 Soil Temperature

Soil temperature was measured weekly within the North test site (figure V-10, V-11) and a selected forest site, at depths of 1, 5, 10, 25, 50, 100 cm. The open site warmed up earlier in the spring due to more intense solar radiation afforded by the clearing, and continued to maintain its high temperature for the rest of the year. Woo (1975) investigated the soil temperature regime of Beverly Swamp and found that as a result of winter flooding of the swamp:

1. At no time was the swamp soil frozen in 1974.
2. Winter fluctuations in near surface temperature was greatly dampened.
3. In spring, the heating up of the ground was delayed.
4. Temperatures generated by the estimated Fourier-parameters gave increasingly better fit towards greater depth, suggesting that ground temperatures

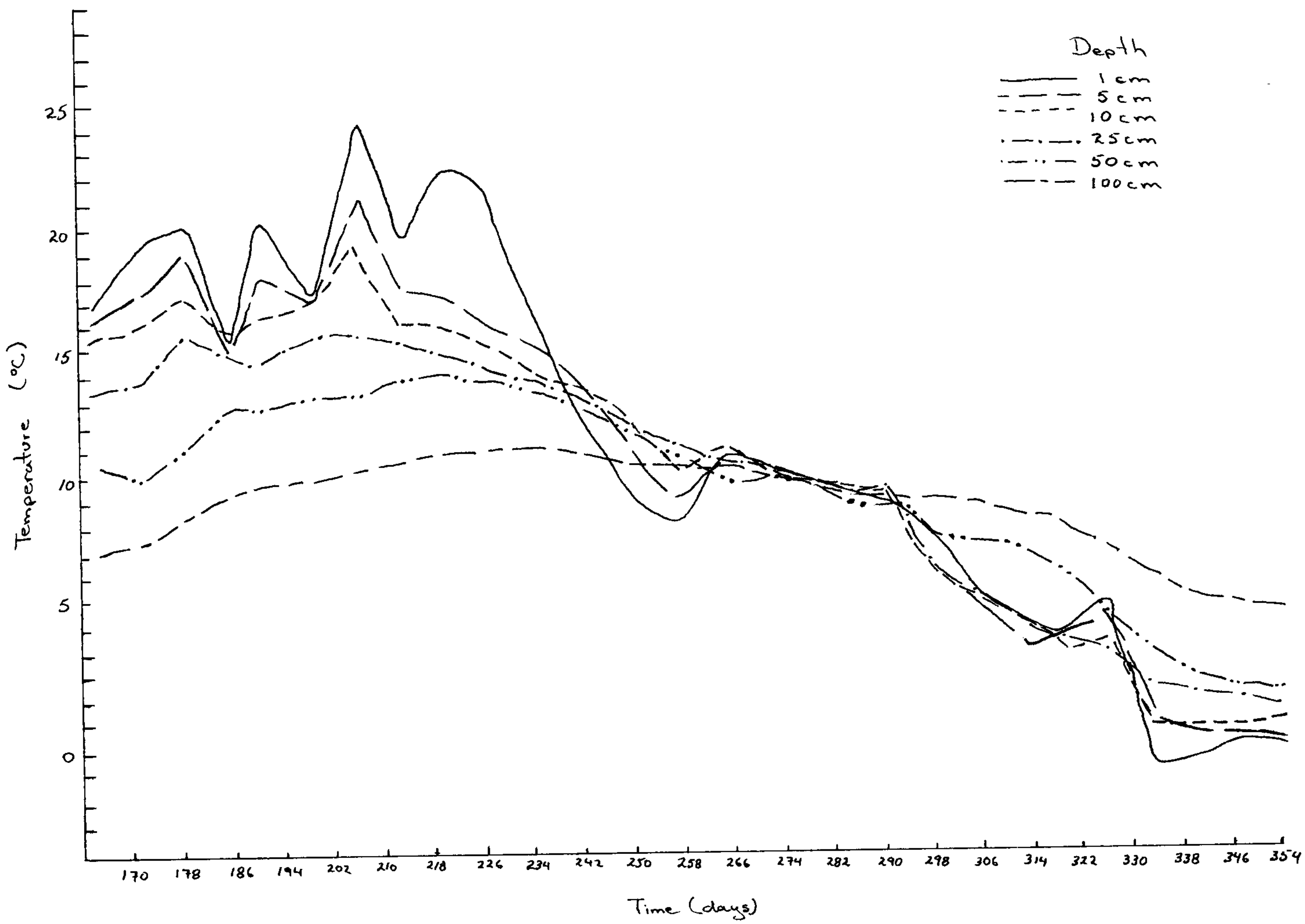


Figure V-10 Variation in ground temperature within forested area

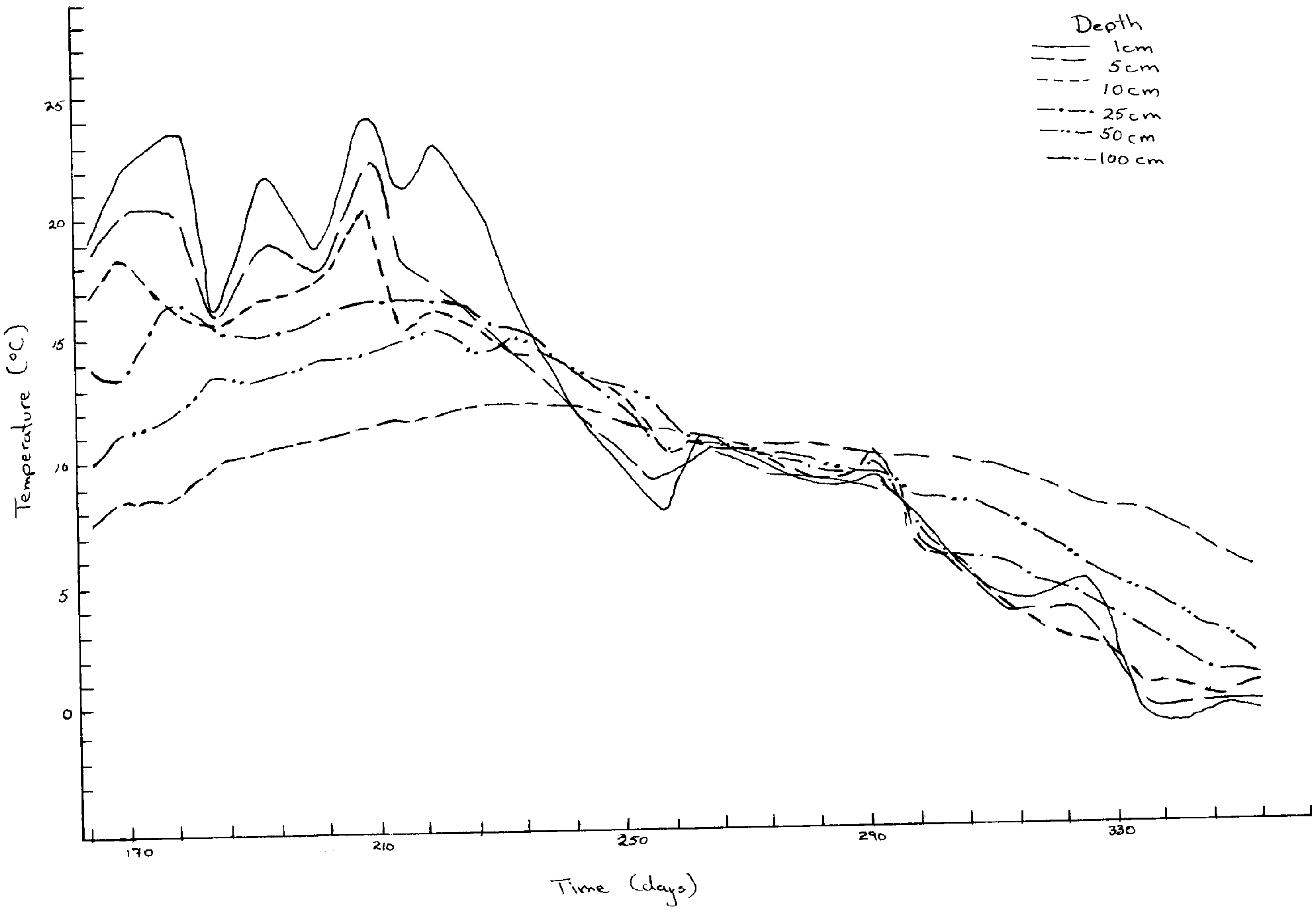


Figure V.11 Variation in ground temperature within opening within the first meter are noticeably affected by winter flooding.

V-4 Groundwater Temperature

Groundwater temperature was measured at ten plots in the North test sites and South test site, and at six plots in the Control site. The open canopy of the mixed wood in the South test site yielded higher groundwater temperatures than at the Control site which had a dense coniferous cover (appendix 1). The effect of the opening at the North test site caused an increase of groundwater temperature by 1-3°C (appendix 1).

The North test site shows a definite spatial pattern with high values centering around the clearing. This distribution is continued to the end of October. Then the pattern started to reverse. The higher temperatures were caused by more intense solar radiation in the clearing (Pluhowski and Kantrowitz, 1963). During the onset of winter the opening experiences cooler temperatures because it lacks the insulating effect afforded by the vegetation (Curgo and Mallory, 1974). The South test site exhibited no definite spatial pattern and this is to be expected of a uniform forest canopy.

V-5 Groundwater Chemistry

The occurrence of a clearing in the North test site increased the groundwater temperature (section V-4), concurrent with an increased production in carbon dioxide (IV-1). The partial pressure of carbon dioxide (PCO_2) was found to be extremely high, averaging approximately 0.3 percent ($\log PCO_2 = -1.5$), a value ten times higher than the global mean of 0.03 percent ($\log PCO_2 = -3.5$), this factor accounts for the reduced pH values through the production of carbonic acid. Sjors (1961) and, Moore and Bellamy (1974) pointed out that organic terrains are characterized by low pH and high dissolved $CaCO_3$ (Appendix 1). South test site exhibits generally lower pH values than the North as a result of the availability of organic material from the decomposition of deciduous leaves. The lowest pH values occurred during the driest period where high evaporation and high biotic activity build up the scils acidity.

High acidity helped to maintain large concentrations of calcium and magnesium in solution, with an increase in concentration towards the centre of the clearing. However there was a slight bias of peak values towards the northern edge of the opening.Such bias may be related to more intense exposure to the sun, thus suggesting a possible link between the microclimate and groundwater chemistry of a forest cutting.

V-6 Groundwater level changes

Groundwater level fluctuations parallel closely seasonal variations in groundwater temperature and stream flow. A continuous record of groundwater level near the South site shows the similarity between groundwater and stream flow regimes (figure V-12). Using the groundwater level of June 20 as the base, the weekly water level changes of the test sites (appendix 1) were computed to obtain a spatial pattern. The North test site showed a greater amount of water level decrease at the centre of the opening than at the edges. By the end of October, increasing rainfall, a reduction in evaporation and the release of water from Valens reservoir raised the water level of all the sites. Flooding of the swamp erased out any variation occurring during the summer months. The Control and North test sites show greater losses in groundwater than the South.

V-7 Conclusion

Field studies have revealed three major characteristics regarding the hydrochemistry of Beverly Swamp:

1. Biotic activities within the Swamp modity the chemistry of the stream water which passes through it. This finding is confirmed by other

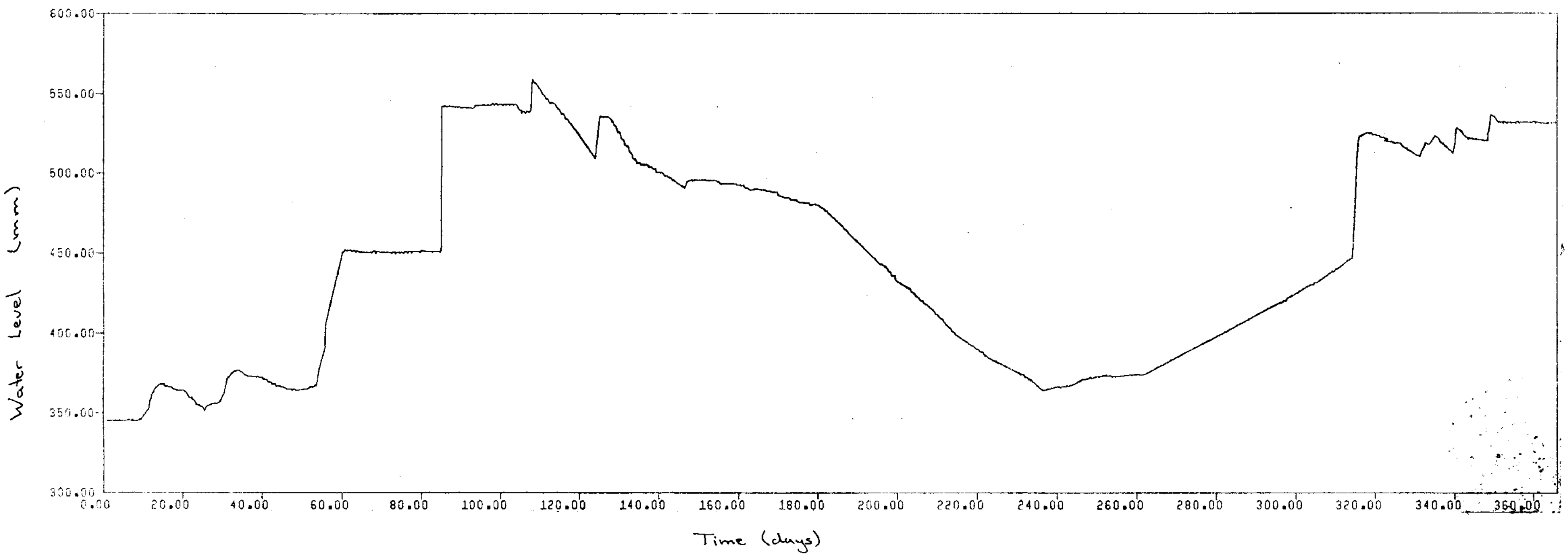
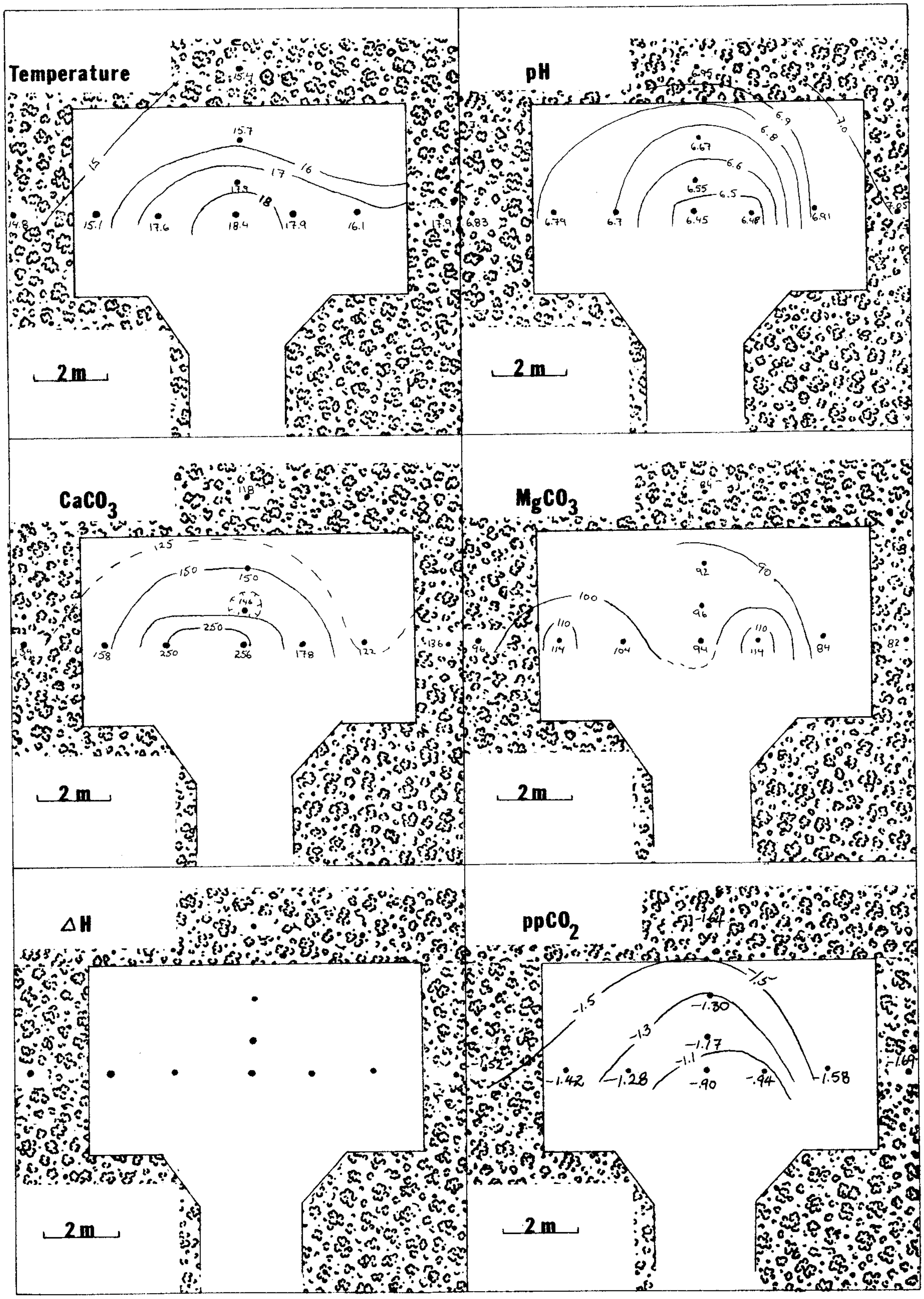


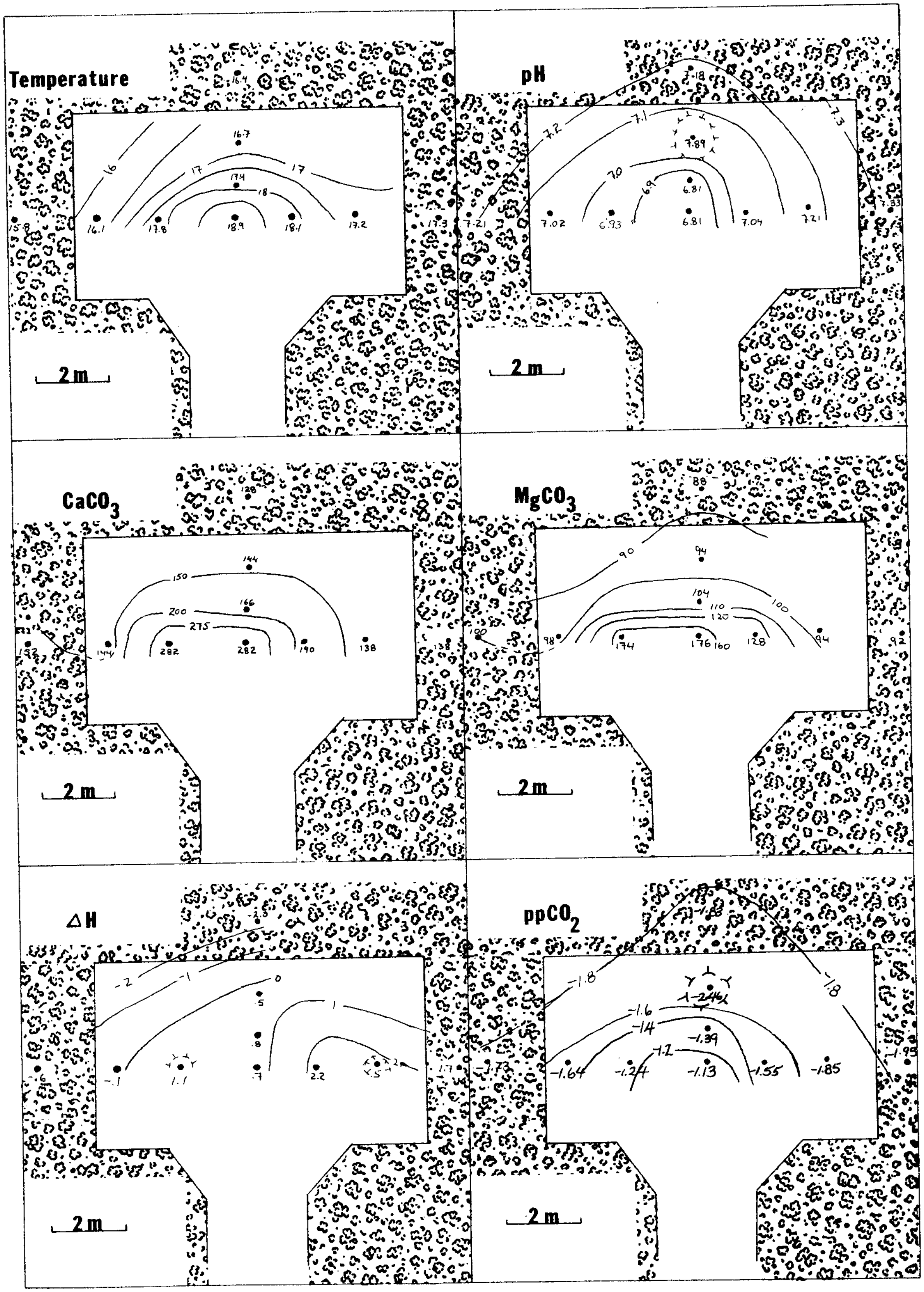
Figure V-12 Beverly Swamp Groundwater levels, 1975 investigators of the swamp-environment.

2. There are significant natural differences between sites located in the southern and northern portion of Beverly Swamp which are particularly dependent upon variations in vegetation type.
3. Forest clearing in the swamp resulted in changes in snow and rainfall distribution, groundwater chemistry, soil and water temperatures. These changes indicate the possibility of an environmental impact likely to be produced by the Hydro construction programme.

