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The University of Oklahoma, Ph.D., 1968
Geology

THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

# GEOMETRY AND DEPOSITIONAL ENVIRONMENTS OF PENNSYLVANIAN RESERVOIR SANDSTONES, NORTHWESTERN OKLAHOMA

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

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degree of

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GEOMETRY AND DEPOSITIONAL ENVIRONMENTS OF PENNSYLVANIAN RESERVOIR SANDSTONES, NORTHWESTERN OKLAHOMA

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DISSERTATION COMMITTEE

## ACKNOWLEDGMENTS

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The geological library of the Oklahoma City Geological Society and the log files of Dr. Busch were the principal sources of mechanical logs and scout tickets used in this study. Additional mechanical and sample logs were borrowed from Mobil and Pan American Oil Companies. Well cuttings and cores were obtained from the University of Oklahoma Core and Sample Library. Twenty-five thin sections were prepared by Mcbil Oil Corporation, and Mr. H. L. Cullins, Geologist with the U. S. Geological Survey, Denver, Colorado, lent the writer 43 thin sections from the Morrow sandstones and limestones. The writer acknowledges his gratitude to these companies and individuals for these sources of basic data.

Financial support throughout the years of the writer's graduate studies came from the Ministry of Education of the Republic of Iraq, through a scholarship granted by the University of Baghdad.

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Plate

# GEOMETRY AND DEPOSITIONAL ENVIRONMENTS OF PENNSYLVANIAN RESERVOIR SANDSTONES, NORTHWESTERN OKLAHOMA

## INTRODUCTION

### General Statement

This study deals with a comprehensive regional evaluation of the geometry, distribution pattern, and depositional environments of four subsurface Pennsylvanian sandstone bodies of the northeastern shelf of the Anadarko Basin of Oklahoma. All except one of these bodies of sandstone are exceedingly productive of hydrocarbons, chiefly gas. In each case, the traps are primarily stratigraphic in nature, structure playing a minor to almost equal role.

The region selected for study consists of approximately 4,320 square miles (130 townships) in Harper, Woodward, and parts of Beaver, Woods, and Ellis Counties of northwestern Oklahoma. The region occupies a restricted portion of the northeastern shelf of the Anadarko basin, as shown in Figure 1.

Approximately 1,600 mechanical logs were utilized in this investigation. Over much of the area the well

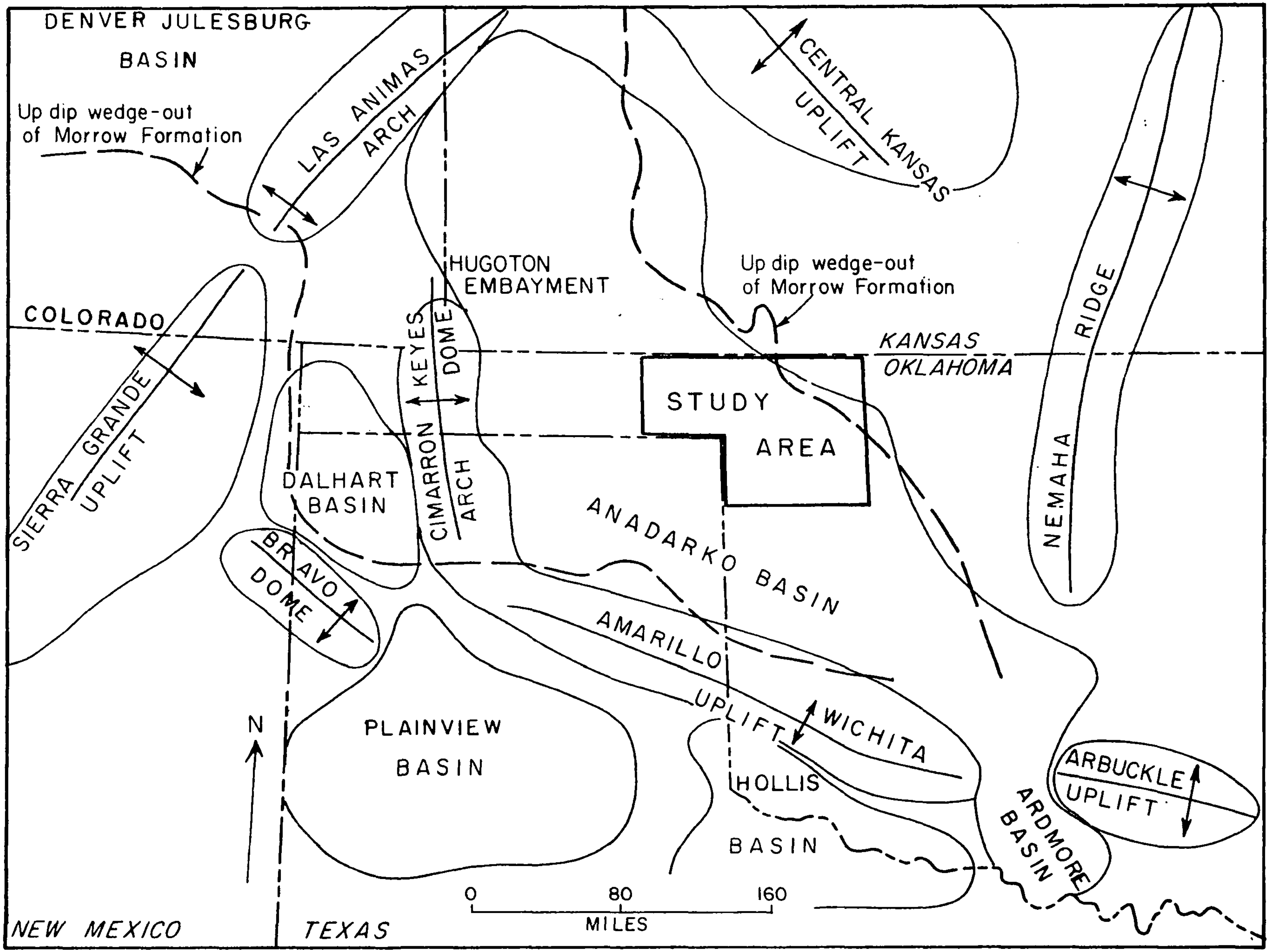



**Fig. 1– Location map. Area of detailed study in relation to major tectonic features. (Adapted from Adams, 1964; Forgotson, 1966; Huffman, 1959; and Riggs, 1960).**

density is one well per section, except for the southeastern part of the study area, where it is considerably less. Sixty thin sections and approximately 45 sets of sample descriptions were used as a basis for resolving problematical correlations and gaining more understanding of the depositional environments of the several reservoir sandstones.

## Purpose and Method of Analysis

Geologic information necessary to comprehend more fully rocks of commercial oil and gas accumulations include geometry (spatial dimensions), paleogeomorphology, structural history, and paleodepositional environments.

Aspects of the geometry of sandstone bodies, primary as well as composite units, include ... "shape, size, trend, and internal characteristics, and their physical and genetic relationship to adjacent sediments" (Peterson and Osmond, 1961, p. 1). Internal structures of sandstone bodies, such as cross-bedding, flow markings, preferred grain orientation, etc., are significant in the study of geometry of sandstones, but in this study, lack of adequate core material prevented detailed examination of such macroscopic internal characteristics.

Geometry, paleogeomorphology, structural history, and paleodepositional environments of the several reservoir sandstones were interpreted by applying conventional mapping techniques. Support of these interpretations was obtained by microscopic studies of thin sections of unoriented cores and rotary cuttings, binocular microscopic sample examination and descriptions of rotary cuttings, and examination of commercial sample logs.

Throughout this study emphasis is focused on stratigraphic intervals constituting "Genetic Sequences," after Busch (1959). He (Busch, 1959) pointed out that a genetic sequence is a stratigraphic interval devoid of any significant breaks in sedimentation and that it may contain sandstones which are significant and distinct facies components. In discussing the Morrow formation he considered this unit as a genetic sequence and defined its top and base by a lithologic time marker (base of "Thirteen Finger" limestone) and the Mississippian unconformity, respectively.

An isopachous map of a given genetic sequence will reveal basin configuration, the degree to which paleogeomorphology has controlled sediment distribution, and successive positions of paleoshorelines. In this broad and somewhat generalized reconstruction, one or more reservoir sandstones can be studied. An isopach of such a genetic sequence will reveal thickness variations which are completely independent of present-day structural configuration. Furthermore, isopaching a genetic sequence permits the assumption that any tectonic activity contemporaneous with the deposition of the stratigraphic interval involved was at a minimum.

Structural maps, constructed on reliable and readily recognizable time horizons within the genetic interval, serve as a means of establishing the relative significance of stratigraphic and structural control of oil and gas accumulation. Finally, the systematic geologic history of an area may be ascertained, once its genetic sequences have been defined and mapped.

## Previous Investigations

Only recently have exploration geologists abandoned the practice of loosely referring to any elongate subsurface sandstone body as a bar without knowledge of its origin. Such loose references are neither geologically nor economically sound, inasmuch as geometry alone cannot provide all of the answers to exploration questions.

Concerning the sandstones of the study area, the first paper emphasizing the geometry-origin approach was published by Busch in 1959. Busch discussed four types of elongate Pennsylvanian sandstone bodies of the Mid-Continent Region, one being the Morrow beach sandstones.

Most of the earlier studies of Pennsylvanian strata in this area describe essentially the stratigraphic sequence. Similar methods of analysis of Pennsylvanian sandstones in areas adjacent to the area of investigation (Arro, 1965; Barrett, 1961; and Cullins, 1959) are described in several Masters theses. These theses described Morrow sandstones in Texas, Beaver, and

Ellis Counties, Oklahoma, respectively. All considered the individual reservoir sandstones of the Morrow with varying degrees of detail, and included a consideration of their respective paleodepositional environments.

Regional studies in areas larger than (and including) that of the present study were made by T. A. Abels and W. H. Capps, University of Oklahoma graduates of geology. Abels (1958) made a subsurface lithofacies study of the Morrowan Series; and Capps (1959) a stratigraphic analysis of the Missourian and Lower Virgilian Series of the Pennsylvanian System.

Pate (1959) described stratigraphic traps along the north shelf of the Anadarko Basin. His study, however, is somewhat regional, and it includes various stratigraphic traps ranging in age from Silurian through Permian (Wolfcamp). Pate also described the producing zones and stratigraphic traps of the Laverne district (the Northwest Highland field of Beaver County, the Laverne gas area, and the Southeast Stockholm fields of Harper County). Pate designated the term, bar, to all of the sandstone bodies in the district.

The majority of oil companies operating in this area have undoubtedly investigated problems involving Pennsylvanian sandstone bodies described in this report. Their studies, however, were not available to the writer. Only a few are available. Adams (1964) discussed the diagenetic aspects of Lower Morrowan sandstones in an area on the northern flank of the Anadarko Basin; the study centered about Ellis County, including the southern part of the present study area. Forgotson (1966) studied the influence of regional and local structures on the deposition of the Morrow formation in an area west of the present study area.

## Regional Tectonic Setting

The significant positive tectonic features bordering the Anadarko Basin are the northward-trending Nemaha Ridge and the northwestward-trending Central Kansas Uplift on the east and northeast, respectively (Figure 1). The northeastward-trending Las Animas Arch is located northwest of the basin; the Cimarron Arch-Keyes Dome, trending northward across the Oklahoma Panhandle, defines its western margin. The northwestward-trending Amarillo-Wichita Uplift and the Arbuckle Uplift border the Anadarko Basin on the southwest and south, respectively.

Huffman (1959) outlined and described the major tectonic features of the Central Mid-Continent Region and their relation to present thickness and distribution of pre-Desmoinesian strata. Only those tectonic features in the vicinity of the study area are discussed briefly herein.

The Central Kansas Uplift is a major post-Mississippian structural uplift in north-central Kansas.

Missourian rocks are the earliest Pennsylvanian units directly overlapping Ordovician and older rocks of this structure.

The Nemaha Ridge is a major post-Mississippian structural feature of Kansas that extends southward into Oklahoma and northward into Nebraska. Upon this structure, Desmoinesian-Cherokee units are the earliest Pennsylvanian rocks directly overlapping the tilted and eroded Mississippian and older rocks, locally, including Pre-Cambrian. The Nemaha Ridge apparently terminates in Oklahoma City Uplift of central Oklahoma, its principal movement being post-Mississippian and pre-Middle Pennsylvanian, probably post-Morrowan.

The Amarillo-Wichita Uplift is a post-Morrowan feature. Beds of Middle Permian are underlain at places by Pre-Cambrian rocks.

# STRATIGRAPHY

## General Statement

### Pennsylvanian System

Several reservoir sandstone bodies characterize the study area. These are (descending): Wabaunsee ("Hoover"), Elgin (upper Endicott), and Endicott, all of Virgilian age; Lovell, Tonkawa, and Cottage Grove ("Layton" or "Osage Layton"), of Missourian age; and Morrow sandstone of Morrowan age (Figure 2). This study deals with only four of these sandstones; namely, "Hoover," Endicott, Tonkawa, and Morrow.

Key marker beds used as reference datums in this investigation are thin, reliable, and readily recognizable. In each instance, individual reference datum markers represent approximate contemporaneity of deposition. These are illustrated in Figure 2 on three electric logs of typical Pennsylvanian sections. The marker beds are (descending): top of Pennsylvanian System (top of Brownville limestone), "Marker A" (unnamed), Topeka limestone, top of Oread Formation, "Haskell" limestone, and base of Atokan "Thirteen Finger" limestone.

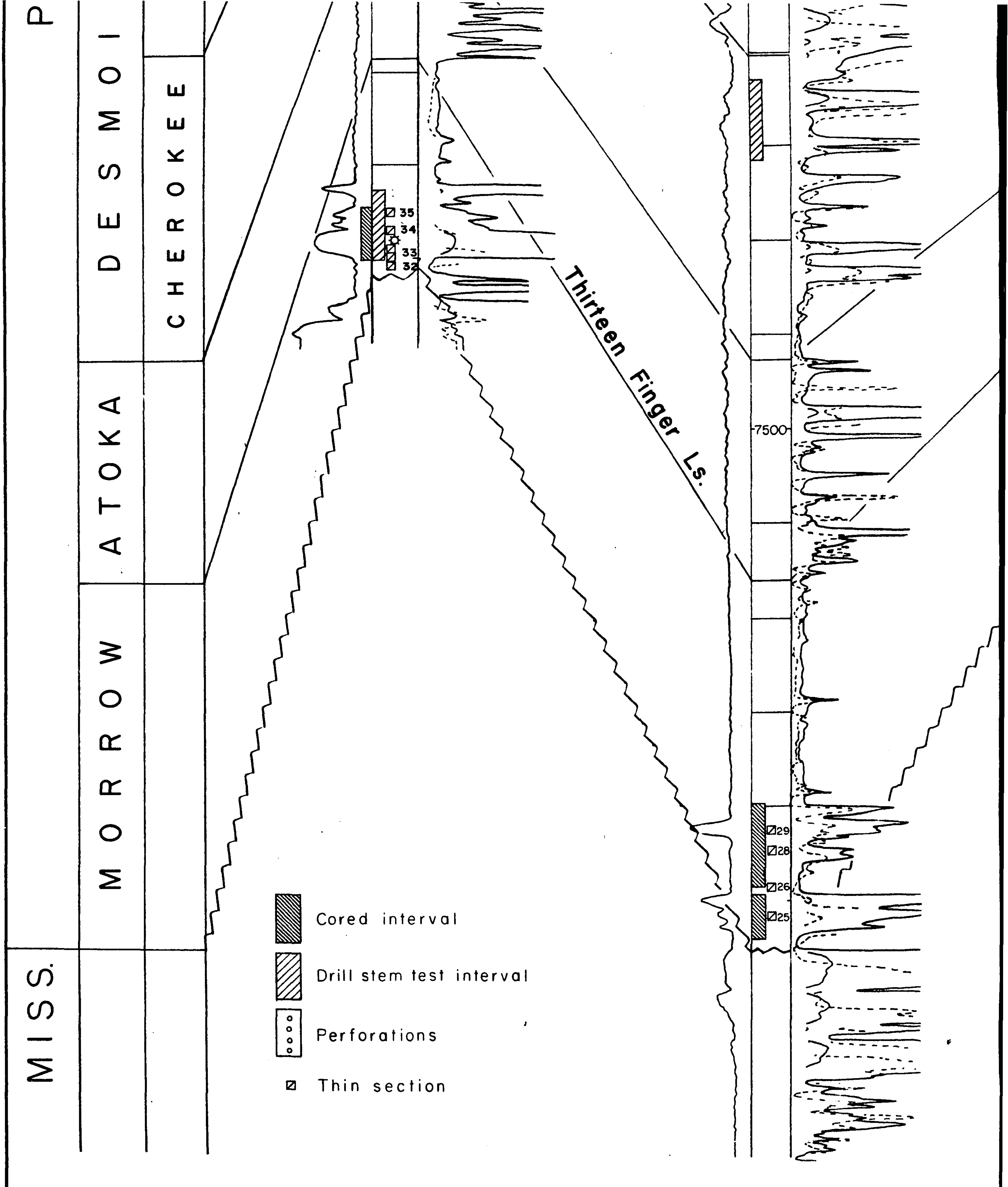
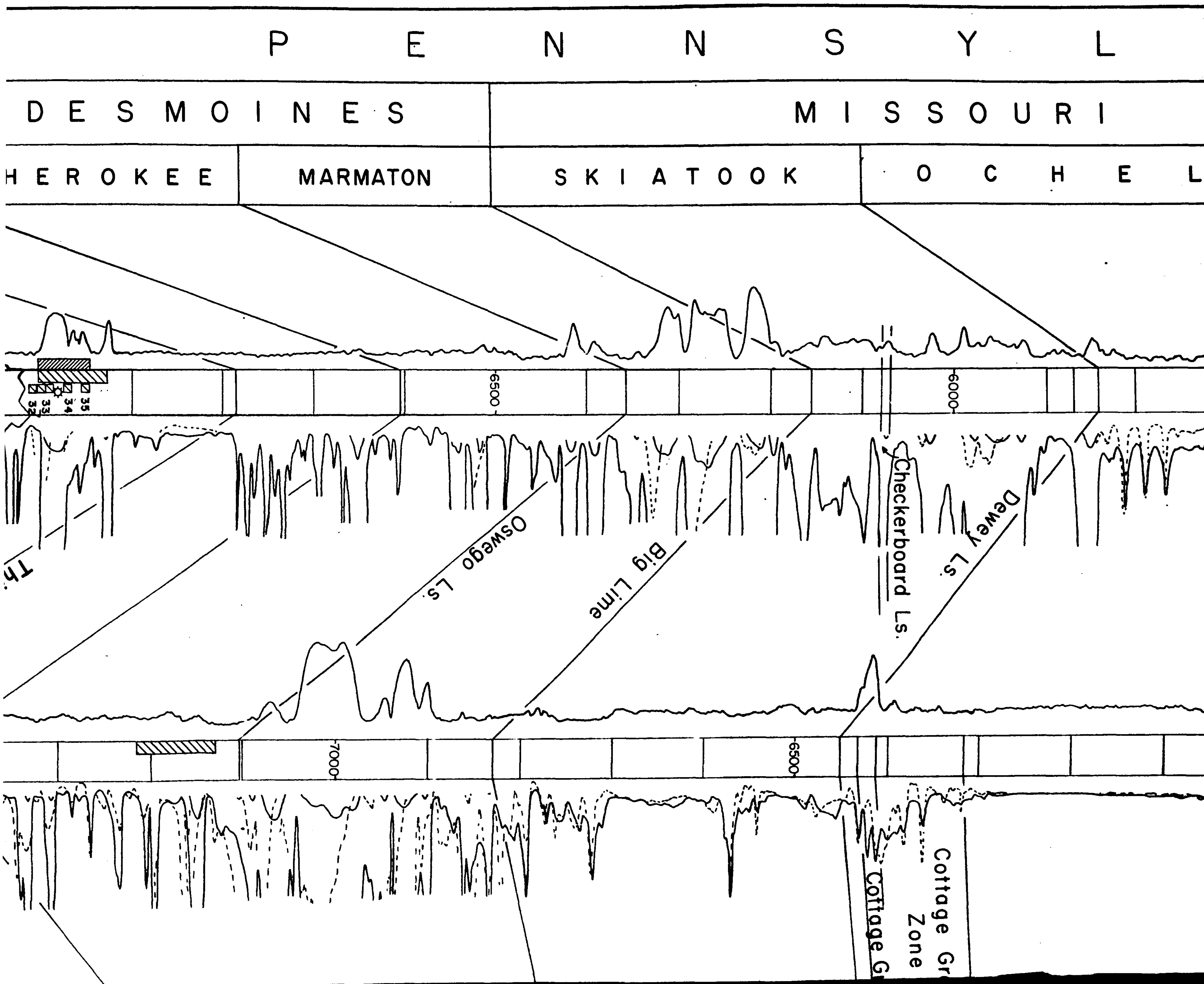
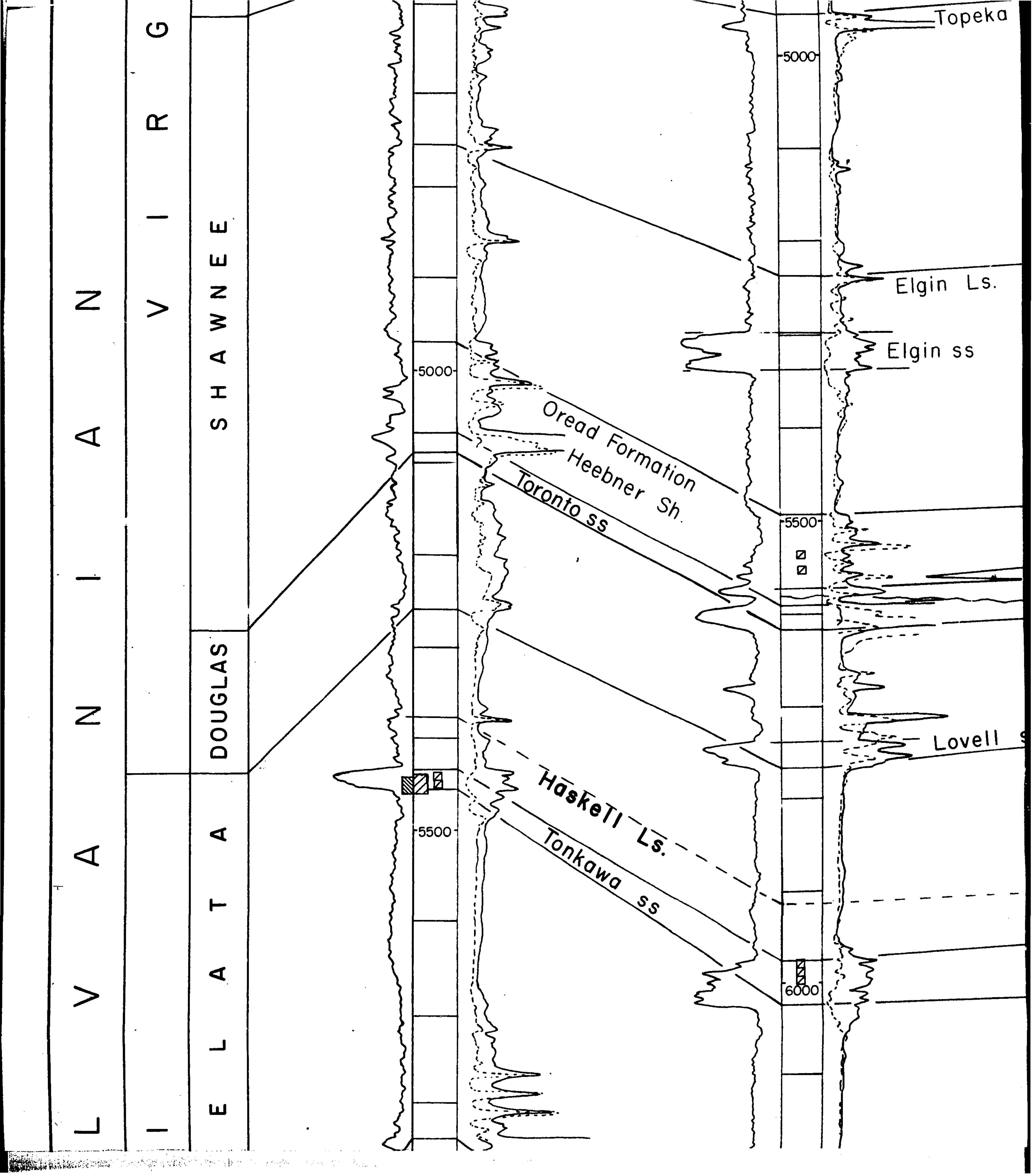
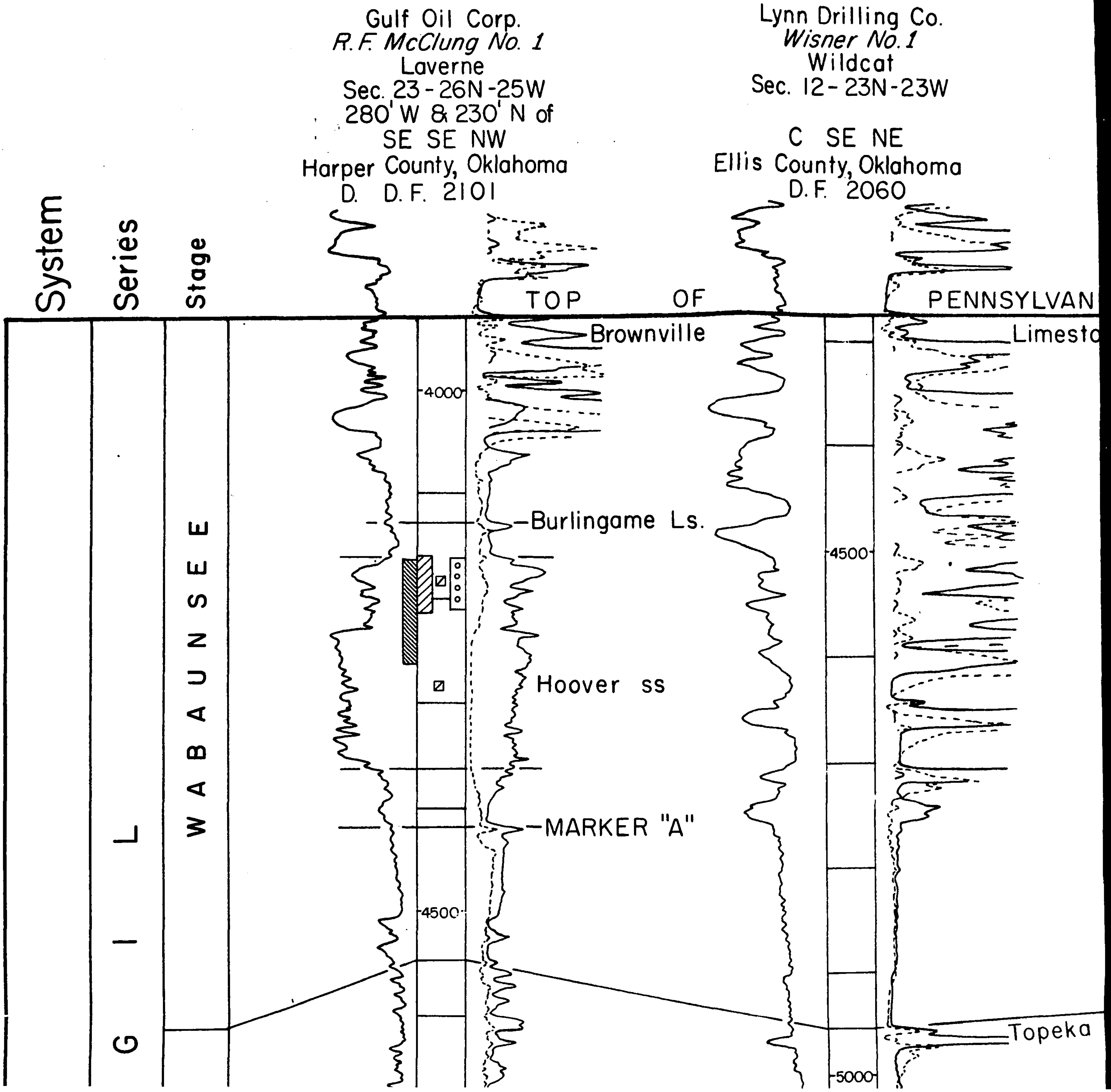