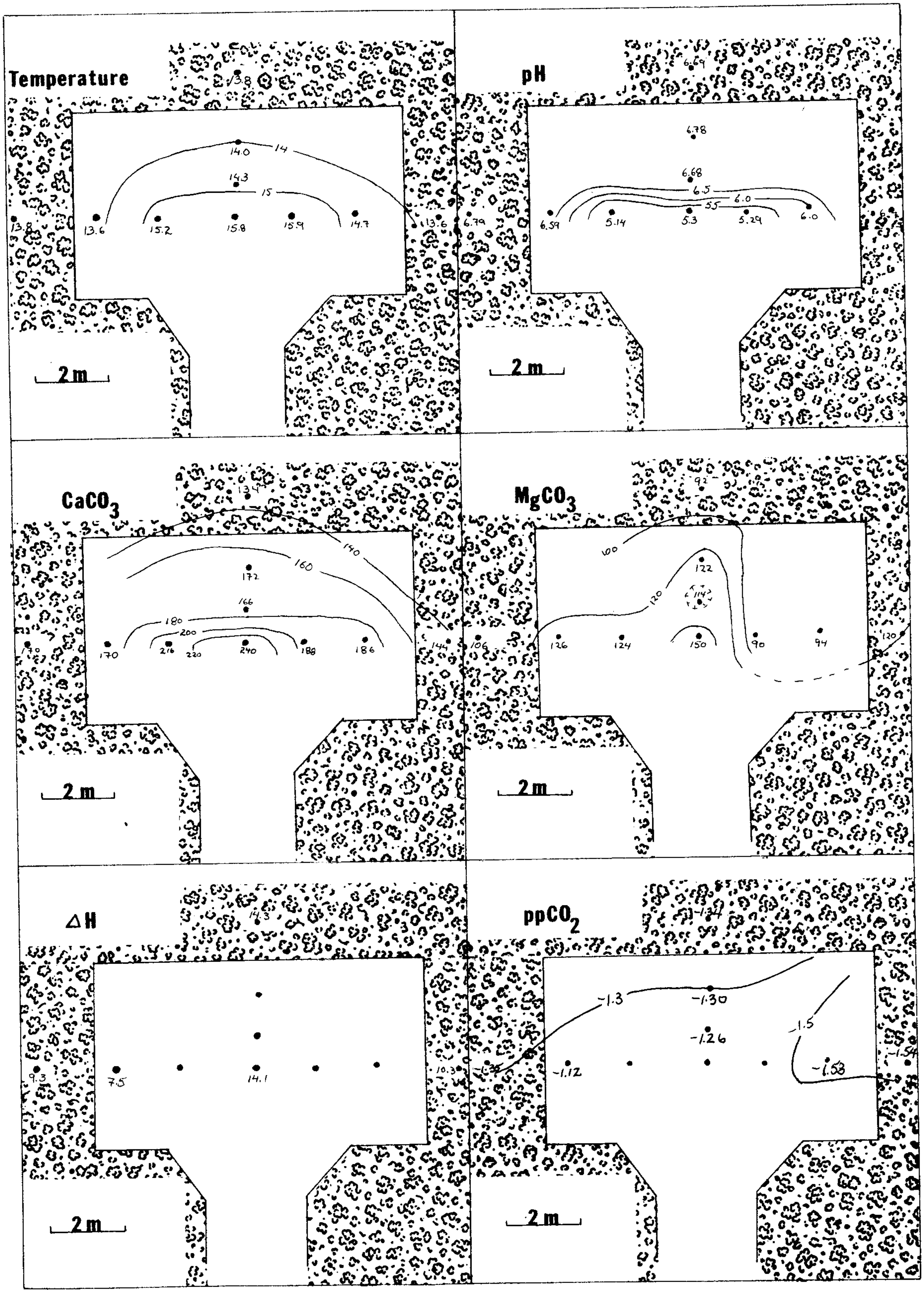
APPENDIX I


Temperature
15.4
15.7
15
16
17
18
17.9
14.8
15.1
17.6
18.4
17.9
16.1
17.9
2 m
pH
6.95
6.9
7.0
6.8
6.67
6.6
6.55
6.5
6.83
6.79
6.7
6.45
6.48
6.91
2 m
CaCO$_3$
118
125
150
150
146
250
134
158
250
256
178
122
136
2 m
MgCO$_3$
84
92
90
100
96
110
110
96
114
104
94
114
84
82
2 m
△H
2 m
ppCO$_2$
-1.64
-1.5
-1.5
-1.30
-1.3
-1.77
-1.1
-1.52
-1.42
-1.28
-.90
-.94
-1.58
-1.69
2 m

June 20 1975



June 24


Temperature
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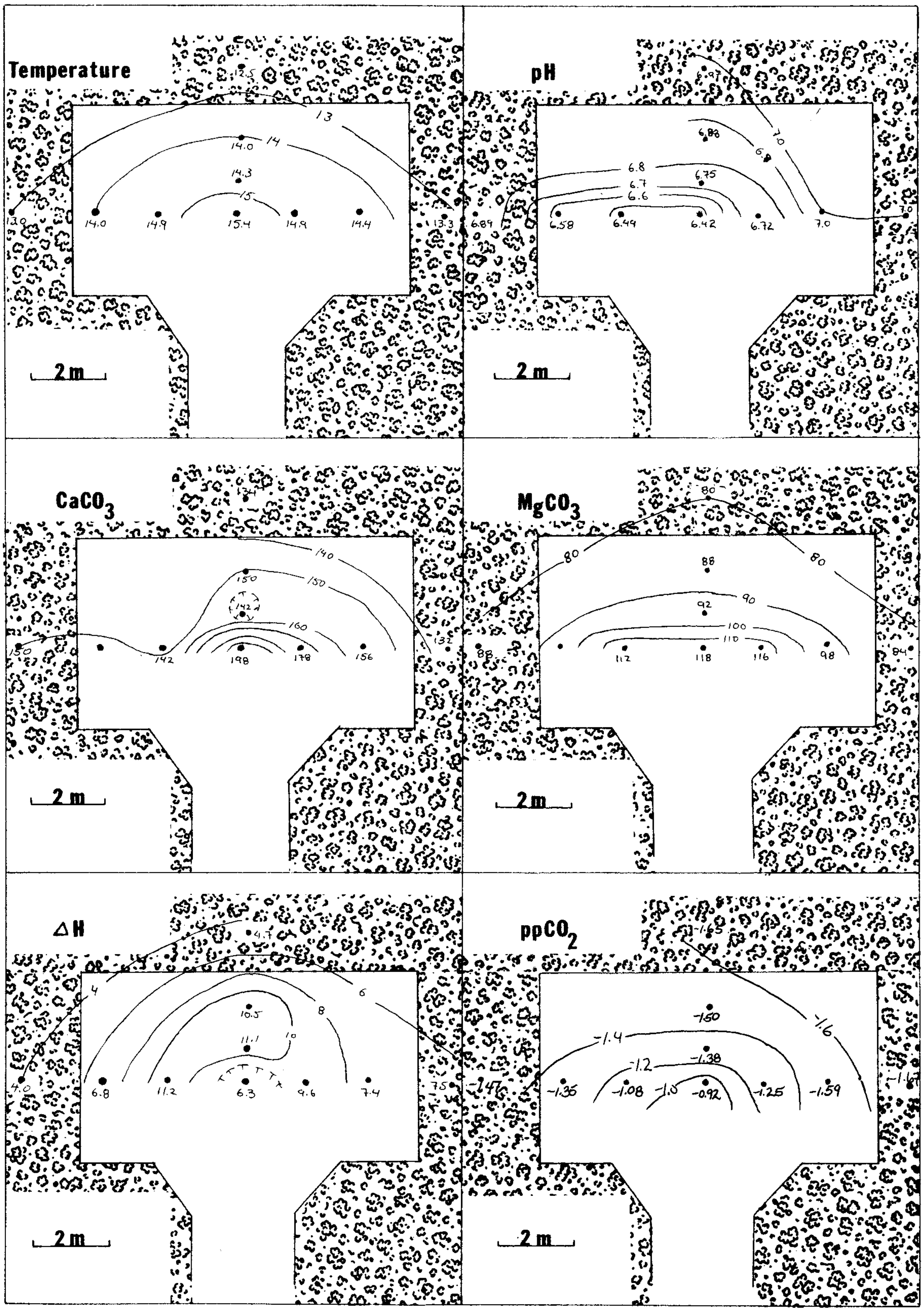
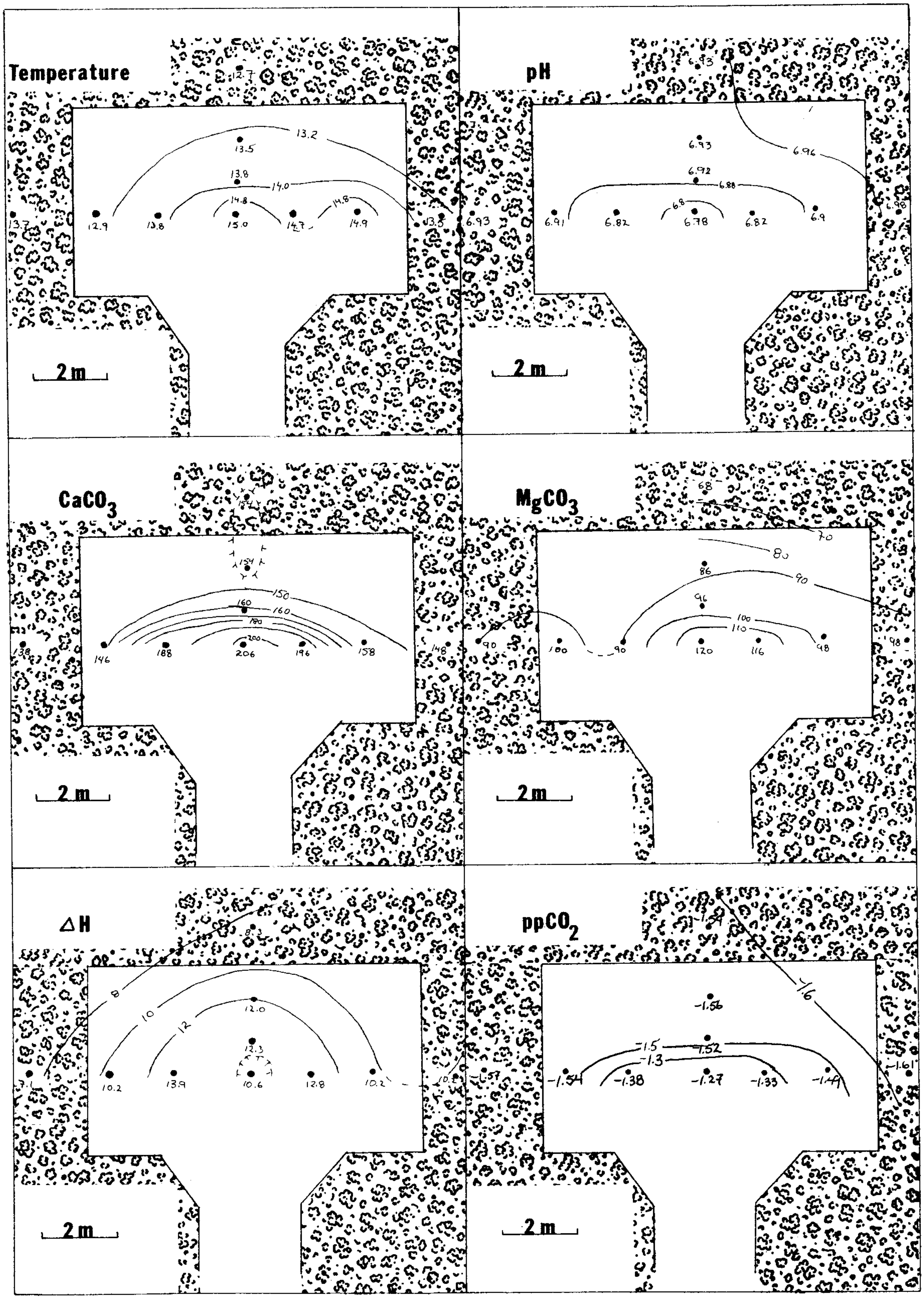
14
14.3
15
13.8
13.6
15.2
15.8
15.9
14.7
13.6
2m
pH
6.69
6.78
6.68
6.5
6.0
5.5
6.79
6.59
5.14
5.3
5.29
6.0
2m
CaCO3
134
140
160
172
166
180
200
170
216
220
240
188
186
144
2m
MgCO3
92
100
122
120
114
106
126
124
150
90
94
120
2m
ΔH
14.3
9.3
7.5
14.1
10.3
2m
ppCO2
-1.34
-1.3
-1.30
-1.26
-1.5
-1.12
-1.53
-1.54
2m

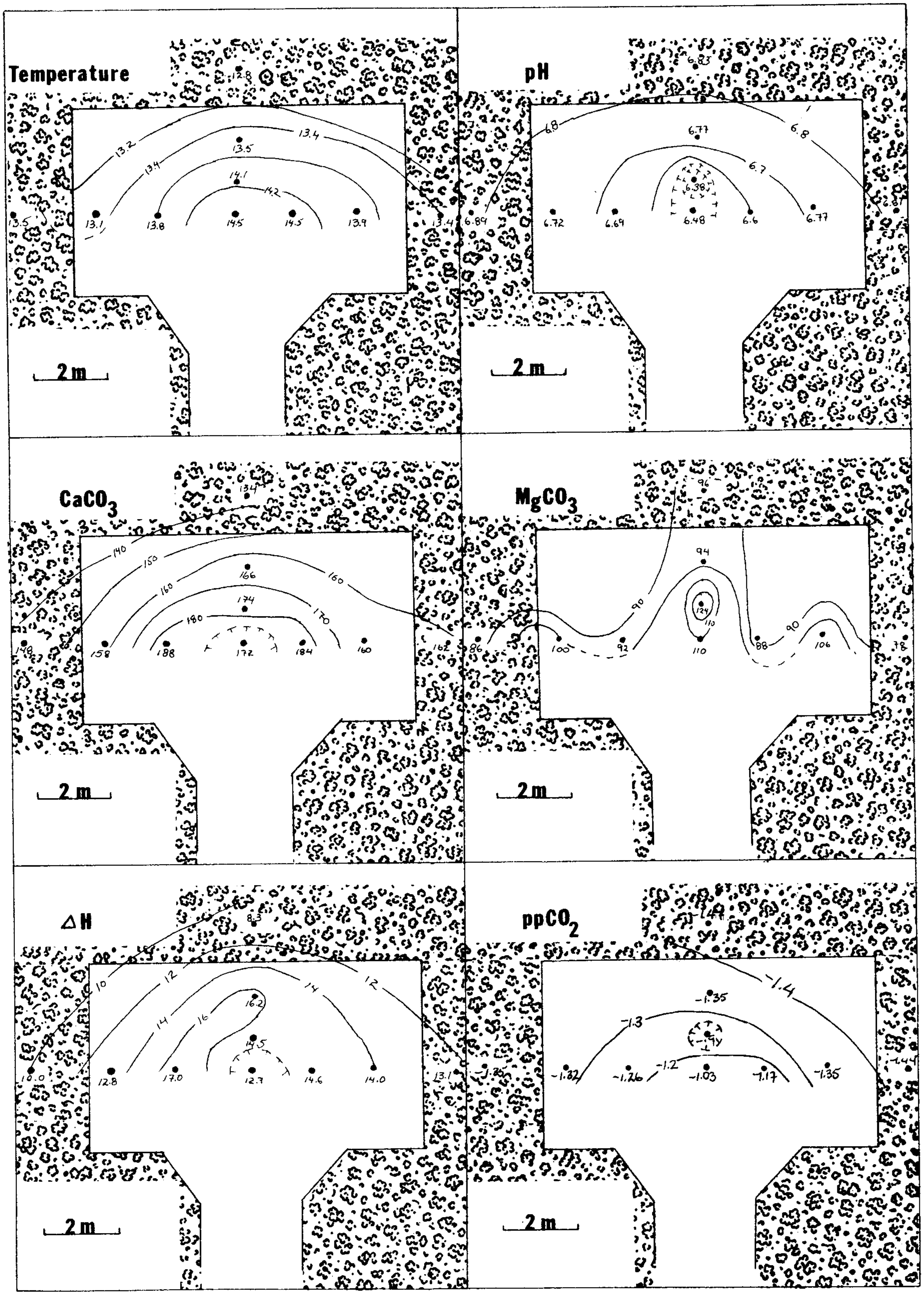
July 4


Temperature
13
14
15
14.0
14.3
13.0
14.0
14.9
15.4
14.9
14.4
13.3
2 m
pH
7.0
6.9
6.8
6.7
6.6
6.88
6.75
6.89
6.58
6.49
6.42
6.72
7.0
7.0
2 m
$CaCO_3$
140
150
160
150
142
142
198
178
156
132
2 m
$MgCO_3$
80
80
80
88
90
92
100
110
88
112
118
116
98
84
2 m
ΔH
4
6
8
10
10.5
11.1
4.0
6.8
11.2
6.3
9.6
7.4
7.5
2 m
$ppCO_2$
-1.4
-1.2
-1.0
-1.6
-1.65
-1.60
-1.38
-1.47
-1.35
-1.08
-0.92
-1.25
-1.59
-1.67
2 m

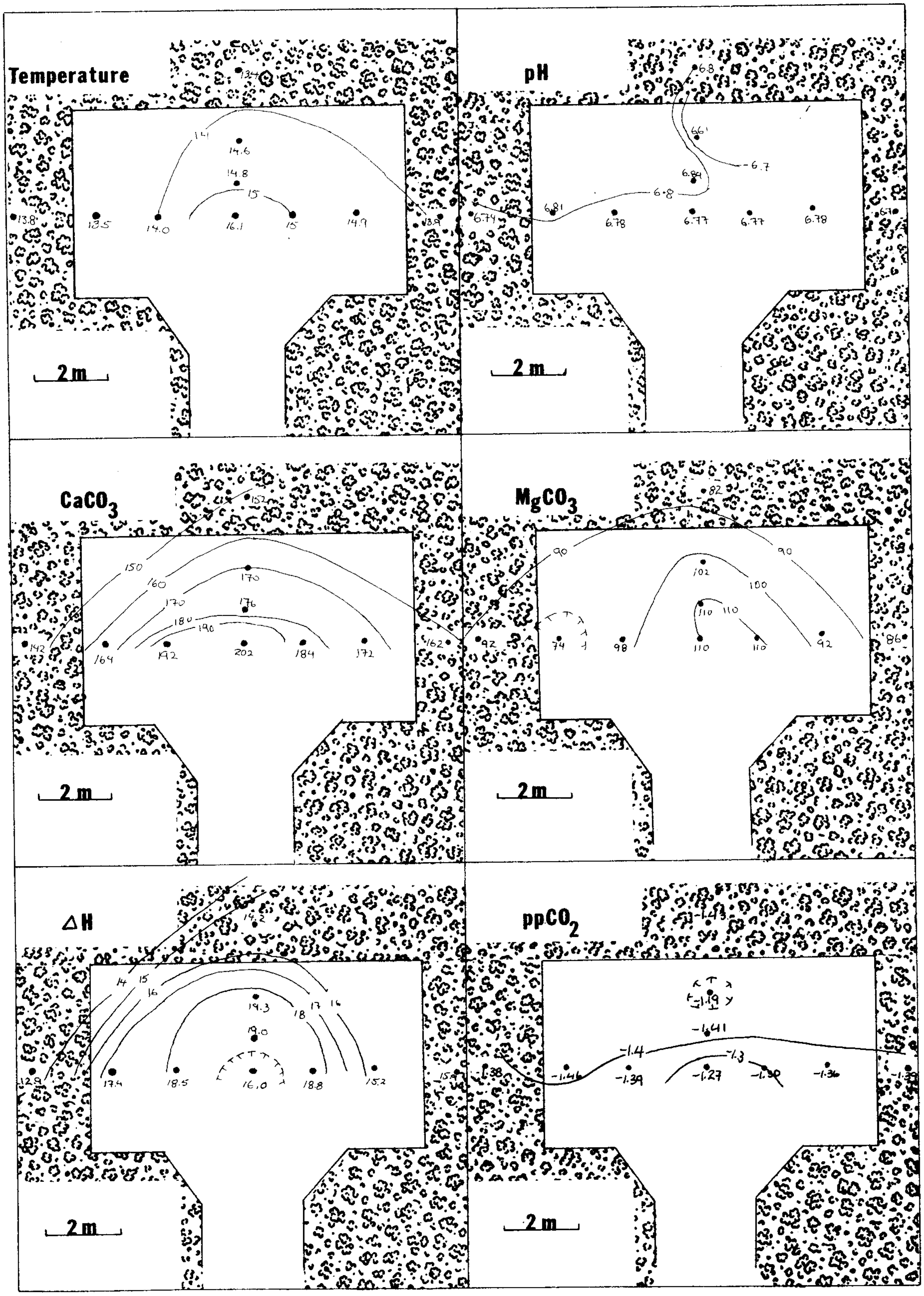
July 11


Temperature
13.2
14.0
14.8
2m
pH
6.96
6.88
2m
$CaCO_3$
150
160
2m
$MgCO_3$
80
90
100
110
2m
ΔH
8
10
12
2m
$ppCO_2$
-1.5
-1.3
-1.6
2m

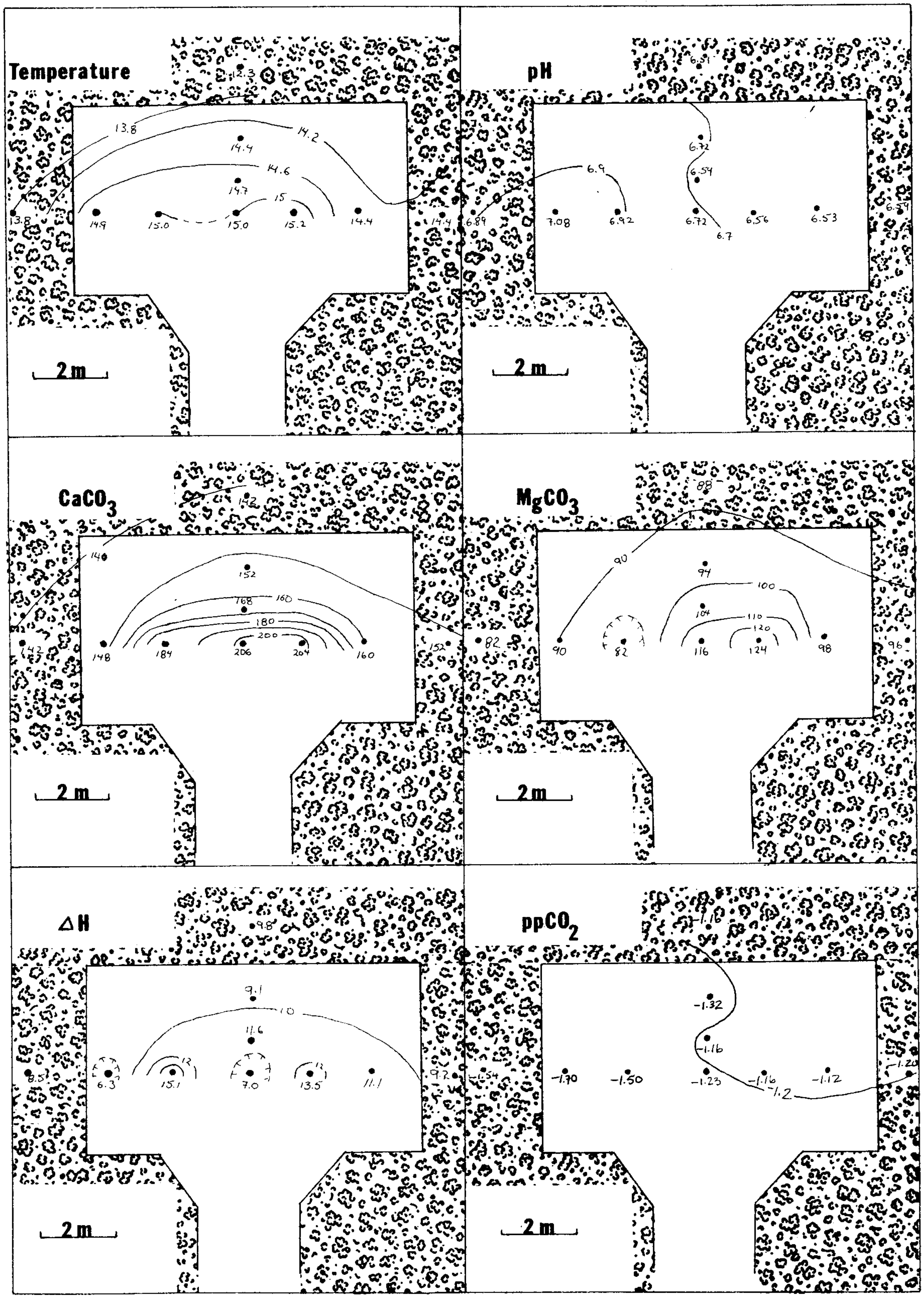
July 16



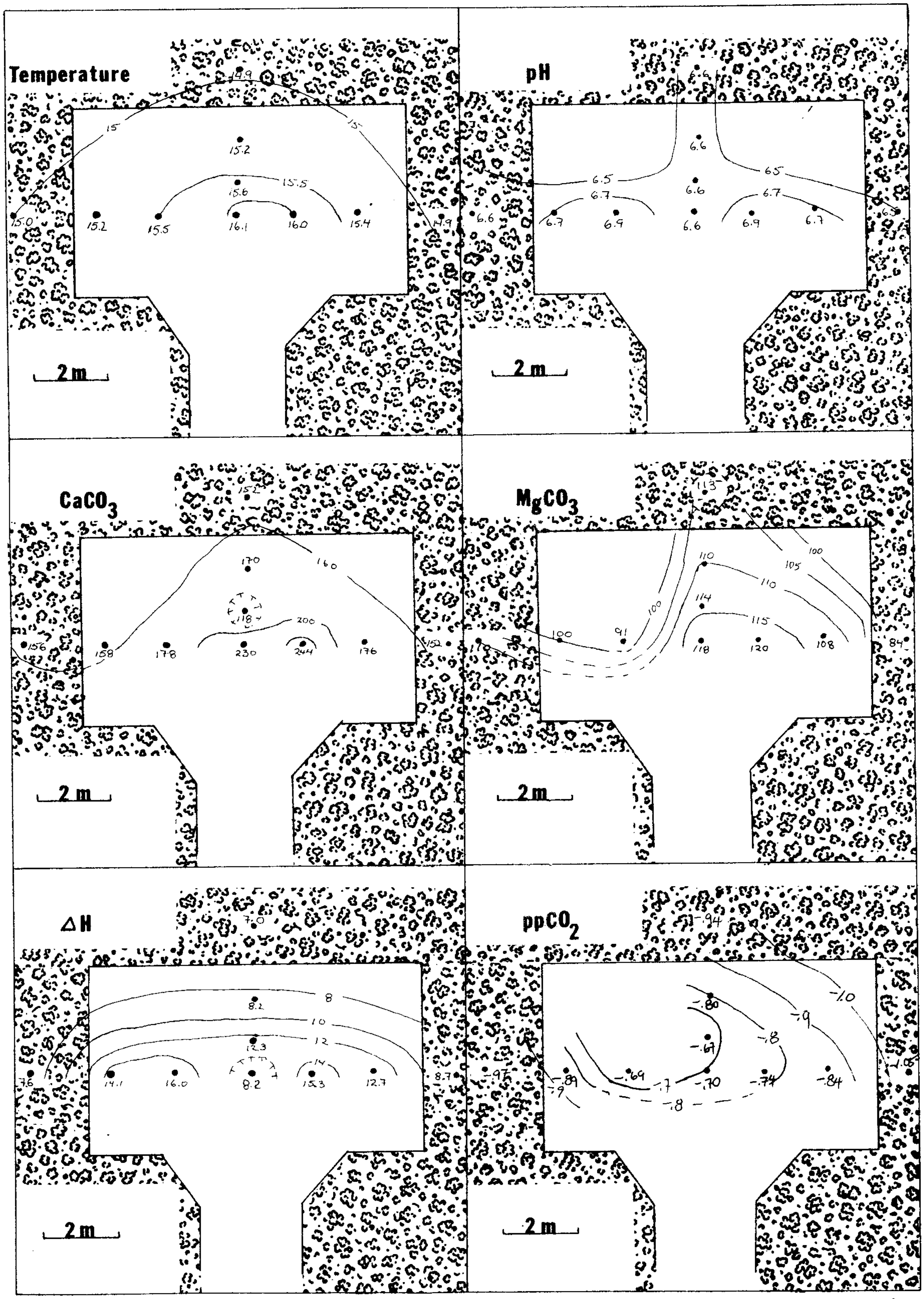
July 25


Temperature
13.4
14
14.6
14.8
15
13.8
13.5
14.0
16.1
15
14.9
13.9
2 m
pH
6.8
6.61
6.7
6.84
6.8
6.81
6.74
6.78
6.77
6.77
6.78
2 m
CaCO3
152
150
160
170
170
176
180
190
142
164
192
202
184
172
162
2 m
MgCO3
82
90
90
102
100
110
110
92
74
98
110
110
92
86
2 m
△H
14.2
14
15
16
19.3
18
17
16
19.0
12.9
17.4
18.5
16.0
18.8
15.2
2 m
ppCO2
-1.43
-1.19
-1.41
-1.4
-1.3
-1.38
-1.46
-1.39
-1.27
-1.30
-1.36
2 m