FIGURE 2. TYPICAL PENNSYLVANIAN SECTIONS SHOWN BY E

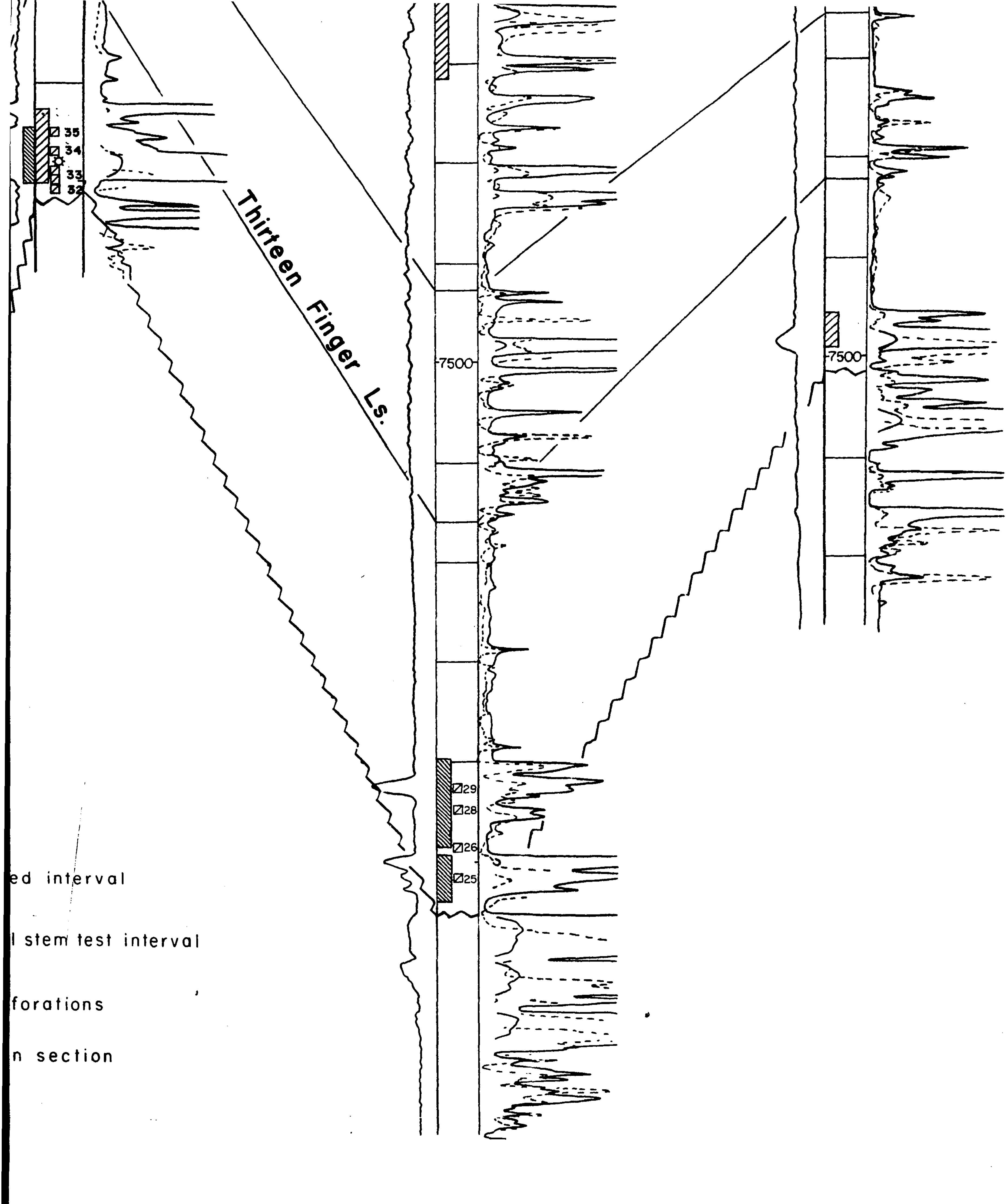

P E N N S Y L
D E S M O I N E S
M I S S O U R I
HEROKEE
MARMATON
SKIATOOK
O C H E L
6000
6500
7000
Dewey Ls.
Checkerboard Ls.
Big Lime
Oswego Ls.
Cottage Gr
Zone
Cottage G
35
34
33
32



LVANIAN
IVIRG
SHAWNEE
DOUGLAS
ELATTA
5000
5500
Oread Formation
Heebner Sh.
Toronto ss
Haskell Ls.
Tonkawa ss
Topeka
5000
Elgin Ls.
Elgin ss
5500
Lovell s
6000



Gulf Oil Corp.
R.F. McClung No. 1
Laverne
Sec. 23-26N-25W
280' W & 230' N of
SE SE NW
Harper County, Oklahoma
D. D.F. 2101
Lynn Drilling Co.
Wisner No. 1
Wildcat
Sec. 12-23N-23W
C SE NE
Ellis County, Oklahoma
D.F. 2060
System
Series
Stage
TOP OF PENNSYLVAN
Brownville
Limesto
4000
Burlingame Ls.
4500
Hoover ss
MARKER "A"
4500
WABAUNSEE
GIL
Topeka
5000



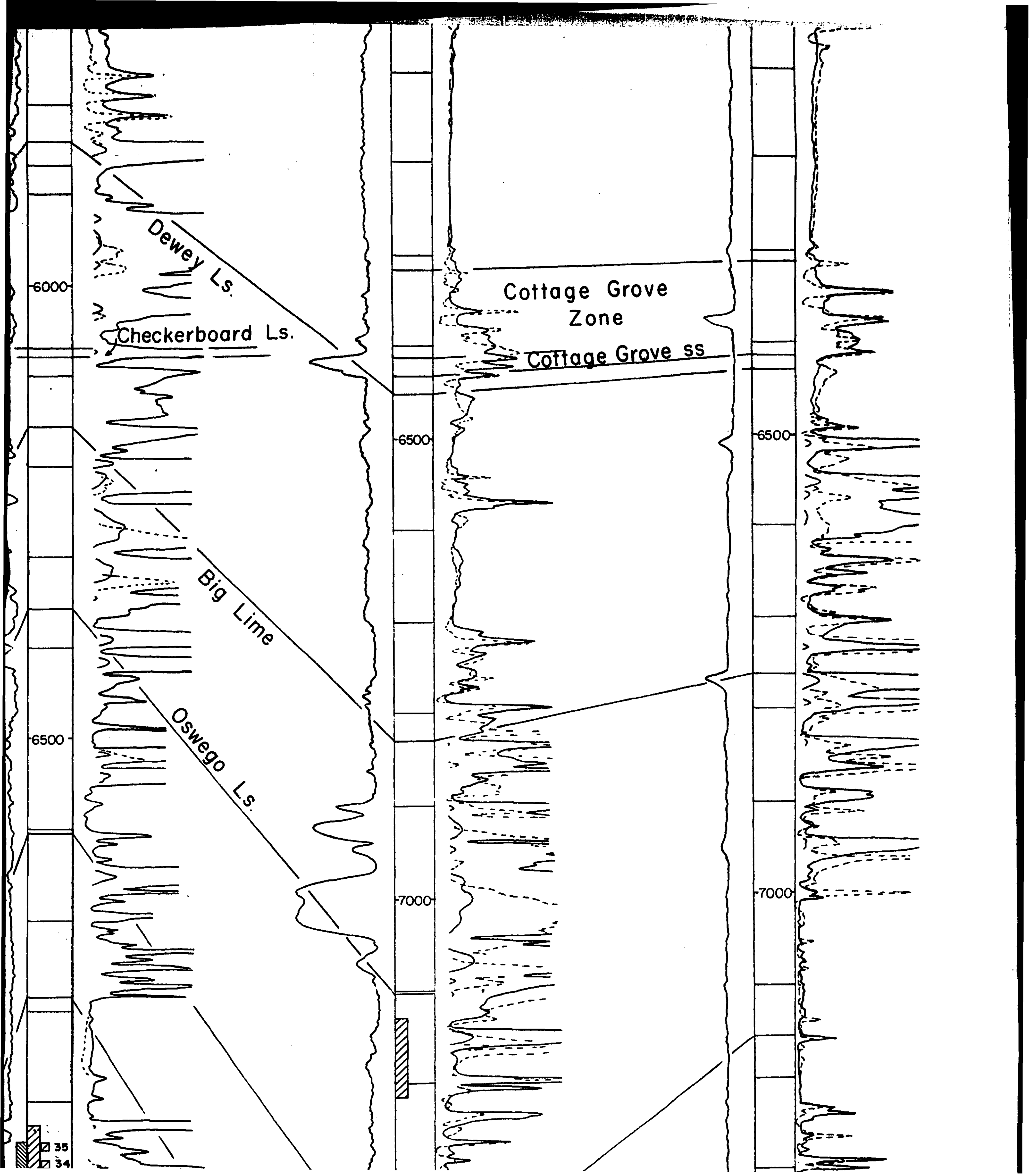

ed interval

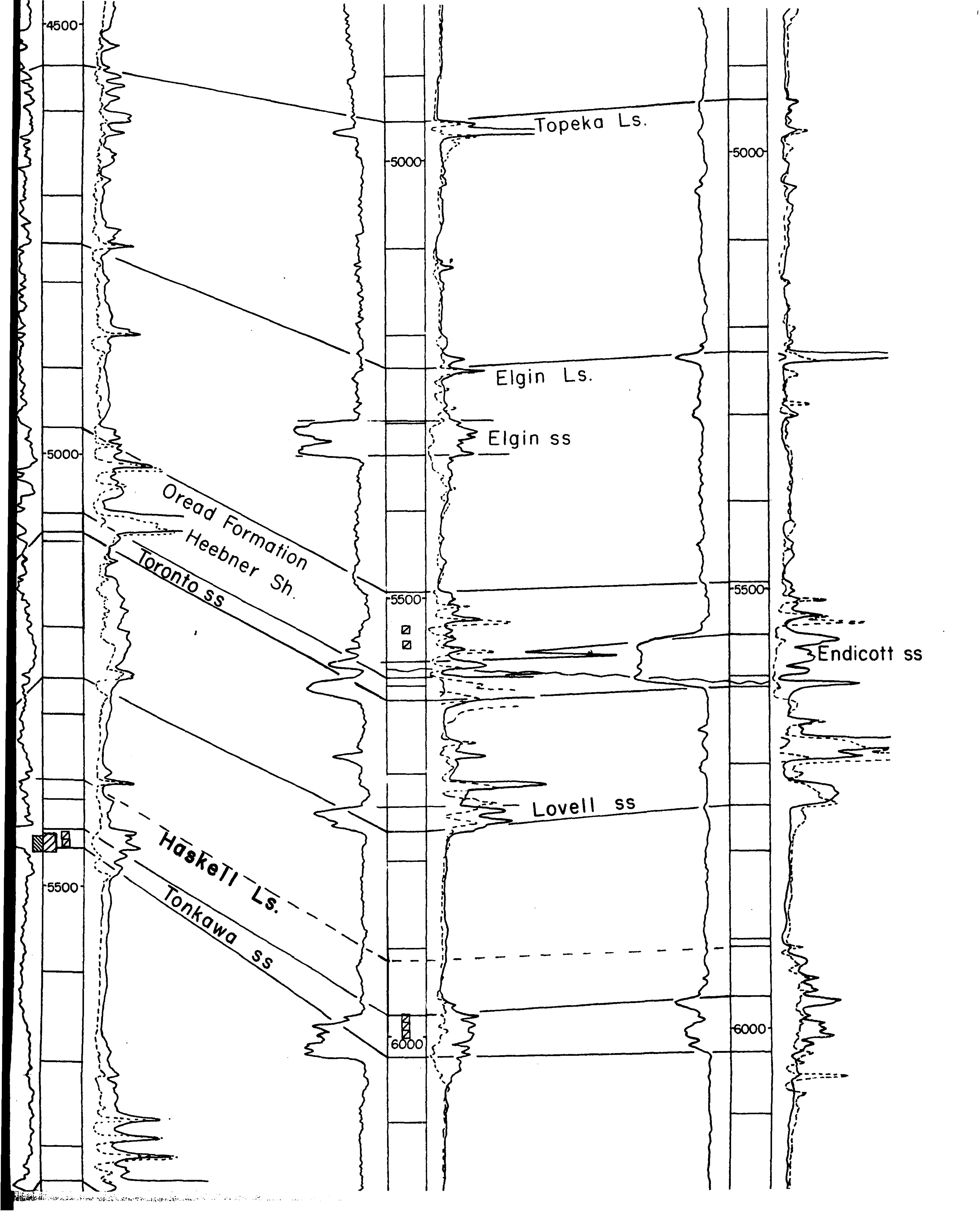
l stem test interval

forations

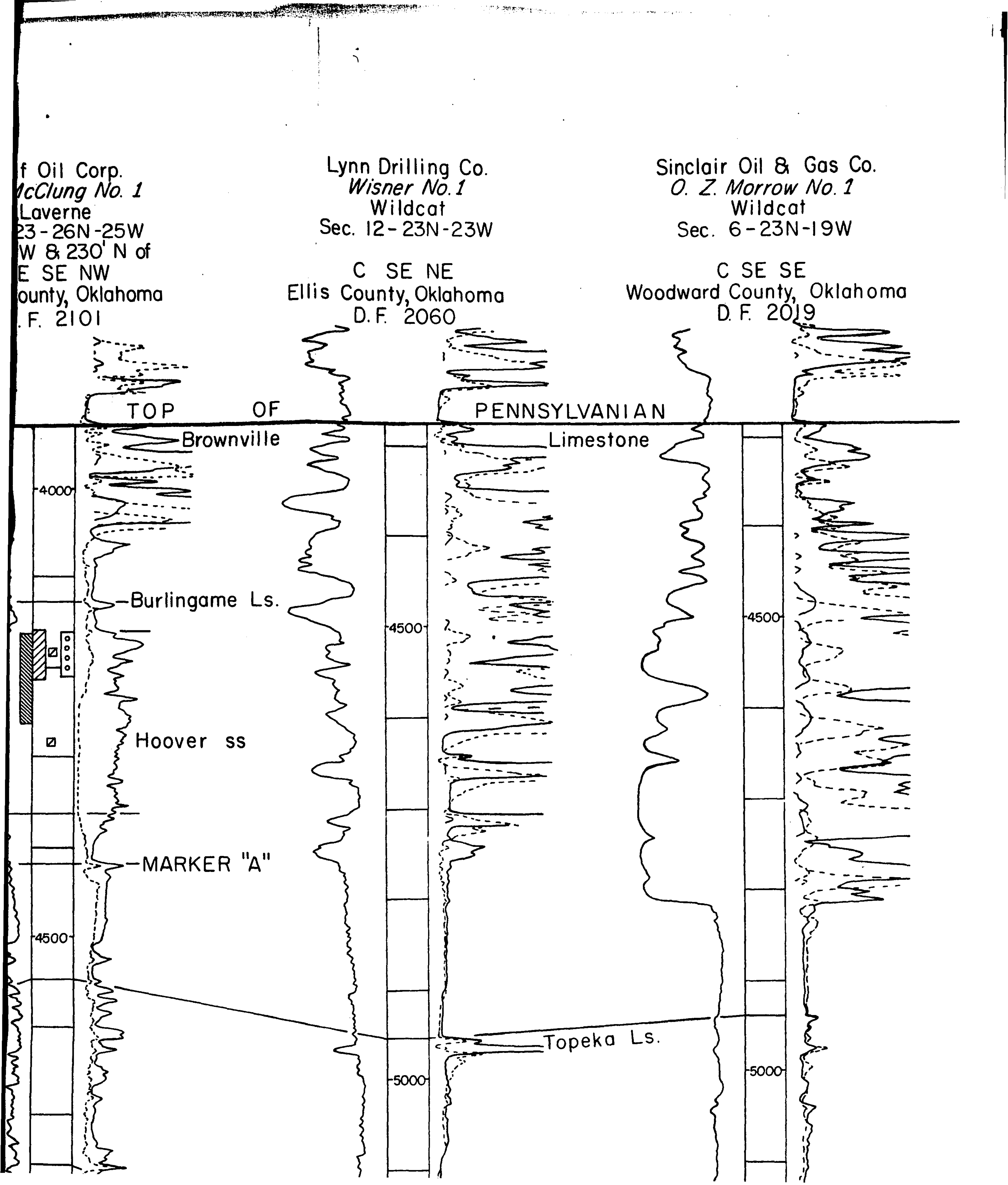
n section

PENNSYLVANIAN SECTIONS SHOWN BY ELECTRIC LOGS


6000
Dewey Ls.
Checkerboard Ls.
Big Lime
Oswego Ls.
6500
35
34
6500
7000
Cottage Grove Zone
Cottage Grove ss
6500
7000



4500
5000
5500
Topeka Ls.
5000
5000
Elgin Ls.
Elgin ss
Oread Formation
Heebner Sh.
Toronto ss
5500
5500
Endicott ss
Lovell ss
Haskell Ls.
5500
Tonkawa ss
6000
6000



f Oil Corp.
lcClung No. 1
Laverne
23-26N-25W
W & 230' N of
E SE NW
ounty, Oklahoma
. F. 2101
Lynn Drilling Co.
Wisner No. 1
Wildcat
Sec. 12-23N-23W
C SE NE
Ellis County, Oklahoma
D.F. 2060
Sinclair Oil & Gas Co.
O. Z. Morrow No. 1
Wildcat
Sec. 6-23N-19W
C SE SE
Woodward County, Oklahoma
D.F. 2019
TOP OF PENNSYLVANIAN
Brownville Limestone
Burlingame Ls.
Hoover ss
MARKER "A"
Topeka Ls.
4000
4500
4500
5000
4500
5000

## Correlations

Identification of named units is consistent with Jordan's (1957) "Subsurface Stratigraphic Names of Oklahoma" and Pate's (1959) "Stratigraphic Traps Along North Shelf of Anadarko Basin, Oklahoma."

Many cross sections were prepared for those genetic sequences that include the aforementioned different sandstones. However, only those cross sections necessary to support this discussion are included.

# MORROW SANDSTONES

## General Statement

Busch studied the Morrow formation in this area and discussed the nature of the Morrowan sandstone units. Busch (1959, p. 2831) stated that these sandstone units "are not one sand body, but bear an _en échelon_ relation to each other, each wedging out in a basinward direction toward the south. Each of these sands represents a shoreline stage in a series of cyclic transgressions of the early Pennsylvanian sea; each shoreline stage is characterized by a separate beach type of sand." Busch depicted the trend of several of these "beach" sandstones superimposed upon an isopachous map of the Morrow formation. This map reveals subparallelism of individual sandstone members with isopachous lines. Such a map established essential information regarding subsurface Morrowan strata as a basis for prospecting the area in its early stages of exploration and development. However, subsequent development drilling, with additional well control, affords an opportunity for testing theories already set forth.

## Correlations

The Morrow formation is a genetic sequence devoid of any significant unconformities. It rests unconformably upon the Mississippian; its top is defined by the base of the Atokan "Thirteen Finger" limestone. The latter is a sequence of thin limestones interbedded with black shales. The base of this series of limestones generally is readily recognizable on mechanical logs by its sharp contact with underlying topmost Morrowan shale.

The Mississippian land surface is identifiable on mechanical logs as the top of the first massive limestone bed in the Mississippian Chester Series (Meramec shelfward), or at the base of the lowest sandstone unit in the Morrowan sequence. Wherever this sandstone unit is absent, Morrowan shale rests directly upon the Mississippian surface. In such instance, the base of this Morrowan shale is considered to be the base of the Morrow formation, because updip the Mississippian surface underlies either Morrow beach and channel sandstones, lagoonal and swampy shales and siltstones behind the sandstones of the Morrow barrier islands, or transgressive shales.

## Morrow Cross Sections

The exceedingly erratic sandstone distribution in the Morrowan sequence of the Anadarko Basin has induced geologists to zone these sandstones in various ways. Forgotson (1966), in describing the Morrowan sequence of the western Anadarko Basin in the Oklahoma and Texas Panhandles, divided the formation into three zones. The lower zone consists entirely of terrigenous clastics overlying the Mississippian surface; the middle zone consists of limestones and shales; and the upper zone is composed predominantly of shale. Arro (1965) subdivided the Morrow formation of Texas County, Oklahoma, into a zone of shales, limestones, and sandstones; and a basal sandstone (Keyes) resting upon the Mississippian unconformity surface.

One of the primary objectives of this study was to identify and trace each of the Morrow sandstone members deposited during successive stillstands of the shoreline. Successive positions of the shoreline are numbered from base upward (only those from 19 to 40 are shown on Table 1). In some cases, thick foreshore sandstones were deposited, and in other cases, only siltstones were deposited. Herein numbers vary from 5 for the oldest (lowermost), and up to forty for the youngest (uppermost) sandstone member.

The identification and correlation of the individual sandstones and siltstones is based on detailed correlations, such as those shown in Figures 3, 4, and 5. The individual sandstones occur within a restricted depth interval below the base of the Atokan "Thirteen Finger" limestone. The locations of the cross sections shown in Figures 3, 4, and 5 are shown on Plate IV. Two of these,

TABLE I

Depths in feet are shown from the base of the Atokan "Thirteen Finger" limestone to the top of the individual Morrow sandstone members; recorded from cross sections AA' and CC' (Figures 3 and 5) in a basinward direction.

| Morrow Sandstone Member | Interval Thickness in feet | |
|---|---|---|
| 40 | 41, 44, 47, 49 | * |
| 39 | 60, 65 | * |
| 38 | 78, 79, 80 | * |
| 37 | 99, 108, 100, 110, 115 | # |
| 36 | 127, 128, 126, 123, 129, 135, 138, 150 | # |
| 35 | 157, 162, 159, 163, 161, 158 | #* |
| 34 | 174, 177, 179, 180, 185 | # |
| 33 | 200, 205, 210, 202, 195 | # |
| 32 | 215, 220, 217 | #* |
| 31 | 232, 239 | # |
| 30 | 245 | |
| 29 | 250, 244, 249, 259, 260 | #* |
| 28 | 285 | # |
| 27 | 305, 317, 310, 304, 298 | # |
| 26 | 327, 319, 334, 343, 346 | * |
| 25 | 350, 343, 344, 340 | # |
| 24 | 400, 395, 398, 412 | # |
| 23 | 470, 461, 459, 470, 462, 472, 463, 479 | # |
| 22 | 490, 491, 500, 496, 494, down to 530 | # |
| 21 | 566, 565, 558, 557, 555, 556, 548, 554 | # |
| 20 | 578, 577, 578, 600 | |
| 19 | 614, 626 | |

* Sandstone rests on unconformity surface.

# Sandstone "shales out" in approaching unconformity surface.

AA' (Figure 3) and CC' (Figure 5), trend north-southward approximately at right angles to the depositional strike. Cross section BB' (Figure 4) trends approximately parallel to the strike. These cross sections are constructed with one well per section to insure that all Morrow sandstone members are illustrated. On Table 1, depths to any given numbered sandstone and siltstone members that are the same at different locations are recorded only once. Although sandstone and siltstone members older than 19, in fact older than 25, lend themselves to stratigraphic zonation in the manner described above, they do not provide information for tracing their landward extents. Table 1 also shows whether the sandstone and/or siltstone nearest the Mississippian unconformity surface rests directly upon the unconformity or grades into shale as it approaches the unconformity. A sandstone member resting upon the erosional surface is considered to be a beach or channel sandstone; whereas a sandstone member grading into shale in approaching the erosional surface is considered to be a barrier island or an offshore bar. Also, the intervals given to tops of different sandstone members beneath the "Thirteen Finger" limestone vary. This variation is a result of general basinward divergence of different members. Variable thicknesses of individual sandstone bodies (which are non-compactable) also are responsible for variations in the depths below the "Thirteen Finger" limestone.

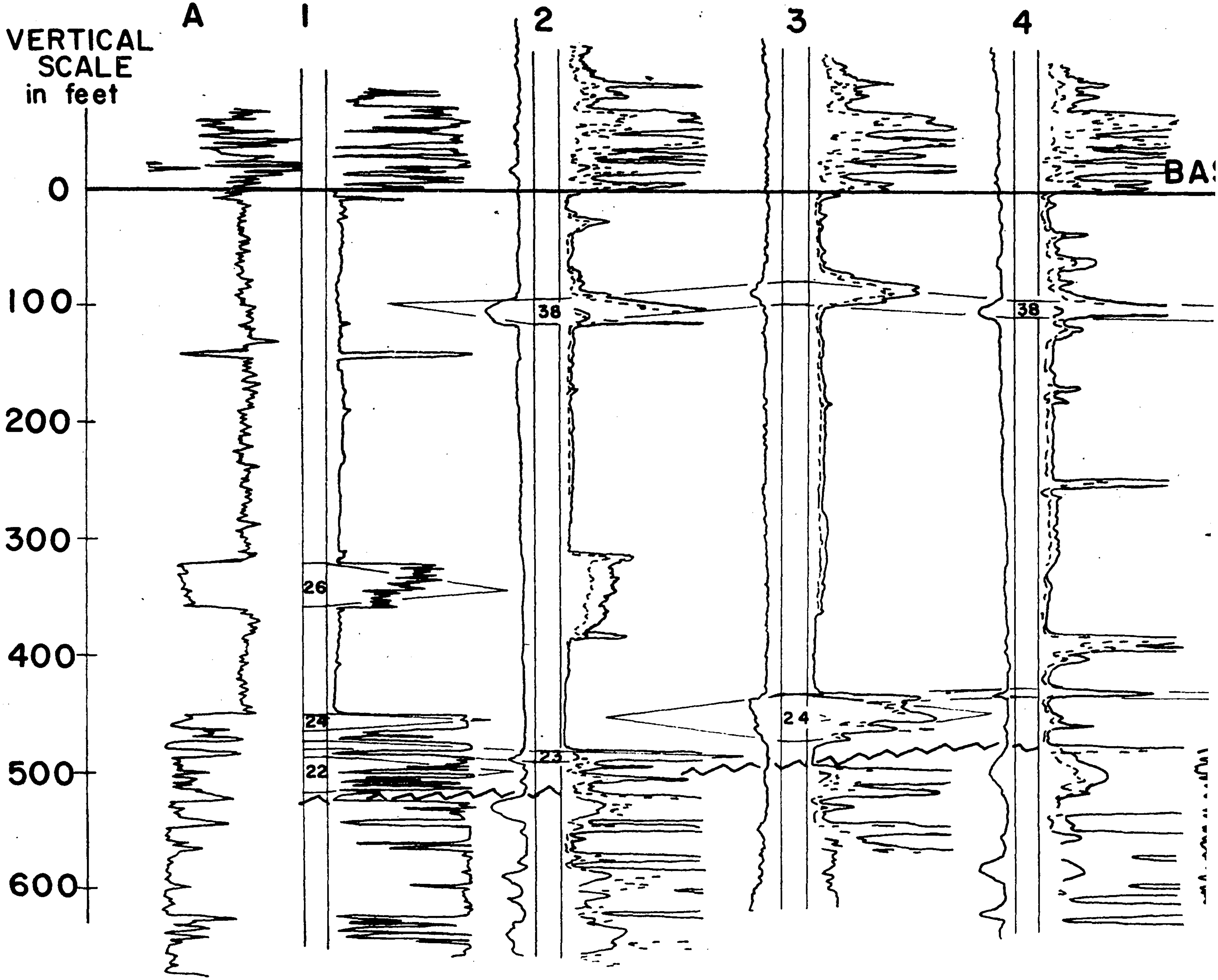
For example, a bar may have a flat base and a convex upper surface, resulting from the development of sand at the expense of the overlying shale. A fluvial or deltaic sand body, however, may have a comparatively flat top and a convex base, resulting from the development of sand at the expense of underlying strata.