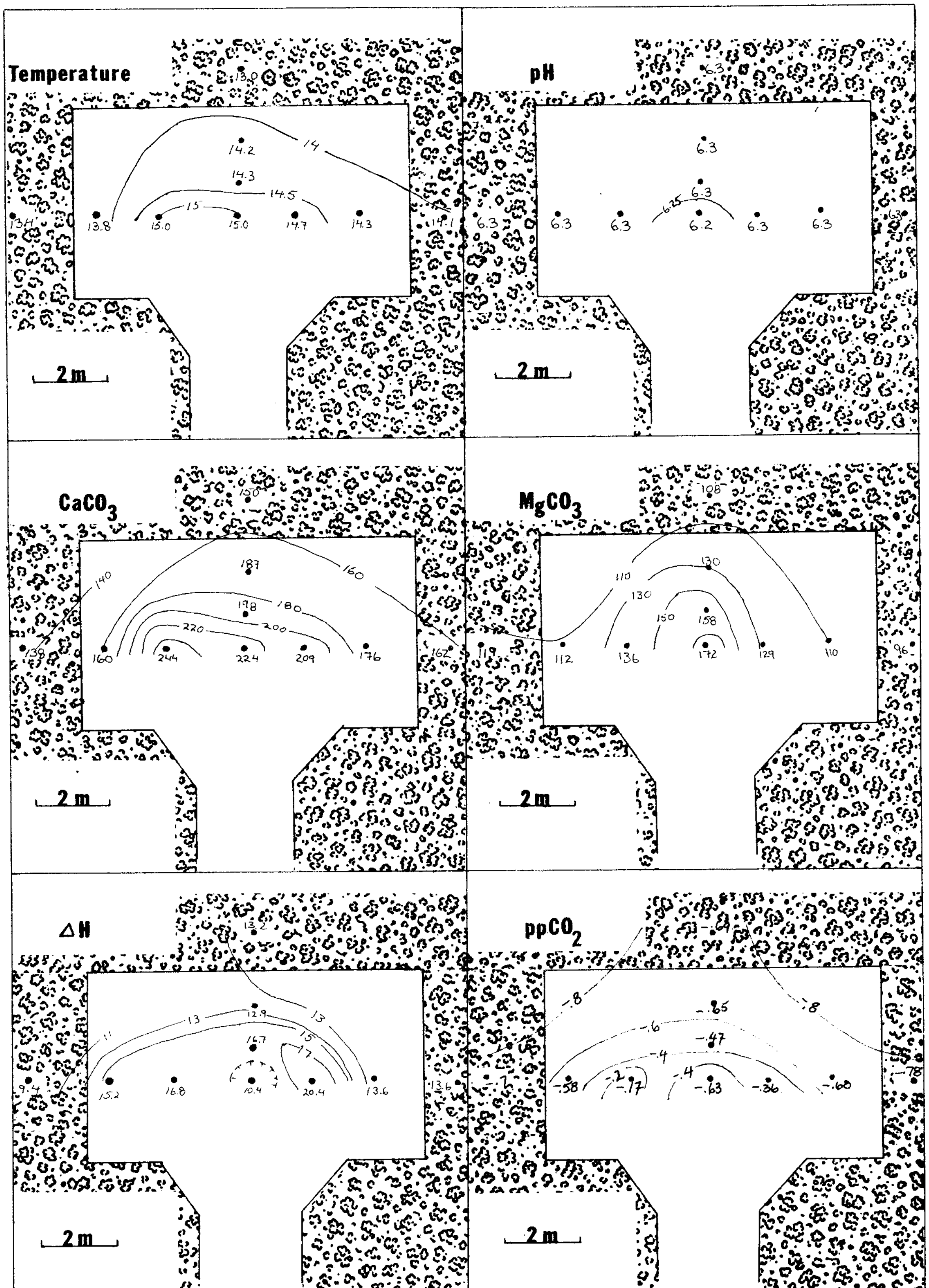
August 1


Temperature
13.8
14.2
14.4
14.6
14.7
15
14.9
15.0
15.0
15.2
14.4
14.4
2 m
pH
6.9
6.72
6.59
6.89
7.08
6.92
6.72
6.56
6.53
6.7
2 m
$CaCO_3$
140
152
168
160
180
200
148
184
206
204
160
152
142
2 m
$MgCO_3$
88
90
94
100
104
110
120
90
82
116
124
98
96
82
2 m
ΔH
9.8
9.1
10
11.6
6.3
15.1
7.0
13.5
11.1
8.5
9.7
2 m
$ppCO_2$
-1.16
-1.32
-1.16
-1.70
-1.50
-1.23
-1.16
-1.12
-1.2
-1.20
-1.54
2 m

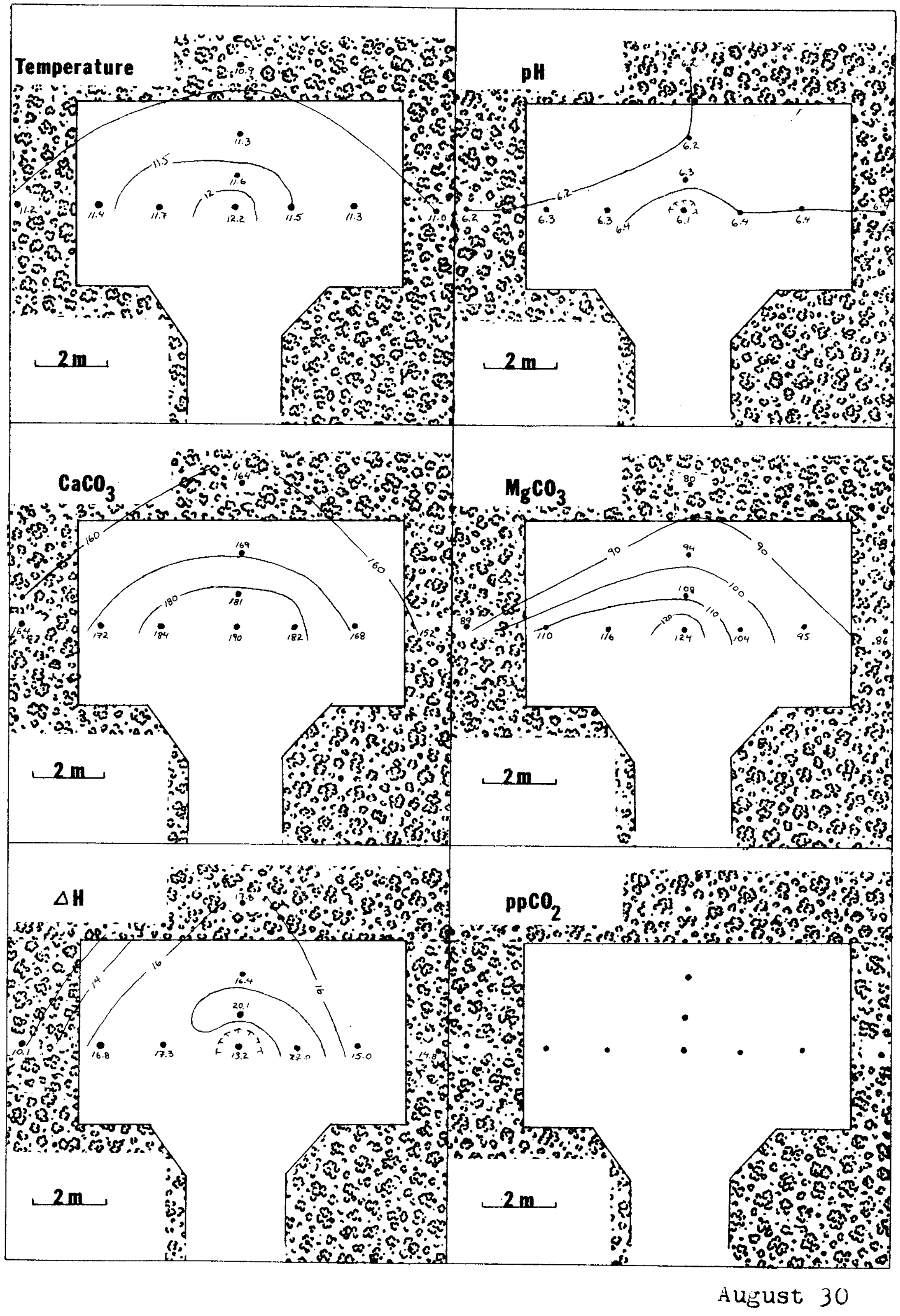
August 8



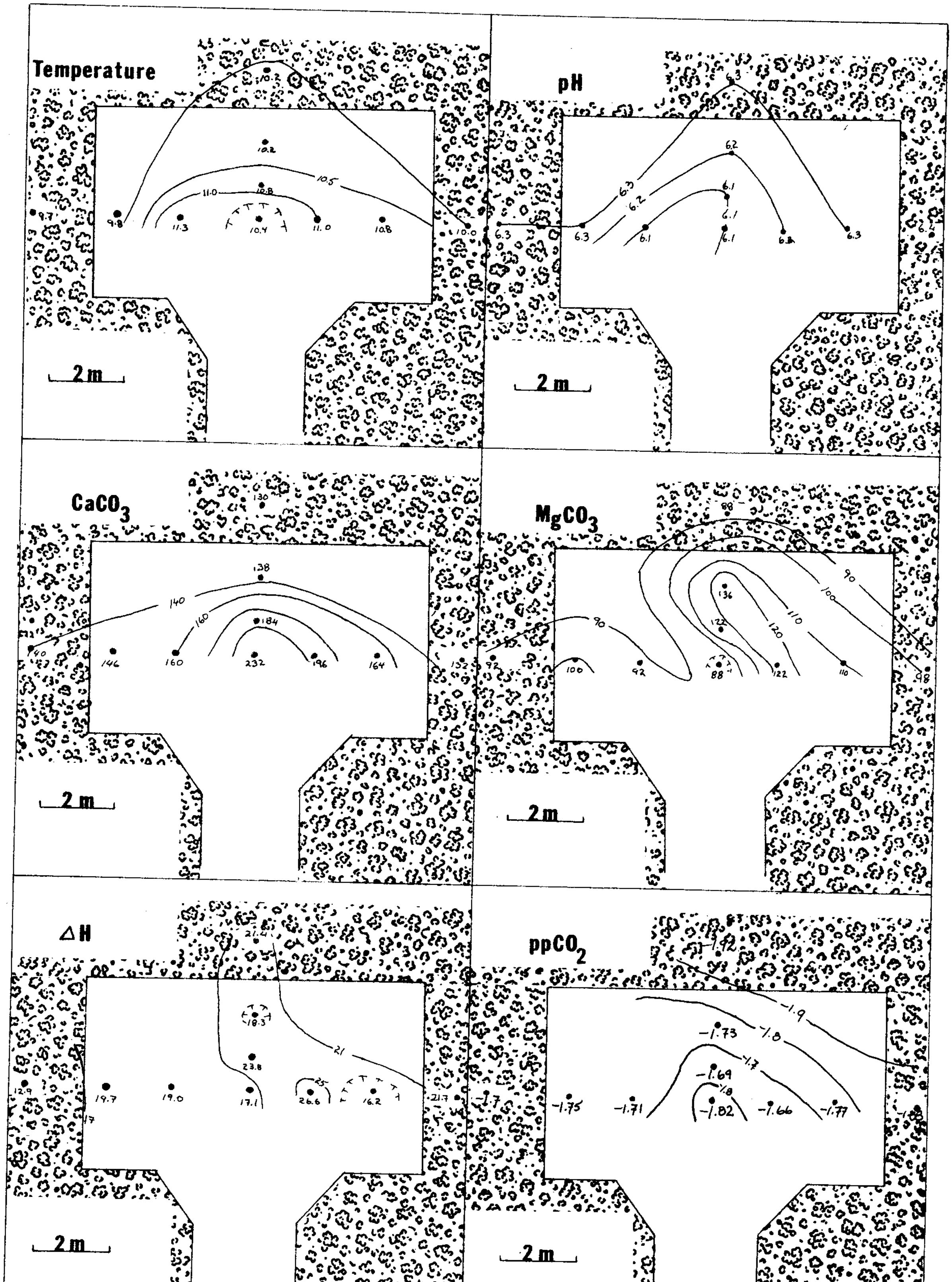
August 16


Temperature
13.0
14.2
14
14.3
14.5
15
13.8
15.0
15.0
14.7
14.3
14.1
2m
pH
6.3
6.3
6.3
6.25
6.3
6.3
6.2
6.3
6.3
2m
$CaCO_3$
150
187
160
140
198
180
200
220
160
244
224
209
176
162
138
2m
$MgCO_3$
108
130
110
130
150
158
119
112
136
172
129
110
96
2m
△H
13.2
12.9
13
13
15
16.7
17
11
9.4
15.2
16.8
10.4
20.4
13.6
13.6
2m
$ppCO_2$
-.8
-.65
-.8
-.6
-.47
-.4
-.2
-.4
-.58
-.77
-.63
-.36
-.68
-.78
2m

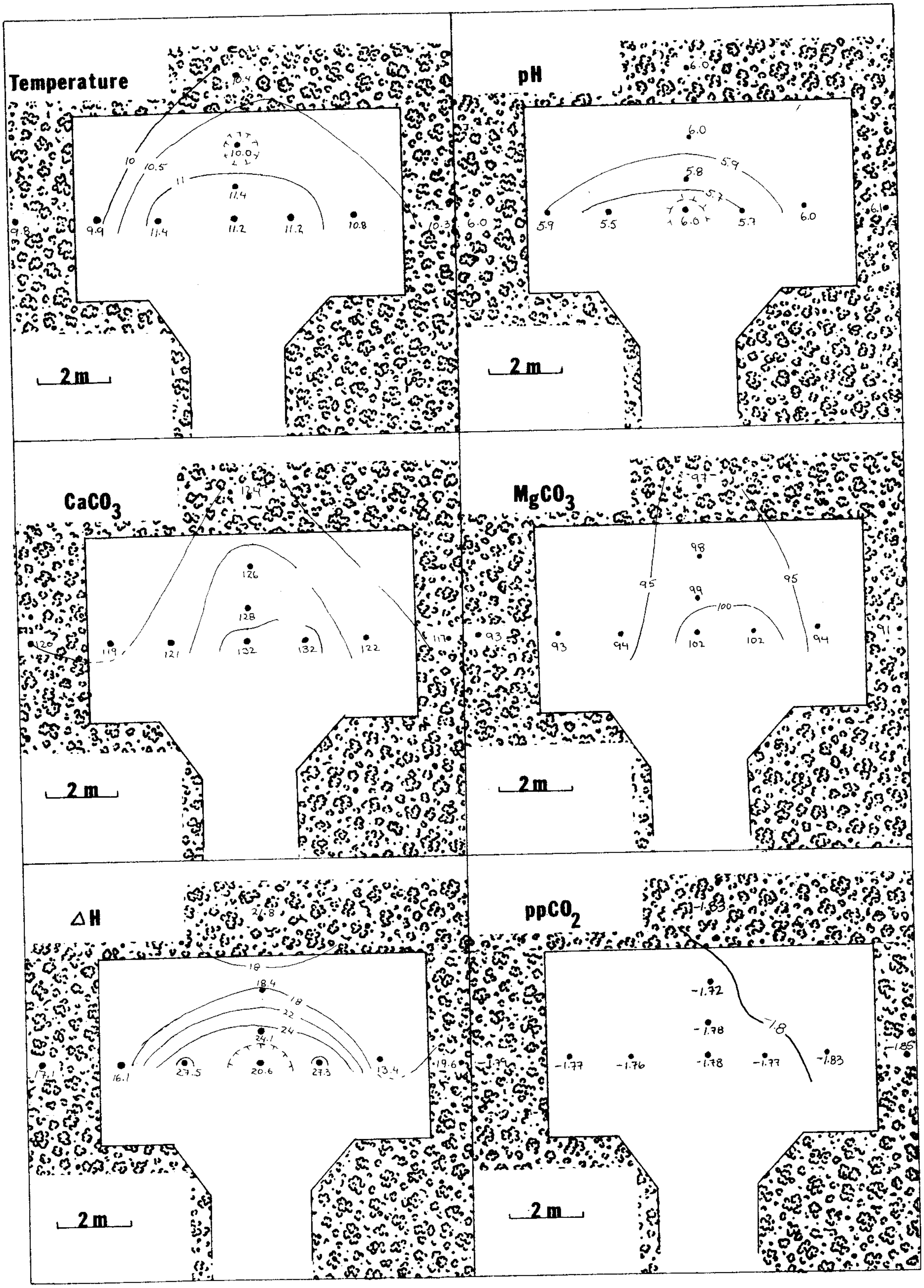
August 23


Temperature
10.9
11.3
11.5
11.6
12
11.2
11.4
11.7
12.2
11.5
11.3
11.0
2m
pH
6.2
6.2
6.3
6.2
6.2
6.3
6.3
6.4
6.1
6.4
6.4
6.4
2m
$CaCO_3$
164
169
160
180
181
160
164
172
184
190
182
168
152
2m
$MgCO_3$
88
90
94
90
100
108
110
120
89
110
116
124
104
95
86
2m
ΔH
17.8
16
16
14
16.4
20.1
10.1
16.8
17.3
13.2
22.0
15.0
14.8
2m
$ppCO_2$
2m

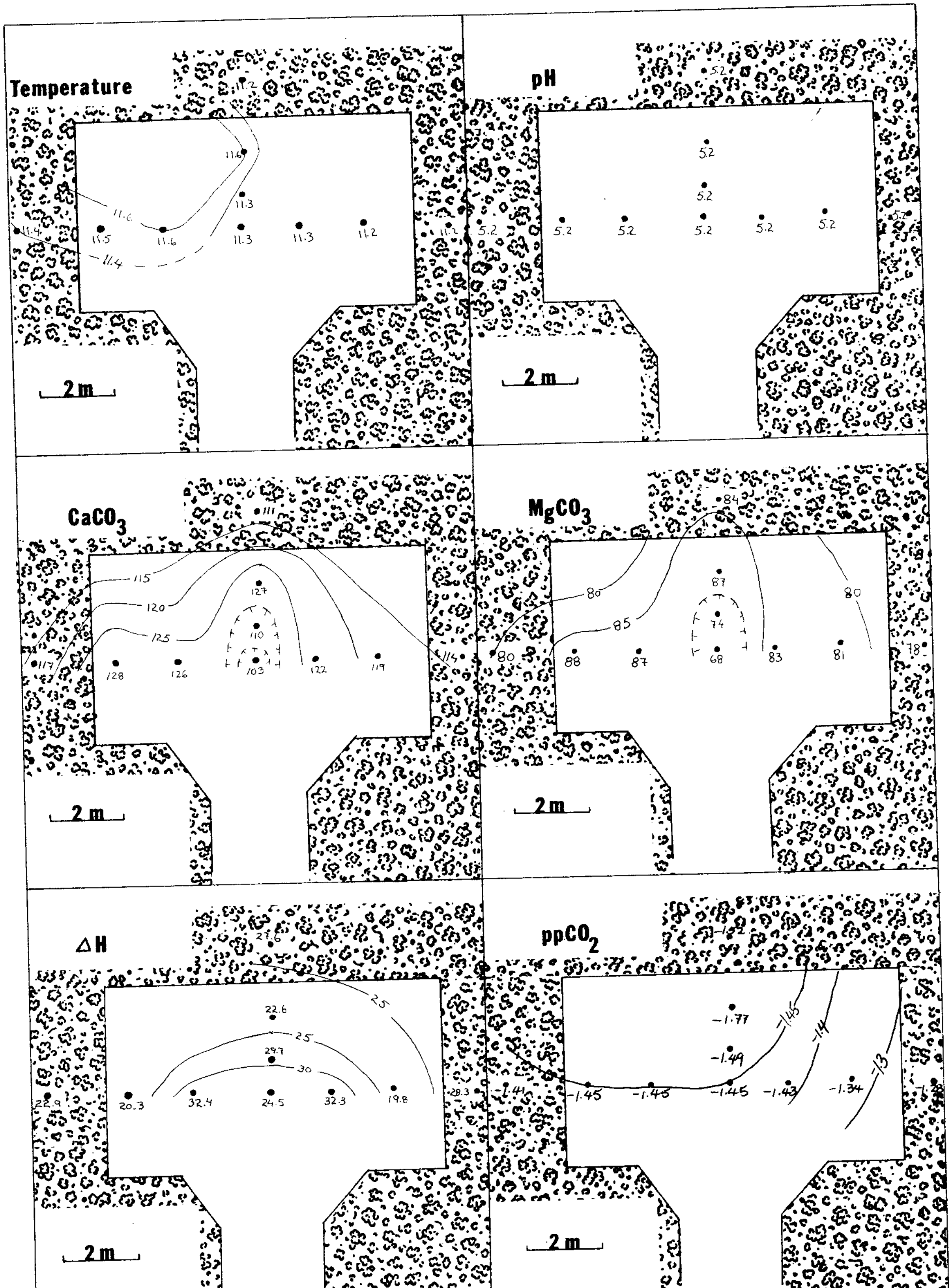
August 30



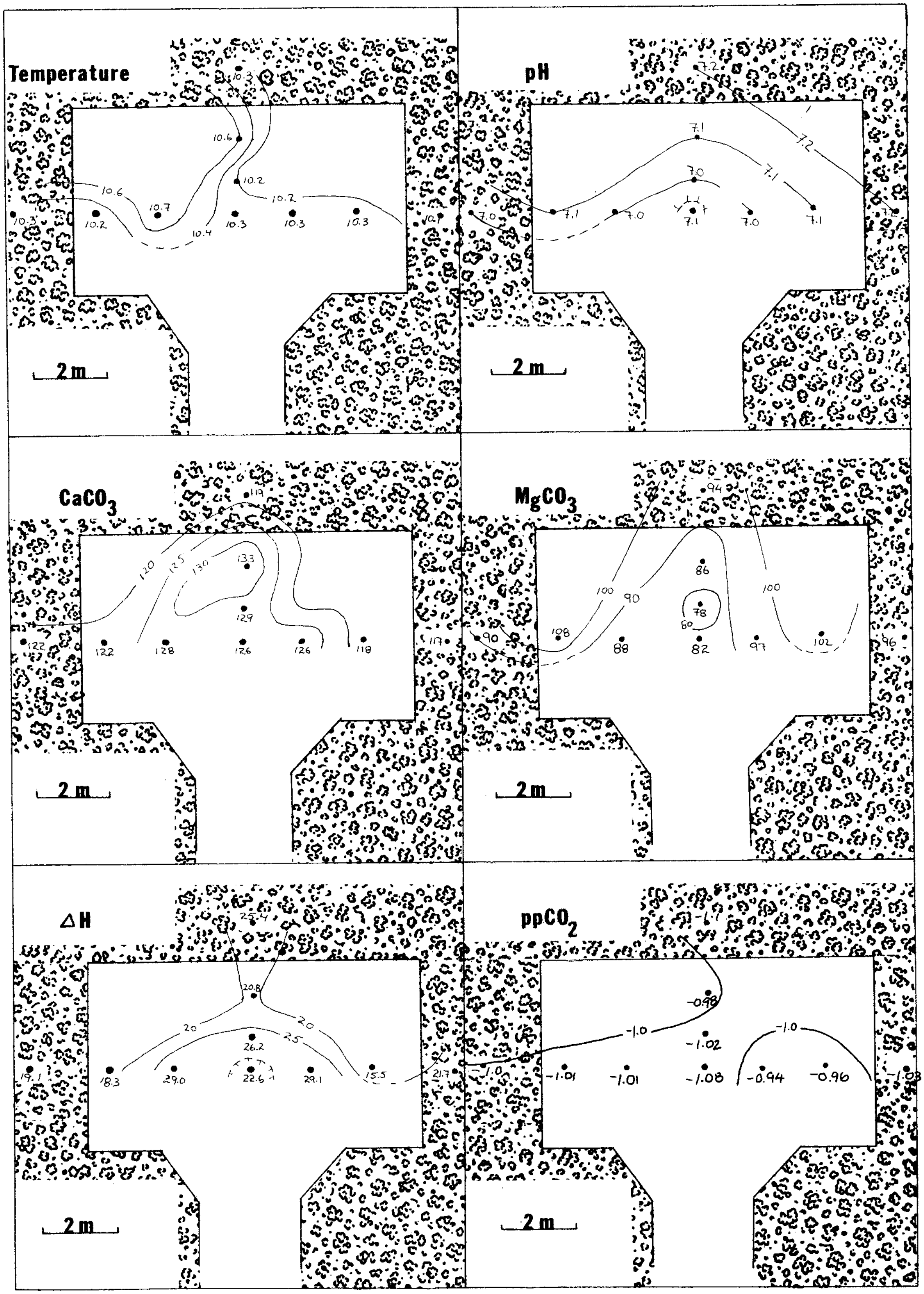
September 14



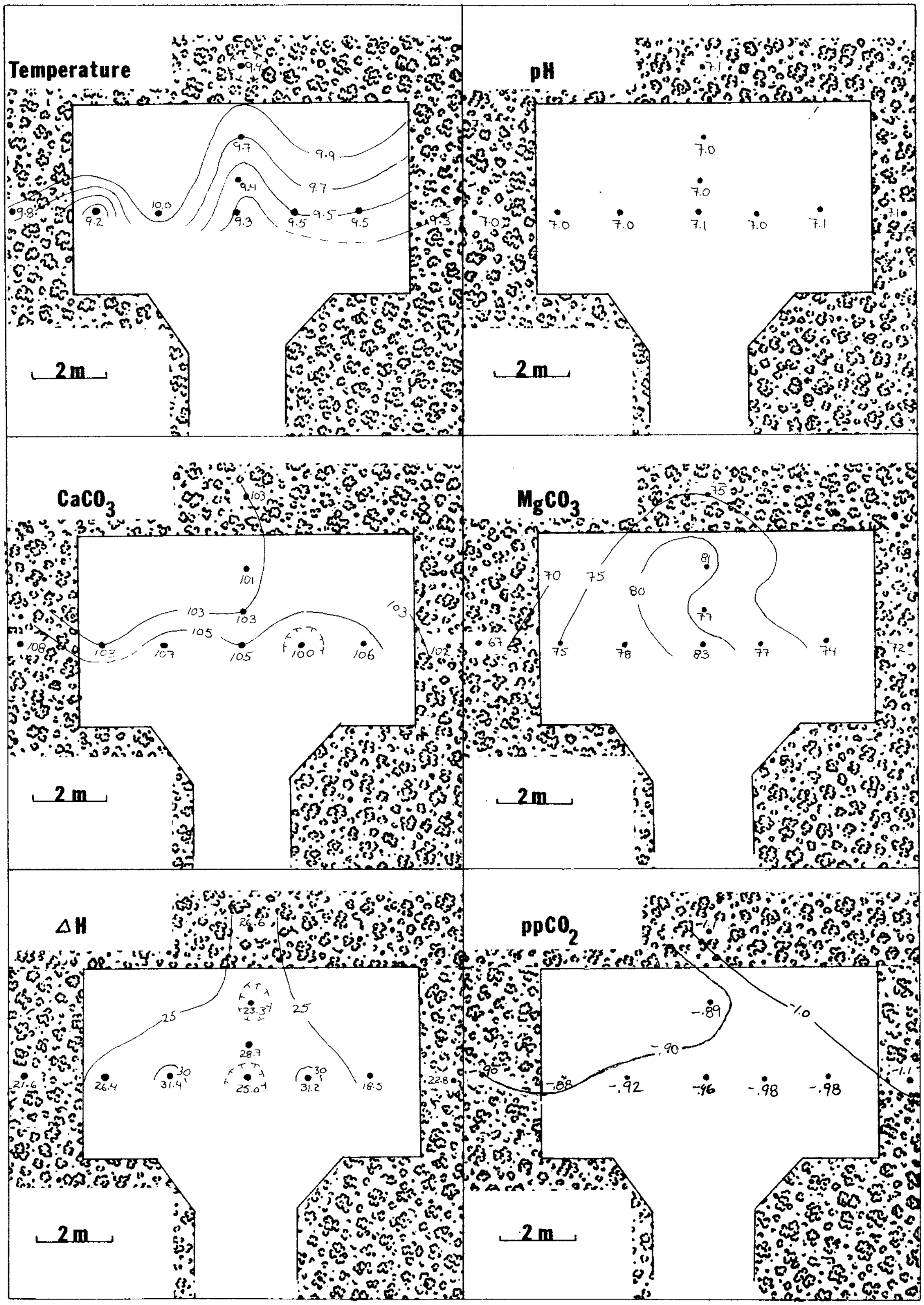
September 22



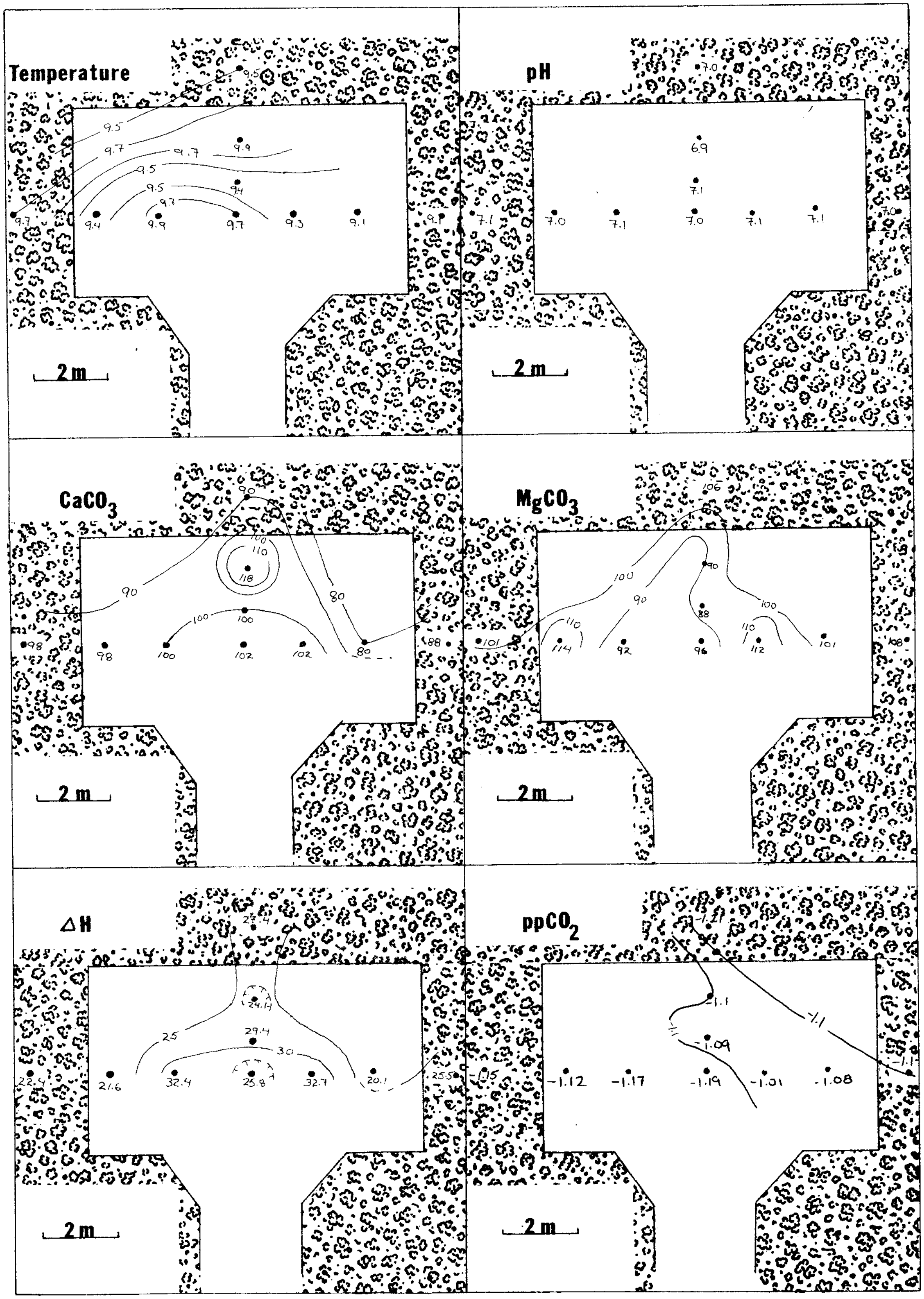
September 30



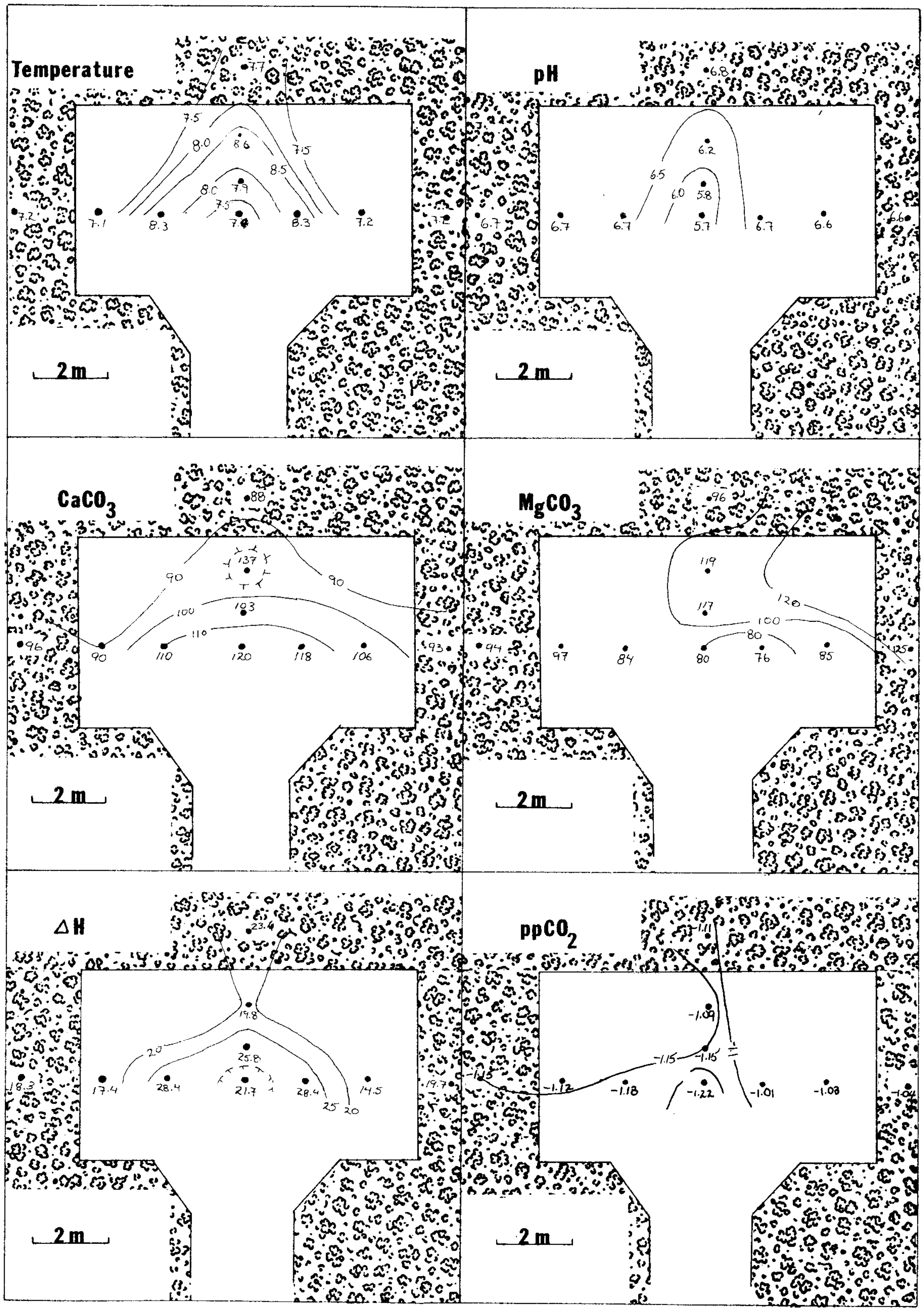
October 13



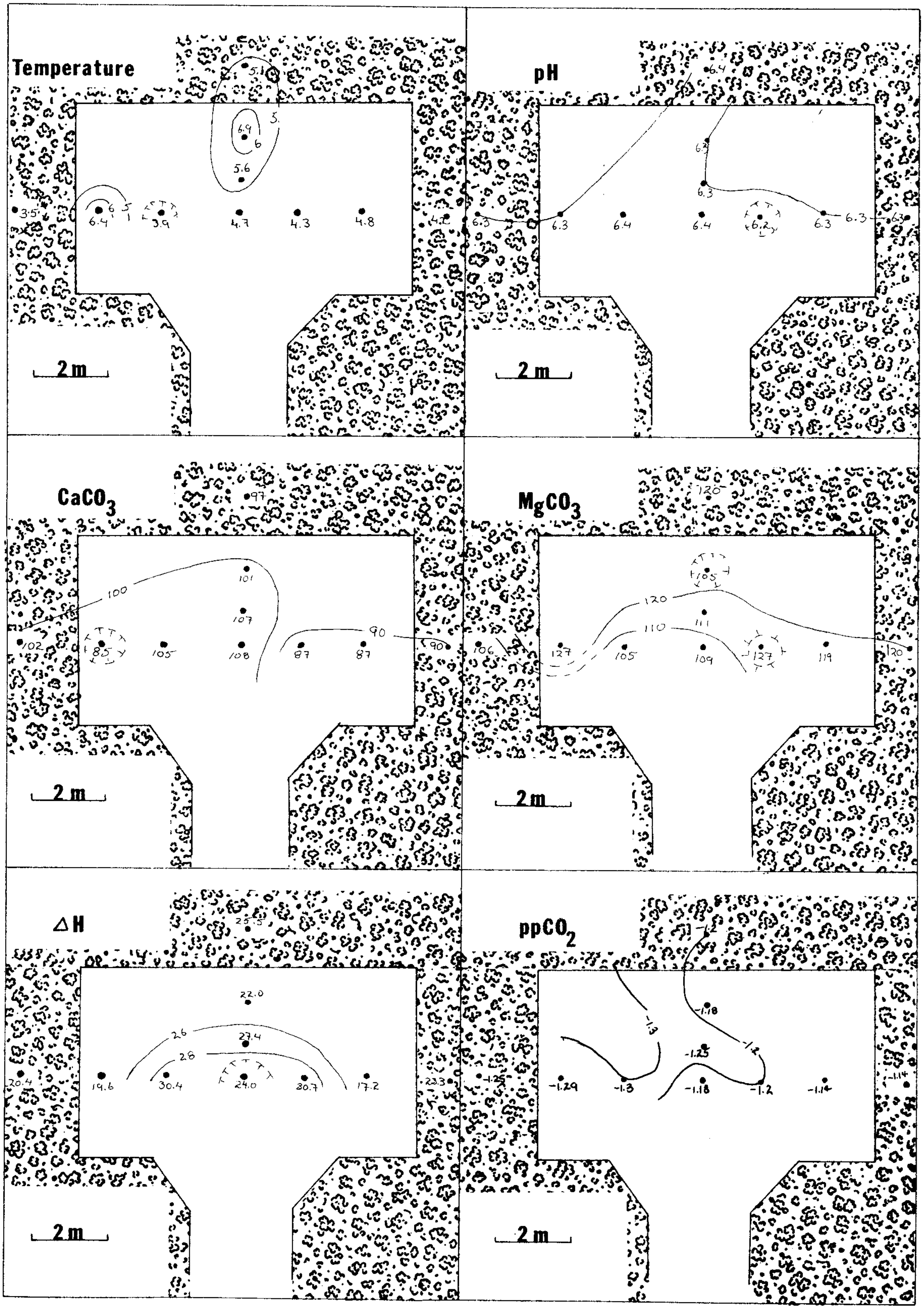
October 21



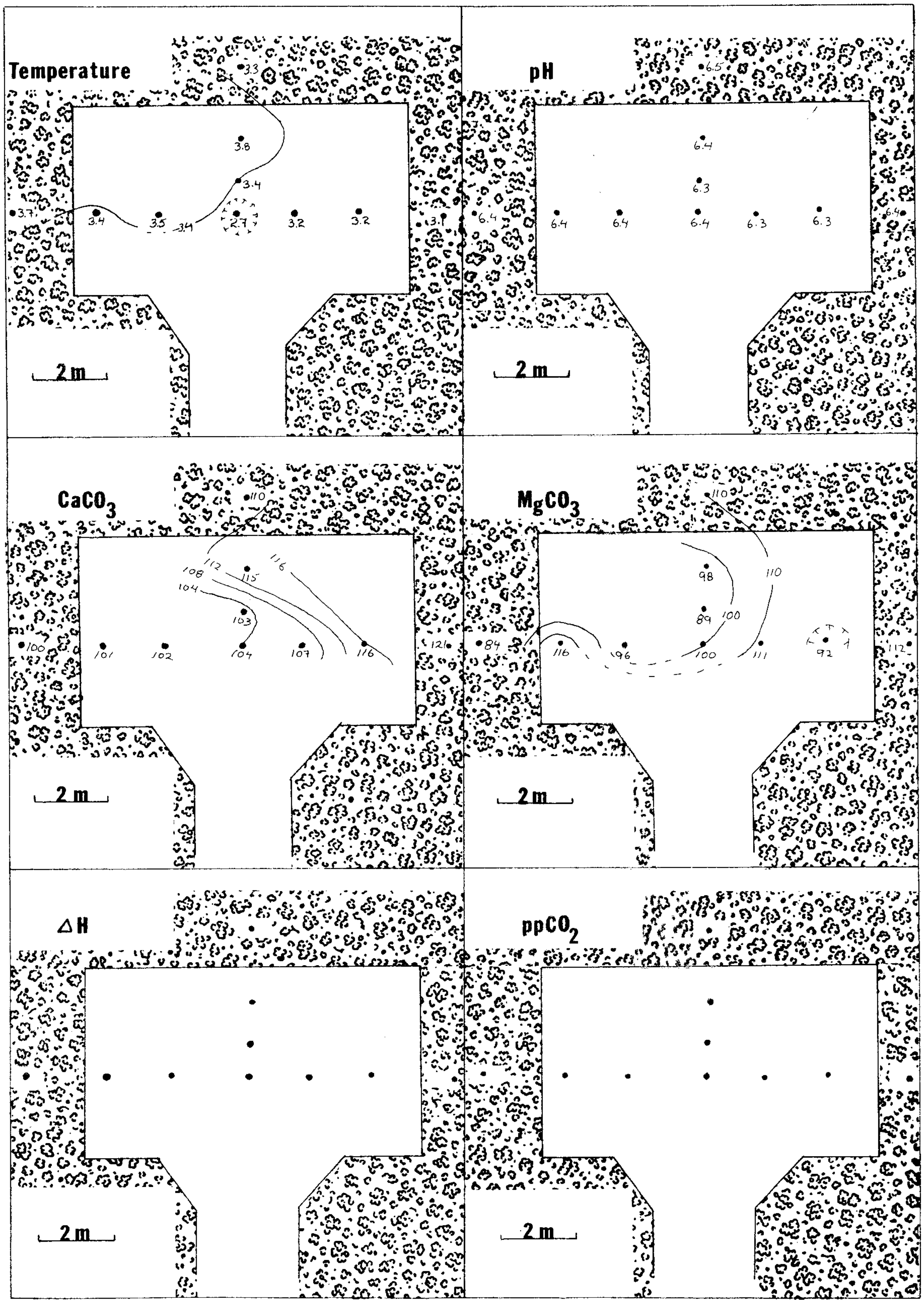
October 26



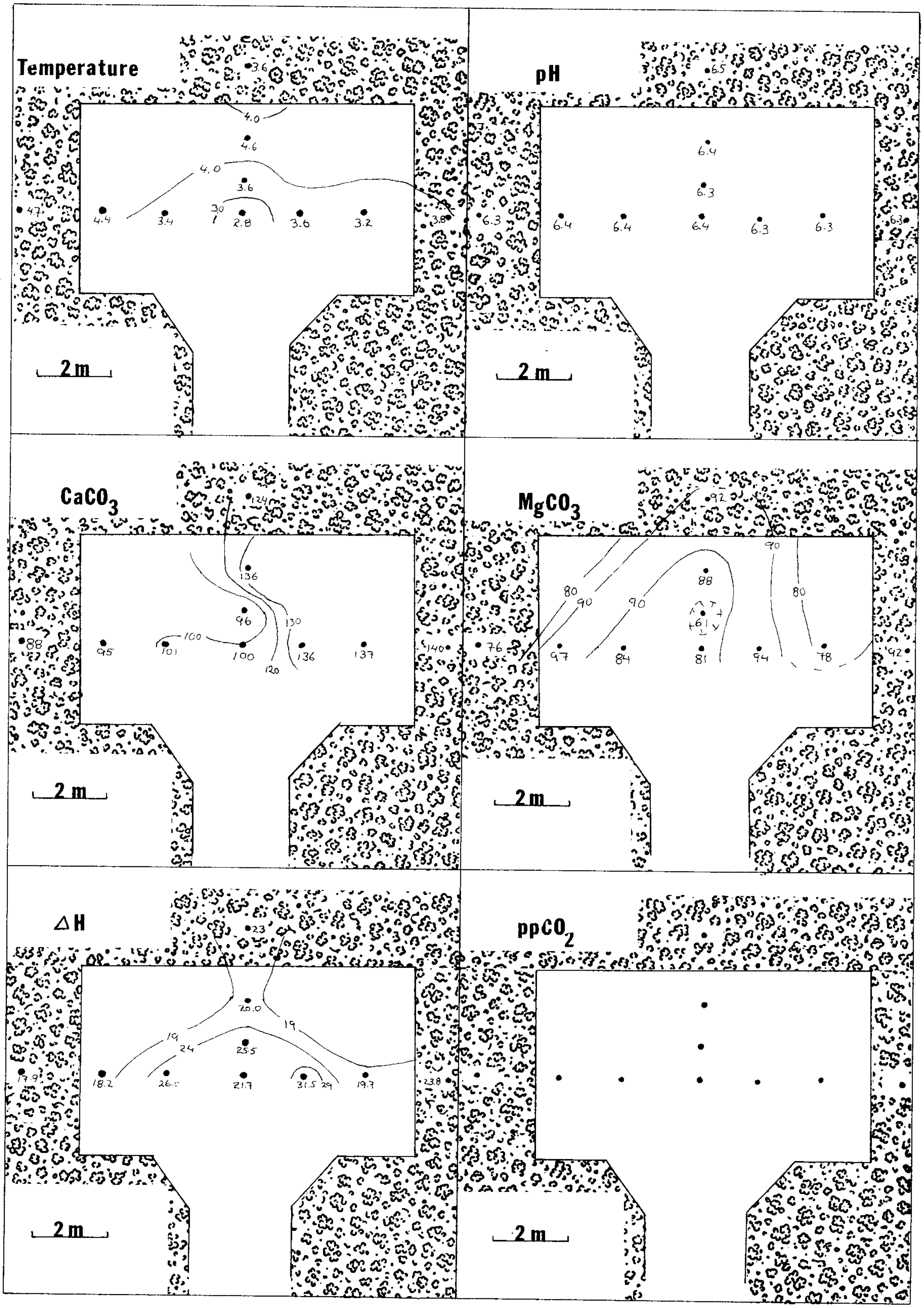
November 2


Temperature
5.1
6.9
6
5.6
3.5
6.4
3.9
4.7
4.3
4.8
2 m
pH
6.4
6.3
6.3
6.3
6.4
6.4
6.2
6.3
6.3
2 m
$CaCO_3$
97
101
100
107
102
105
108
87
87
90
90
2 m
$MgCO_3$
120
105
120
111
110
106
127
105
109
127
119
120
2 m
ΔH
22.0
26
27.4
28
20.4
19.6
30.4
24.0
30.7
17.2
23.3
2 m
$ppCO_2$
-1.2
-1.3
-1.18
-1.2
-1.25
-1.25
-1.29
-1.3
-1.18
-1.2
-1.14
-1.14
2 m

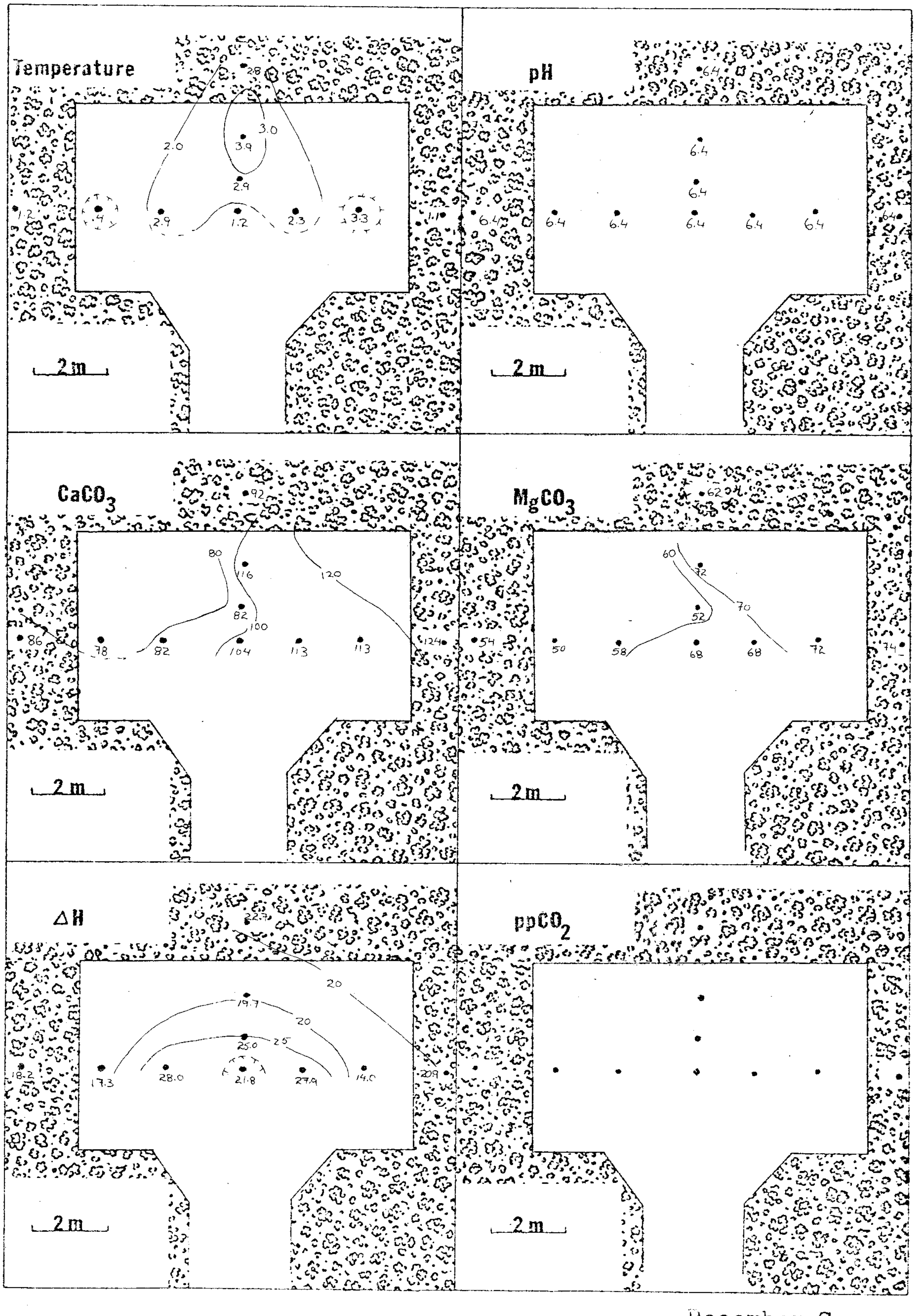
November 16


Temperature
3.3
3.8
3.4
3.7
3.4
3.5
3.4
2.7
3.2
3.2
3.1
2m
pH
6.5
6.4
6.3
6.4
6.4
6.4
6.4
6.3
6.3
6.4
2m
$CaCO_3$
110
112
116
108
115
104
103
100
101
102
104
107
116
121
2m
$MgCO_3$
110
110
98
89
100
84
116
96
100
111
92
112
2m
ΔH
2m
$ppCO_2$
2m