It is emphasized that this arbitrary designation by numbers for various sandstone bodies is intended only to aid in the interpretation of the succession of still-stand positions of the transgressive Morrowan sea. These local detailed correlations should not be applied to regional work. Offset wells may contain at the same level different sandstone bodies. A given well may contain two different sandstone bodies with less than five feet of intervening shale, e.g., sec. 23, T. 26 N., R. 25 W. Such difference is due to mineralogical, textural, and post-depositional conditions. The vertical *en échelon* arrangement of the numerous member sandstones of the Morrow formation is clearly illustrated in Figures 3 and 5. The concept of a blanket-type sandstone in Morrow time does not apply in this area.

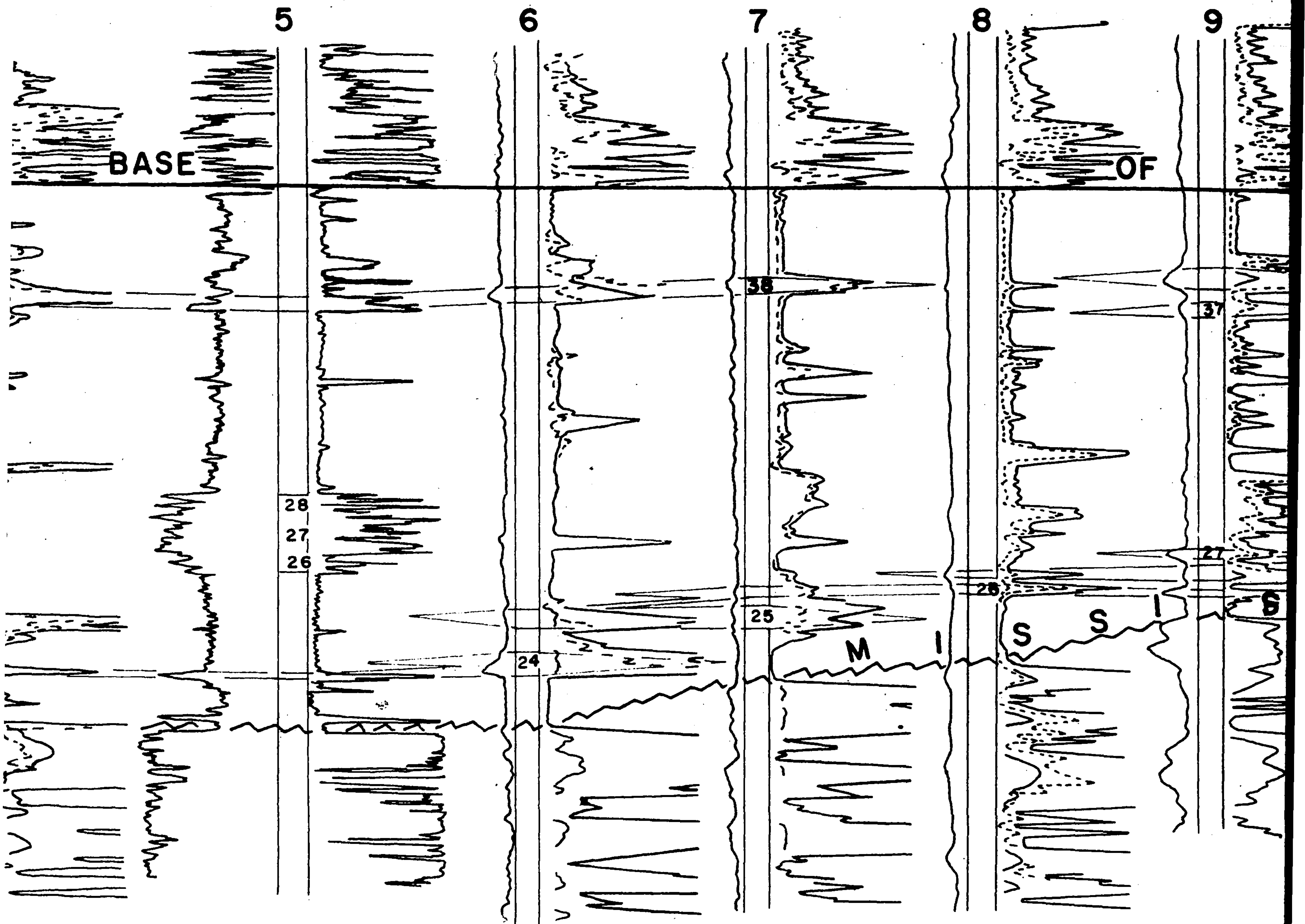
Cross section AA' (Figure 3) trends in the depositional-dip direction. Sandstone 38 is shown here as it developed away from the shoreline, with a biconvex cross section; it represents two offshore bars. Sandstone 37 represents a barrier island that developed two to three miles from the mainland, and failing to impinge against the Mississippian unconformity; it reappears as an offshore bar some distance basinward. Sandstone 36 is a barrier island developed two to three miles from the mainland. Sandstone 35 appears to be of two types; namely, a fringing beach sand and an offshore bar. The more seaward offshore bar thickened at the expense of overlying shales. Sandstones 34 and 33 suggest barrier islands. Sandstones 32 and 29 suggest fringing beach sandstones; 30, 28, and 27, barrier islands; 26 is a fringing beach sandstone and an offshore bar; 25 and 24 seem to represent multiple barrier islands and offshore bars; 23 may be a beach sandstone; and 22 appears to be a barrier island.

Cross section BB' (Figure 4) is approximately parallel with the depositional strike of the Morrow formation. It is presented in four parts to facilitate reference. Figure 4a includes wells 1 and 24 to 34; Figure 4b includes wells 35 to 54; Figure 4c includes wells 55 to 82; and Figure 4d includes wells 83 to 96. Cross section BB' is located approximately in the middle of the area of investigation and shows Morrow sandstone members occurring at an intermediate depth below the base of the "Thirteen Finger" limestone.

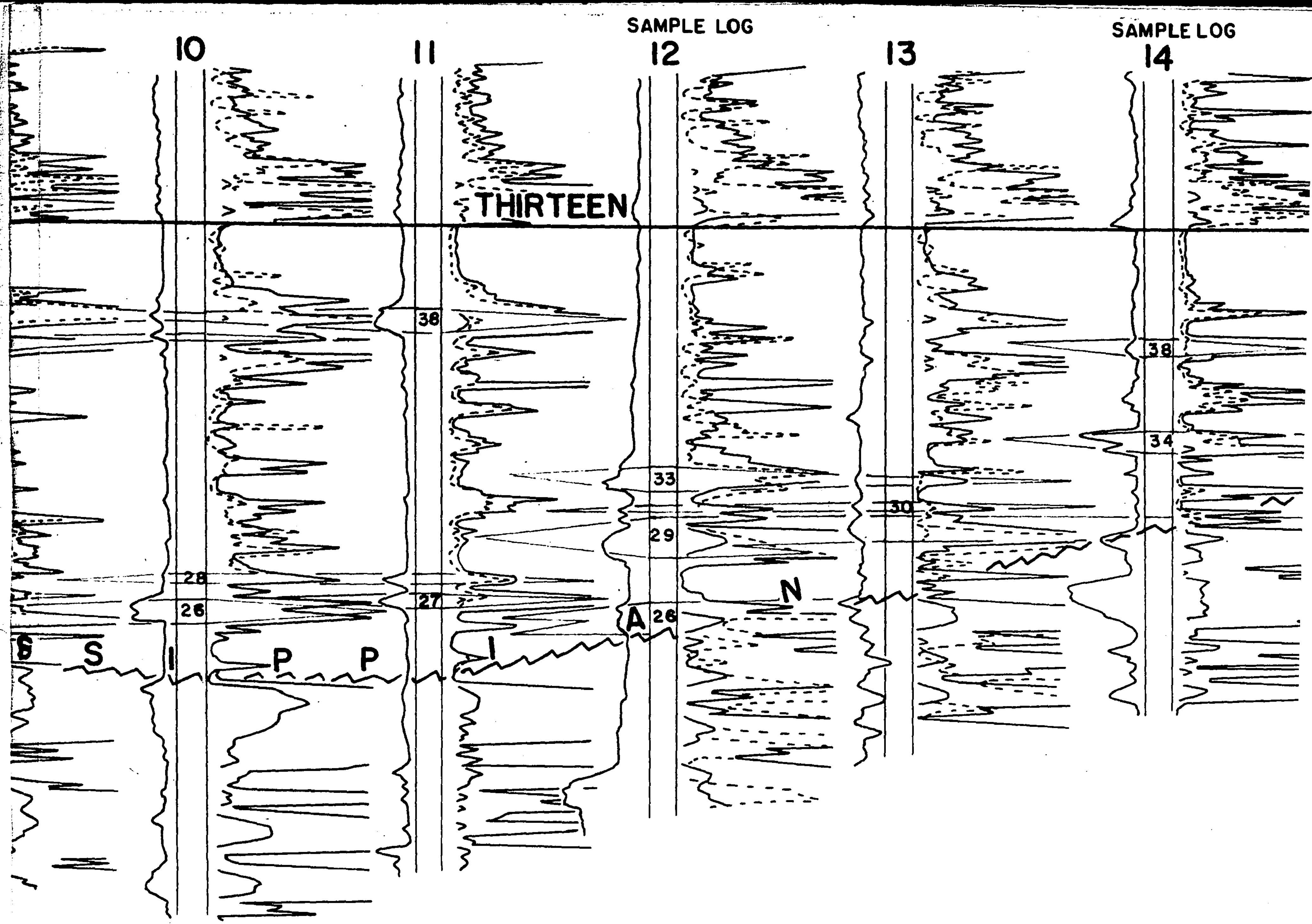
The longitudinal cross sectional profile of the individual sandstone members is shown with a flat base



VERTICAL SCALE in feet
0
100
200
300
400
500
600
A
1
2
3
4
BAS
38
38
26
24
24
23
22



5
6
7
8
9
BASE
OF
M I S S I S
28
27
26
24
25
38
26
27
37


SAMPLE LOG
SAMPLE LOG
10
11
12
13
14
THIRTEEN
38
28
26
27
33
29
26
30
38
34
S I P P I A N

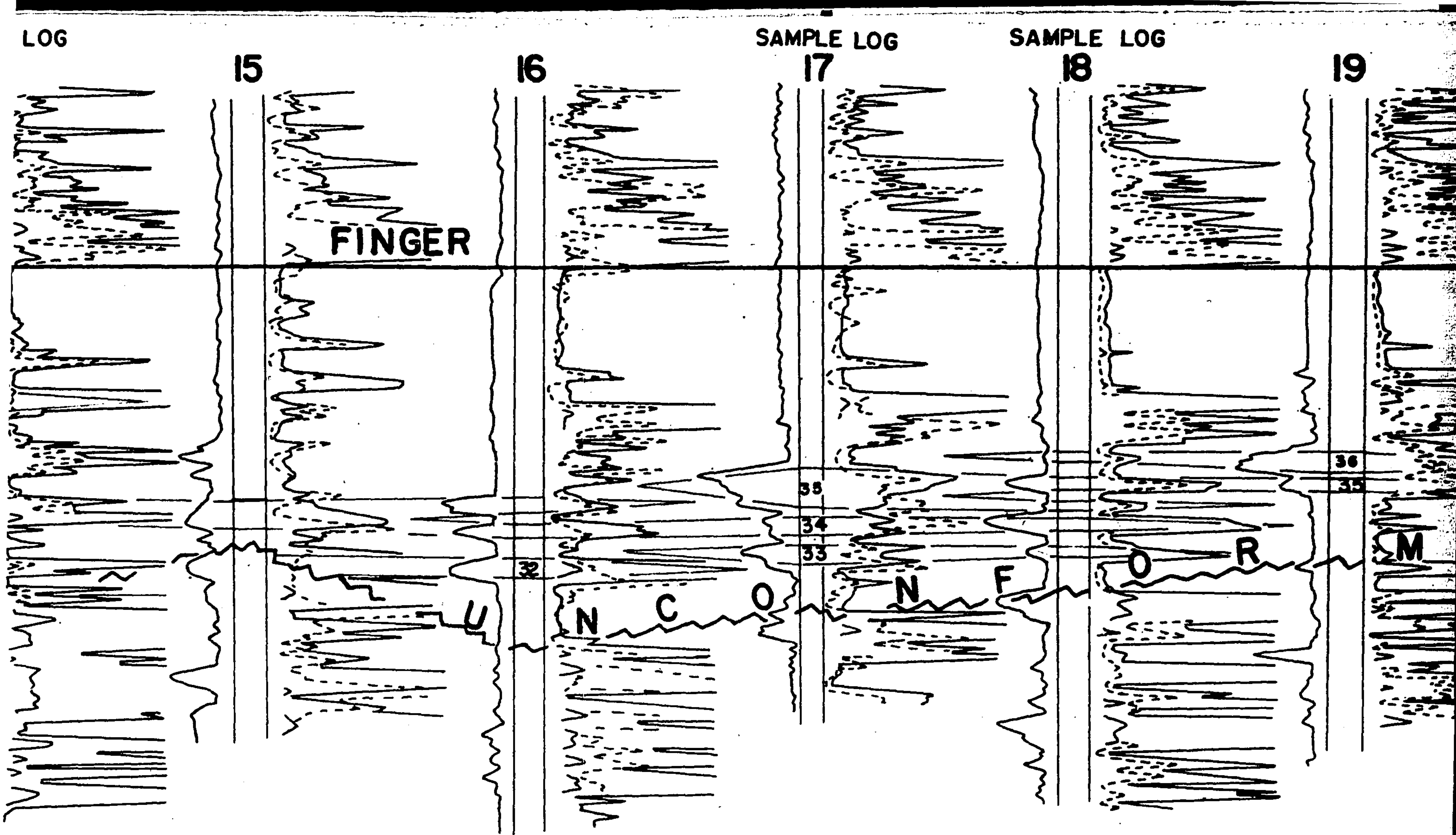
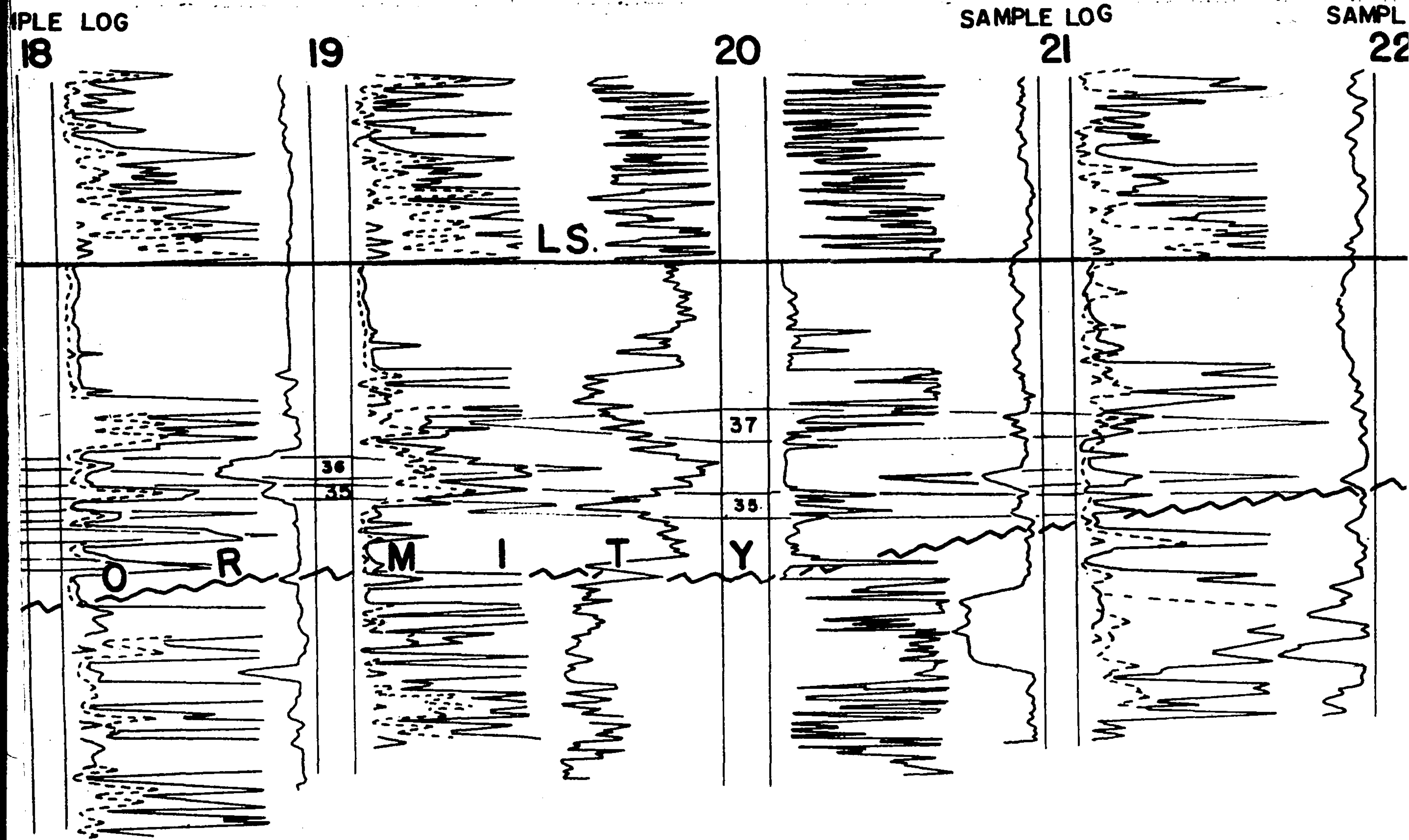



FIGURE 3
CROSS-SECTION A-A'
(No horizontal scale)




N A-A'

:)

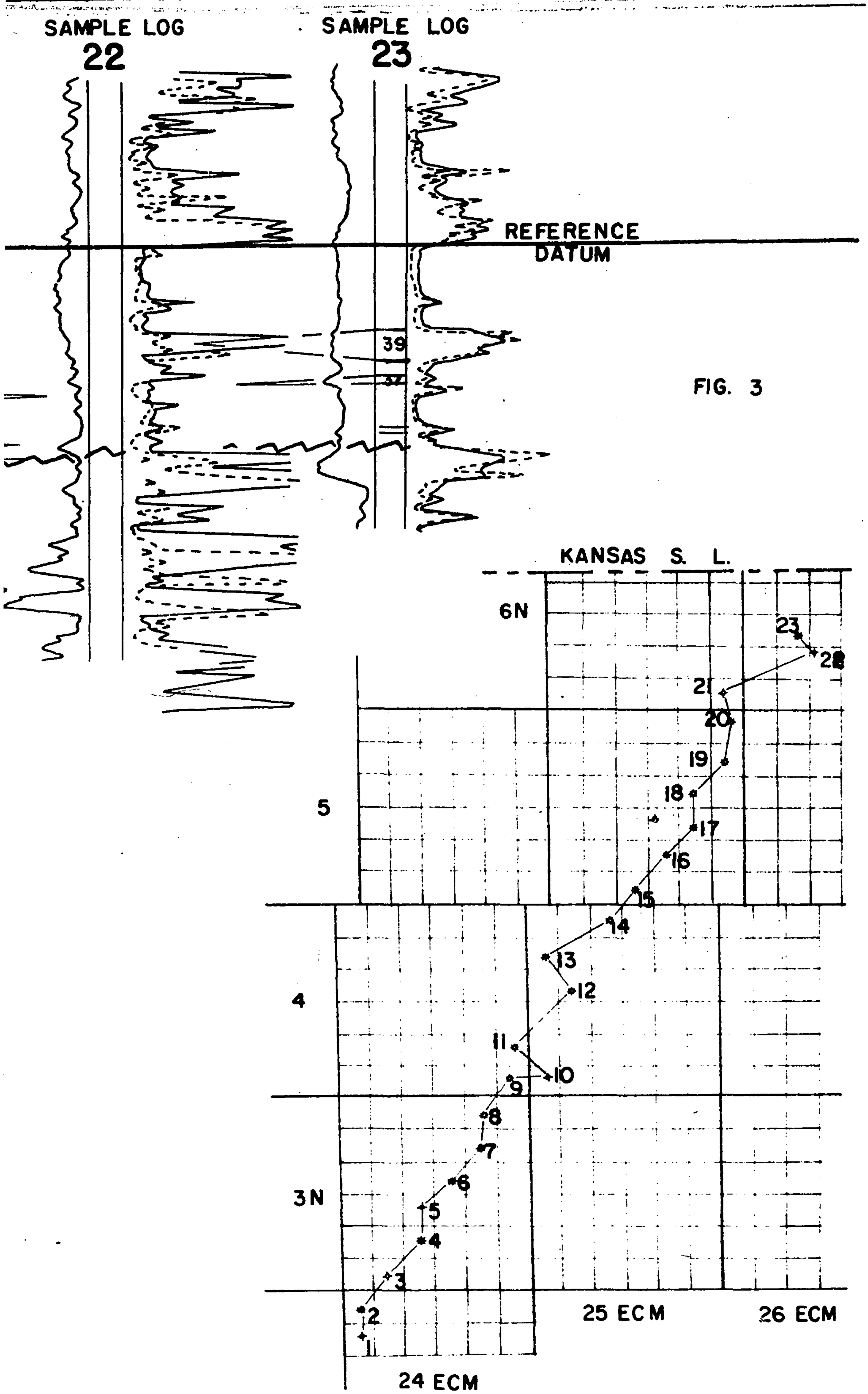
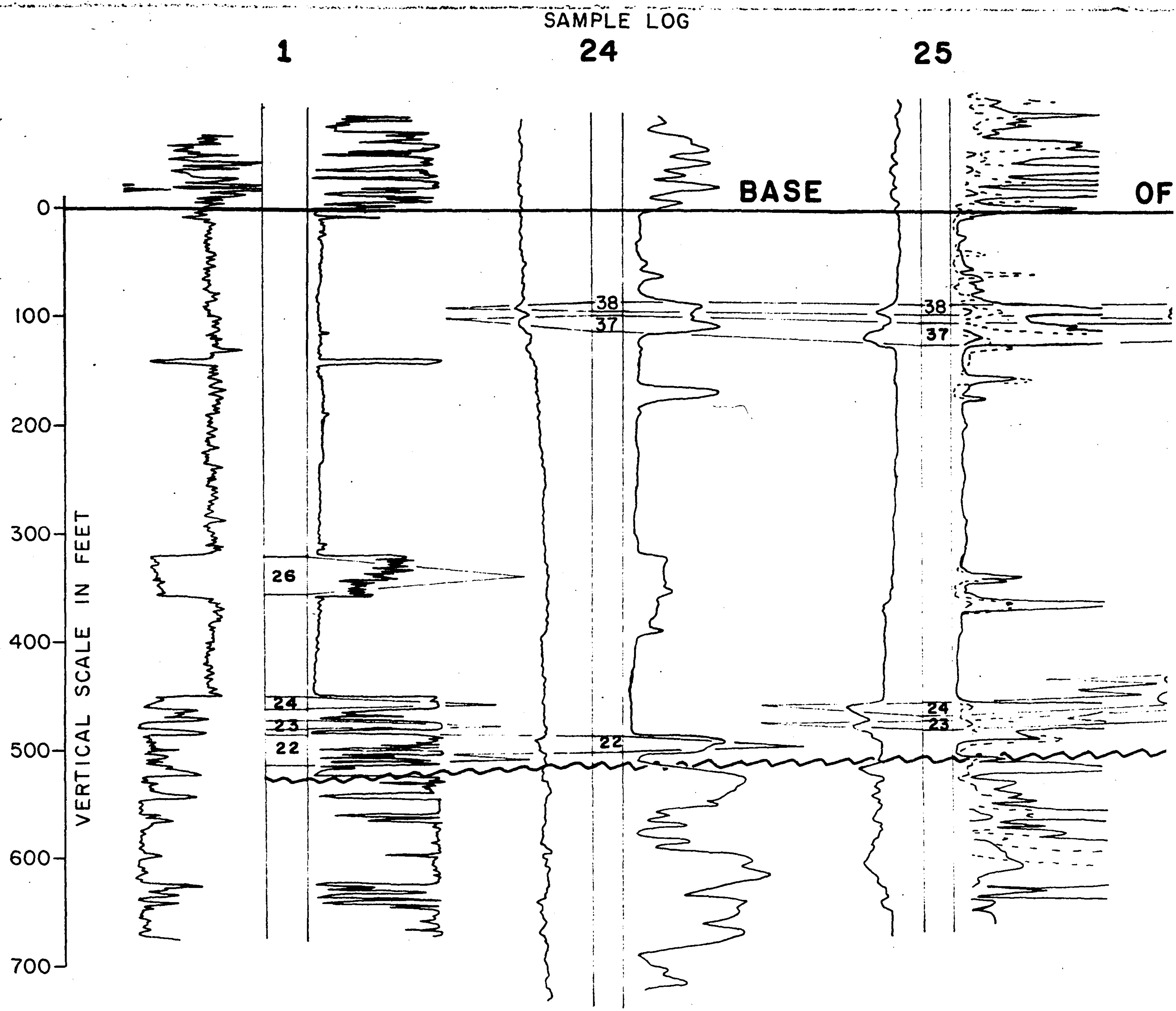



FIG. 3

INDEX MAP


SAMPLE LOG
1
24
25
BASE
OF
VERTICAL SCALE IN FEET
0
100
200
300
400
500
600
700
38
37
26
24
23
22

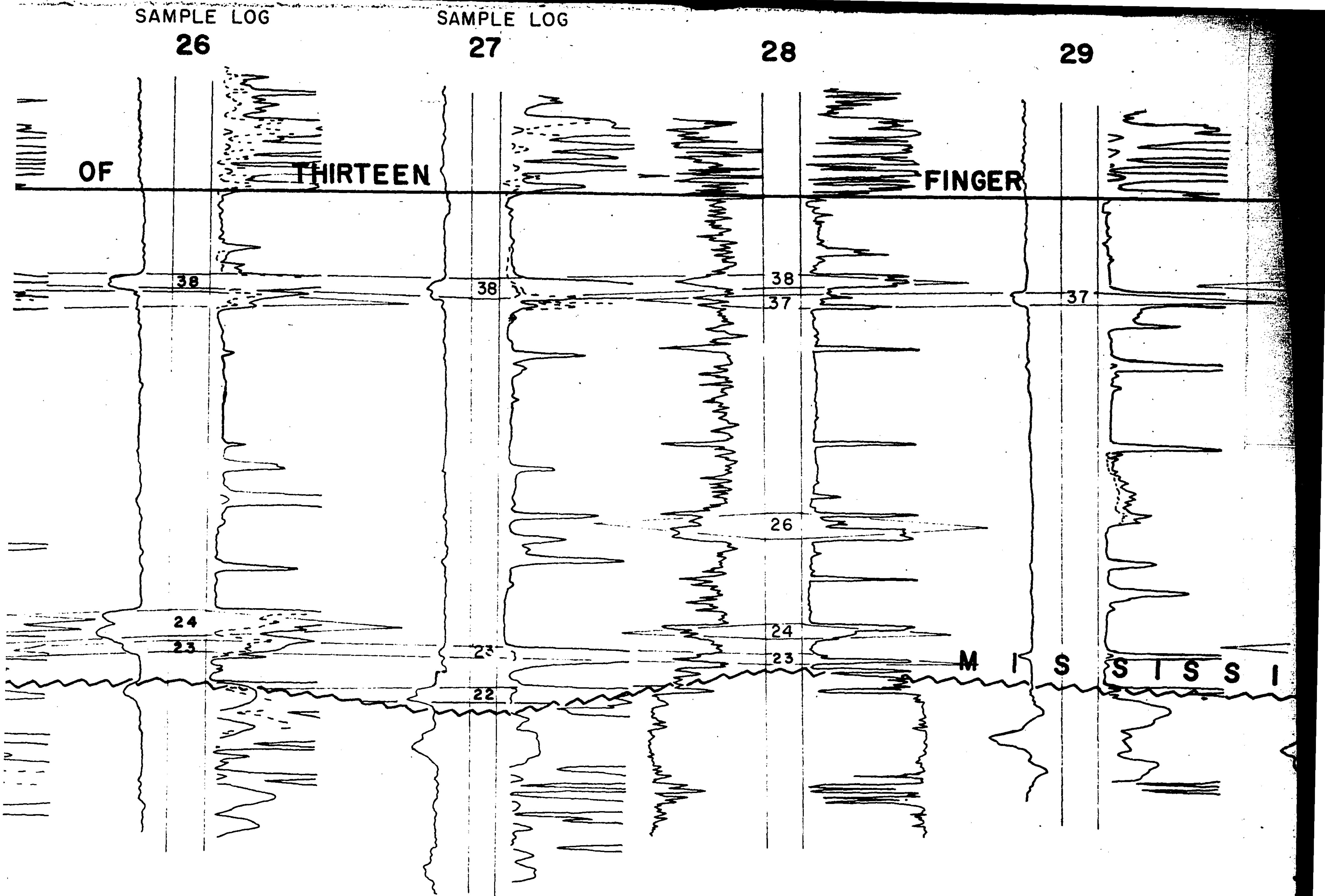



FIGURE 4a

CROSS-SECTION B-B'