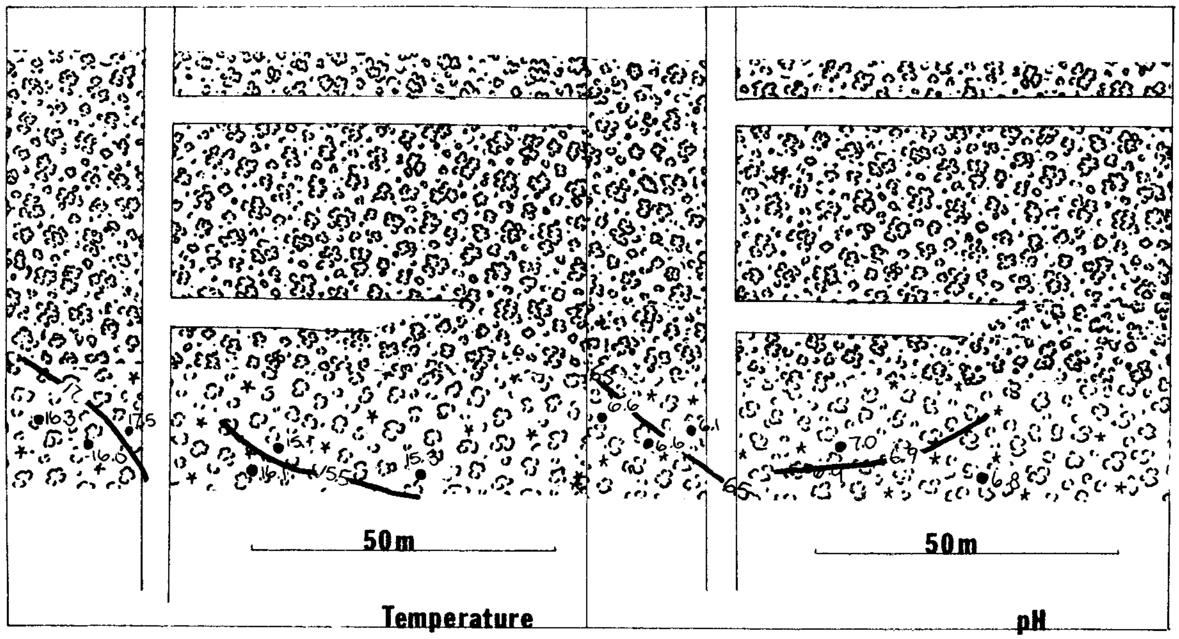
November 23

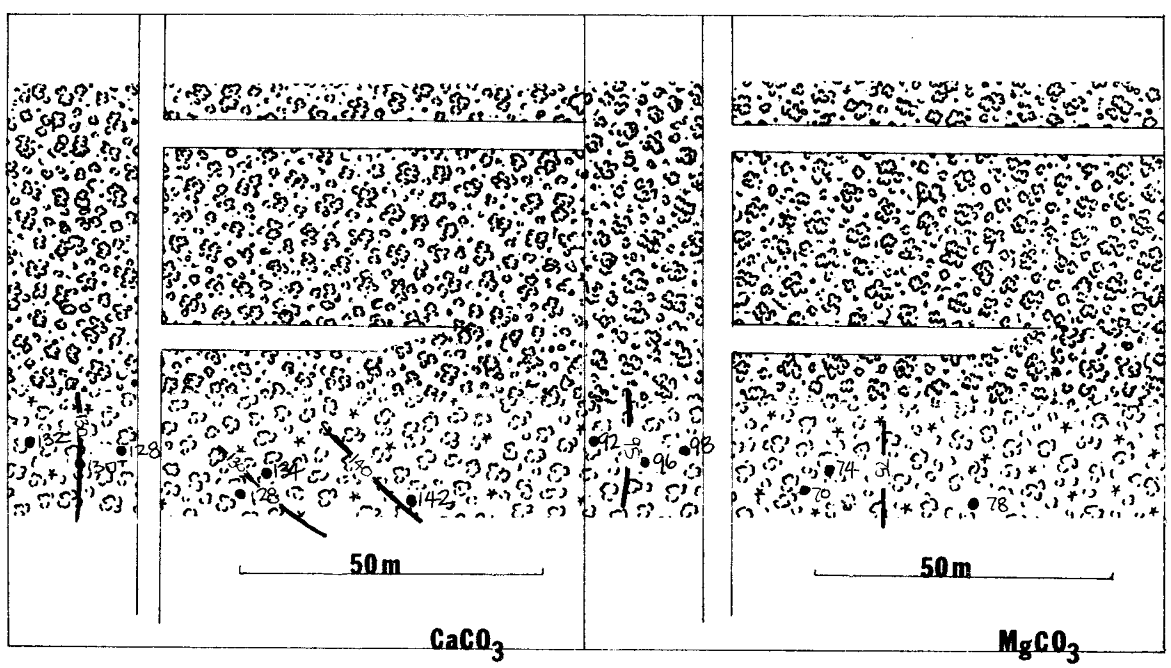

Temperature
4.0
4.6
4.0
3.6
3.0
4.7
4.4
3.4
2.8
3.6
3.2
3.8
2 m
pH
6.5
6.4
6.3
6.3
6.4
6.4
6.4
6.3
6.3
6.3
2 m
CaCO3
124
136
96
130
88
95
101
100
100
136
137
140
120
2 m
MgCO3
92
90
88
80
90
90
80
76
97
84
81
94
78
92
2 m
ΔH
23
20.0
19
19
24
25.5
17.9
18.2
26.
21.7
31.5
29
19.7
23.8
2 m
ppCO2
2 m

November 30

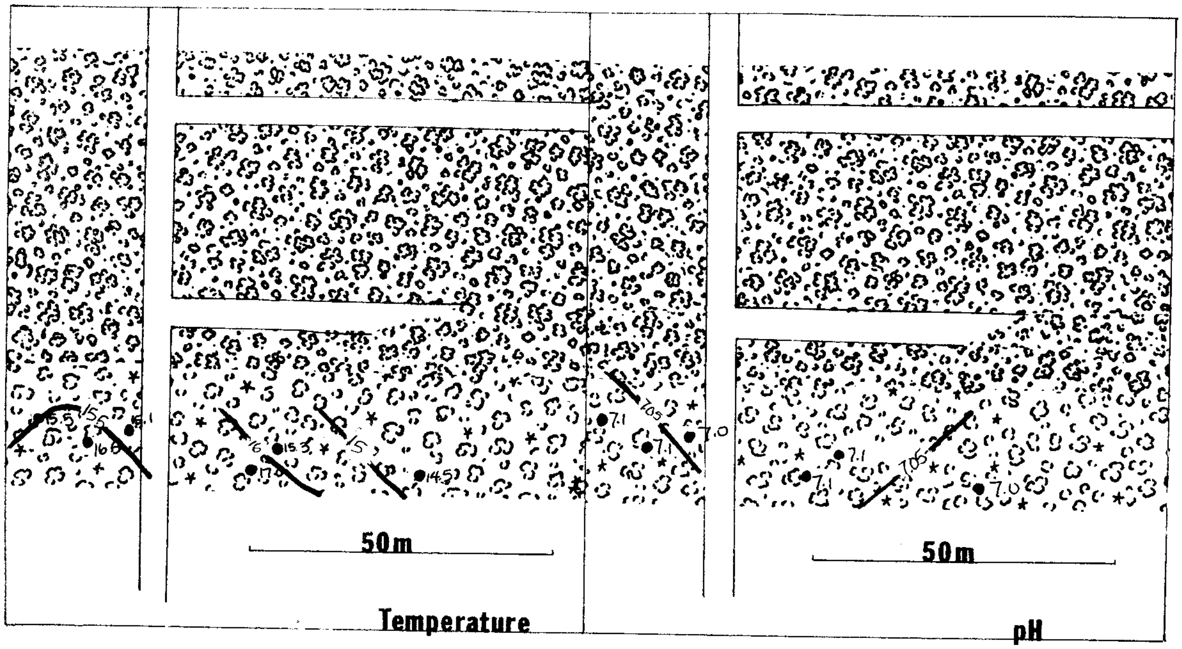

Temperature
2.8
3.0
2.0
3.9
2.9
1.2
4
2.9
1.2
2.3
3.3
1.1
2m
pH
6.4
6.4
6.4
6.4
6.4
6.4
6.4
6.4
6.4
6.4
2m
$CaCO_3$
92
80
116
120
82
100
86
78
82
104
113
113
124
2m
$MgCO_3$
62
60
72
70
52
54
50
58
68
68
72
74
2m
ΔH
22.9
20
19.7
20
25.0
25
18.2
17.3
28.0
21.8
27.9
14.0
20.9
2m
$ppCO_2$
2m

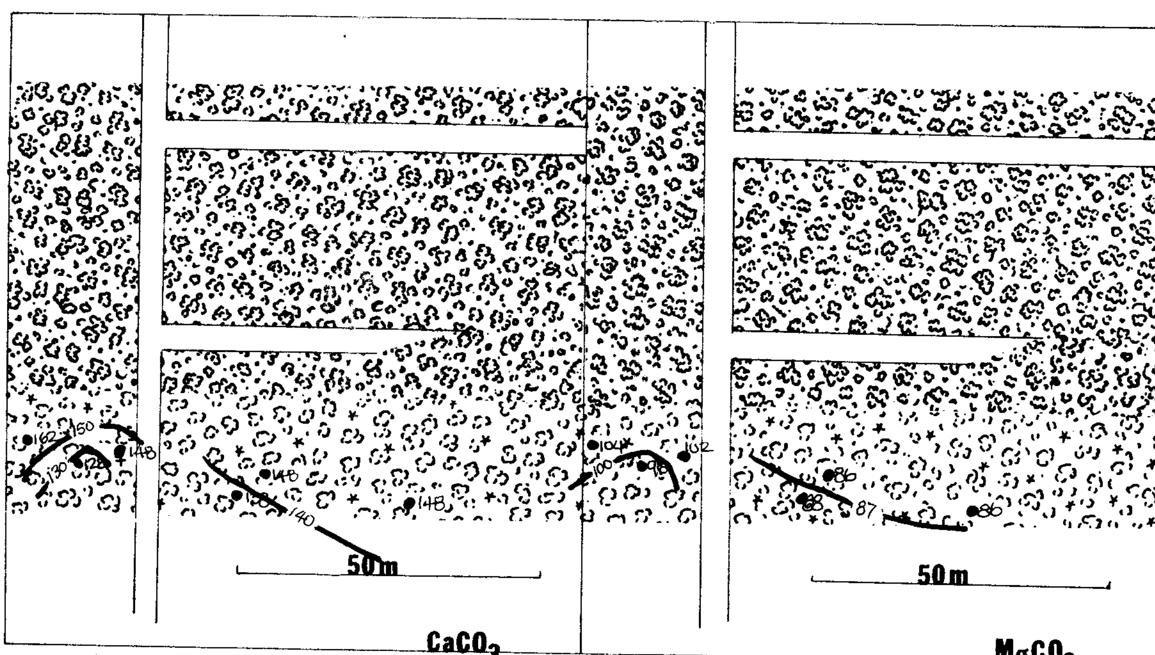
December 7



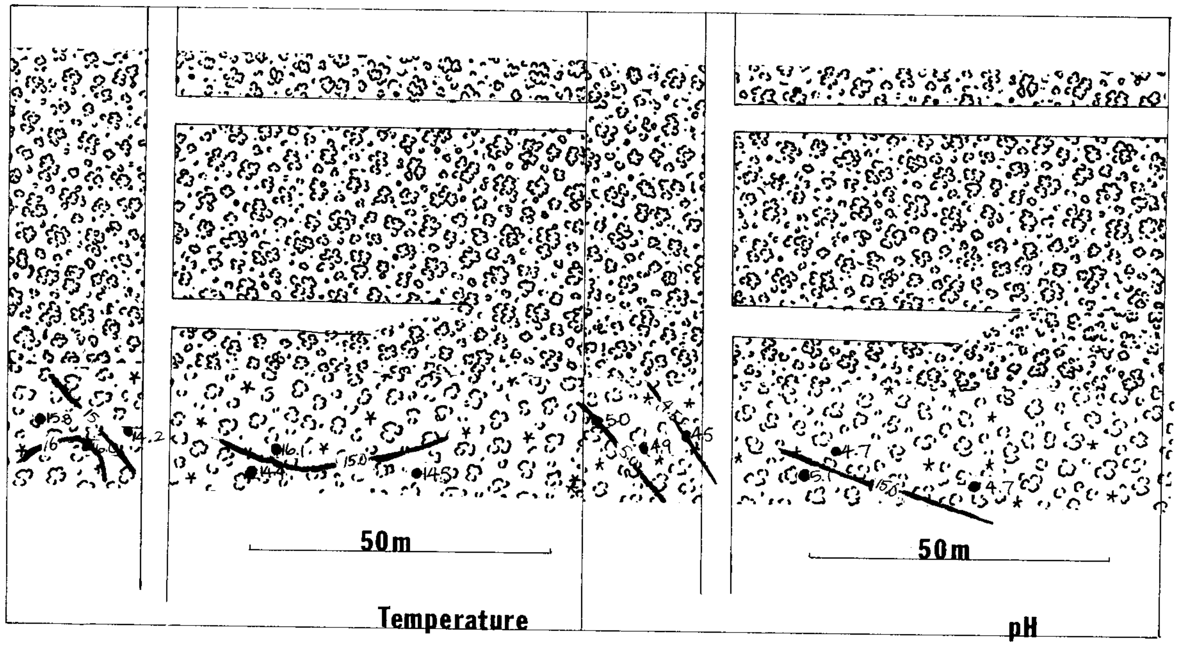


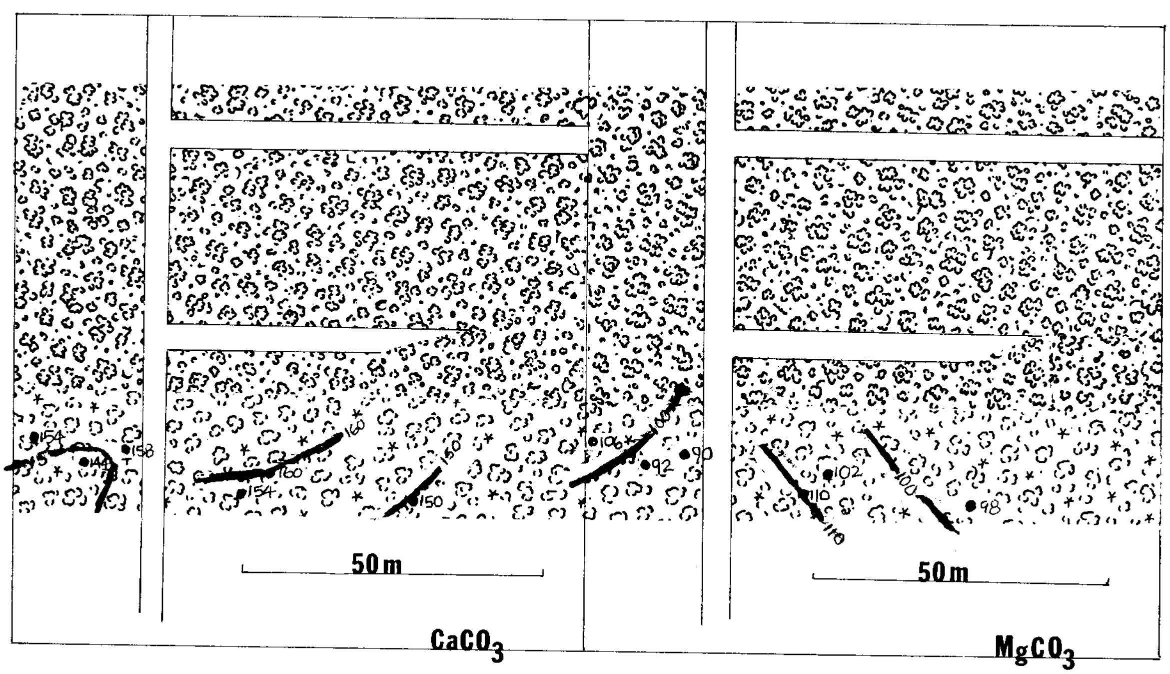
June 20 1975



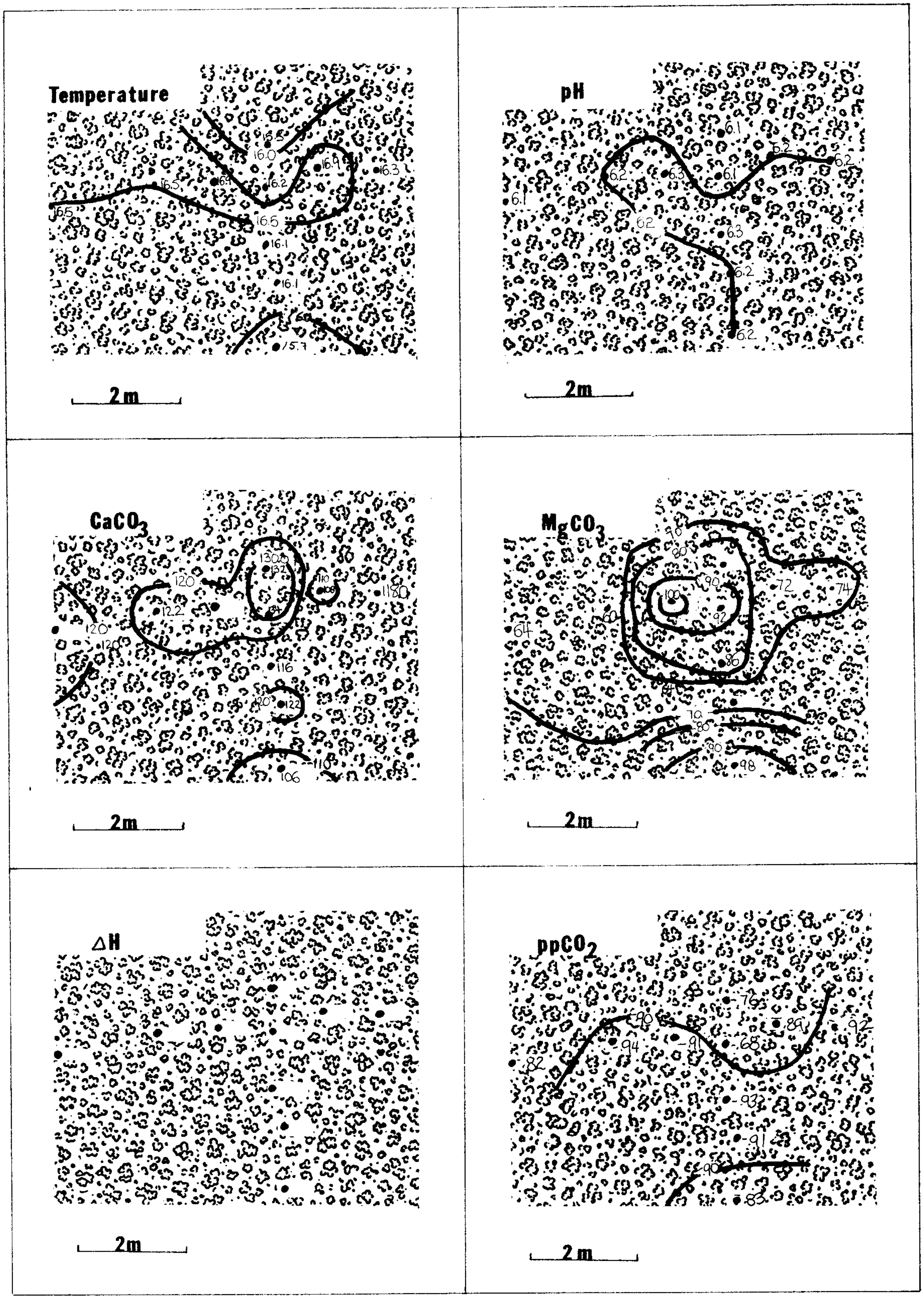


June 24

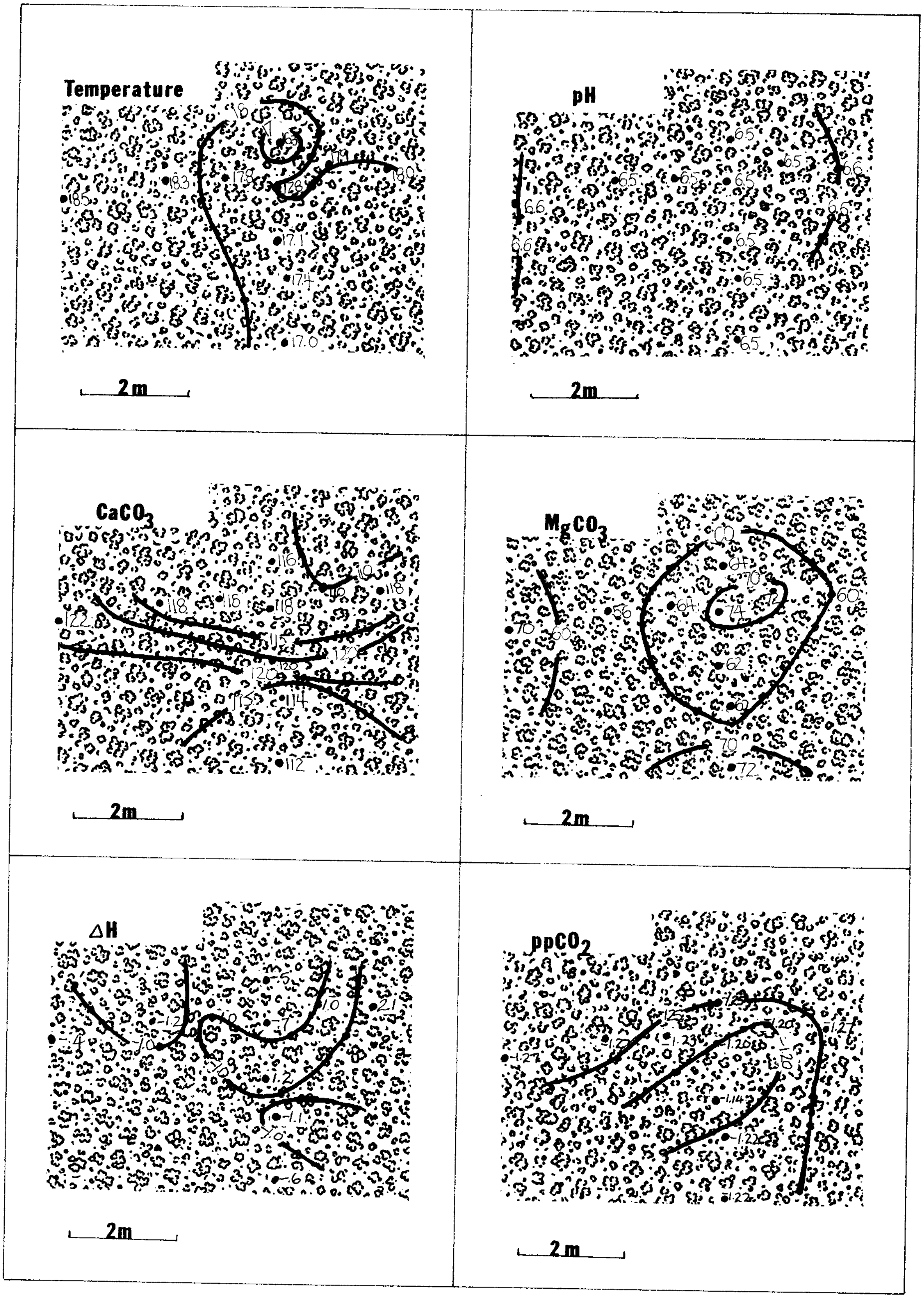




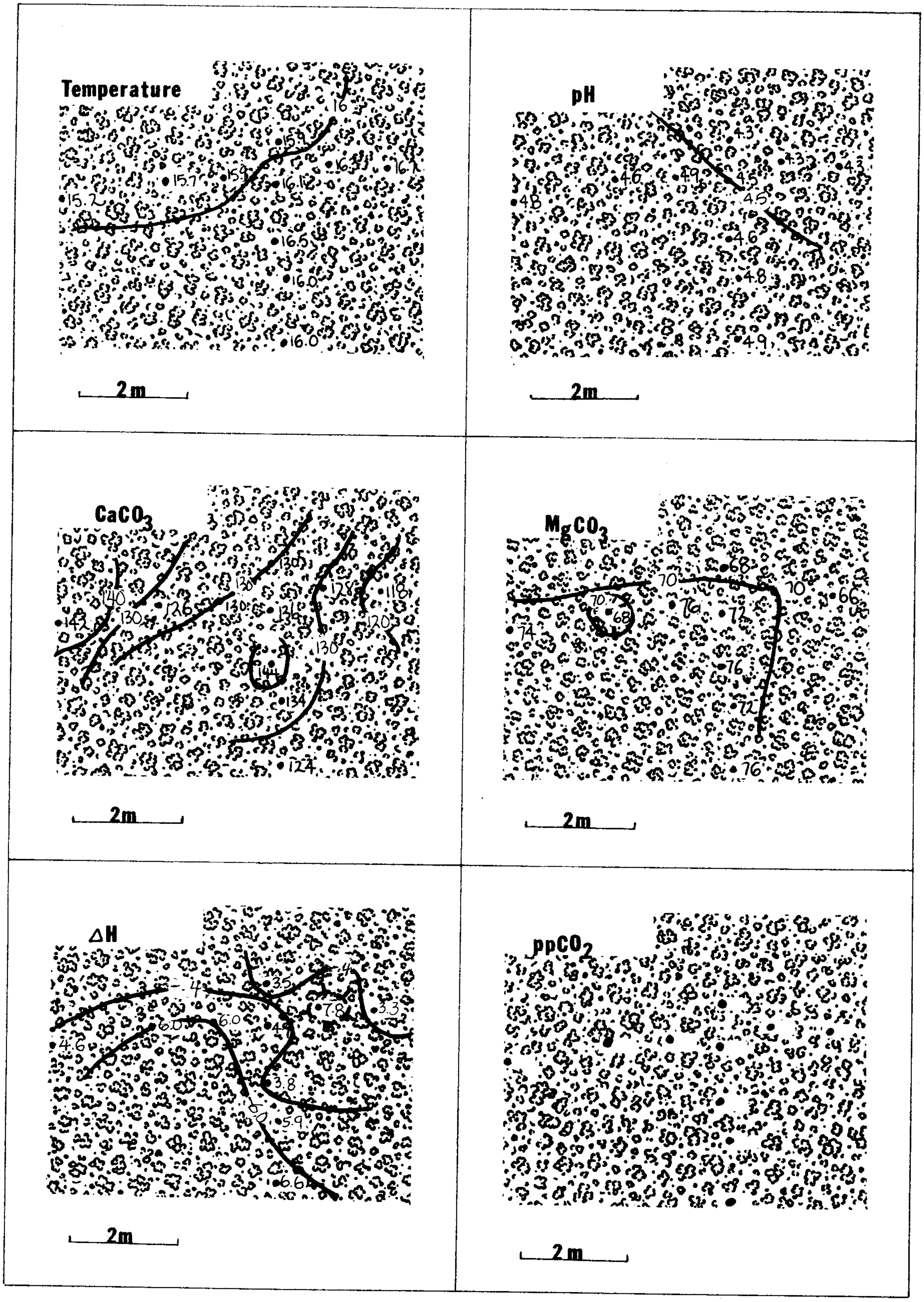
July 4



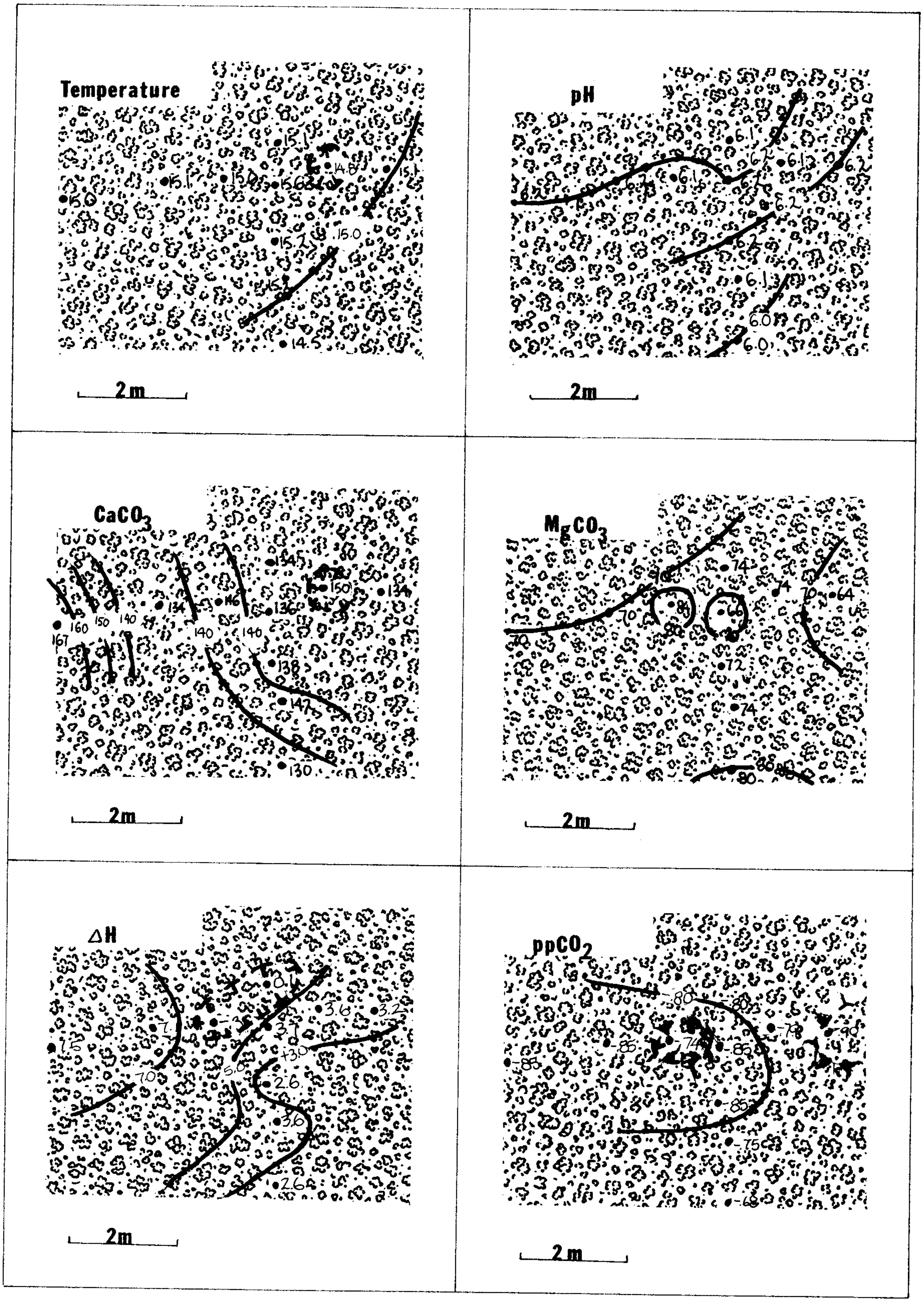
June 20



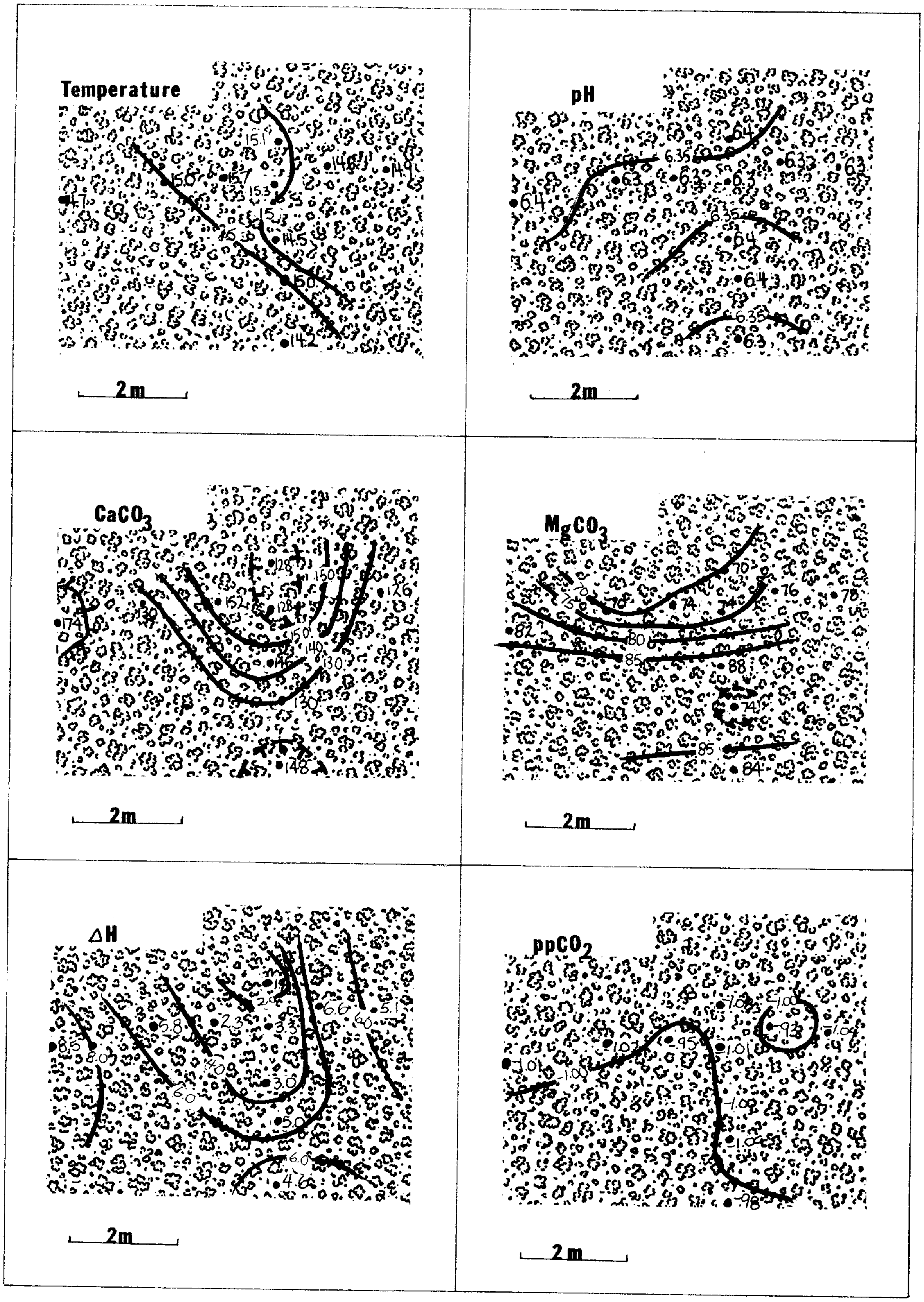
June 24



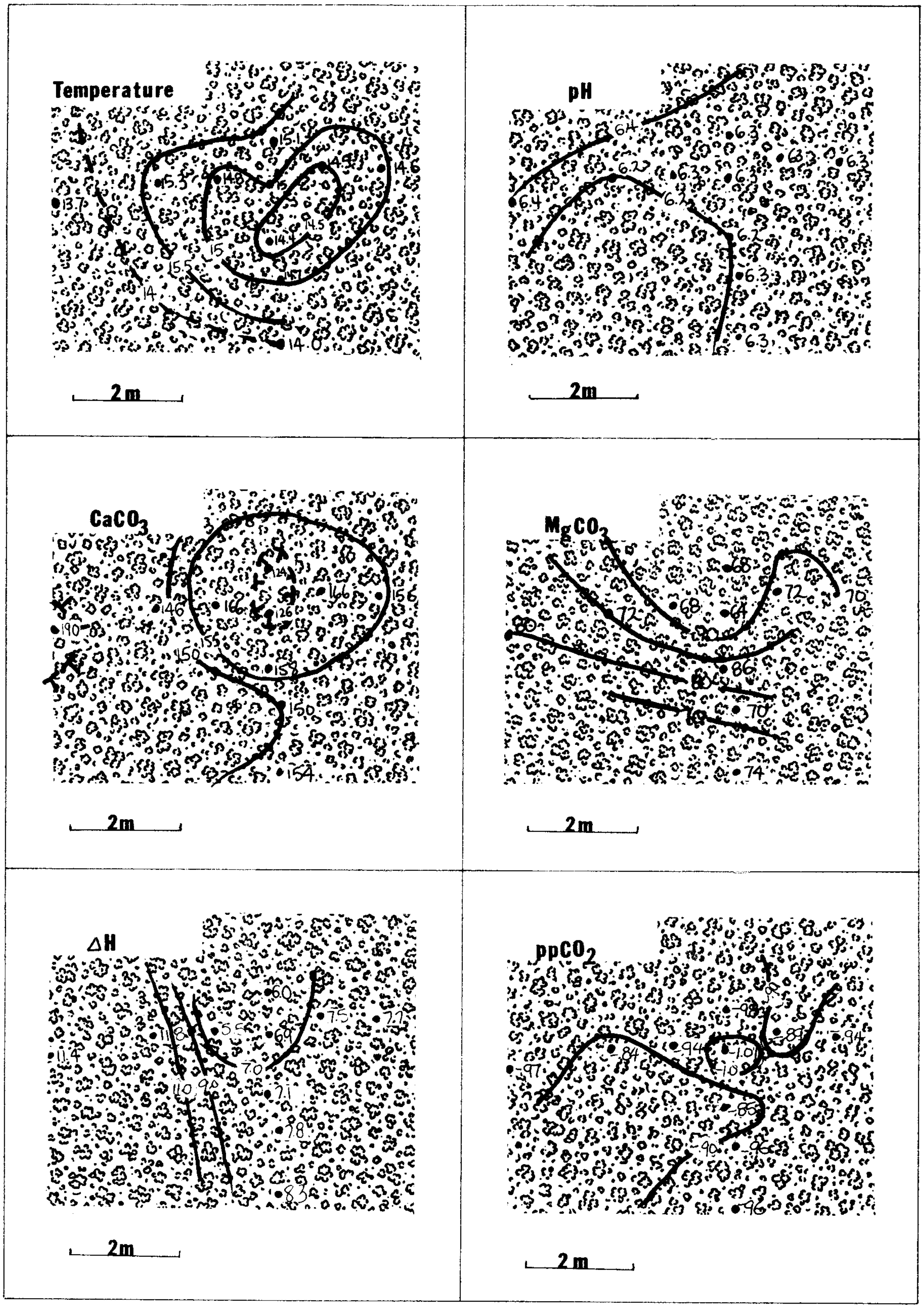
July 4