(Wells 1, 24-34)

(No horizontal scale)

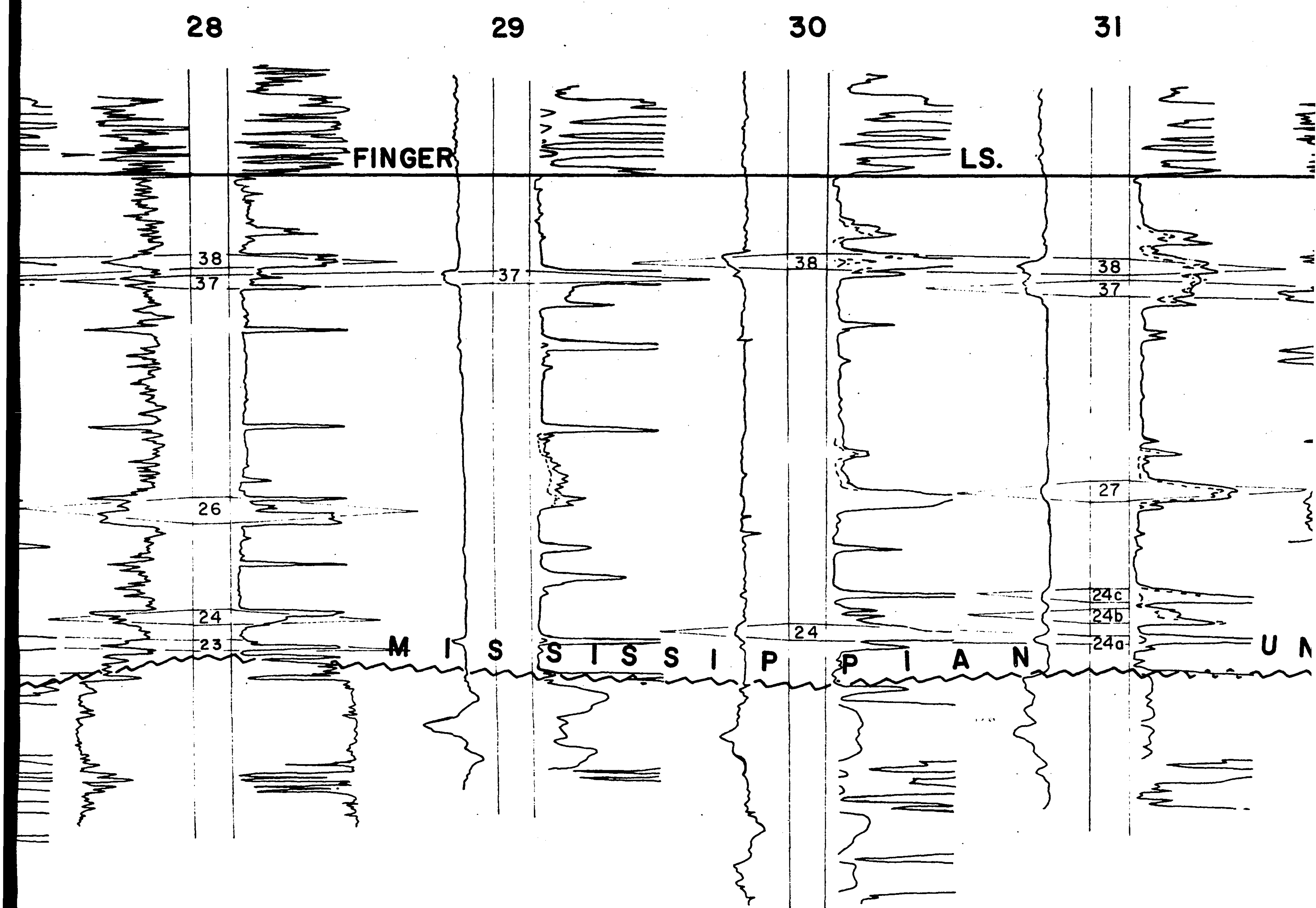



FIGURE 4a

# CROSS-SECTION B-B'

(Wells 1, 24-34)

(No horizontal scale)

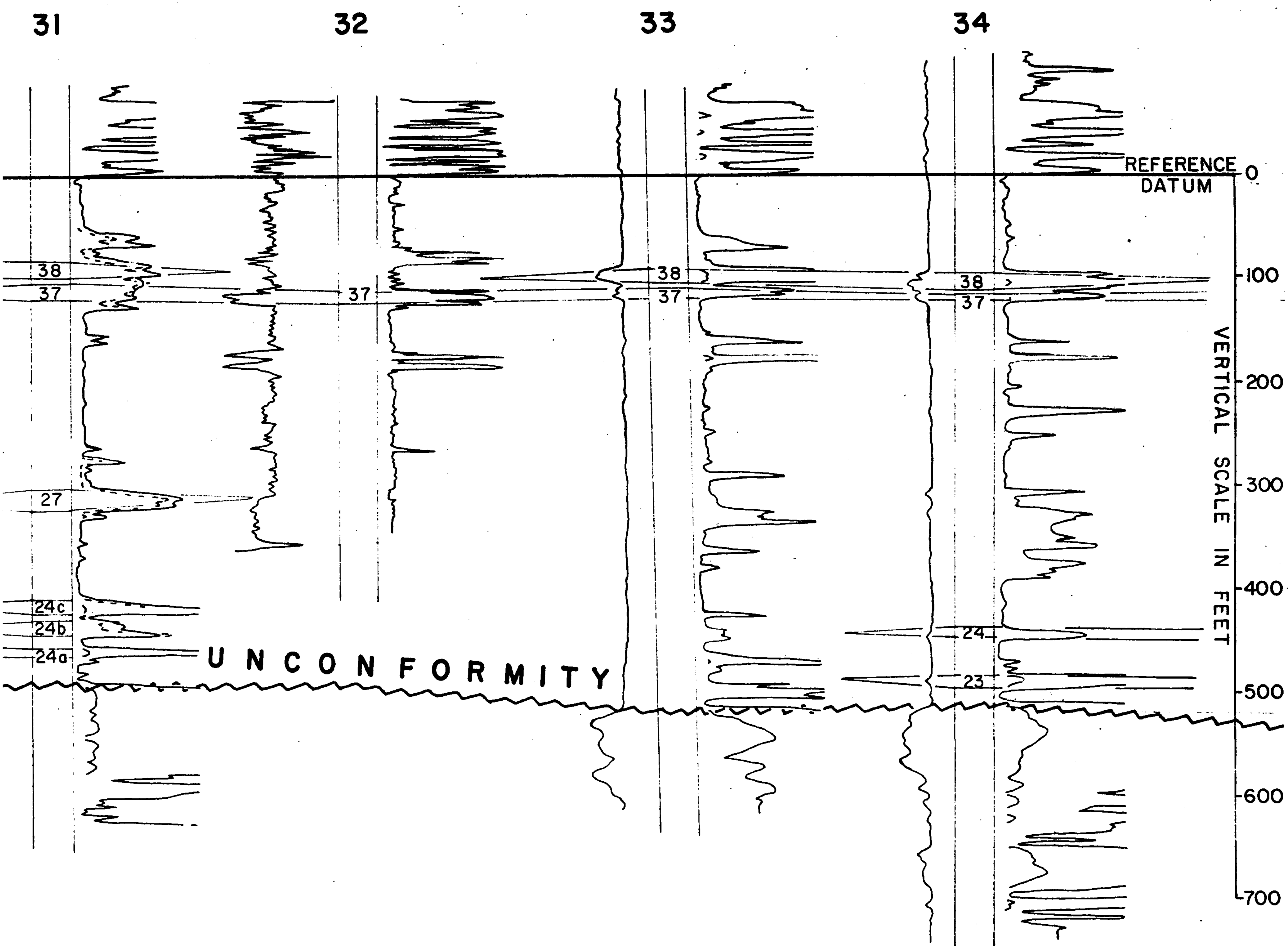
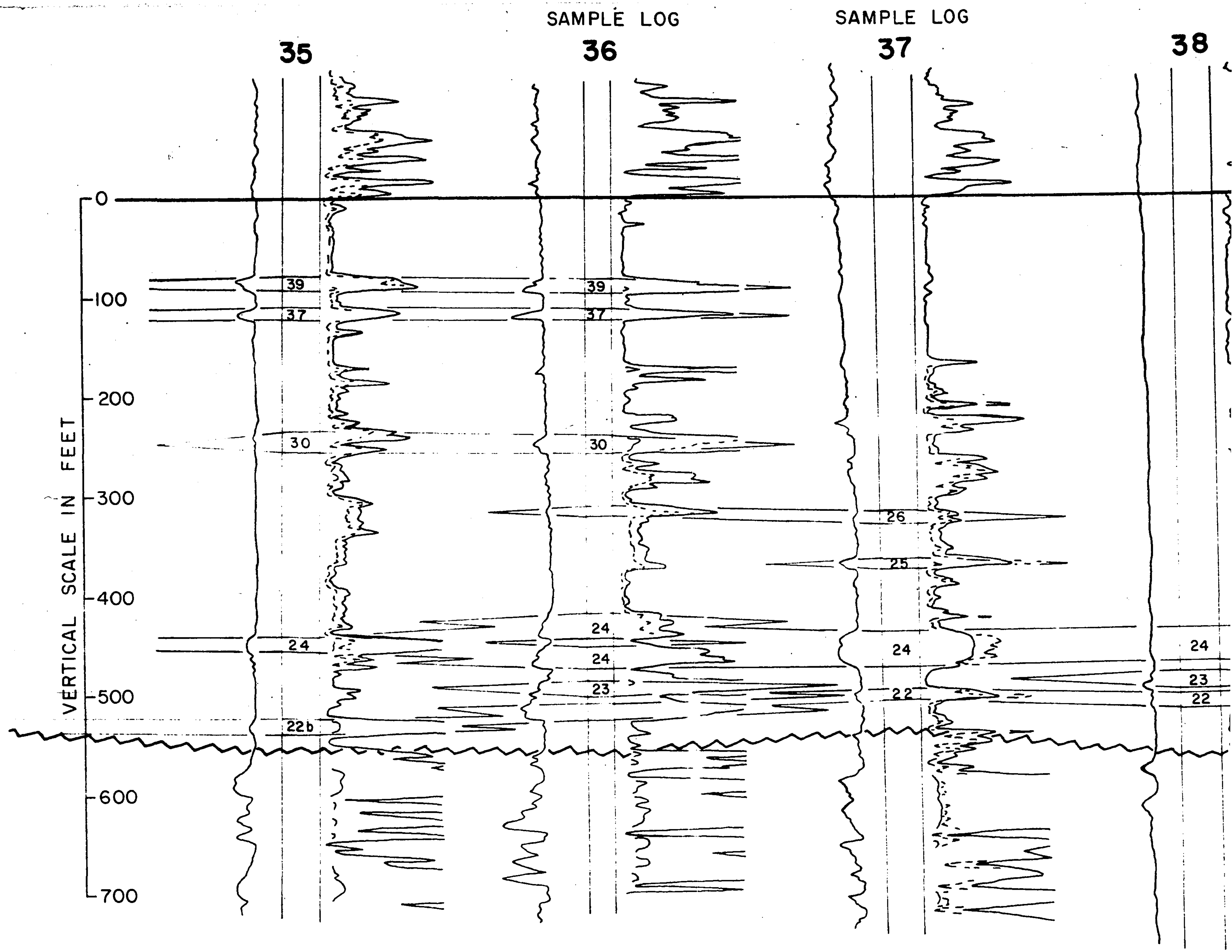
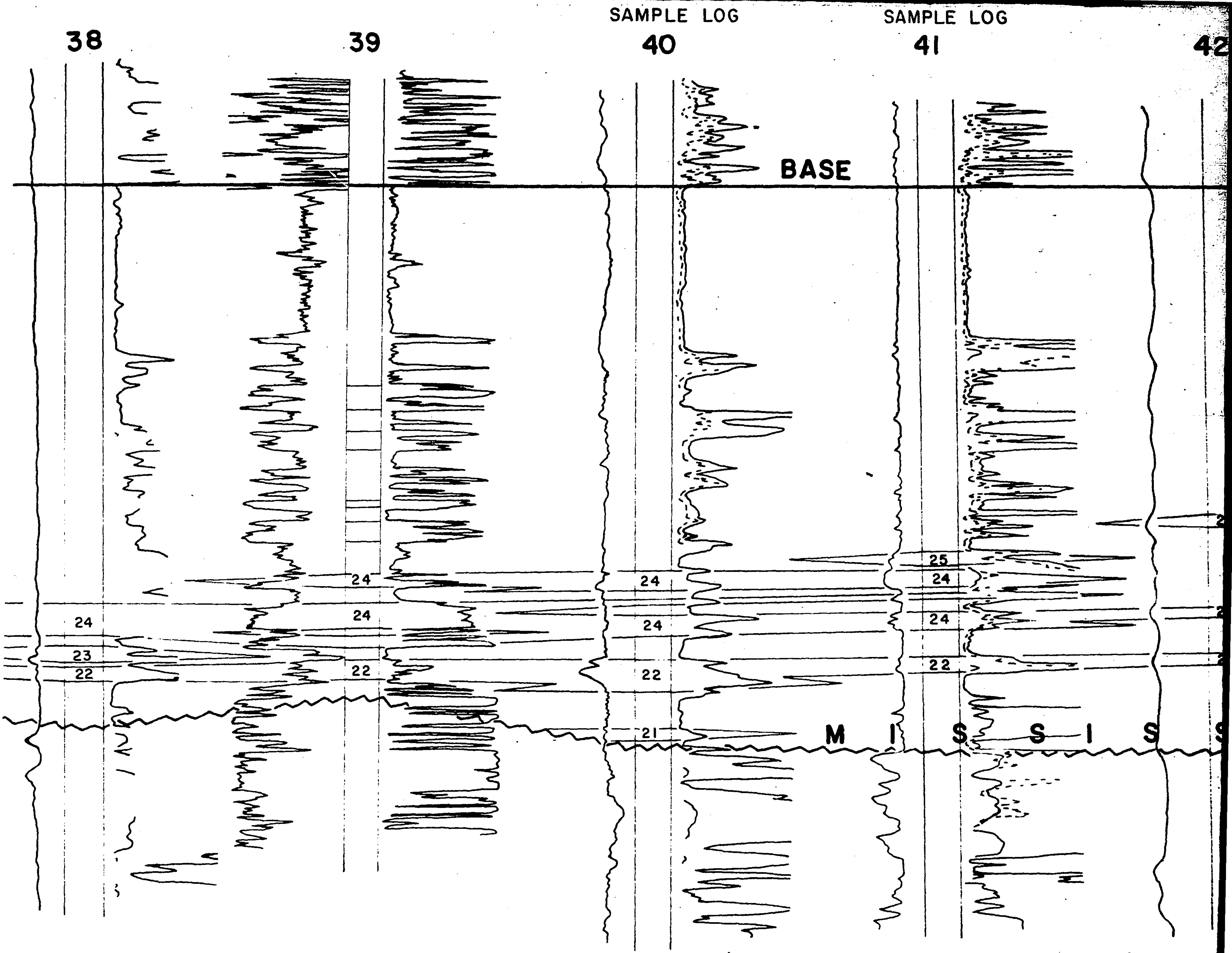
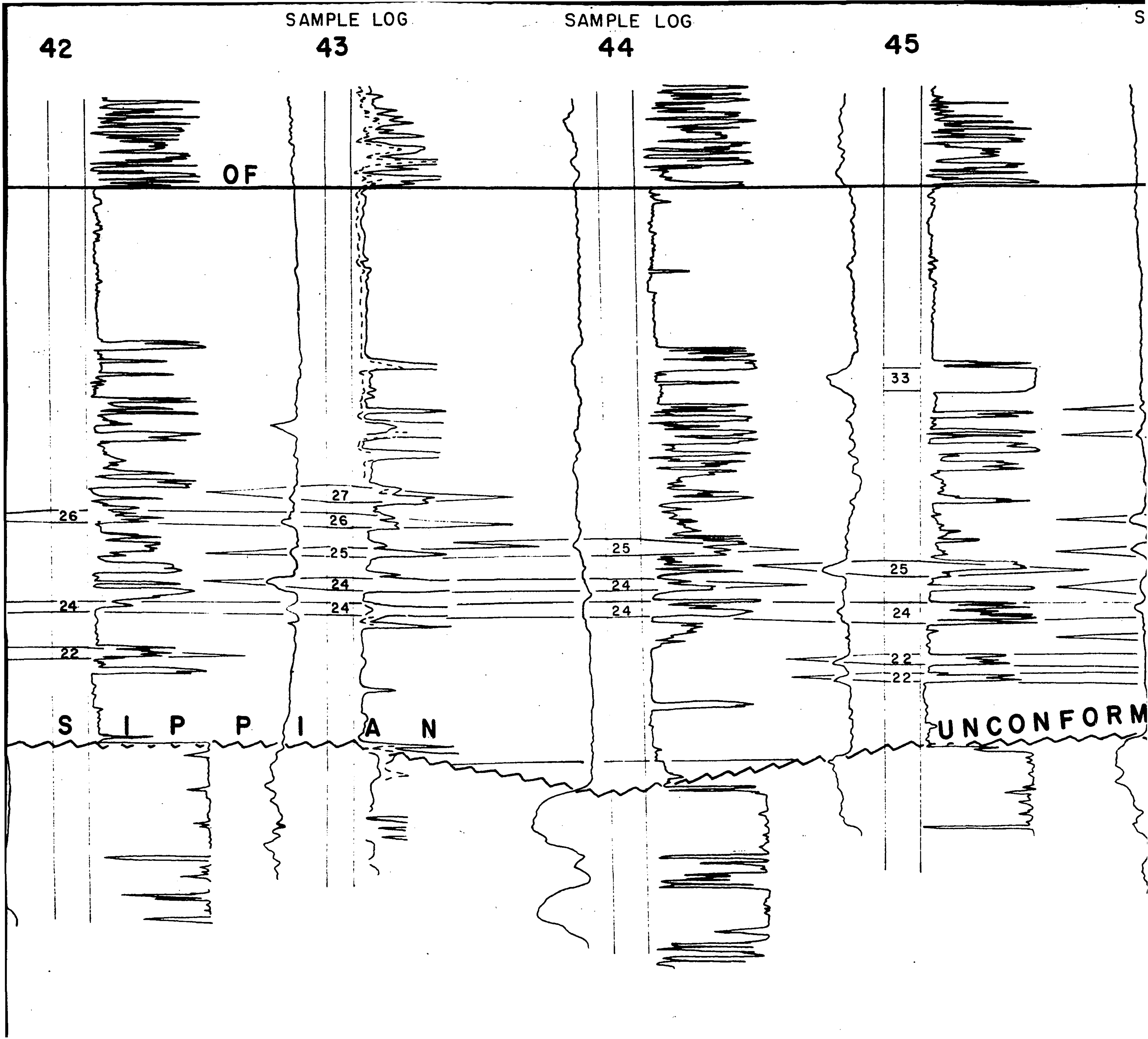

31
32
33
34
REFERENCE DATUM
0
100
200
300
400
500
600
700
VERTICAL SCALE IN FEET
38
37
27
24c
24b
24a
24
23
UNCONFORMITY

FIG. 4a


SAMPLE LOG
SAMPLE LOG
35
36
37
38
VERTICAL SCALE IN FEET
0
100
200
300
400
500
600
700
39
37
30
24
22b
39
37
30
24
24
23
26
25
24
22
24
23
22



SAMPLE LOG
SAMPLE LOG
38
39
40
41
42
BASE
24
24
24
24
24
24
24
23
22
22
22
22
25
21
M I S S I S S



SAMPLE LOG
SAMPLE LOG
S
42
43
44
45
OF
33
27
26
26
25
25
25
24
24
24
24
24
24
22
22
22
S I P P I A N
UNCONFORM

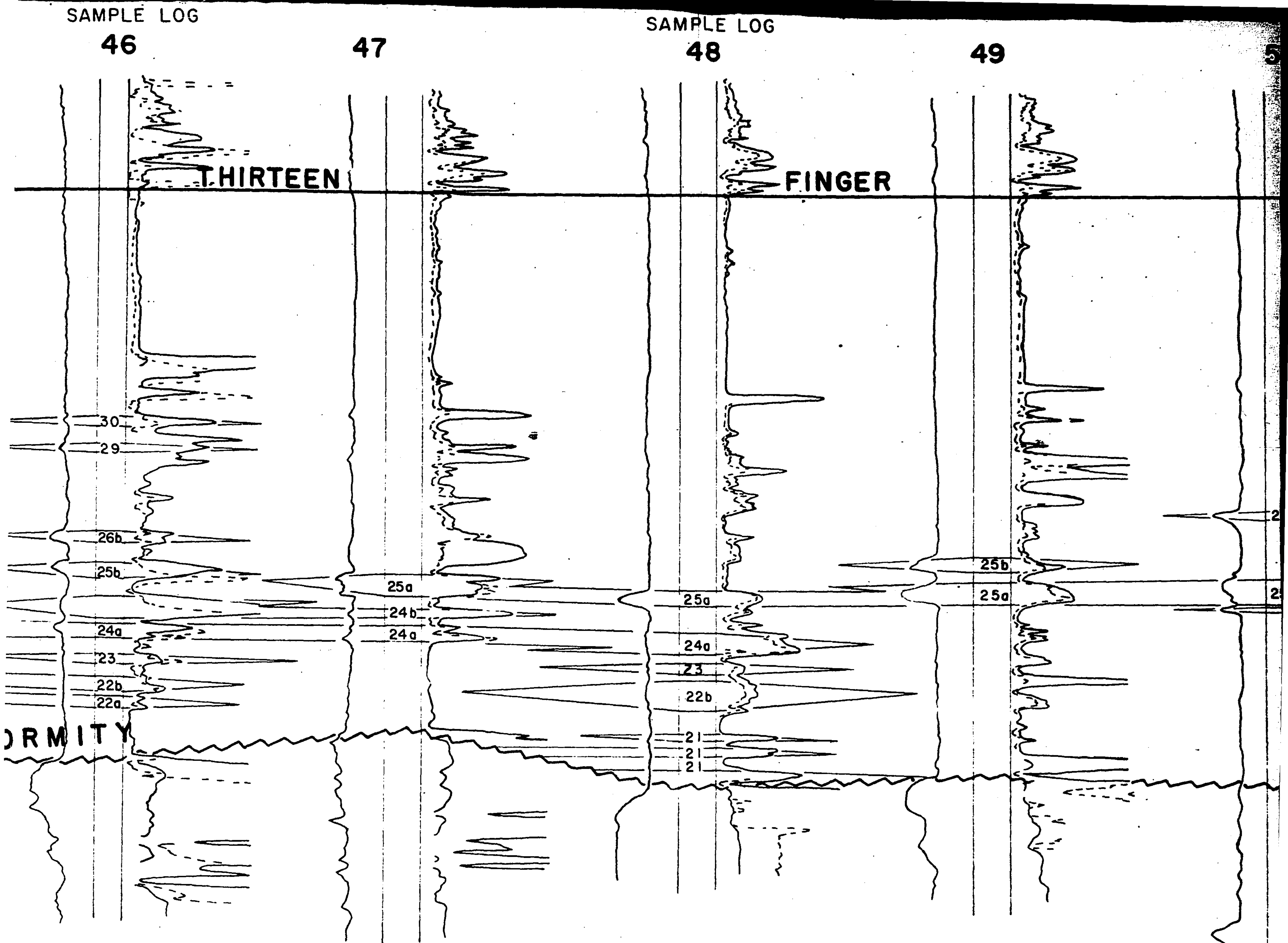
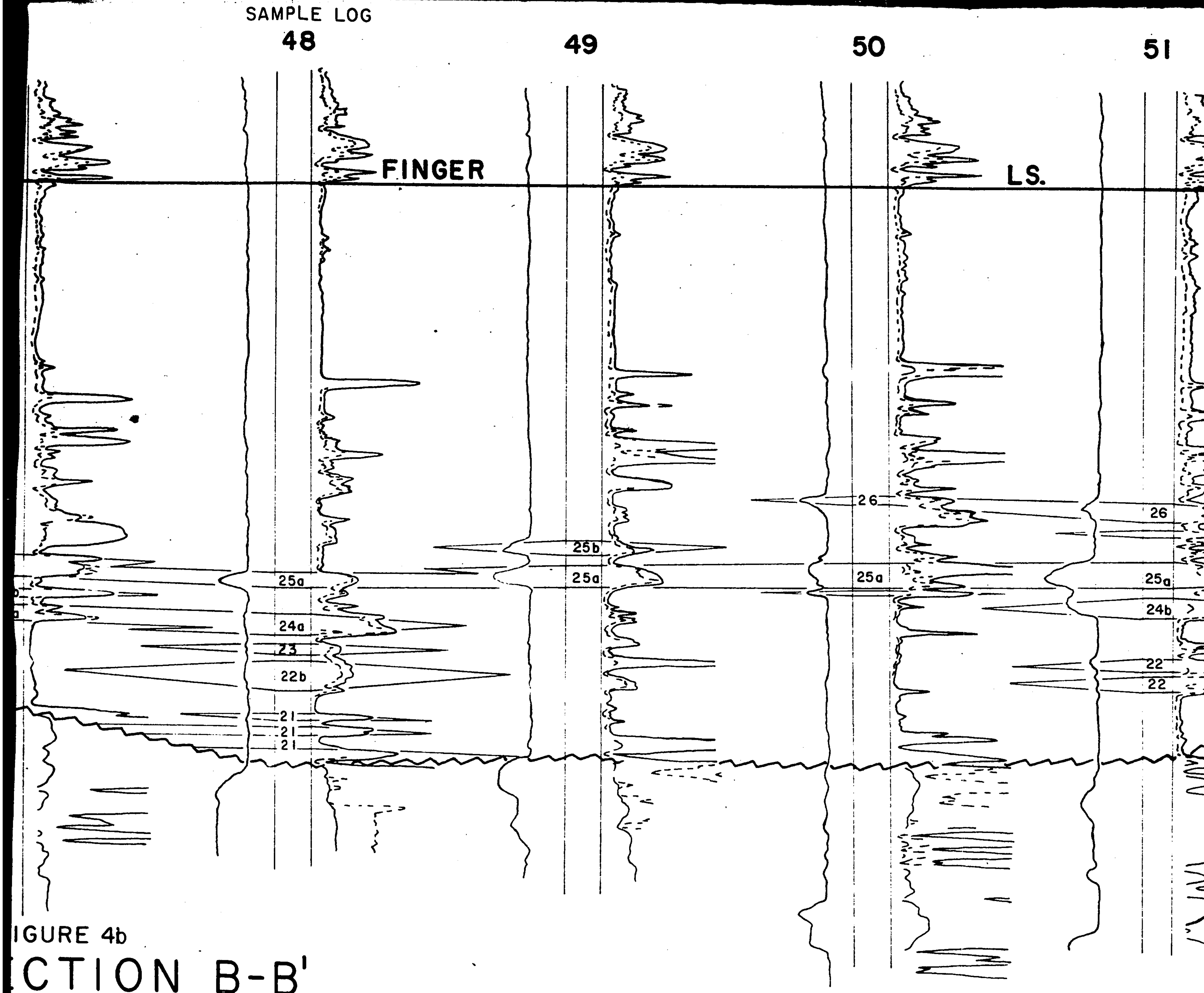



FIGURE 4b

# CROSS SECTION B-B'

(Wells 35-54)

(No horizontal scale)




IGURE 4b

# CTION B-B'

s 35-54)

ontal scale)

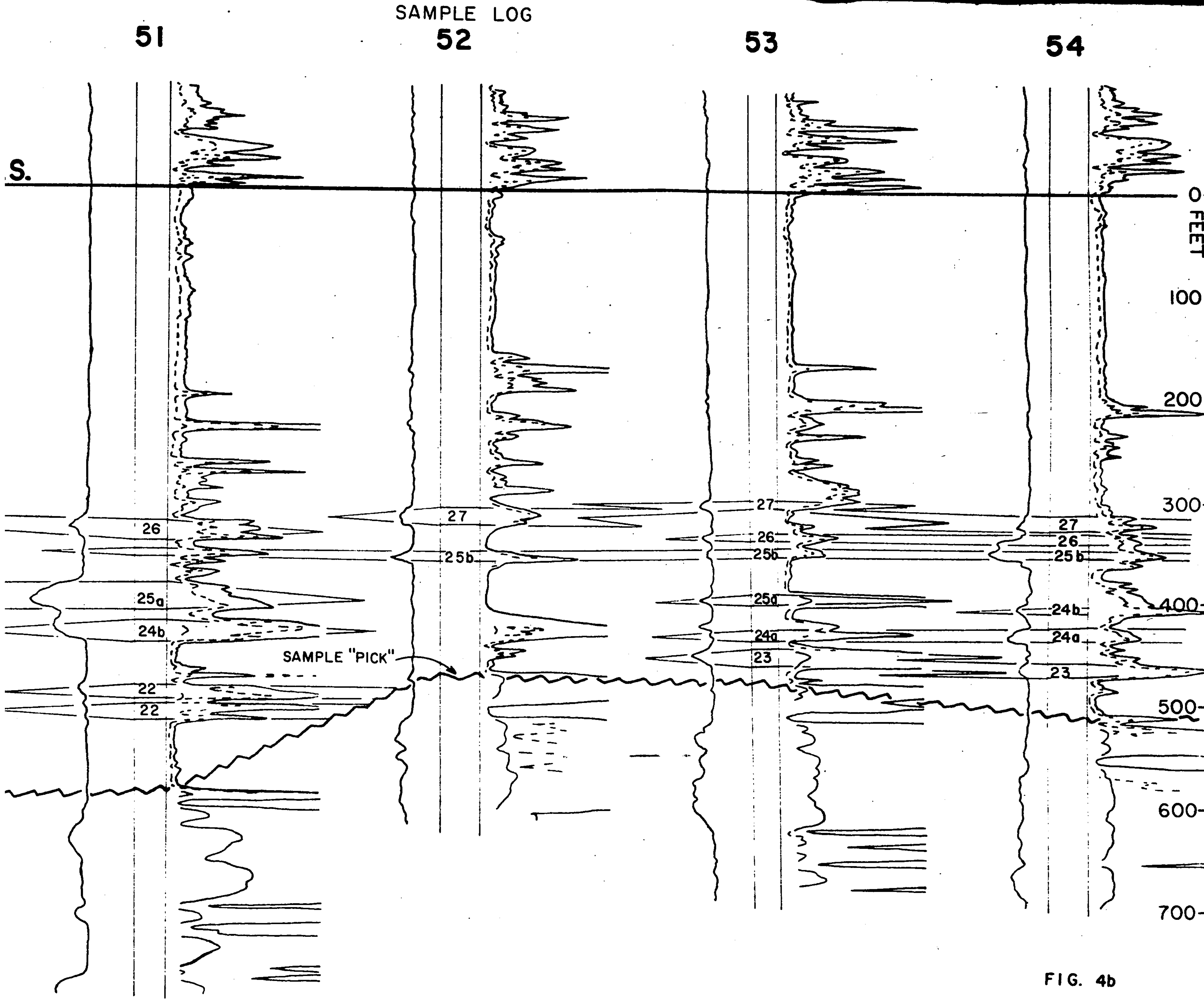
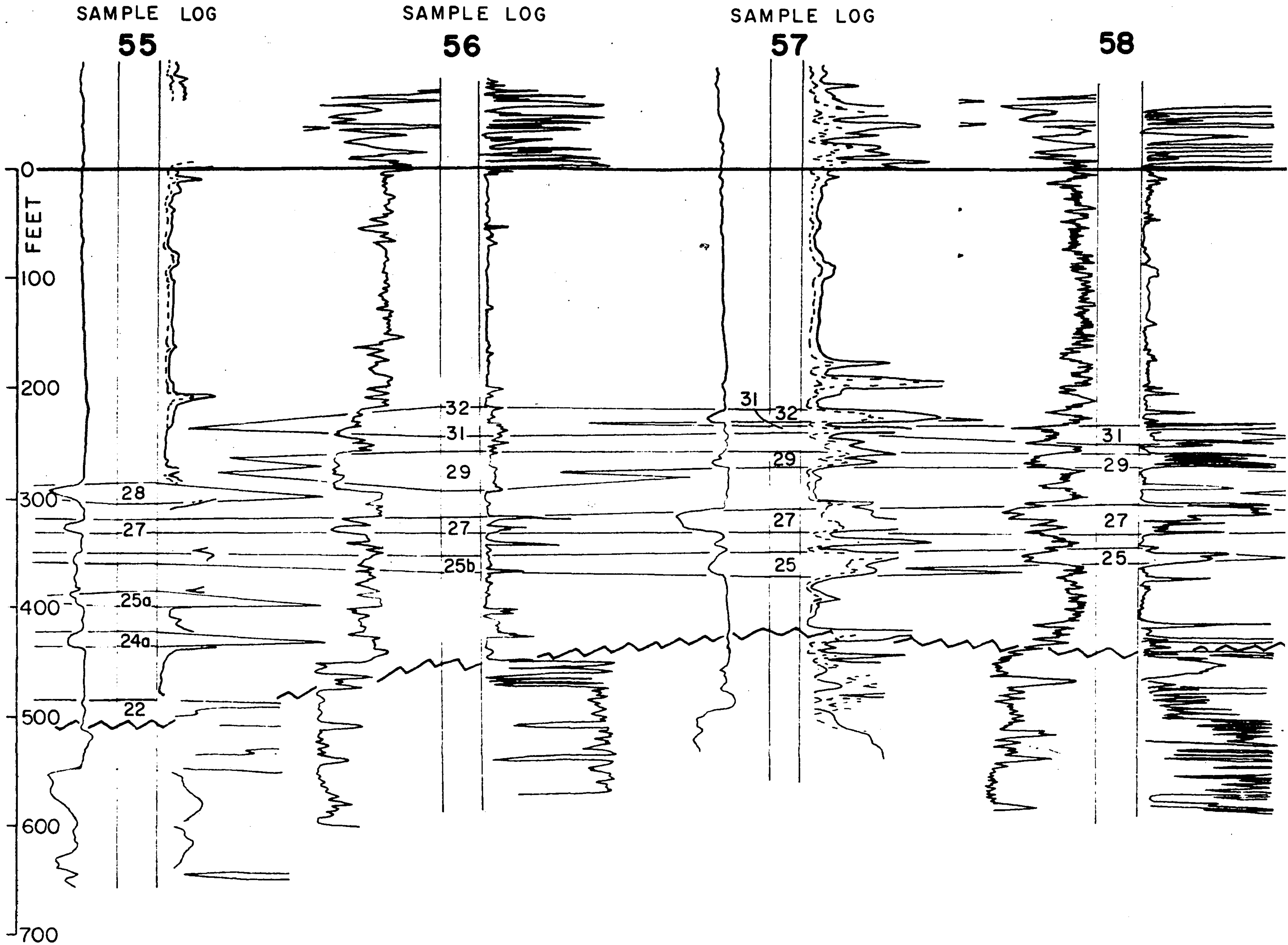
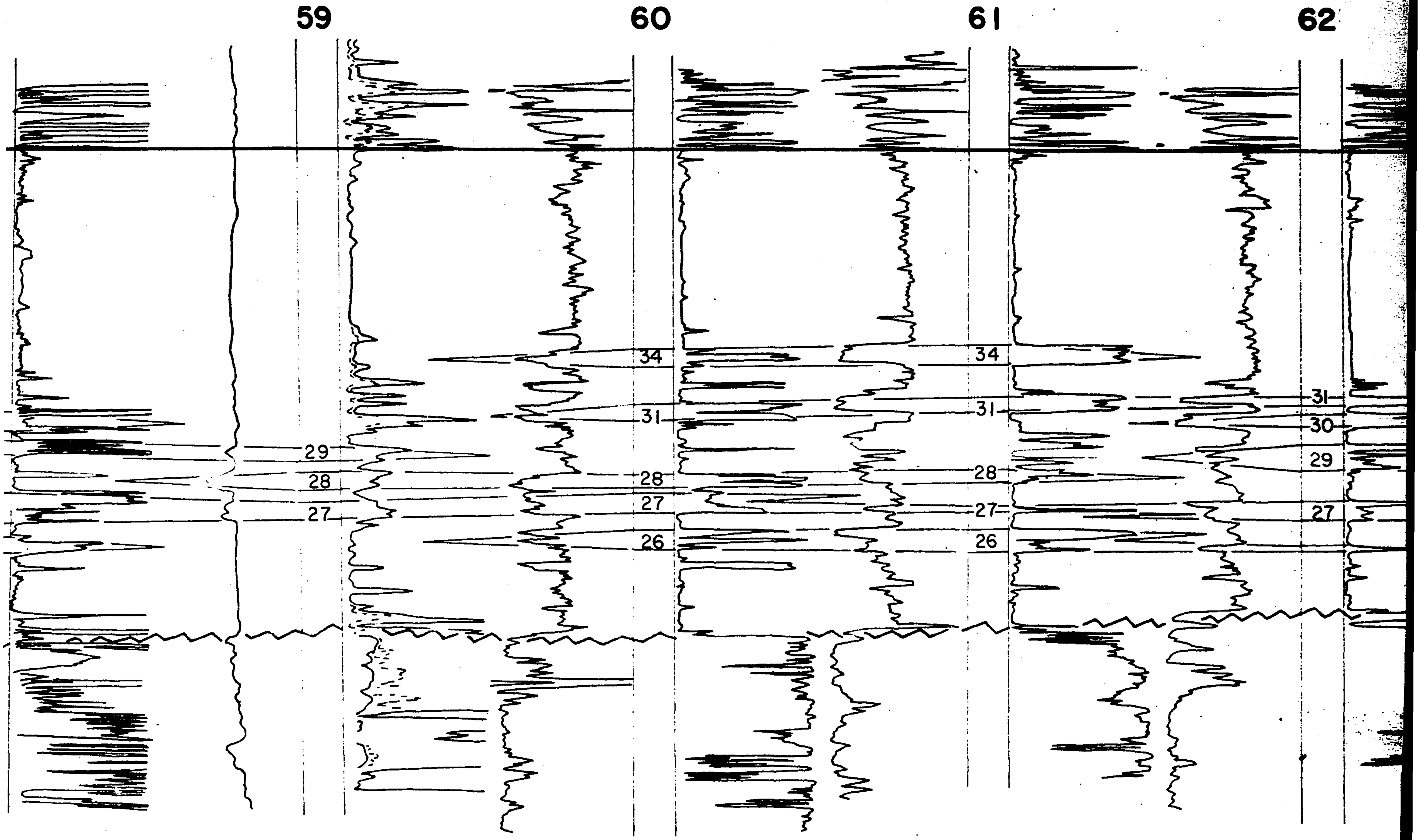
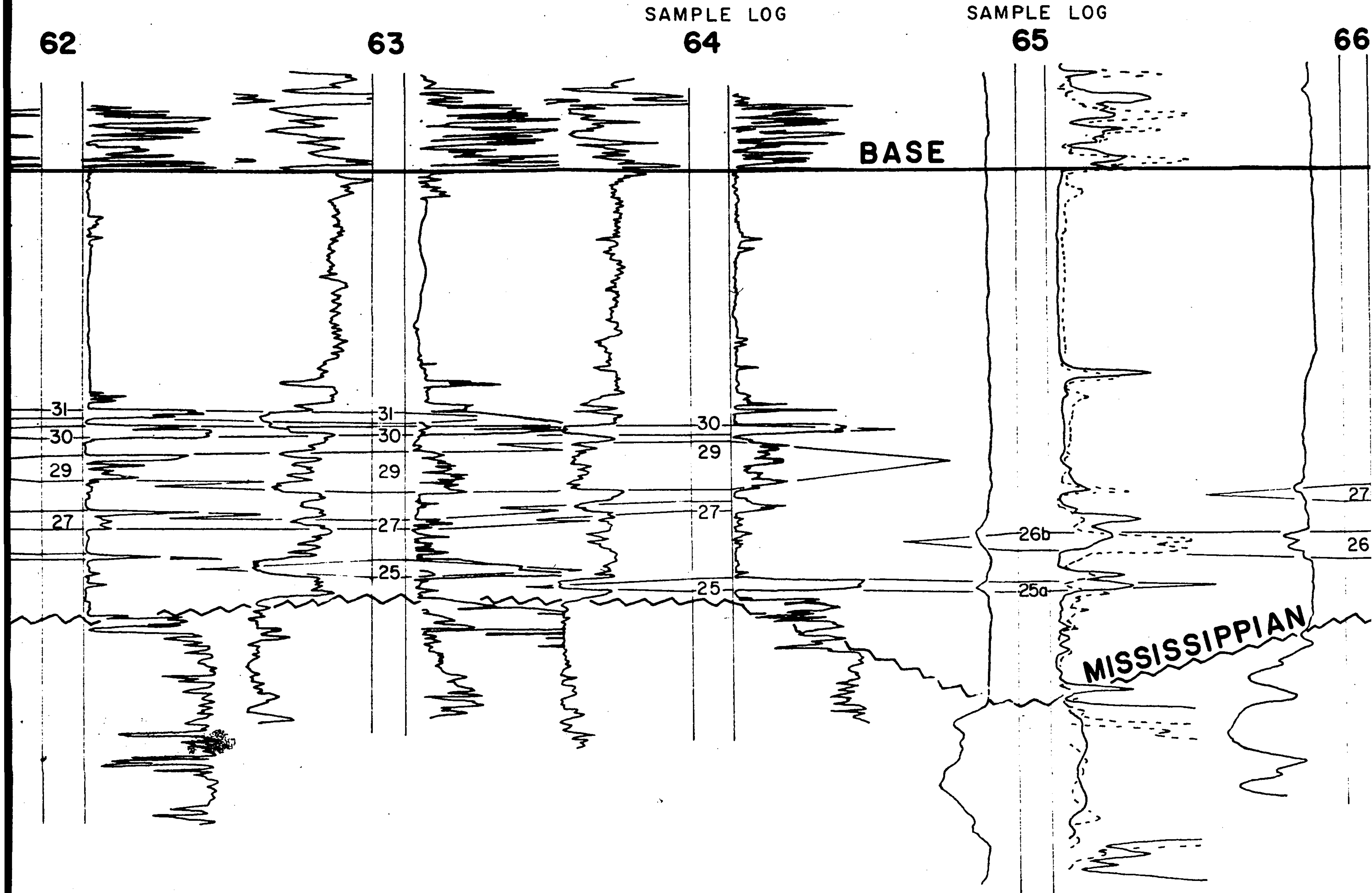

SAMPLE LOG
51
52
53
54
S.
0 FEET
100
200
300
400
500
600
700
27
26
25b
25a
24b
24a
23
22
22
SAMPLE "PICK"

FIG. 4b



SAMPLE LOG
55
SAMPLE LOG
56
SAMPLE LOG
57
58
FEET
0
100
200
300
400
500
600
700
28
27
25a
24a
22
32
31
29
27
25b
31
32
29
27
25
31
29
27
25


59
60
61
62
34
31
30
29
28
27
26



SAMPLE LOG
SAMPLE LOG
62
63
64
65
66
BASE
31
30
29
27
31
30
29
27
25
30
29
27
25
26b
25a
27
26
MISSISSIPPIAN

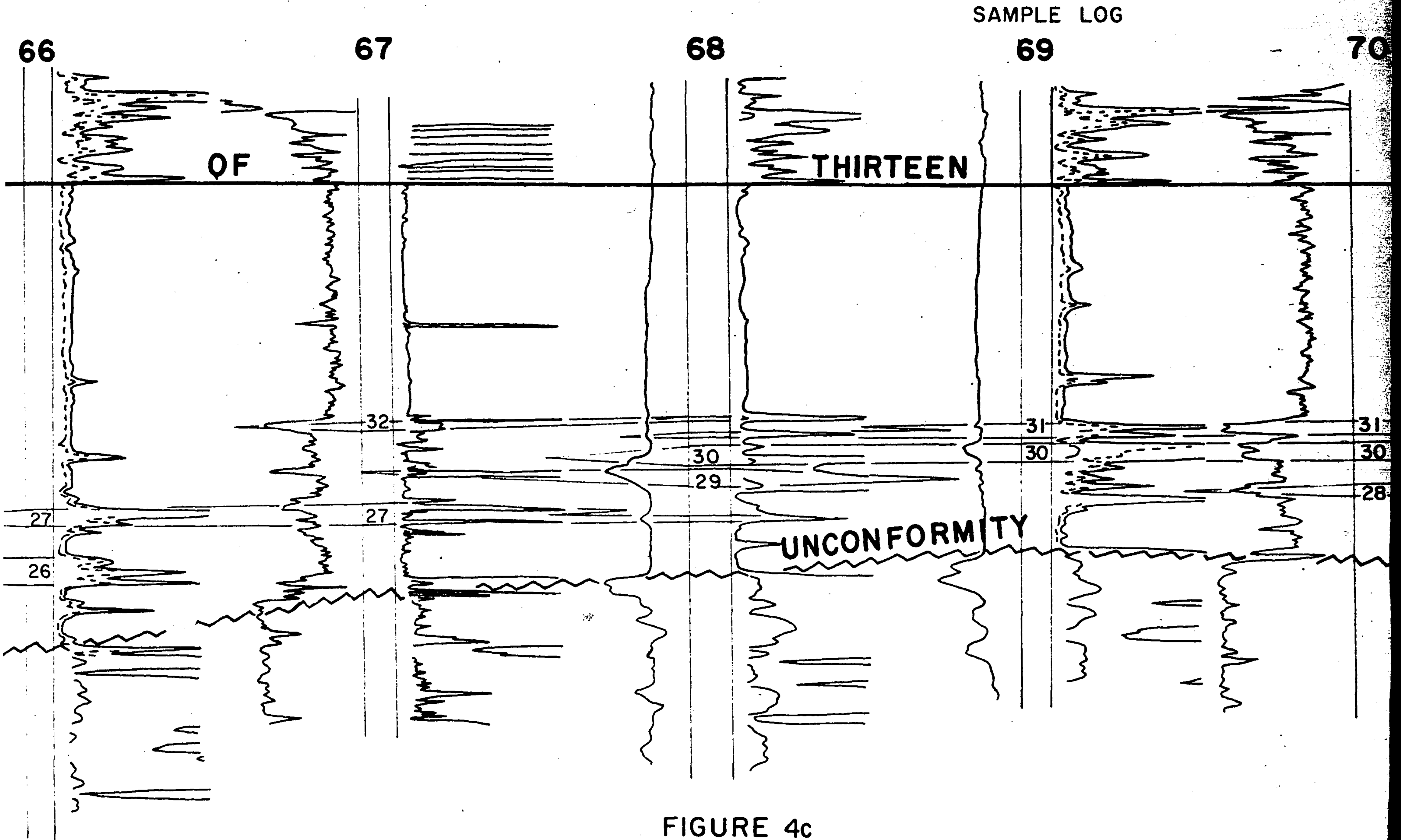
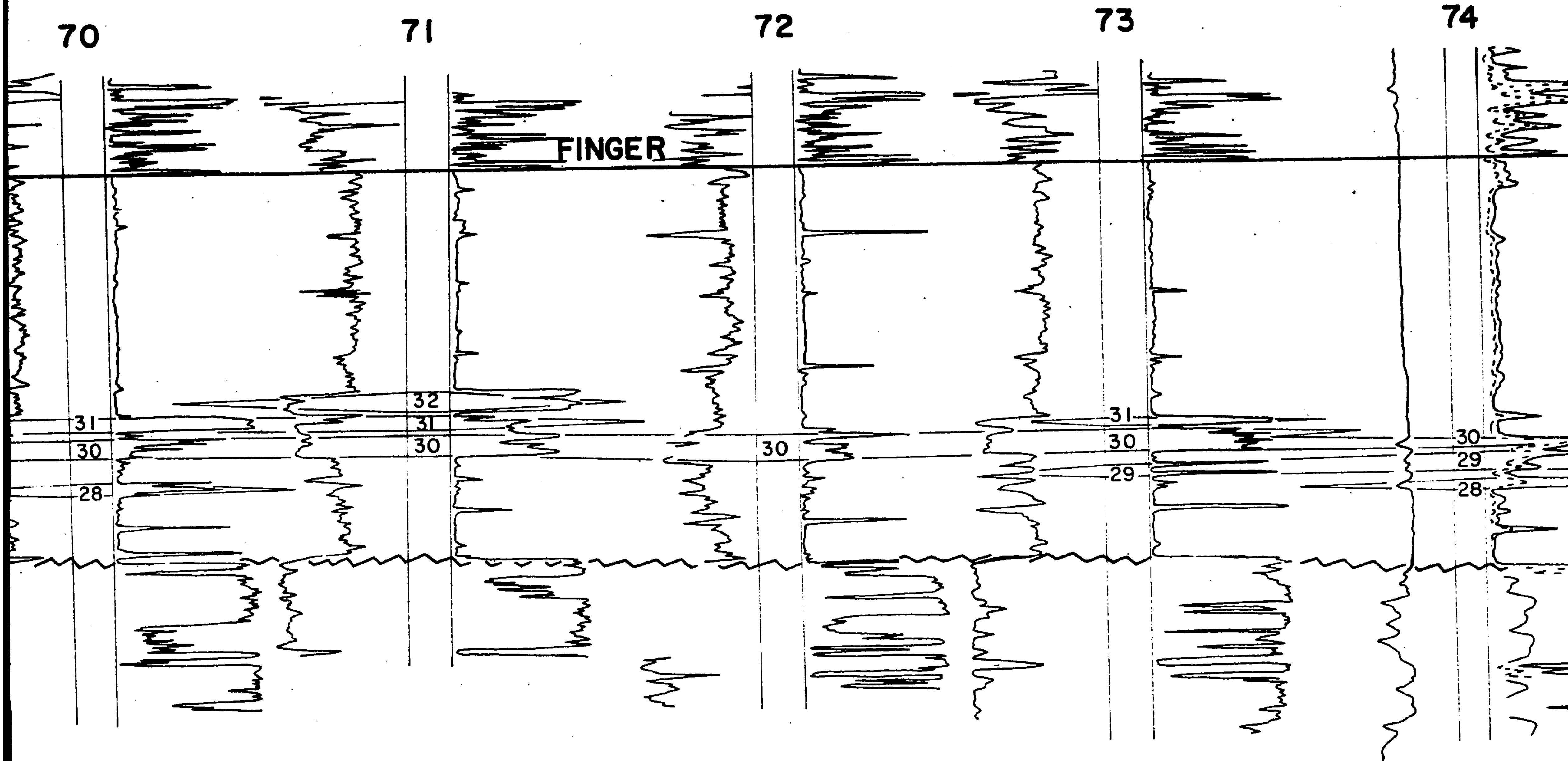


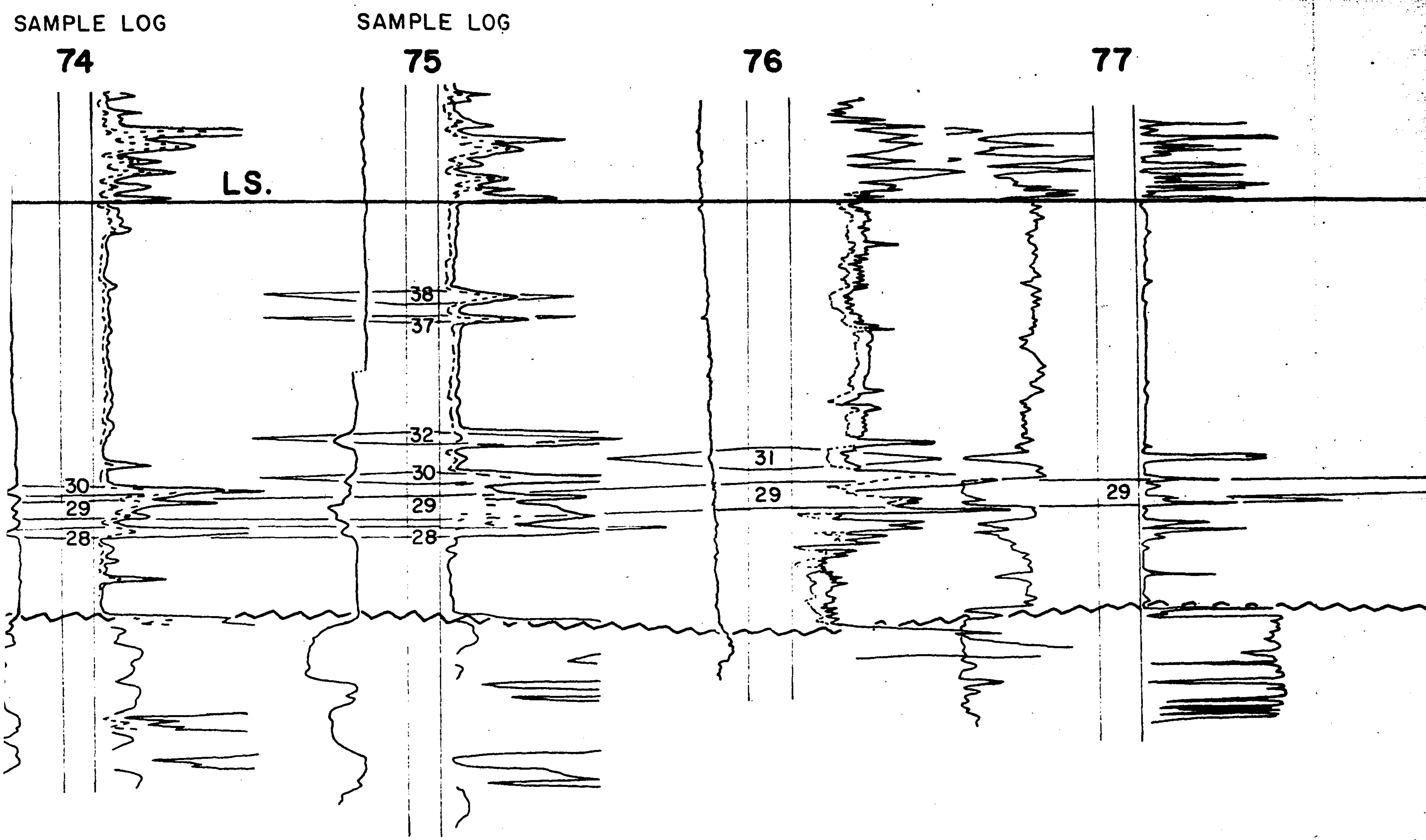

FIGURE 4c

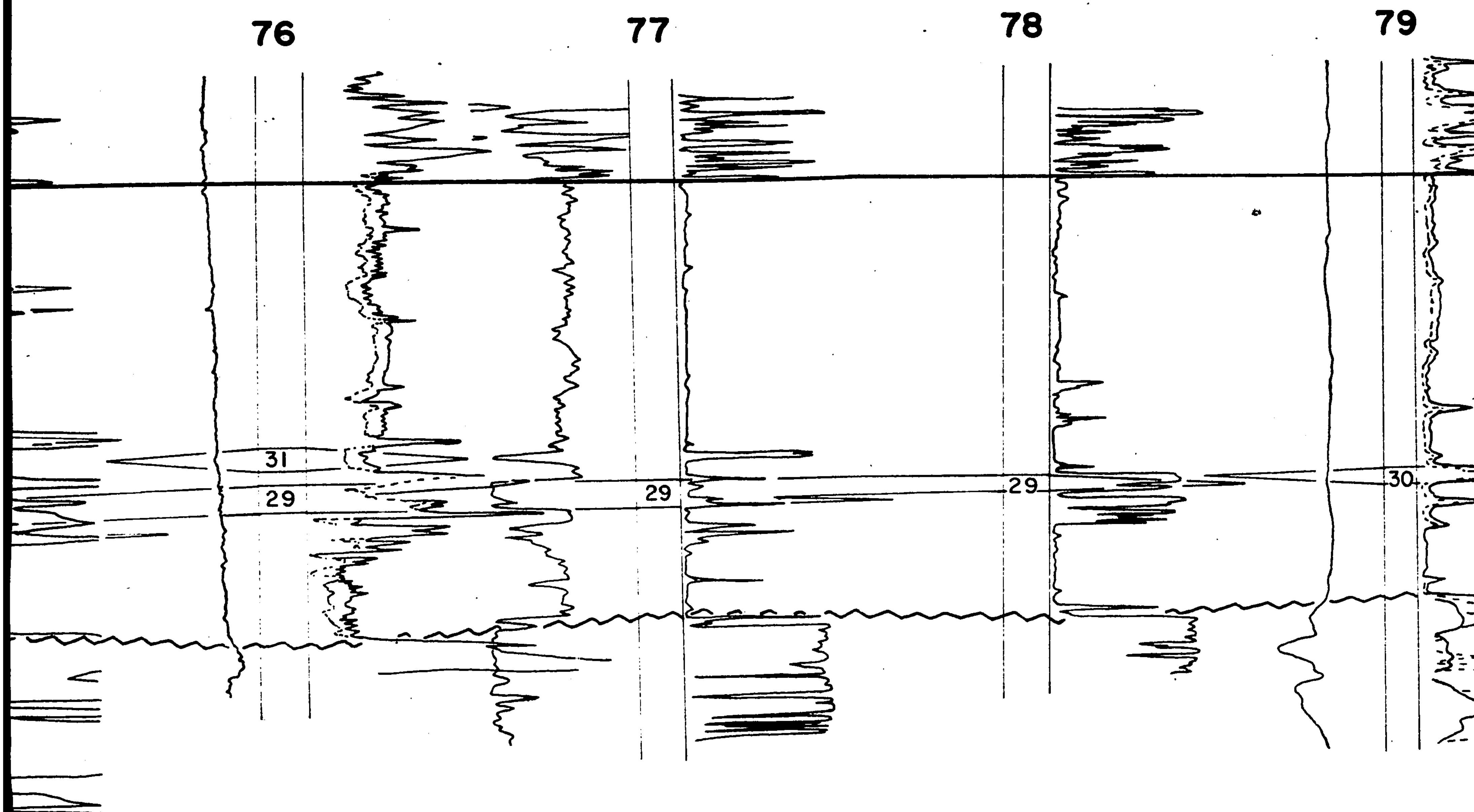
# CROSS-SECTION B-B'