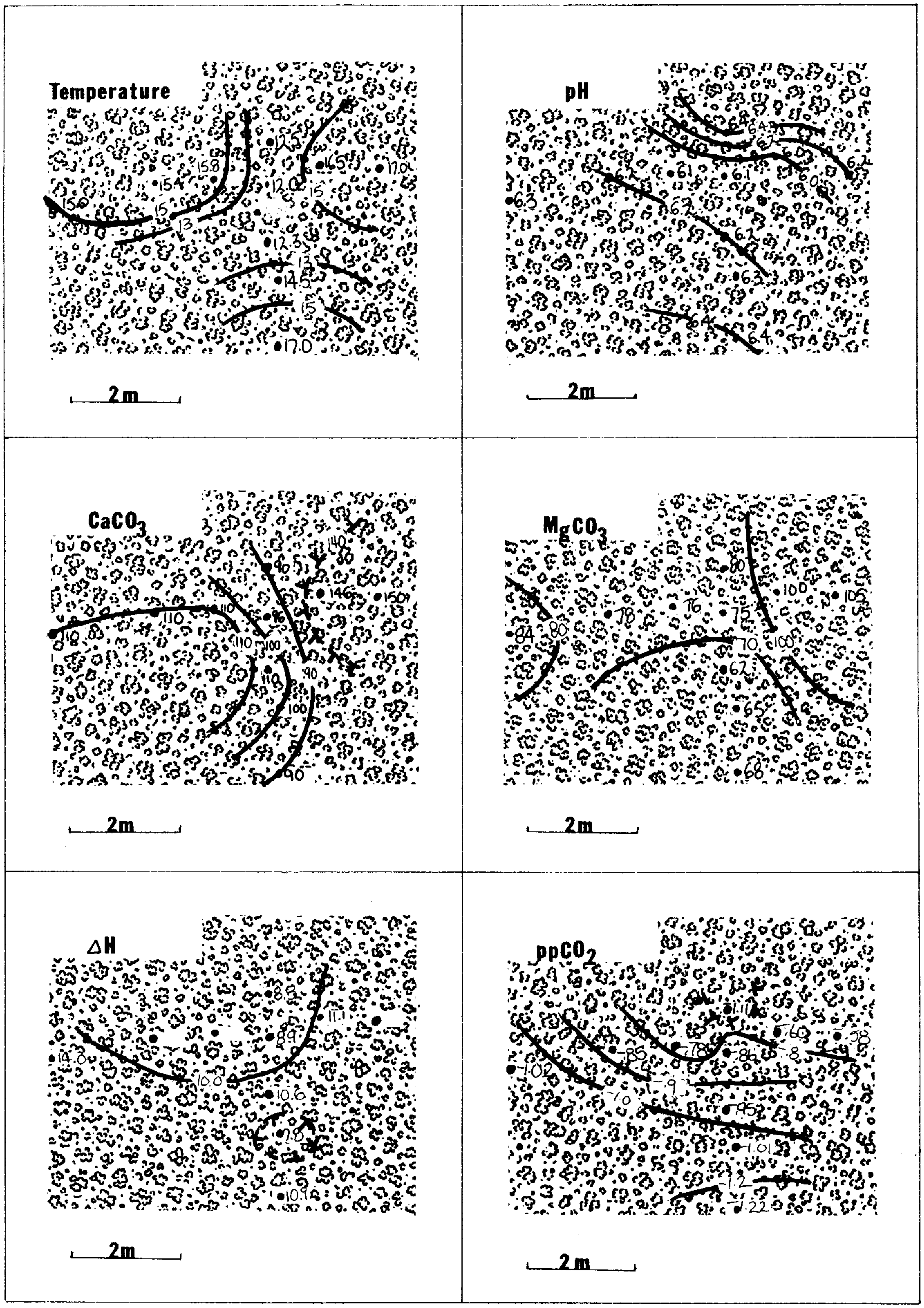
July 11



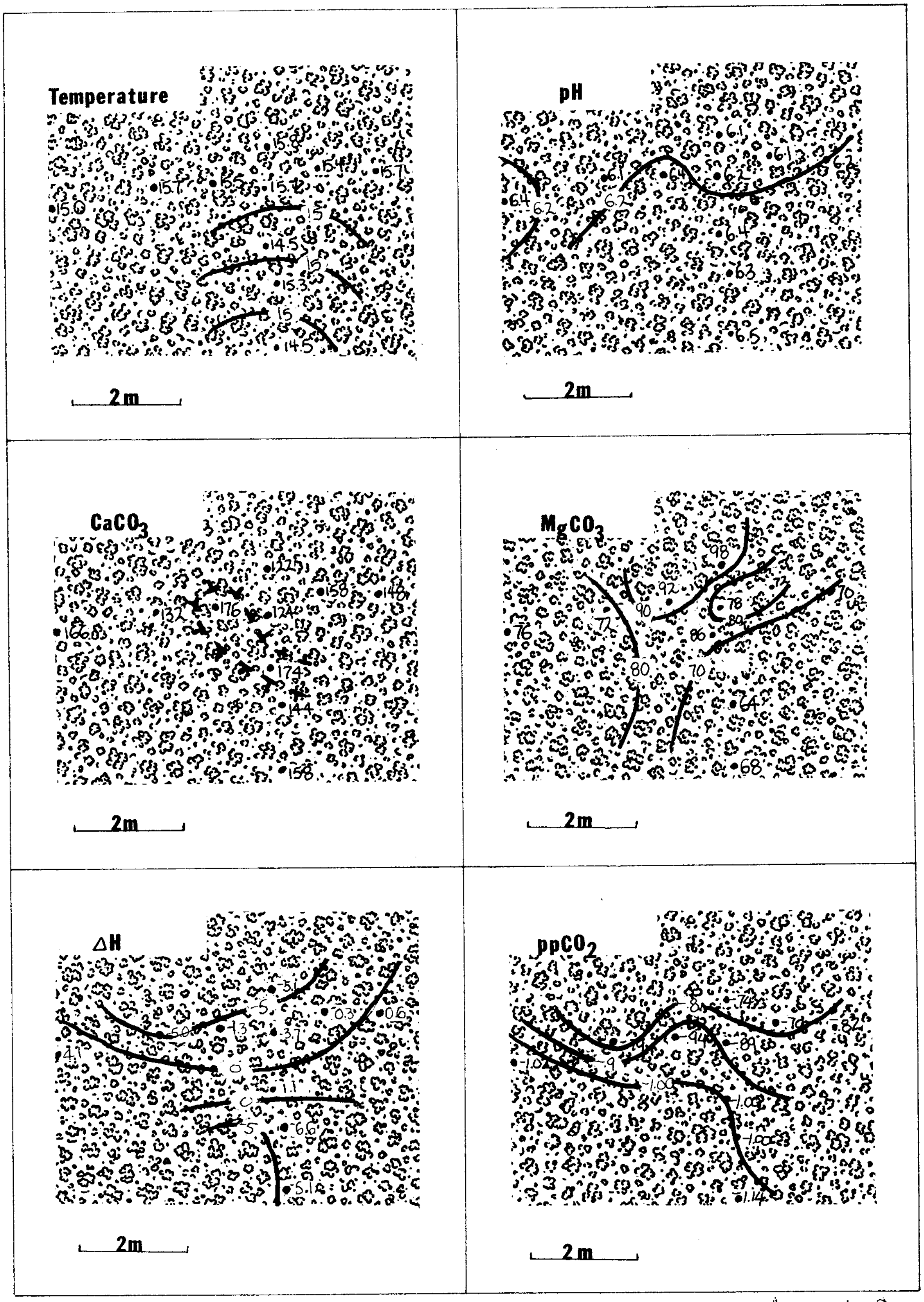
July 16



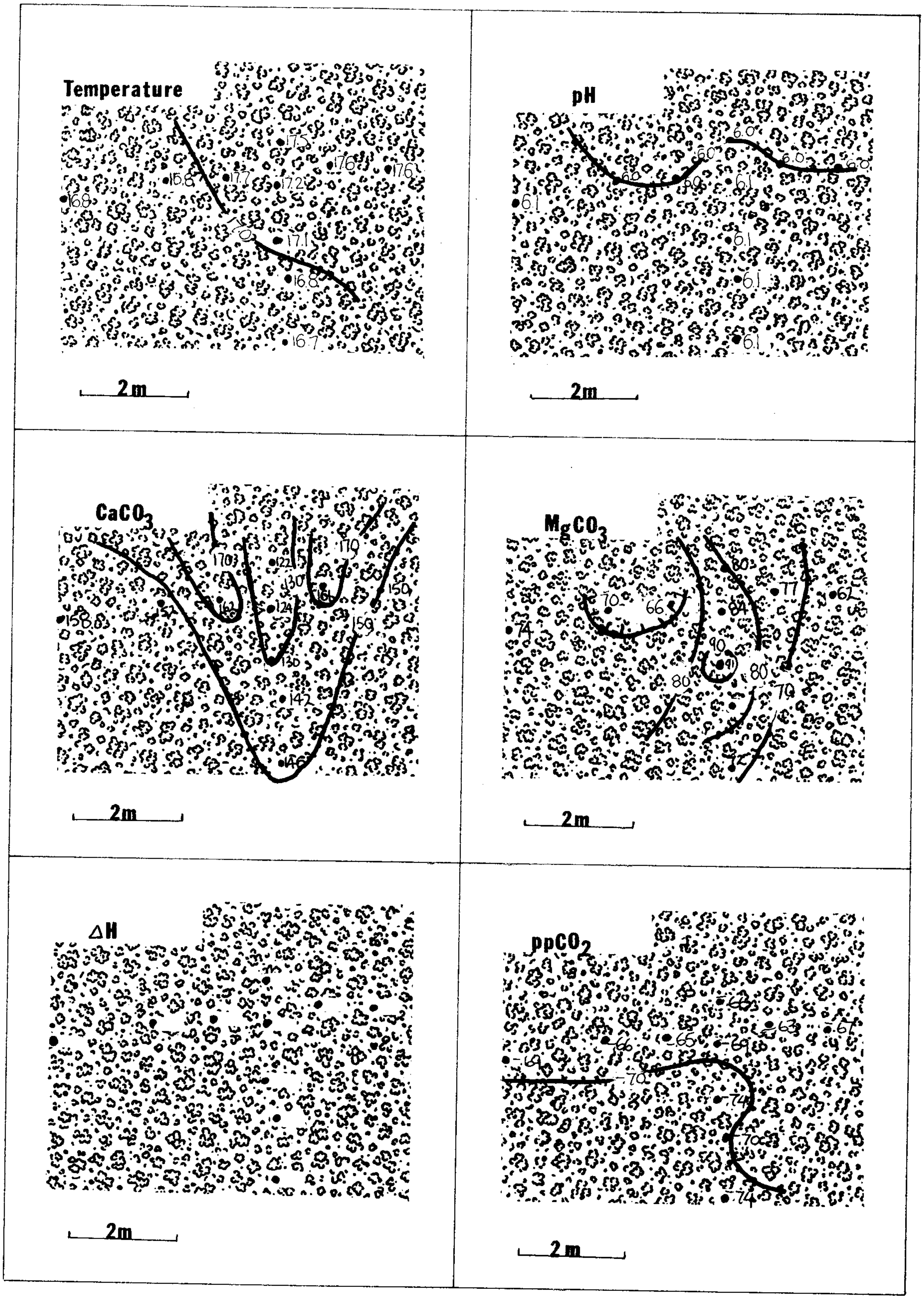
July 25



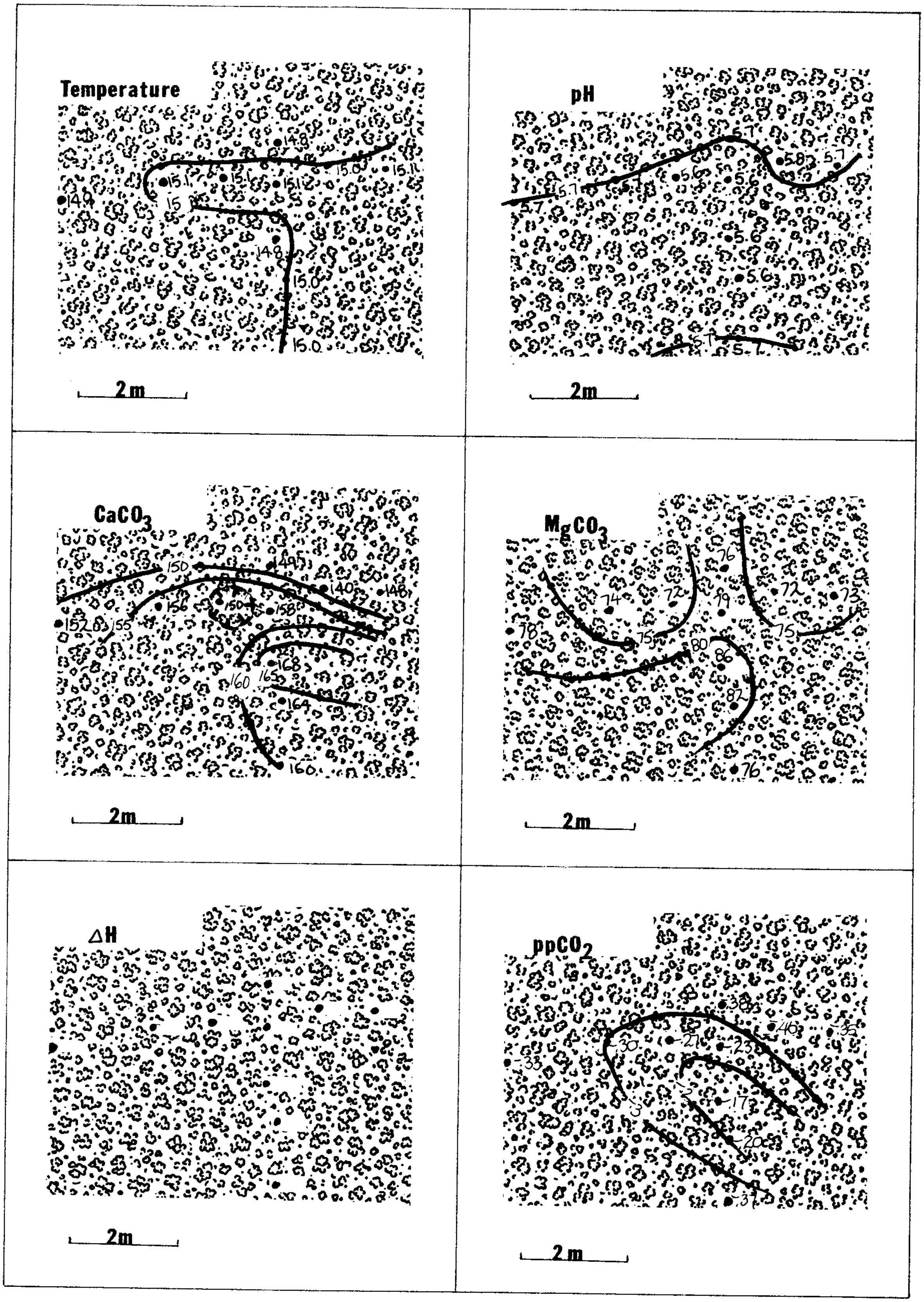
August 1



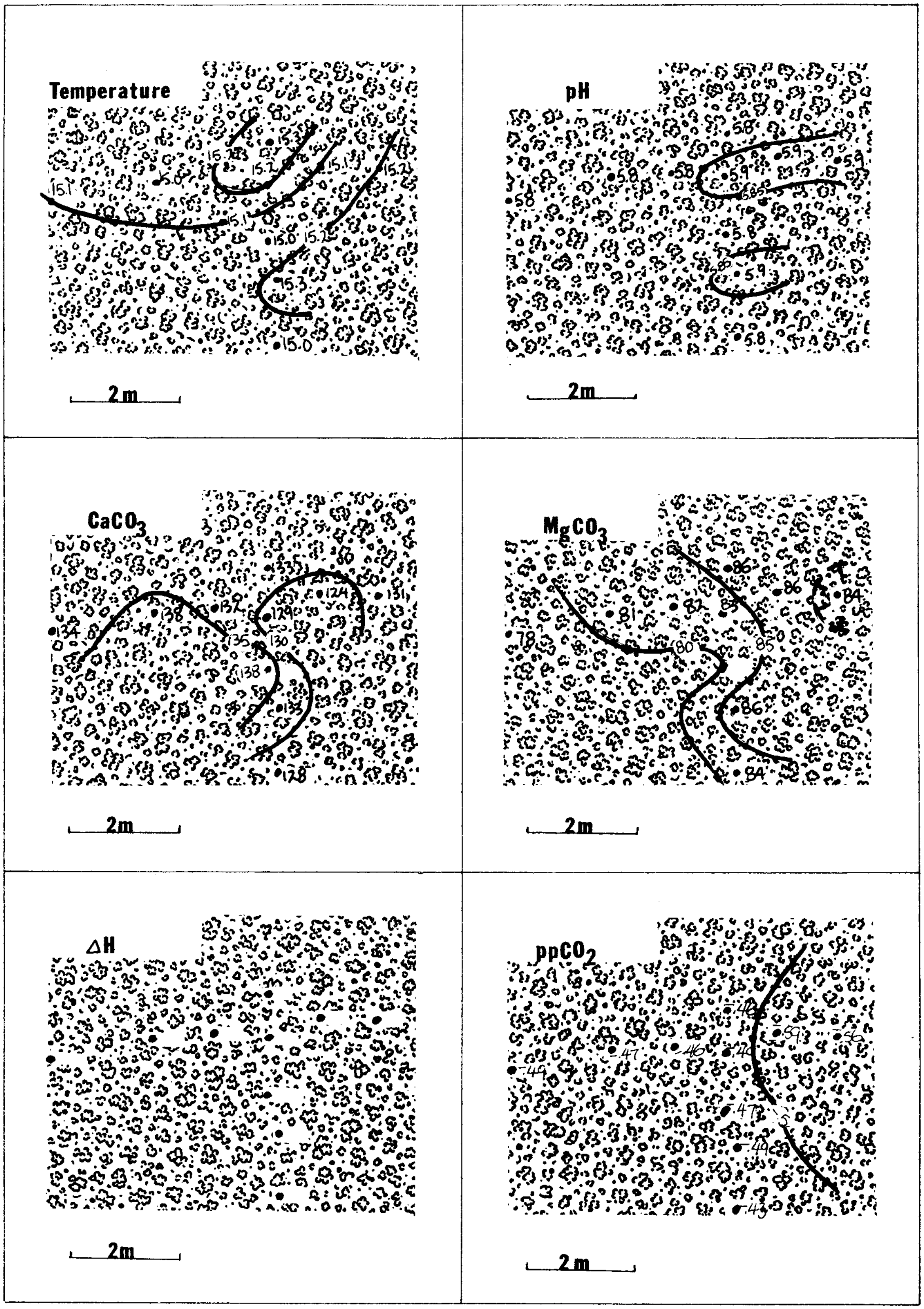
August 8



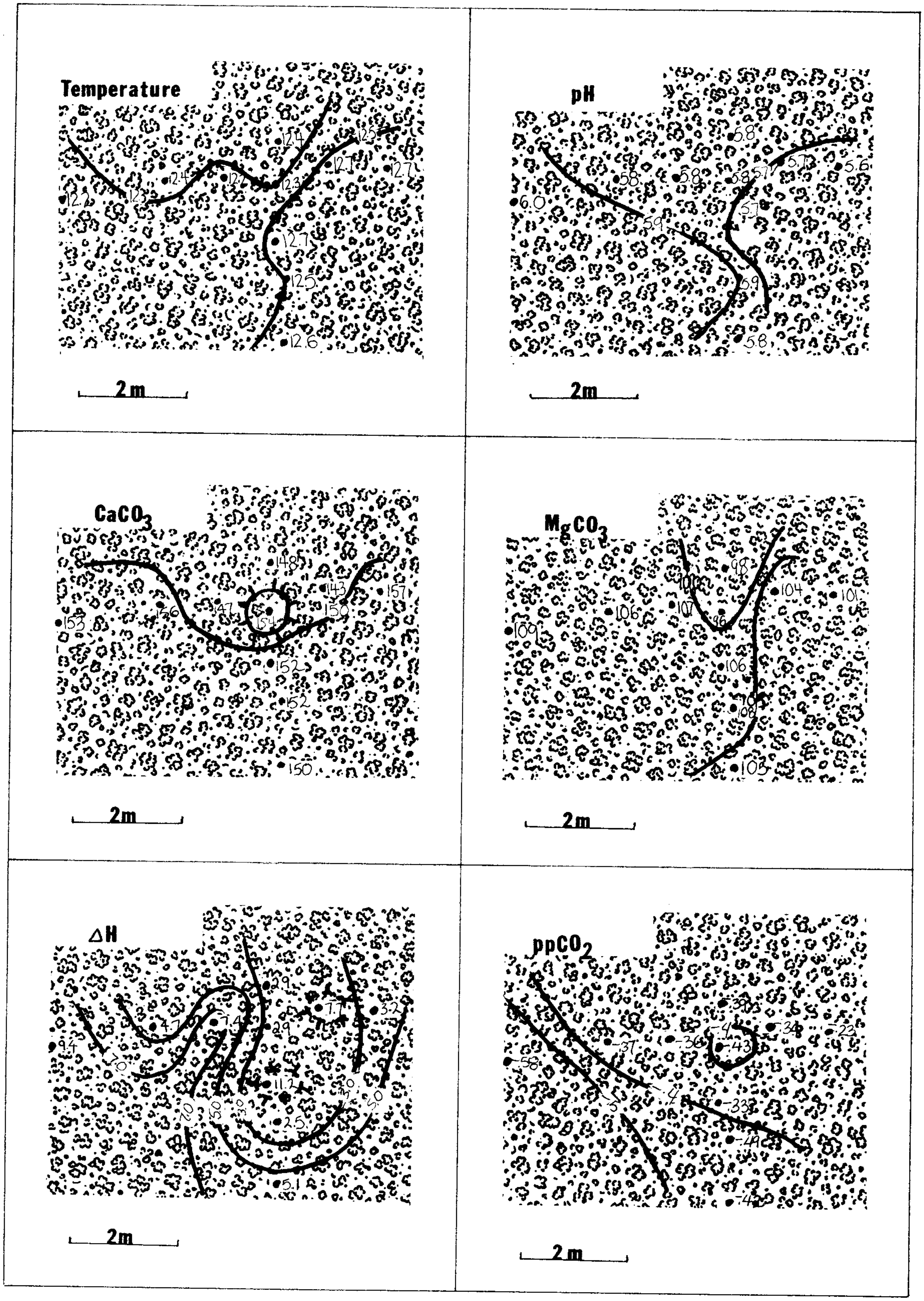
August 16



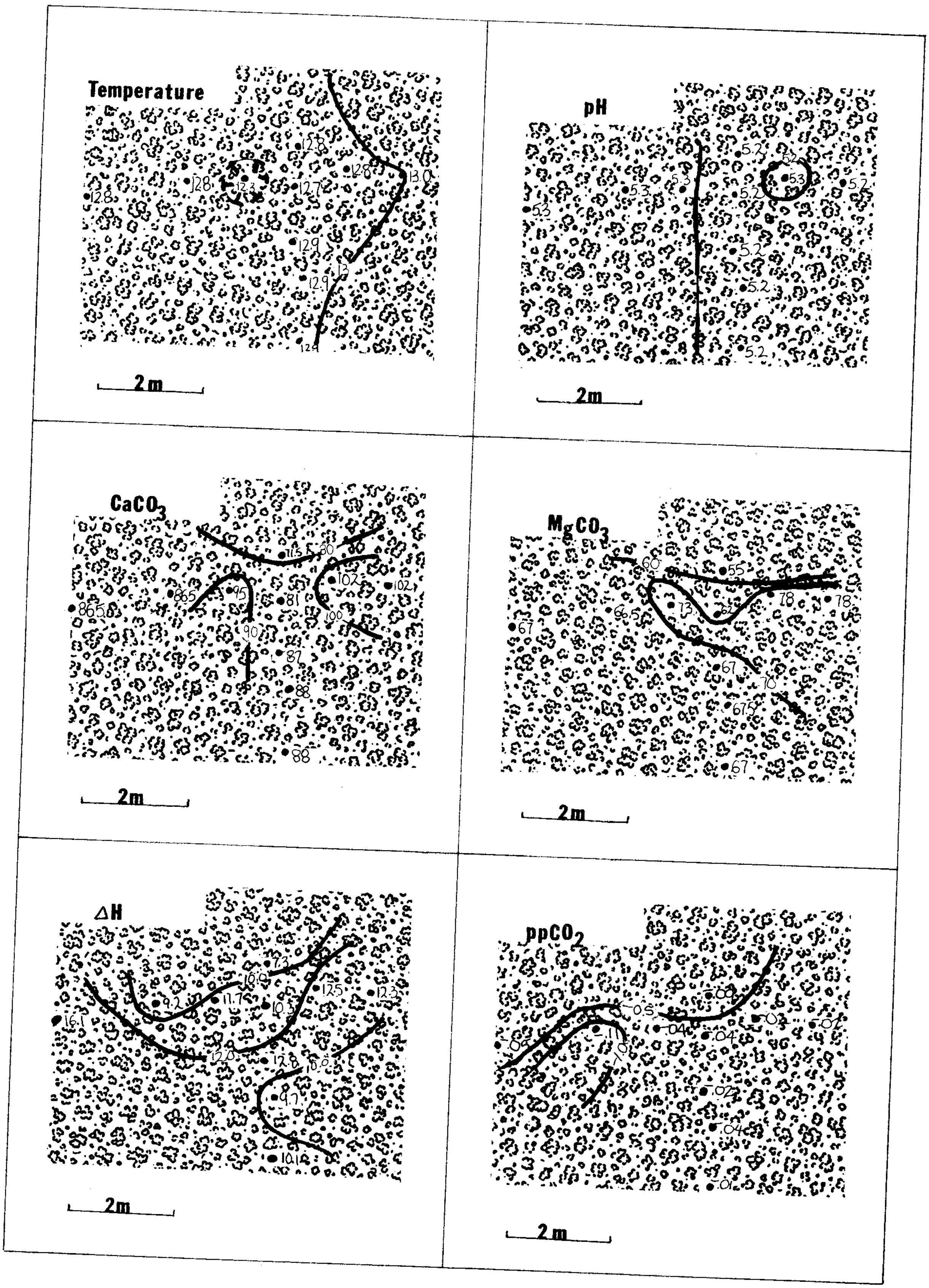
August 23



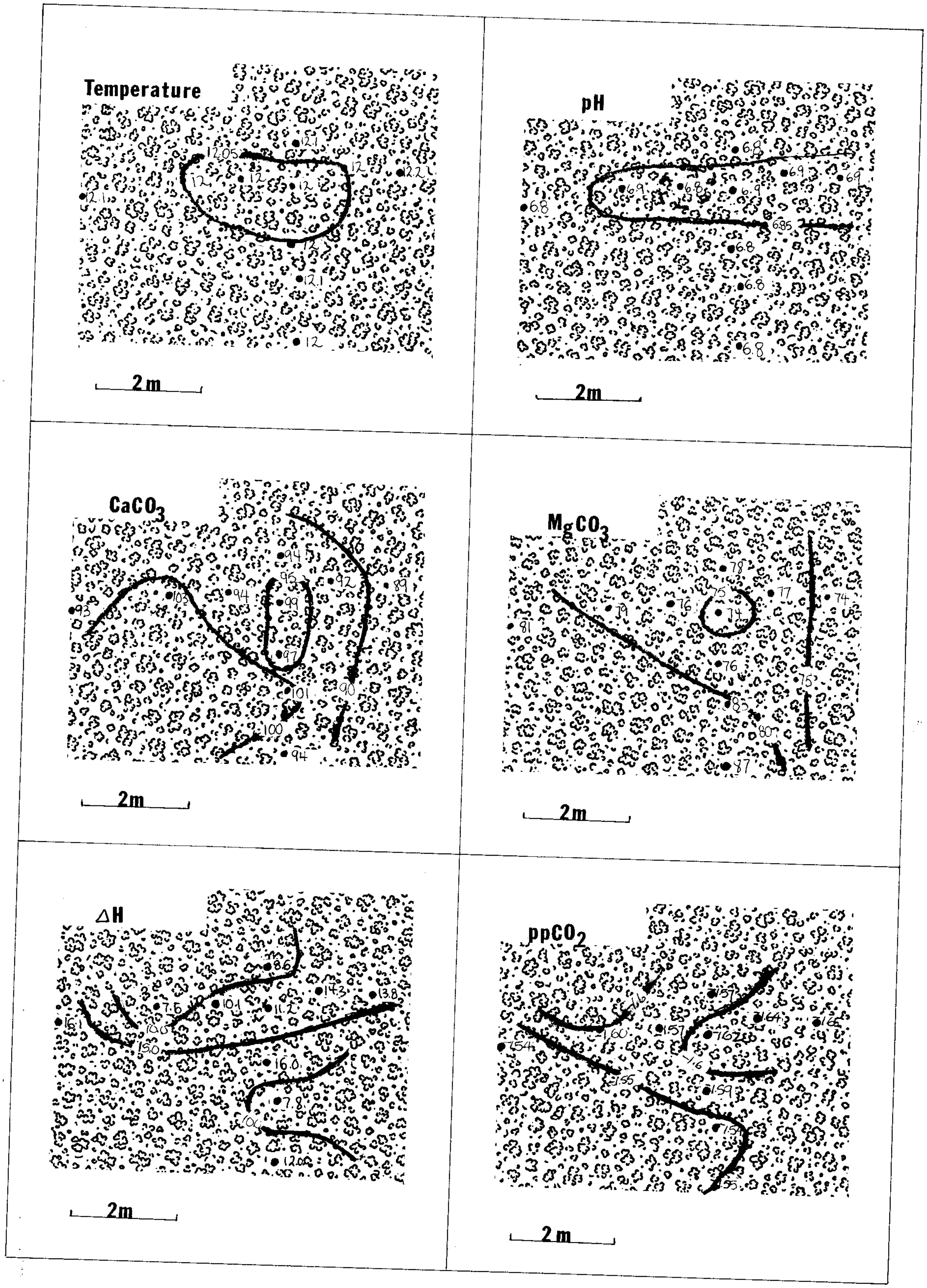
Temperature
2m
pH
2m
CaCO3
2m
MgCO3
2m
ΔH
2m
ppCO2
2m