(Wells 55 - 82)
(No horizontal scale)

SAMPLE LOG




SAMPLE LOG
SAMPLE LOG
74
75
76
77
LS.
38
37
32
30
31
30
29
29
29
29
28
28


76
77
78
79
31
29
29
29
30

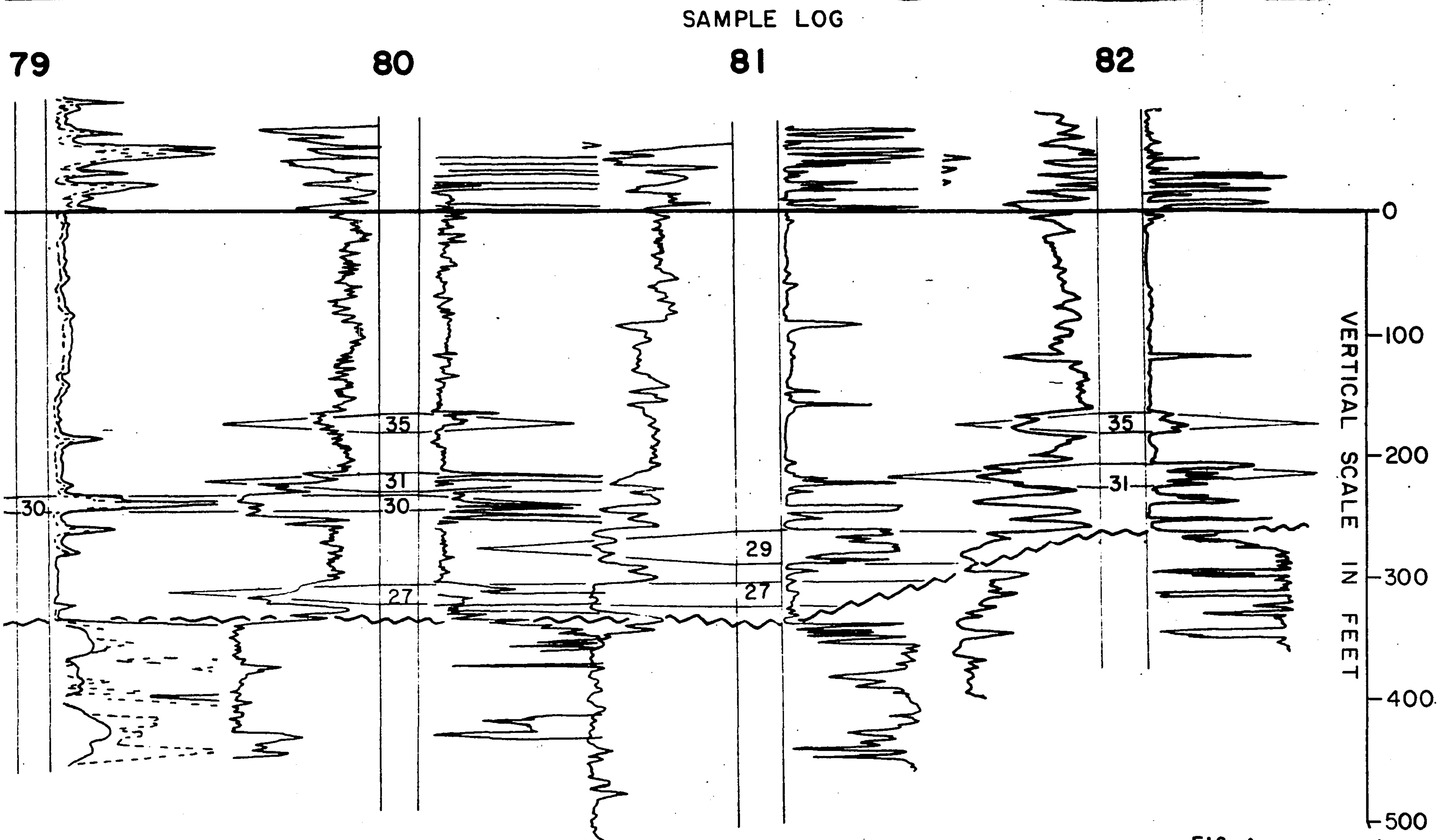
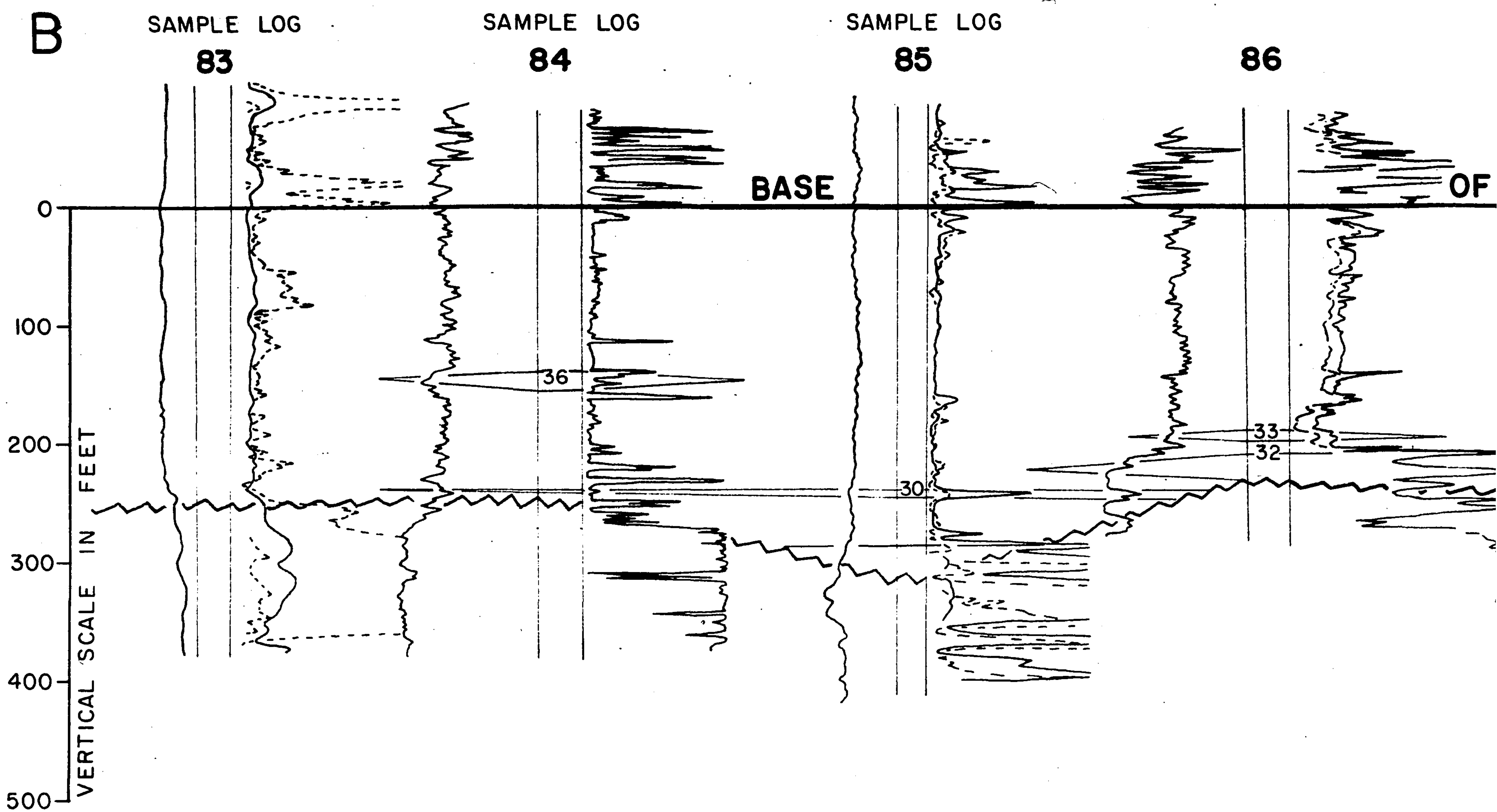

SAMPLE LOG
79
80
81
82
35
31
30
30
29
27
27
35
31
0
100
200
300
400
500
VERTICAL SCALE IN FEET

FIG. 4c



B
SAMPLE LOG
83
SAMPLE LOG
84
SAMPLE LOG
85
86
BASE
OF
0
100
200
300
400
500
VERTICAL SCALE IN FEET
36
33
32
30

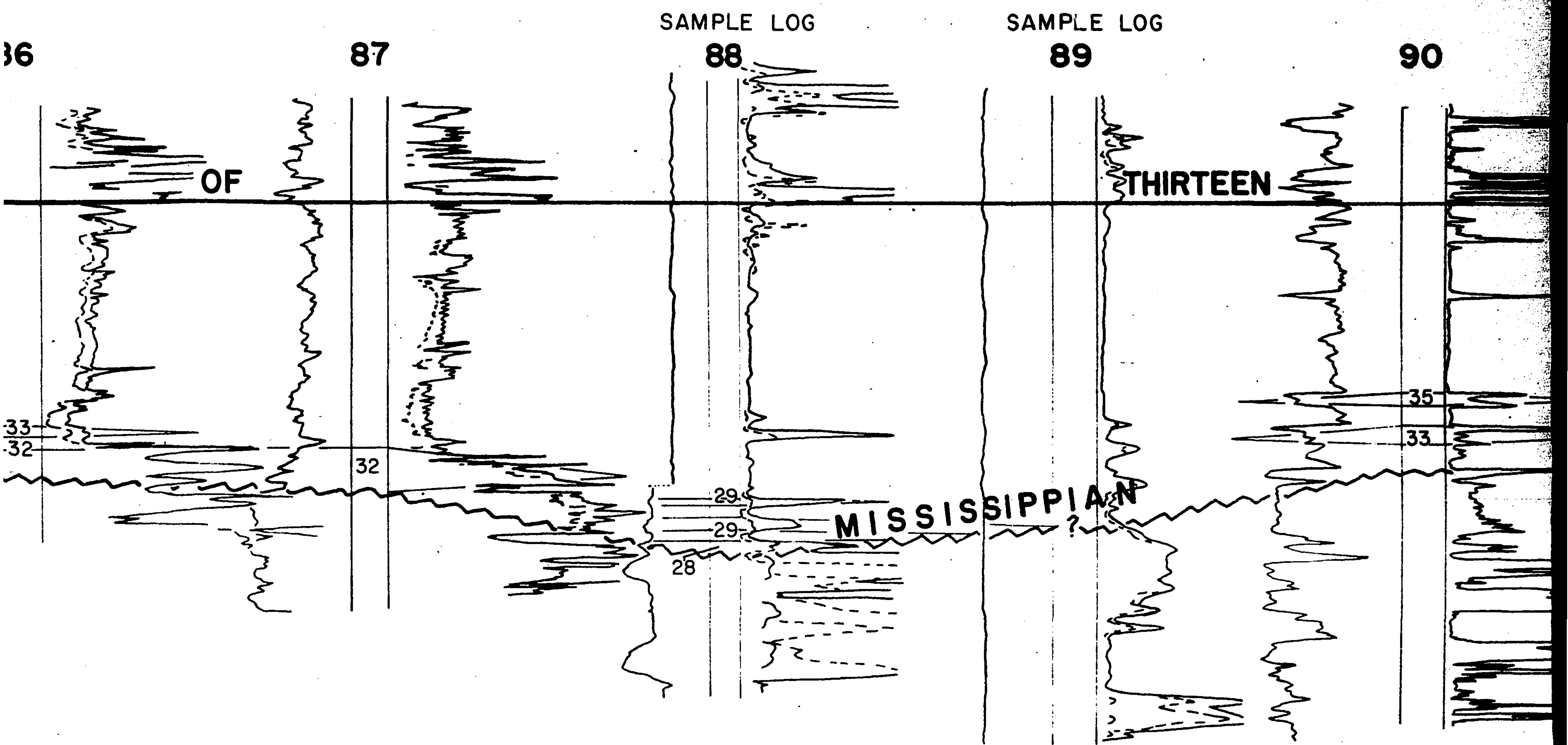



FIGURE 4d

# CROSS-SECTION B-

(Wells 83-96)

(No horizontal scale)

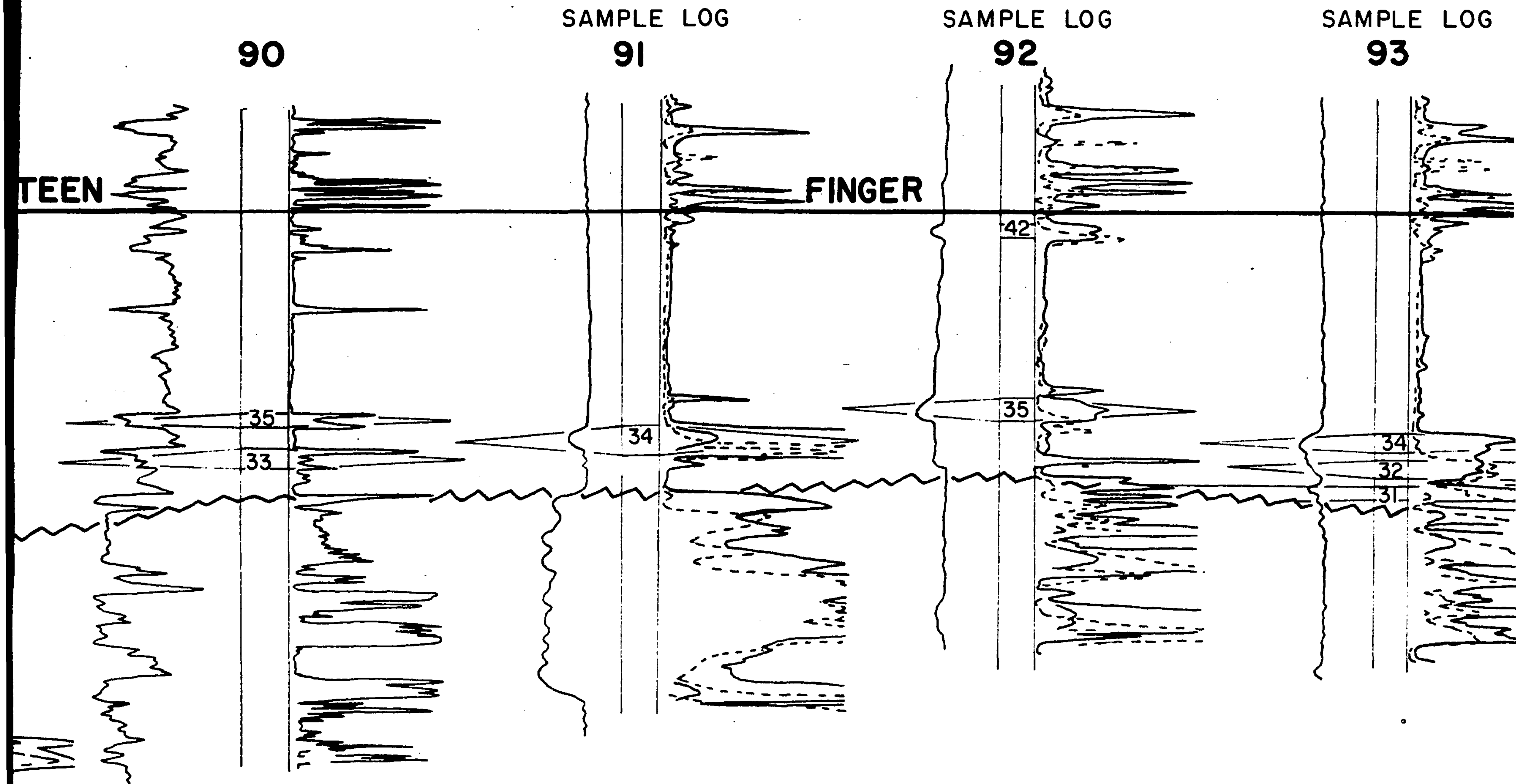



FIGURE 4d

SECTION B-B'

Wells 83-96)

orizontal scale)

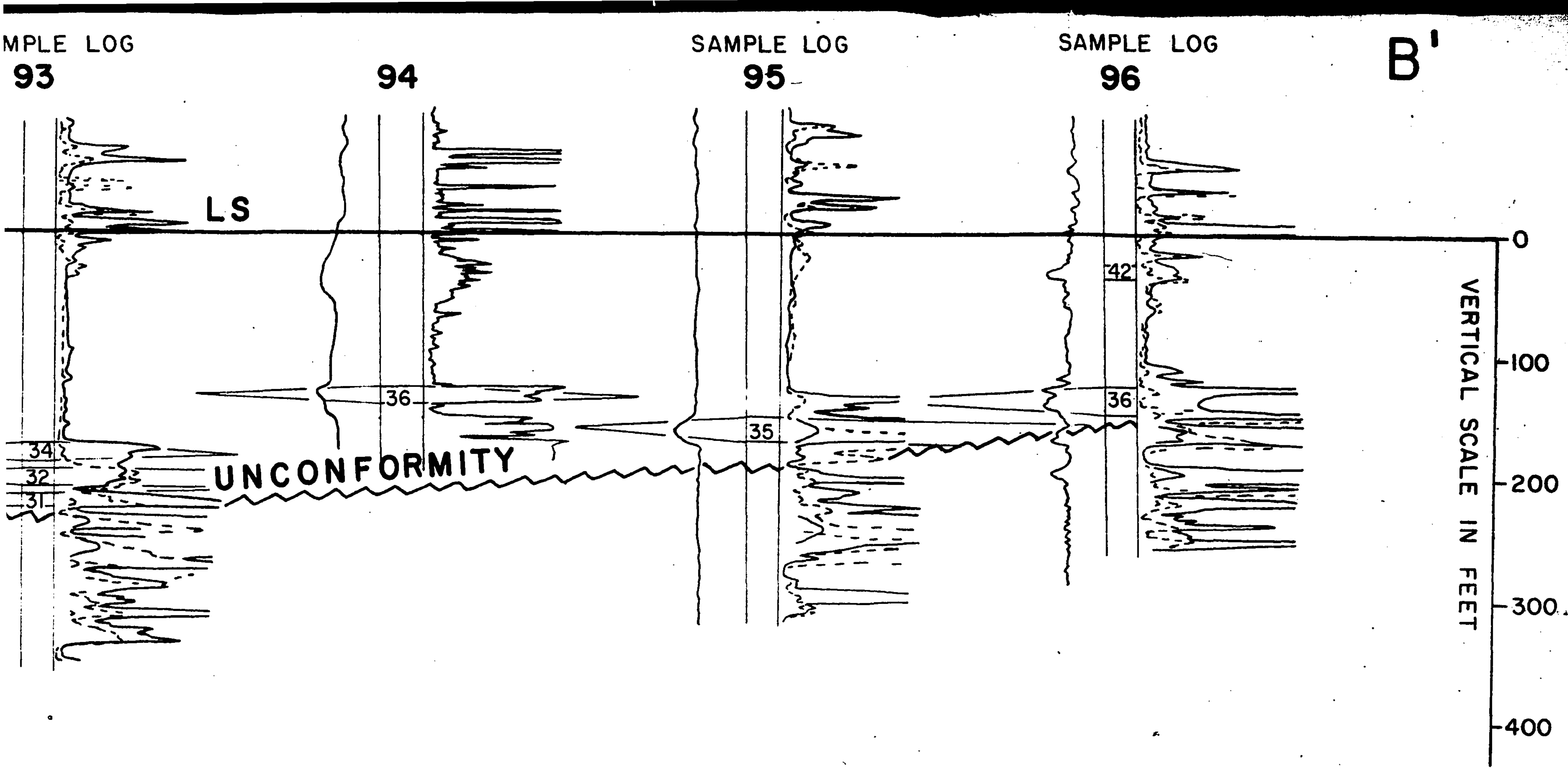
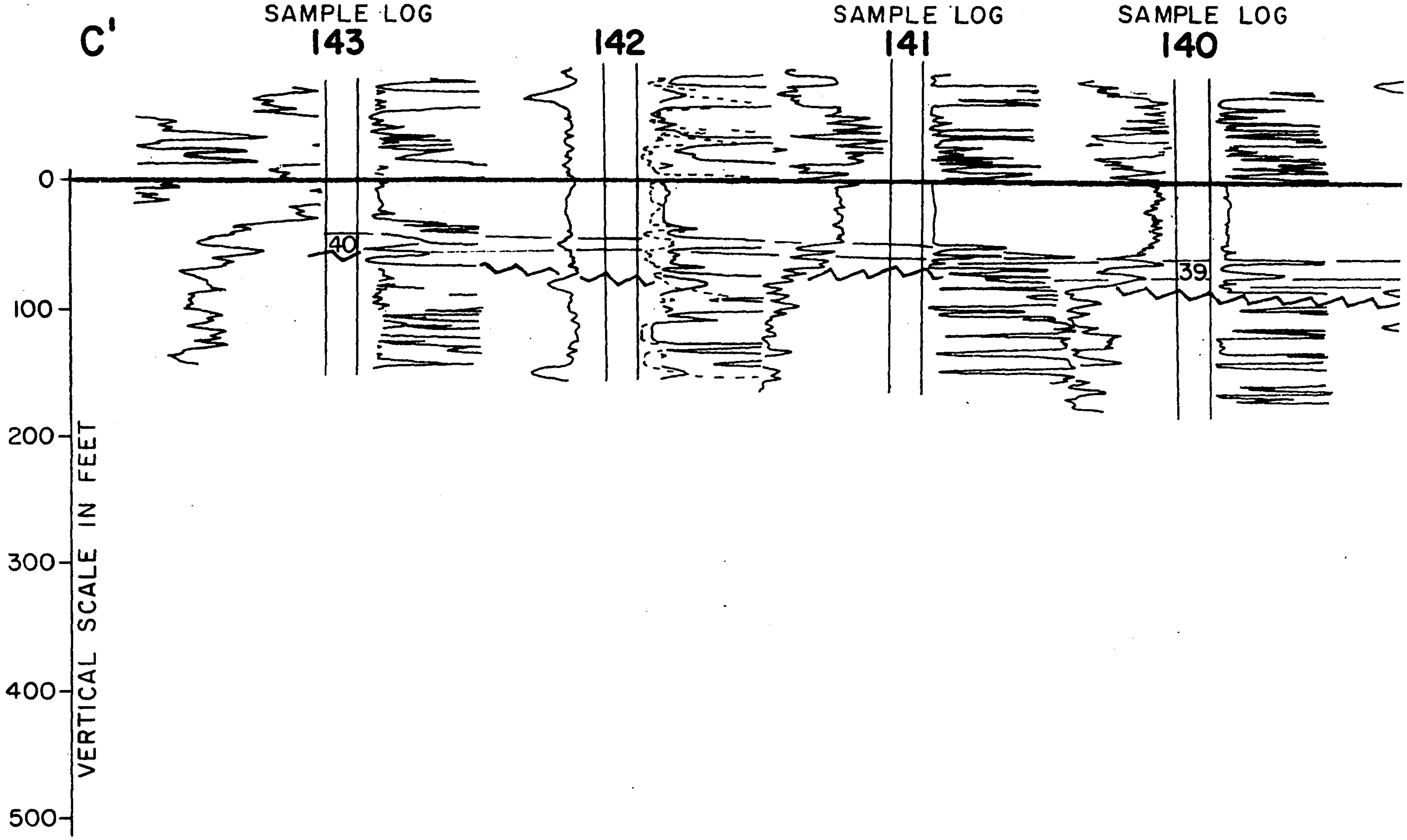

MPLE LOG
93
94
SAMPLE LOG
95
SAMPLE LOG
96
B'
LS
UNCONFORMITY
34
32
31
36
35
36
42
0
100
200
300
400
VERTICAL SCALE IN FEET

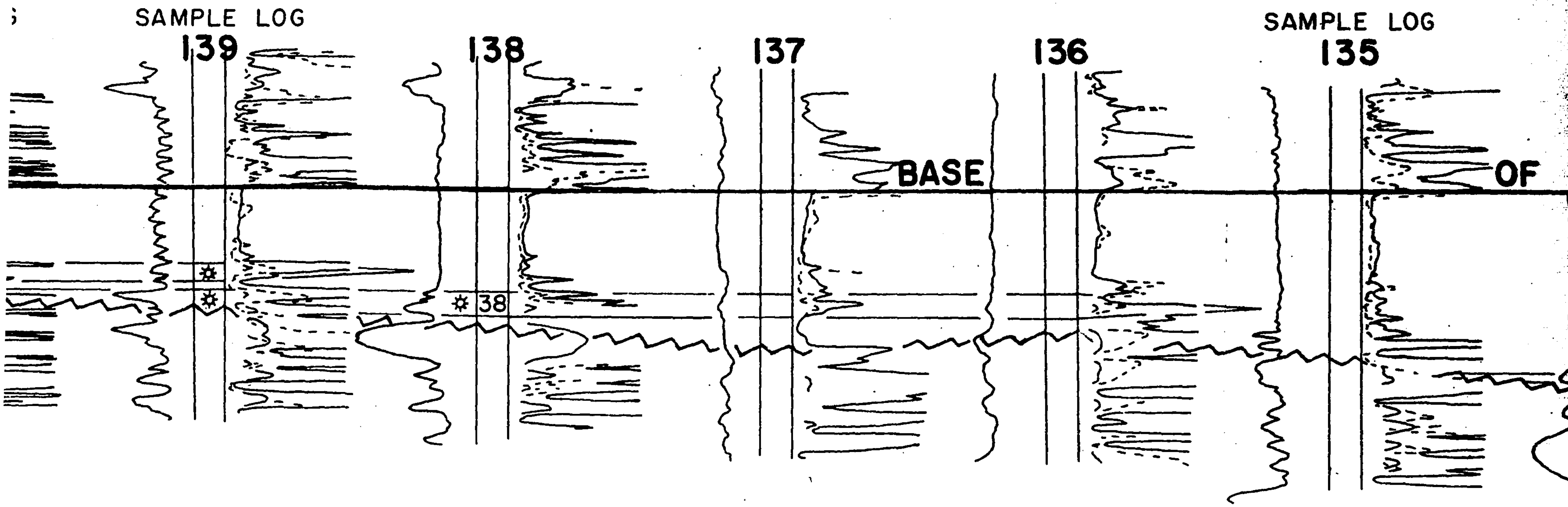
FIG. 4d

(except where complicated by channel sand deposition) and a slightly convex upper surface. In Figure 4a, sandstone 38 represents three offshore bars (see also Figure 3) inasmuch as they all developed some distance offshore and fail to impinge against the Mississippian unconformity. Sandstone 37 represents three offshore bars related to barrier island 37 shown on Figure 3. Sandstone 26 and 27 are offshore bars related to beach sandstone 26 and barrier island 27, respectively, shown on Figure 3. Sandstones 24, 23, and 22 appear to represent offshore bars. In Figure 4b, sandstone 39 is an offshore bar related to beach sandstone 39, shown on Figure 5a. Sandstone 27 is an offshore bar related to barrier island 27 shown on Figure 5a. Identification of the remaining sandstone members as fringing beach sandstones, barrier islands, or offshore bars is difficult, because this section is parallel with the depositional strike, and its location is within a few miles from the landward wedgeouts of these members. The same applies for those sandstone members shown on Figure 4c. In Figure 4d, sandstone 35 impinges against the Mississippian unconformity as a fringing beach sandstone, with two offshore bars located seaward.

Cross section CC' (Figure 5), as Figure 3, is drawn normal to the depositional strike. It is presented in two parts for ready reference. The cross sectional profiles of the different Morrow sandstone members are well illustrated in this cross section.

In Figure 5a, sandstone 40, 39, and 38 all impinge against the Mississippian unconformity to suggest fringing beach sandstones. Sandstone 36 is an excellent illustration of the cross sectional profile of a barrier island, with an essentially flattened base and a convex upper surface (see also Figure 3). However, sandstone 36 is so near the unconformity surface that one might consider it a fringing beach sandstone and question its having "shaled out" as it approached the unconformity surface. Several short cross sections across the landward part of sandstone 36 show that it "shaled out" as it approached the unconformity surface. Moreover, sandstone 36, shown on the electric log of well 134 (sec. 11, T. 27 N., R. 26 W.), may be lagoonal and containing eolian, well rounded sand grains blown from barrier island 36. A similar lagoonal, swampy sandstone on the mainland and behind barrier island 33 occurs in sec. 23, T. 26 N., R. 25 W. (see Figure 15 D and E). Sandstone 35 is an offshore bar (see Figure 3); sandstones 34 and 33 are barrier islands with offshore bars; sandstones 32 and 31 "shaled out" some distance before they reach the unconformity surface; their essentially flattened bases suggest offshore bars. Sandstone 31 was deposited many miles from the shoreline, probably during extreme storm conditions when the depth


C'
SAMPLE LOG
143
142
SAMPLE LOG
141
SAMPLE LOG
140
40
39
0
100
200
300
400
500
VERTICAL SCALE IN FEET




FIGURE

CROSS - SECT

(Wells 143-122, 56

(No horizonta

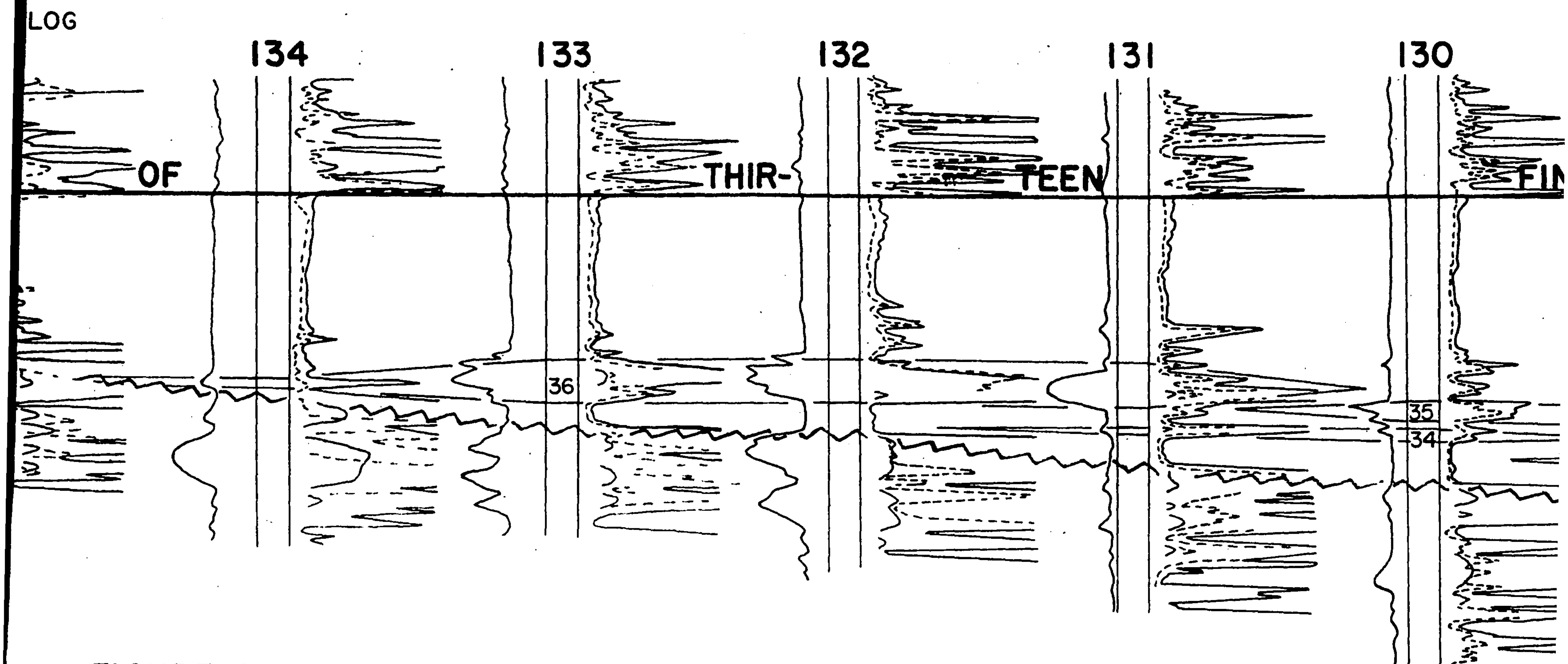
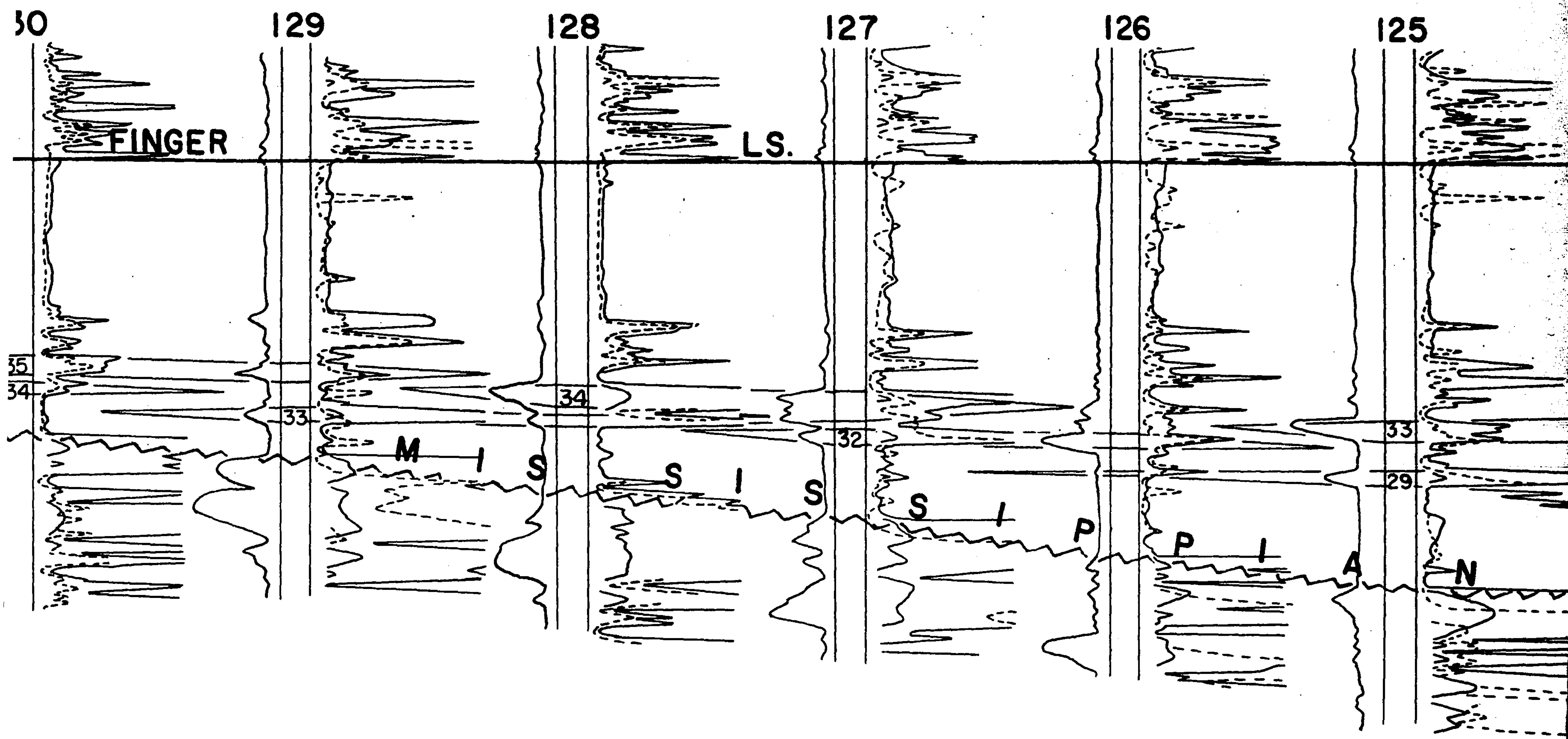



FIGURE 5a

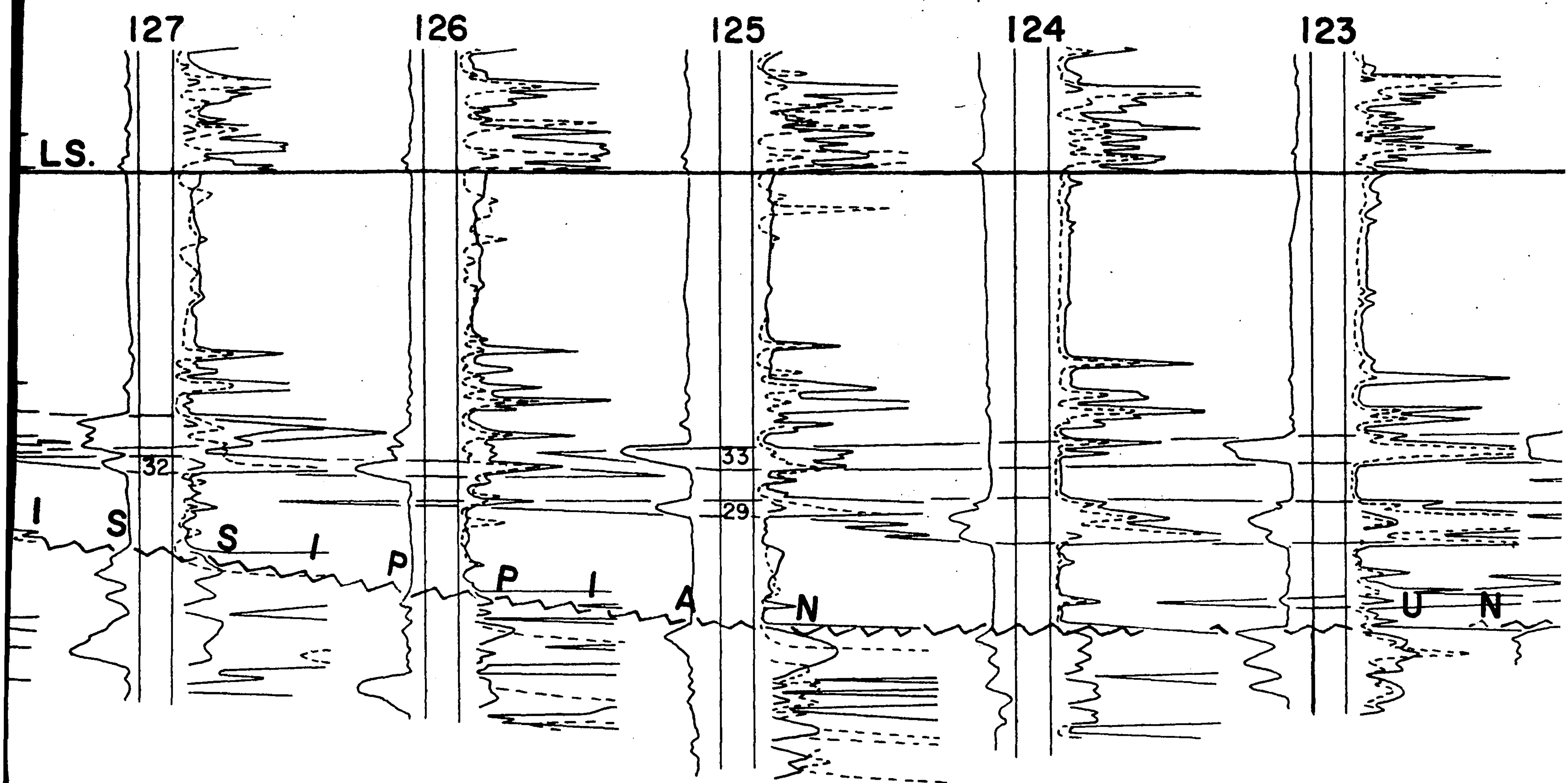
SECTION C'-C

(143-122, 56, 57, and 58)

No horizontal scale)



30
129
128
127
126
125
FINGER
LS.
35
34
33
34
32
33
29
M I S S I S S I P P I A N



127
126
125
124
123
LS.
32
33
29
I S S I P P I A N
U N

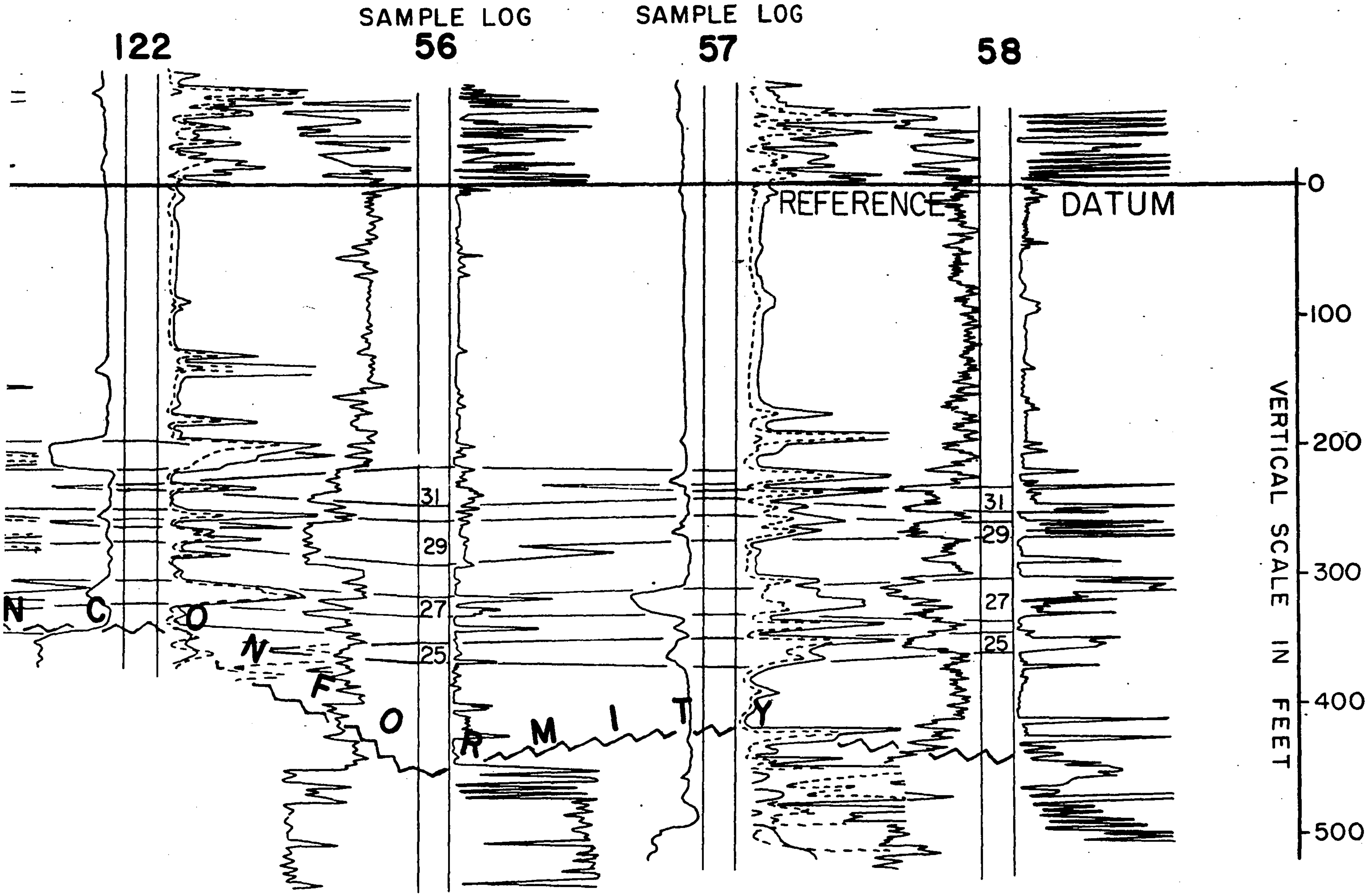
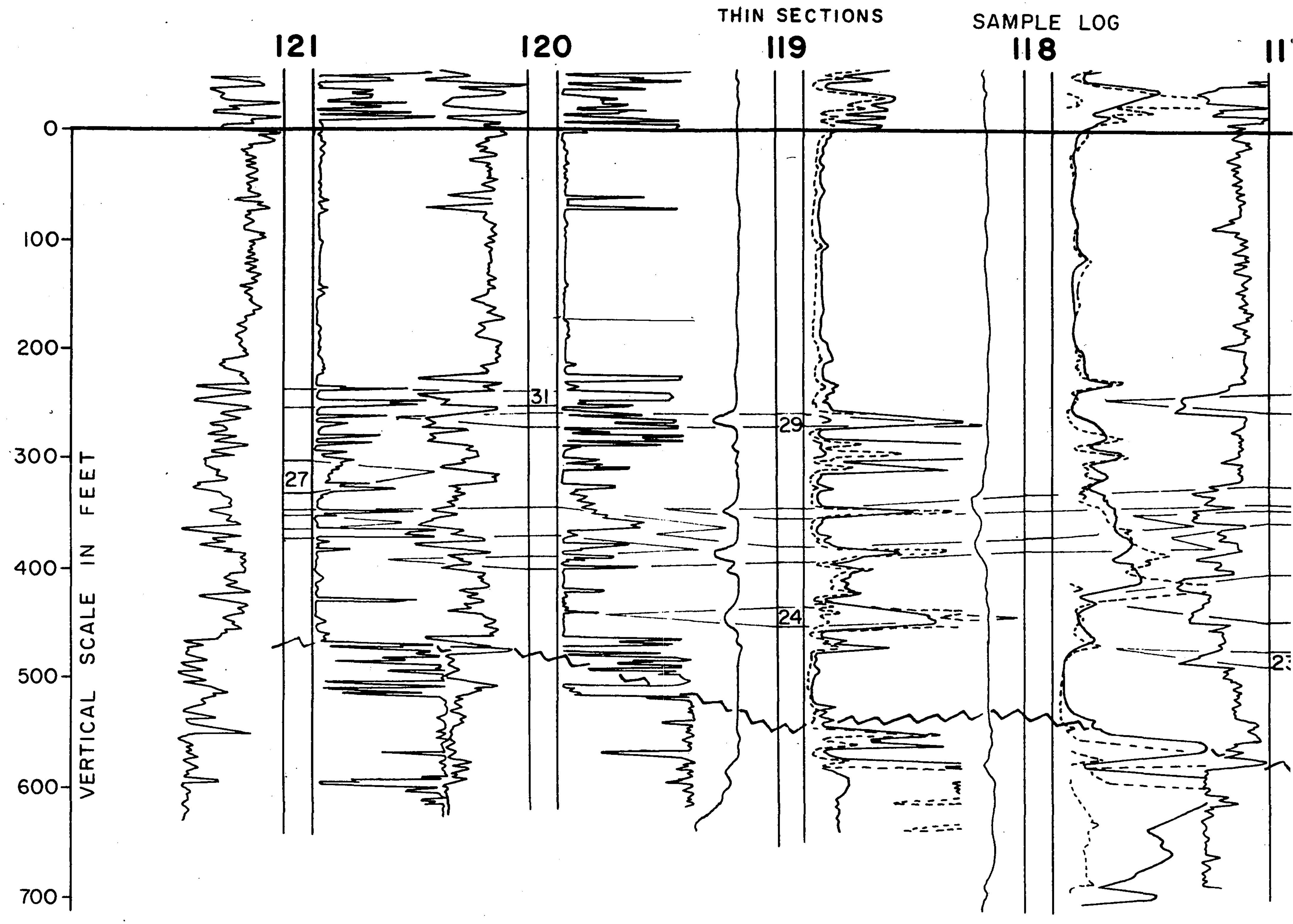

SAMPLE LOG
SAMPLE LOG
122
56
57
58
REFERENCE
DATUM
31
29
27
25
31
29
27
25
N C O N F O R M I T Y
0
100
200
300
400
500
VERTICAL SCALE IN FEET

FIG. 5a




FIG

CROSS-SEC

(Wells

(No horizo

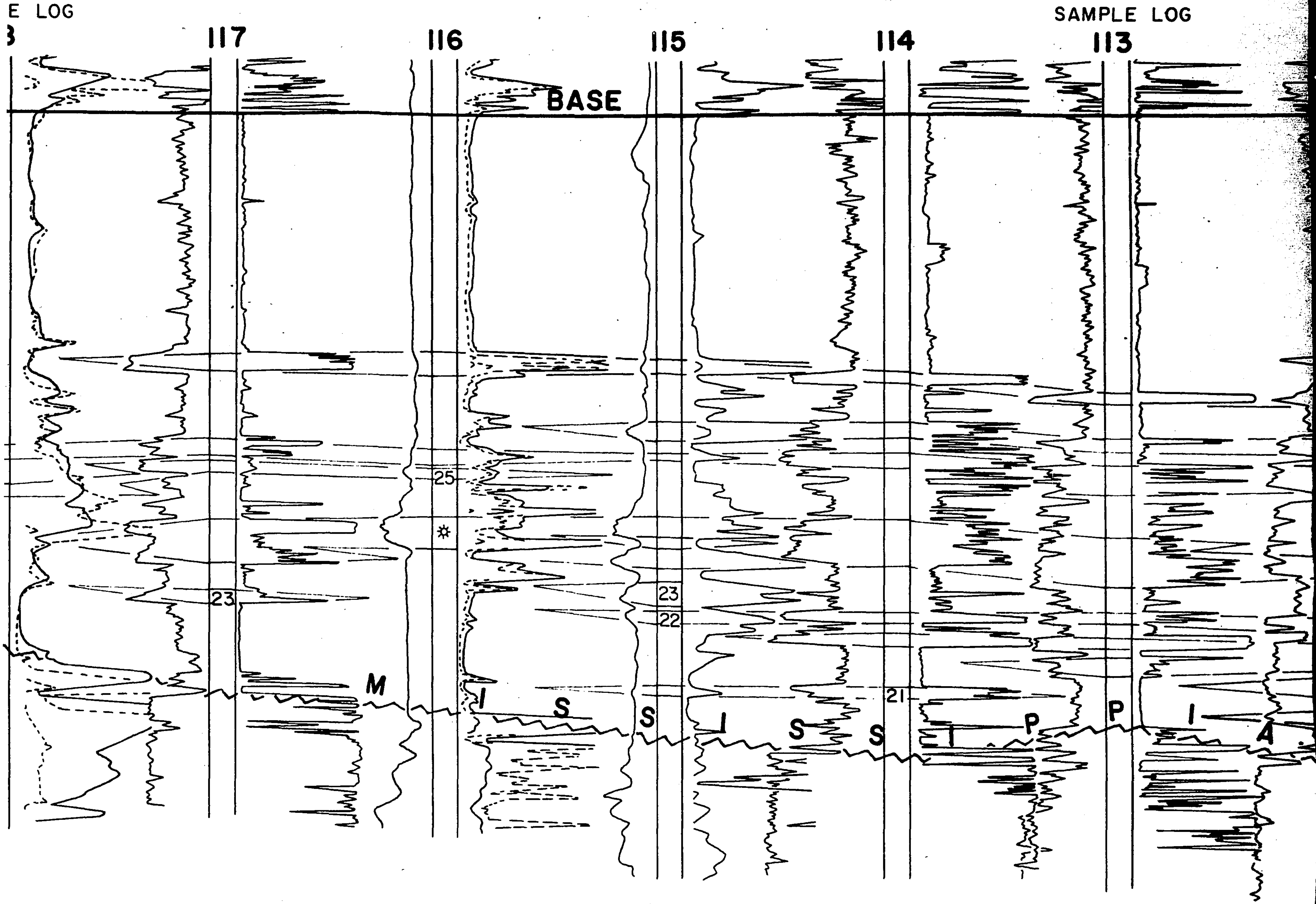
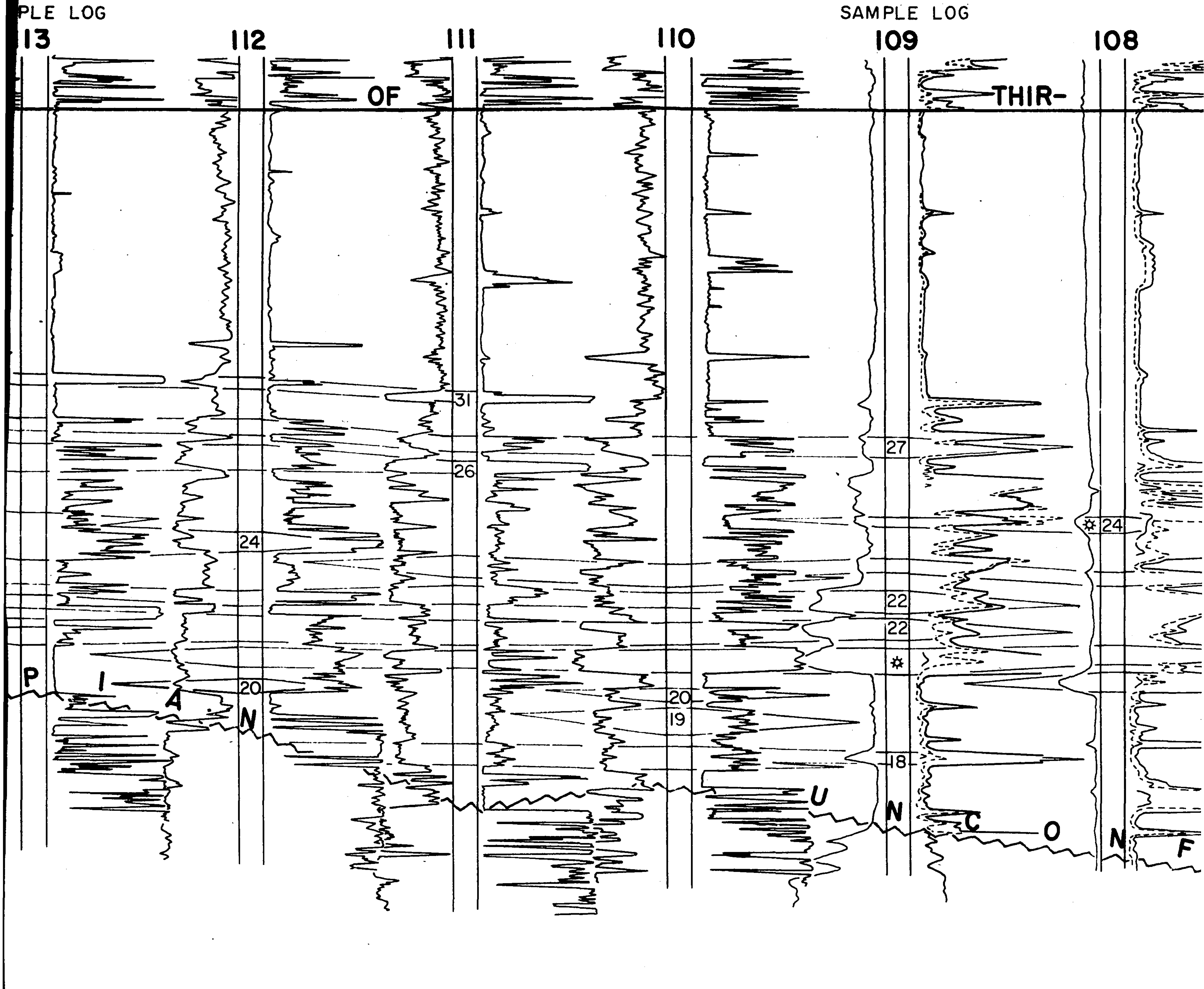