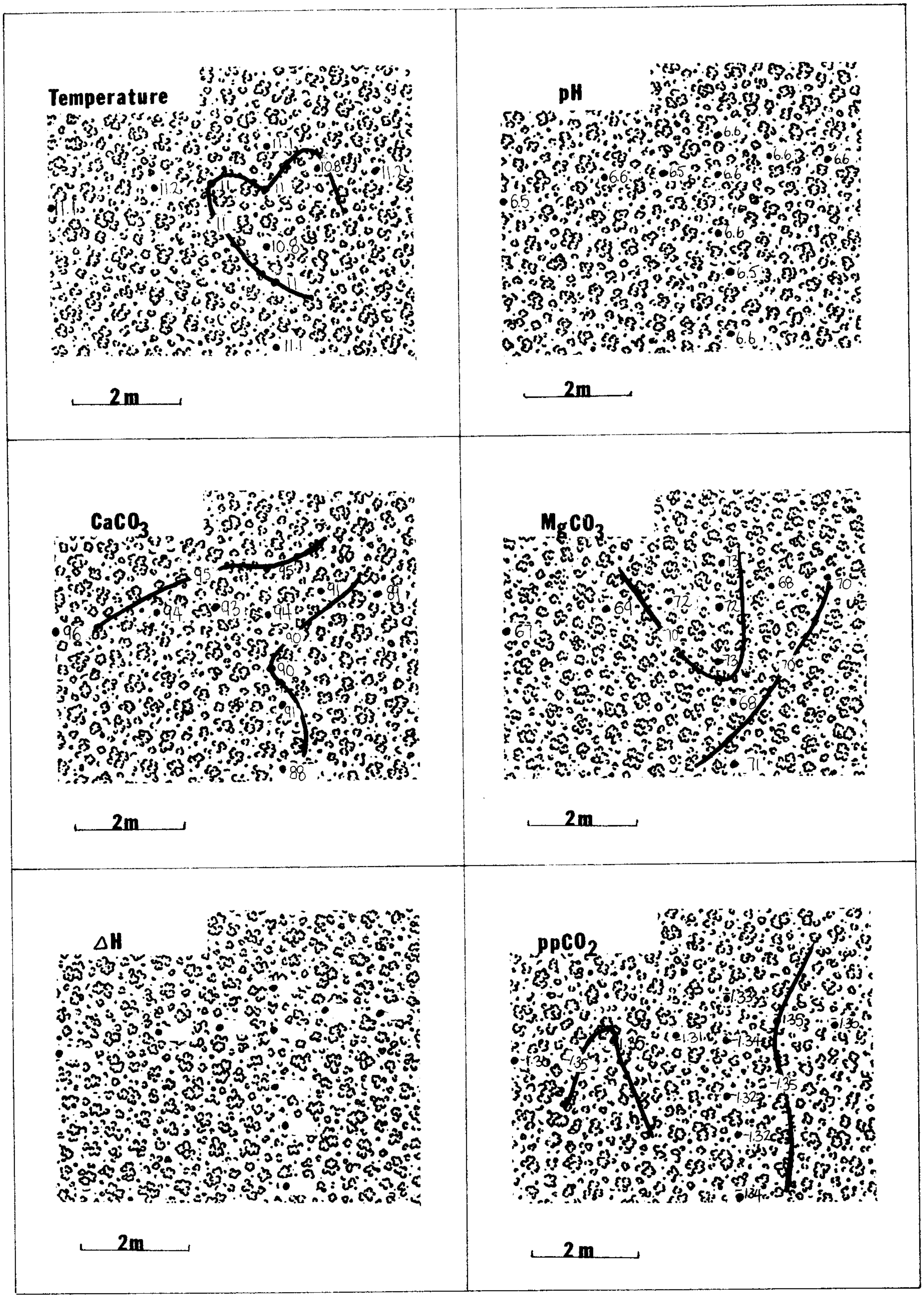
September 14



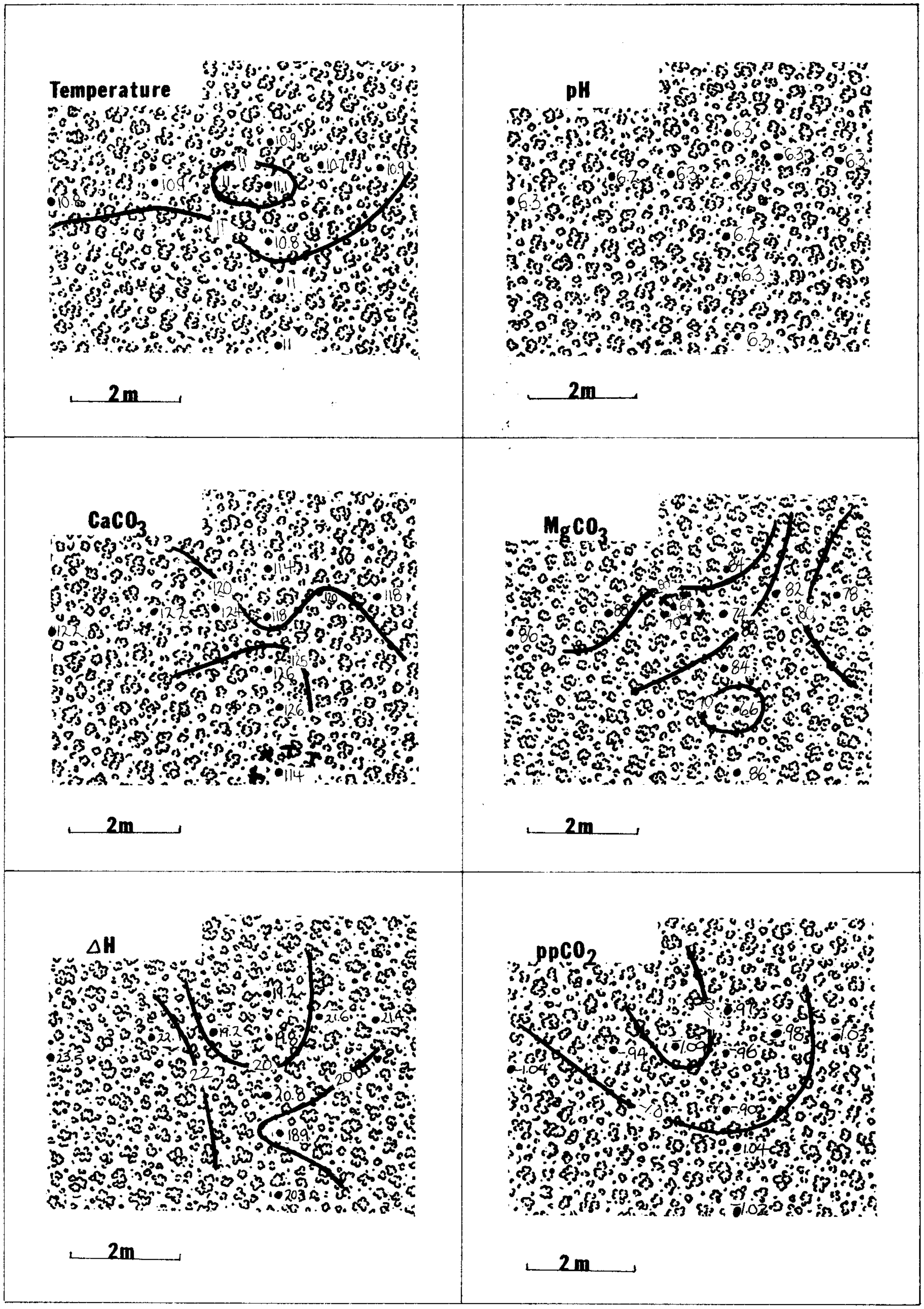
September 30



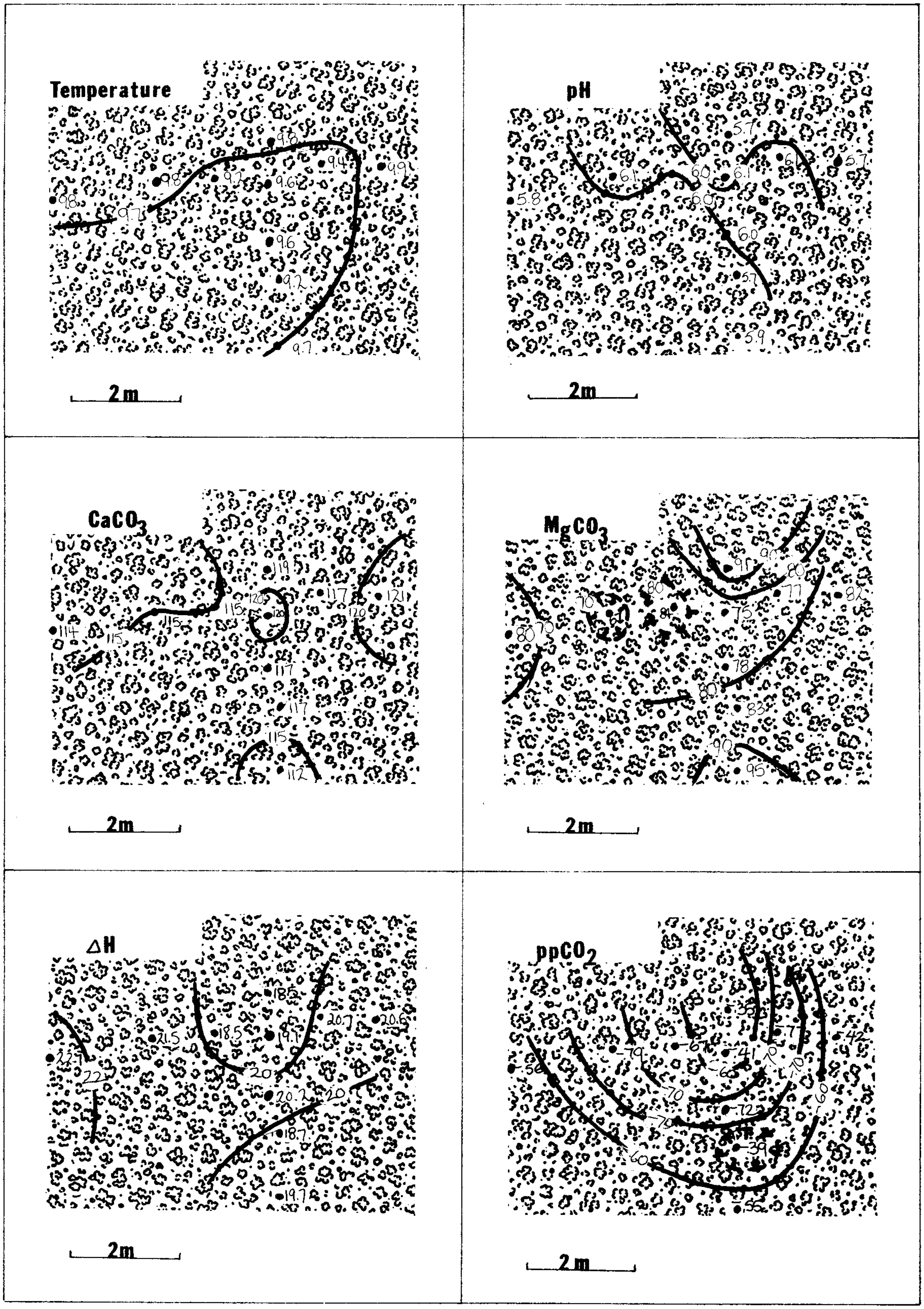
October 13



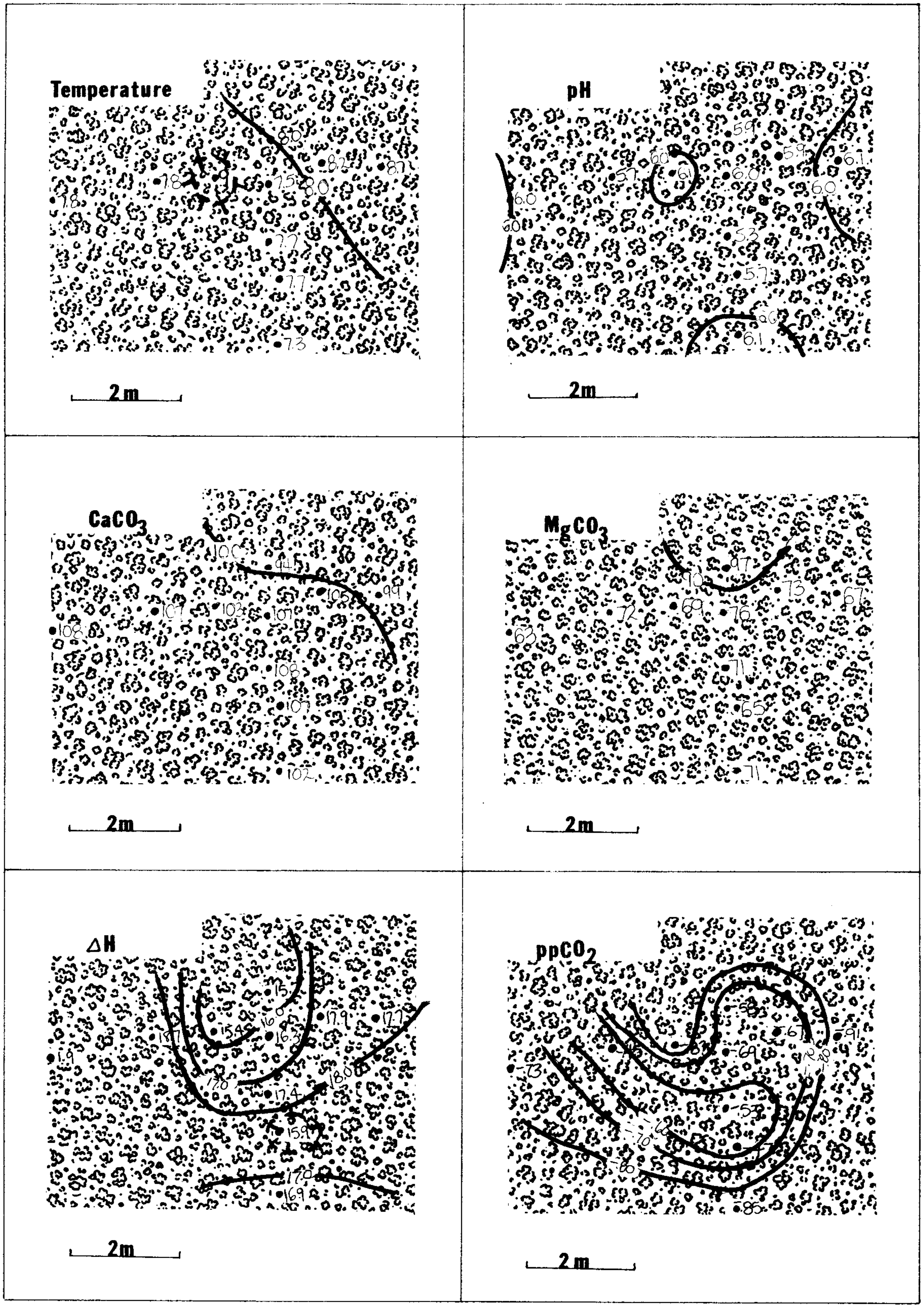
October 21



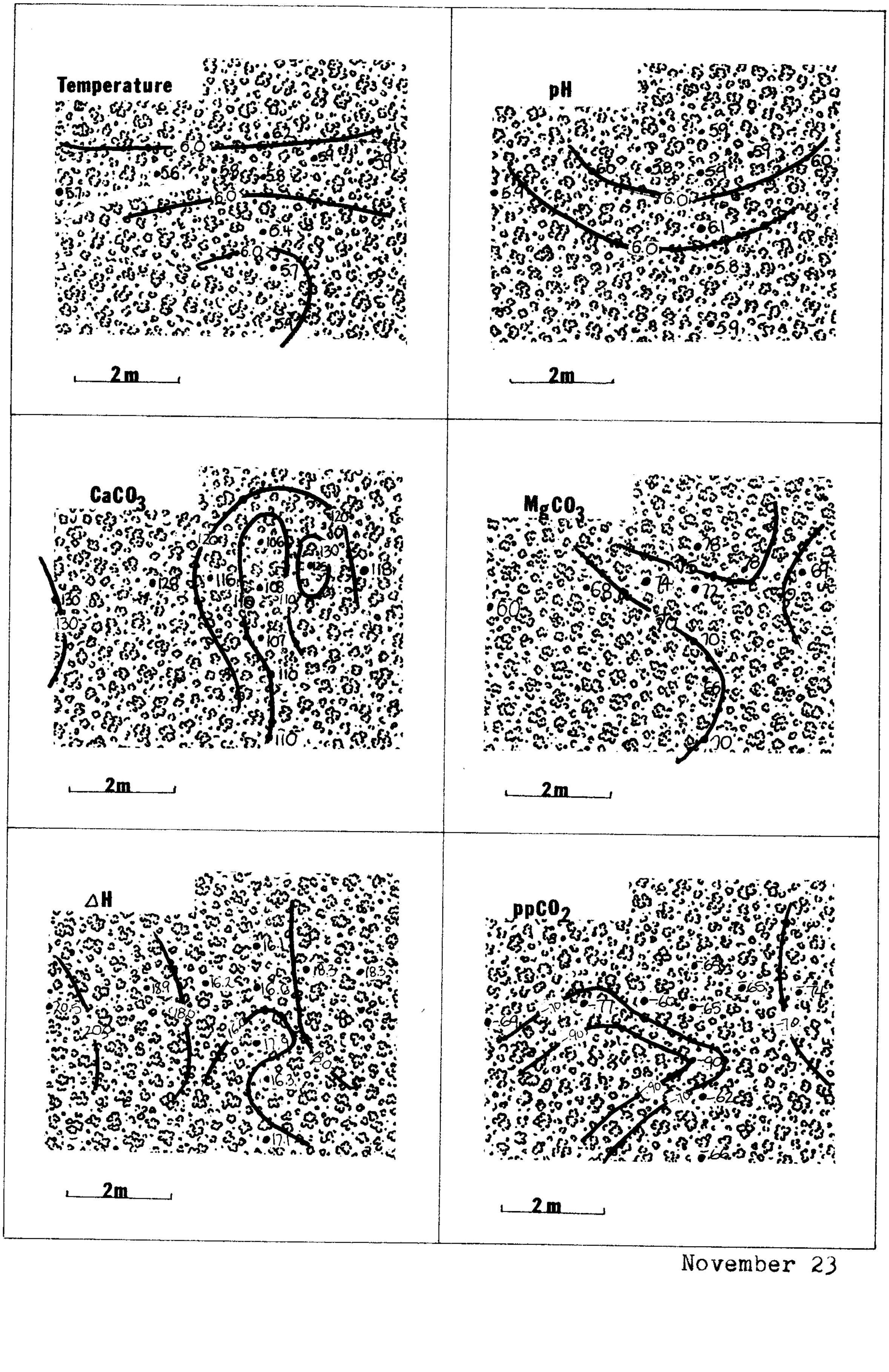
October 26



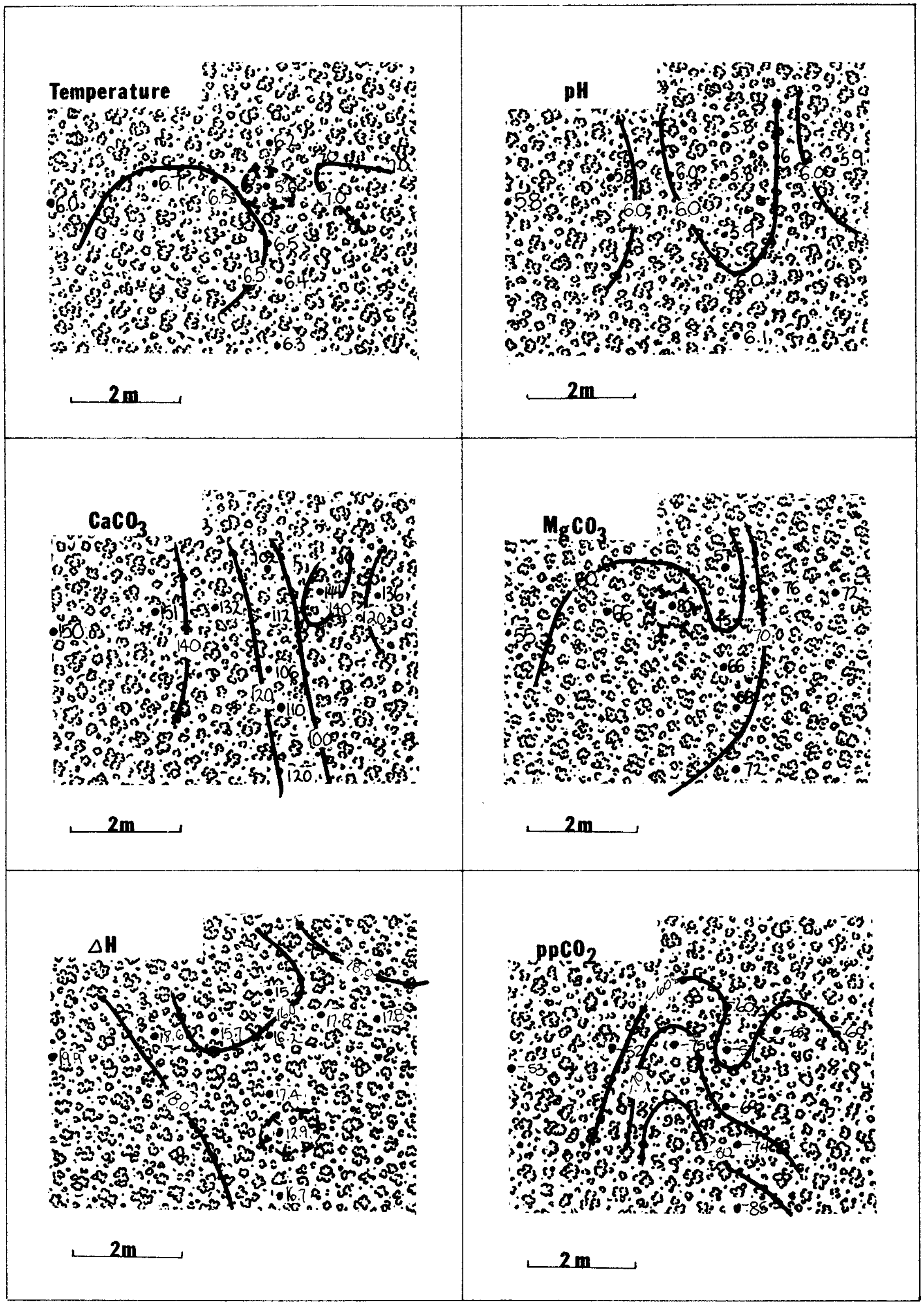
November 2



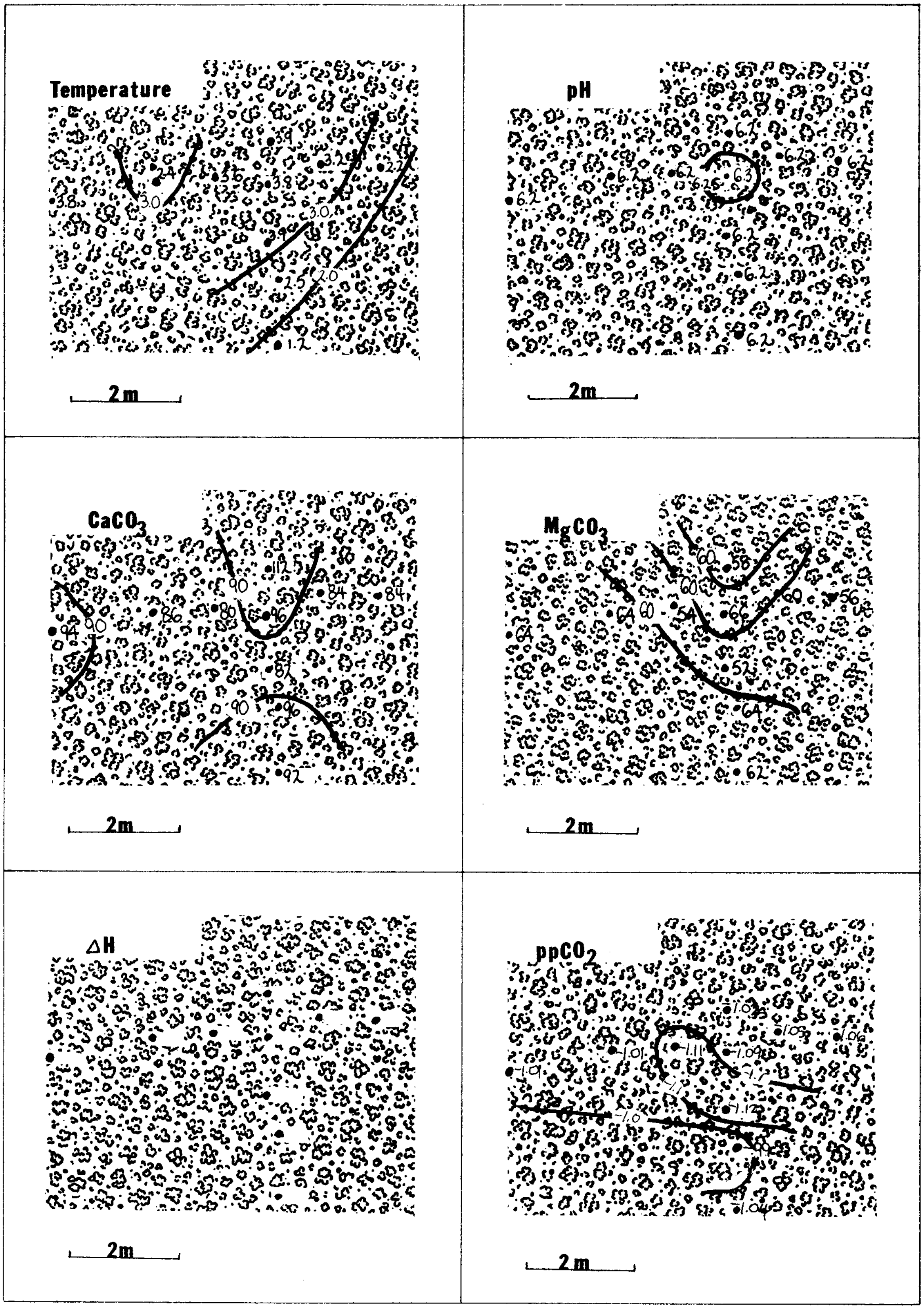
November 15



November 23



November 30


Temperature
2m
pH
2m
CaCO3
2m
MgCO3
2m
ΔH
2m
ppCO2
2m

Date	Site	T	pH	Ca^{++}	Mg^{++}
July 11	CA	12.9	6.5	118	76
	CB	14.9	6.2	120	86
	CC	14.5	6.1	156	98
	CD	12.5	6.8	154	88
	CE	12.9	6.8	138	84
	CF	12.5	6.8	138	86
July 16	CA	13.7	6.9	136	84
	CB	14.2	6.9	126	92
	CC	12.3	6.6	168	94
	CD	12.7	7.0	152	102
	CE	12.3	7.0	144	82
	CF	12.9	7.1	142	90
July 25	CA	12.8	6.9	144	90
	CB	13.0	6.8	150	90
	CC	11.9	6.4	180	102
	CD	12.1	6.8	162	90
	CE	12.2	6.8	144	90
	CF	12.0	6.8	156	100
Aug 1	CA	13.9	6.4	166	68
	CB	14.1	6.2	156	118
	CC	12.2	6.5	174	112
	CD	12.6	6.6	182	68
	CE	13.1	6.7	154	94
	CF	13.9	6.7	158	88
Aug 8	CA	13.6	6.8	152	84
	CB	13.8	6.8	134	86
	CC	13.5	6.8	160	94
	CD	12.8	6.9	124	86
	CE	12.5	7.1	148	88
	CF	12.3	6.7	136	86
Aug 16	CA	15.0	6.7	162	105
	CB	14.6	6.6	158	102
	CC	14.1	6.6	164	92
	CD	14.3	6.7	162	98
	CE	13.2	6.7	156	110
	CF	12.8	6.4	146	132

Date	Site	T	pH	Ca^{++}	Mg^{++}
Aug 23	CA	13.9	6.3	158	92
	CB	13.5	6.3	155	89
	CC	13.1	6.3	156	88
	CD	13.8	6.2	142	82
	CE	12.7	6.3	131	76
	CF	12.2	6.3	112	70
Aug 30	CA	15.0	6.4	148	92
	CB	14.8	6.3	143	111
	CC	14.8	6.1	142	116
	CD	14.9	6.1	140	101
	CE	14.8	6.2	149	96
	CF	14.7	6.2	154	82
Sept 14	CA	11.3	6.1	138	98
	CB	8.3	6.2	160	94
	CC	9.1	6.6	169	103
	CD	10.9	6.2	132	108
	CE	9.2	6.3	136	86
	CF	8.8	6.3	143	95
Sept 22	CA	9.2	6.4	122	92
	CB	9.2	6.3	122	94
	CC	8.8	5.6	122	95
	CD	9.0	6.1	108	84
	CE	9.3	6.2	114	89
	CF	9.7	6.3	156	90
Sept 30	CA	11.2	5.6	110	85
	CB	11.1	5.9	116	88
	CC	11.0	5.7	118	92
	CD	11.0	5.7	116	90
	CE	11.2	5.6	116	89
	CF	11.2	5.4	117	90
Oct 13	CA	10.0	7.2	120	91
	CB	10.0	7.3	119	90
	CC	10.1	7.3	124	94
	CD	10.3	7.1	126	94
	CE	10.3	7.2	123	90
	CF	10.2	6.7	120	90
Oct 21	CA	9.4	7.1	106	77
	CB	9.3	6.8	105	77
	CC	9.4	6.9	110	78
	CD	9.2	6.8	107	80
	CE	9.5	6.8	102	76
	CF	9.4	6.9	104	77

Date	Site	T	pH	Ca^{++}	Mg^{++}
Oct 26	CA	9.5	7.0	94	108
	CB	9.3	7.0	104	88
	CC	9.8	6.9	112	96
	CD	9.7	6.9	108	94
	CE	9.5	6.9	106	94
	CF	9.7	6.9	98	102
Nov 2	CA	7.3	6.7	94	102
	CB	7.3	6.5	106	94
	CC	7.6	6.6	91	104
	CD	6.9	6.6	100	102
	CE	7.6	6.3	104	107
	CF	7.4	6.4	87	100
Nov 15	CA	4.7	6.2	100	114
	CB	3.8	6.2	103	118
	CC	4.2	6.4	103	112
	CD	5.6	6.1	100	115
	CE	4.9	6.4	101	117
	CF	5.0	6.3	102	126
Nov 23	CA	4.3	6.2	108	108
	CB	3.8	6.2	108	115
	CC	4.5	6.3	110	114
	CD	4.4	6.1	103	117
	CE	4.5	6.3	109	122
	CF	4.7	6.2	112	106
Nov 30	CA	4.0	6.2	115	101
	CB	3.8	6.3	113	113
	CC	4.3	6.3	118	118
	CD	3.1	6.0	112	120
	CE	3.4	6.3	118	135
	CF	3.2	6.2	124	88
Dec 7	CA	1.2	6.8	108	70
	CB	0.9	6.7	106	70
	CC	1.2	6.7	98	66
	CD	2.1	6.7	92	64
	CE	4.3	6.8	90	62
	CF	3.2	6.7	96	66

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