FIGURE 5b

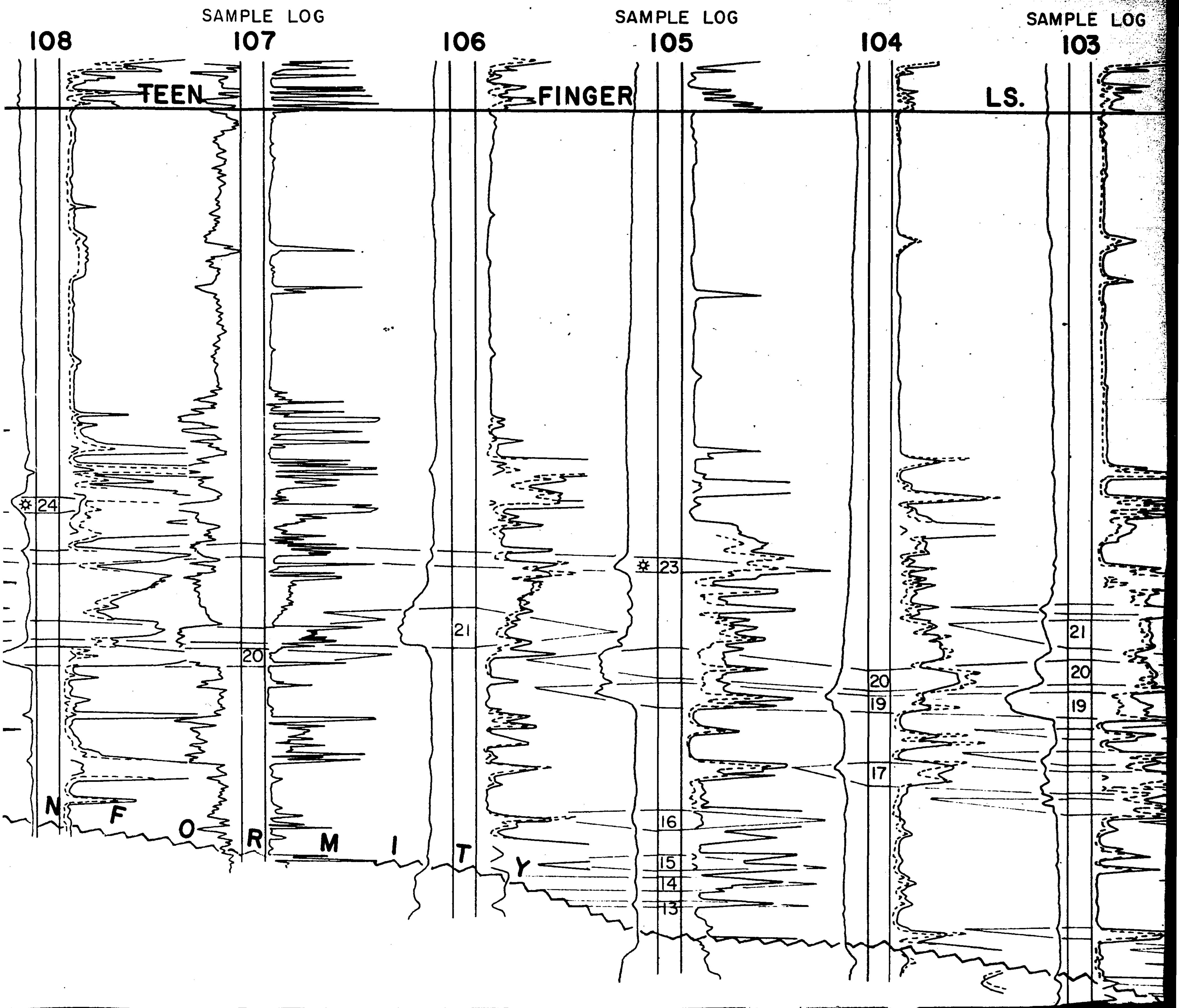
OSS-SECTION C'-C

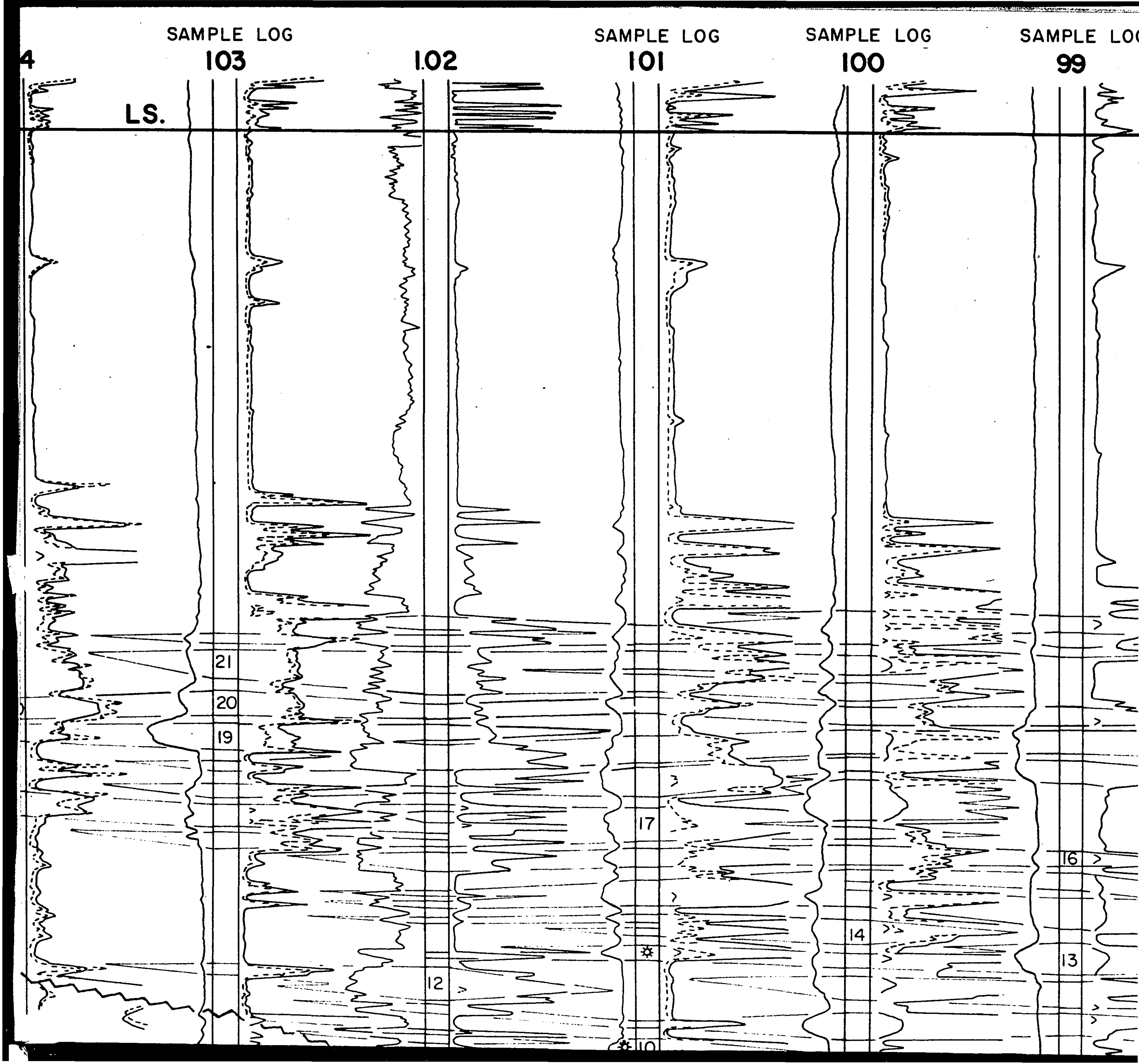
(Wells 121-97)

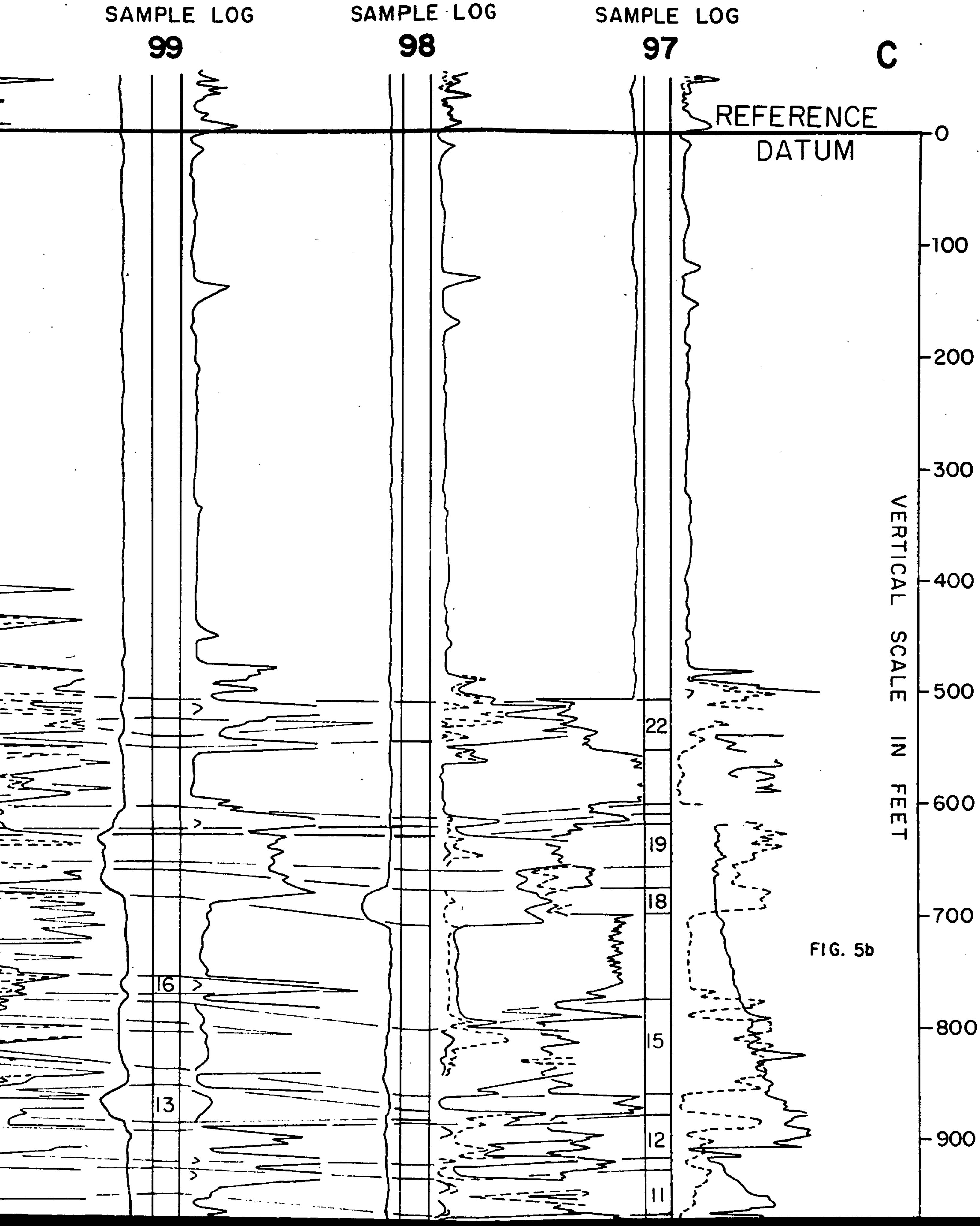
(No horizontal scale)



PLE LOG
SAMPLE LOG
13
112
111
110
109
108
OF
THIR-
31
27
26
24
24
22
22
20
20
19
18
P
I
A
N
U
N
C
O
N
F

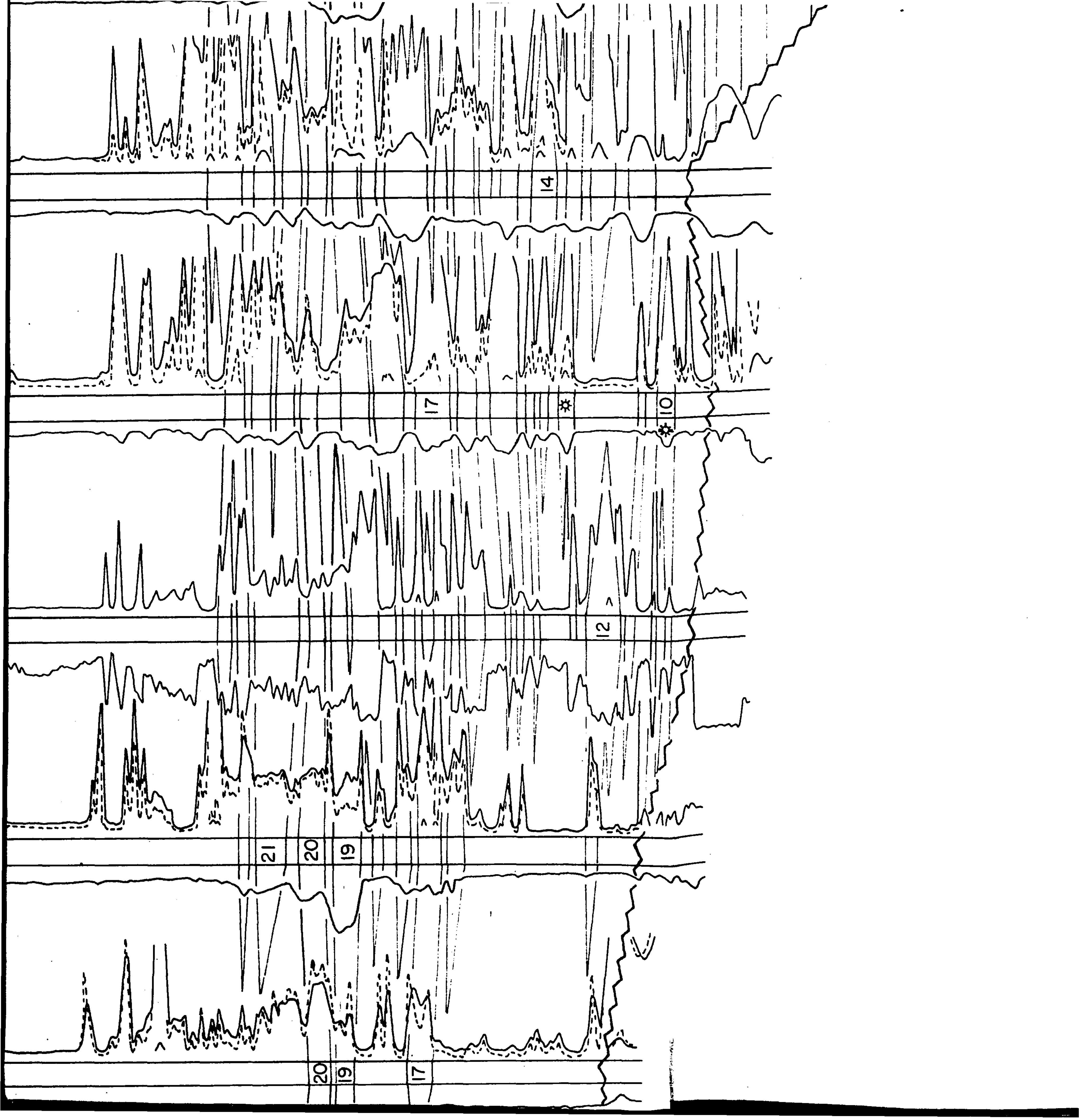

SAMPLE LOG
SAMPLE LOG
SAMPLE LOG
108
107
106
105
104
103
TEEN FINGER LS.
24
23
21
20
21
20
19
20
19
17
16
15
14
13
N F O R M I T Y


4
SAMPLE LOG
103
1.02
SAMPLE LOG
101
SAMPLE LOG
100
SAMPLE LO
99
LS.
21
20
19
17
16
14
13
12
10



SAMPLE LOG
99
SAMPLE LOG
98
SAMPLE LOG
97
C
REFERENCE
DATUM
0
100
200
300
400
500
600
700
800
900
VERTICAL SCALE IN FEET
22
19
18
16
15
13
12
11


FIG. 5b



14
17
10
12
21
20
19
20
19
17

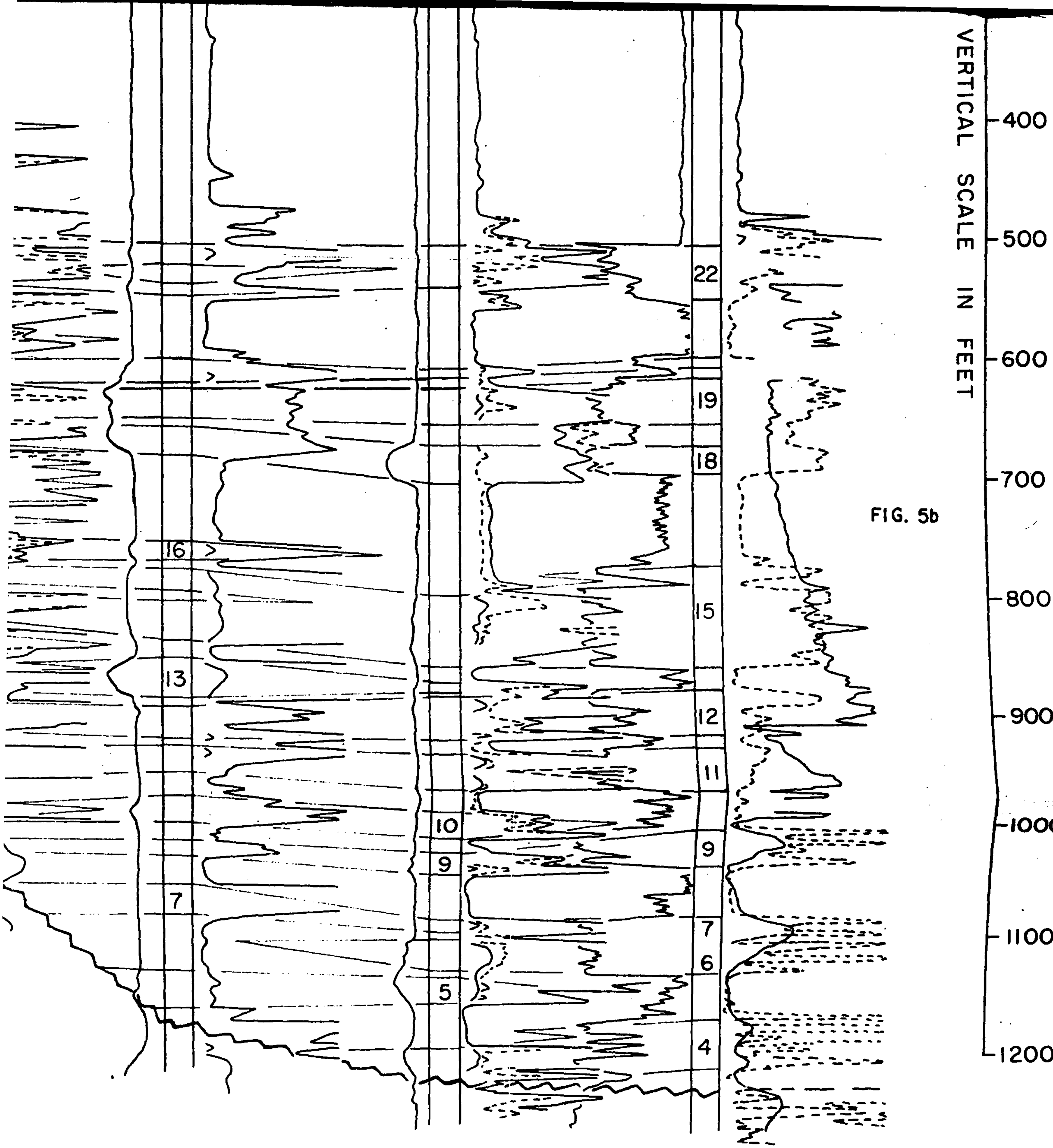

VERTICAL SCALE IN FEET
400
500
600
700
800
900
1000
1100
1200
22
19
18
16
15
13
12
11
10
9
9
7
7
6
5
4

FIG. 5b

of wave activity was maximal. Sandstone 29 is unusually interesting; in wells 124, 123, and 122 (see Plate IV for locations), it displays a flattened top and a convex base. In well 56, the base of sandstone 29 is considerably lower than in adjacent wells on either side. This is the cross sectional profile of a deltaic sand, confirmed by the isopachous map of sandstone 29 (Plate V). Sandstone 29 is interpreted in this part of the area of investigation as a delta-tied barrier island. It "shaled out" two to three miles before encountering the unconformity surface; widened by tidal deltas and eolian plains, it prograded to form extensive beach plains. Northwest of the area of investigation, however, sandstone 29 impinges against the unconformity surface to form a fringing beach sandstone (see Figure 3). Barrier islands, such as barrier island 29, that developed northwestward as fringing beach sandstones is not an unusual Morrowan situation. Sandstone 27 is a barrier island (see Figure 3) dissected by a channel (shown in well 56, and confirmed by the location of a channel shown on Plate I).

Figure 5b illustrates the correlation of Morrow sandstone members in wells 121 to 97. Sandstone 26 represents multiple offshore bars; sandstone 25 and 24 reflect a complex of barrier islands and offshore bars.

The remaining sandstones apparently "shaled out" before they encountered the Mississippian surface. They are further complicated by fluvial and deltaic deposition. Their shelfward extents cannot be traced meaningfully, although stratigraphic zonation is possible, and definite depth intervals below the base of the "Thirteen Finger" limestone are maintained.

## Morrow Maps

It is assumed that the thin limestones at the base of the Atokan Series were deposited essentially horizontal, each representing but a "moment" of geologic time. Accordingly, the base of the Atokan is considered to represent a depositional interface and sea level at the close of Morrowan time.

Swanson (1967) showed in a cross section involving the northeastern part of the study area that the top of the Morrow formation was removed by erosion in about a five-mile strip along the updip wedge-out of the Morrow formation. Forgotson (1966) reported evidences of truncation of upper Morrow beds, at least locally, in the northeastern part of Beaver County. No apparent unconformable relationship at the top of the Morrow was confirmed herein in correlation of all the electric logs in the area. Nevertheless, these reported areas of erosion, if documented, would represent no more than a diastem, a common phenomenon of the geologic record. A locally eroded Morrowan surface would not preclude either the assumption that the base of the "Thirteen Finger" limestone approximates an isochrone (a time plane) or that the Morrow formation represents a genetic sequence.

Busch (1959) stated that Morrow sandstones tend to subparallel thickness contours of the genetic sequence of which the sandstones are a part. To graphically illustrate the subparallelism of individual Morrow sandstones a detailed isopachous map of this formation was constructed (Plate I). In isopaching the Morrowan interval, any effects of structural activity contemporaneous with its deposition may be considered minimal, especially in such an area of known relative stability. The effects of differential compaction of Morrowan shale components were also insignificant.

The isopachous map of the Morrow formation represents a cast of the Mississippian surface; and local thickening reveals its paleodrainage pattern. The influence of pre-Morrowan topography on Morrowan deposition and the relationship between paleodepositional environments and Morrow sand distribution are presented elsewhere in this report.

This method of reconstructing the topography of a buried erosional land surface is well-known by geologists; in essence, the method is an expansion of the "datum plane-valley floor isopach method" (Andresen, 1962).

The dominant direction of paleoslope in the northern Anadarko basin was south-southwestward during pre-Pennsylvanian time. The pre-Morrowan surface exposed Chester limestones over most of the area, and Meramec limestones subcrop along a band approximately six to seven miles before encountering northeastward the updip wedge-out of the Morrow formation. This surface is of uniform hardness, and consists of strata that are slightly tilted south-southwestward and progressively truncated north-northeastward. Upon this surface a dendritic drainage pattern developed, as illustrated in Plate I.

The Morrow formation varies in thickness from zero along the updip wedge-out in the northeast to a maximum of 1,300 feet in the extreme southwestern corner of the map area.

The average southwesterly paleogradient of the pre-Pennsylvanian streams was 17 feet per mile. The average paleoslope of the general land surface was 34 feet per mile. Basinward, the paleoslope changed its rate of tilt southwestward to an average of 50 feet per mile. The present rate of basinward tilt of this surface is considerably greater because of post-Morrowan tilting. The effects of this tilting, however, are completely eliminated by selective isopaching of a genetic sequence. A "line of flexure" or "hinge-line" separates the stable northeastern shelf area from the less stable (more rapidly subsiding) southwestern basin area. The use of the terms "line of flexure" or "hinge-line" is deliberate since differential structural downwarping is implied.

In the general paleotopography of the study area, valleys are represented by locally thickened trends, and interstream areas are represented by locally thin areas. The cross-sectional profiles of the valleys seem to indicate that the upper reaches were in the youthful stage and the lower reaches in the early mature stage of development of an idealized fluvial cycle of erosion. The tributaries, on the other hand, with V-shaped, with steep valley sides, except at junctions with the trunk valleys; are all in a youthful stage of development.

The region in pre-Pennsylvanian time displayed a well-integrated drainage system. The paleogradient of major valleys and the relief of the area are functions of the vertical distance above sea level, relative abundance of precipitation, duration of subaerial exposure, and lateral distance from the strand line.

Major topographic highlands include the interstream tracts in T. 25 N., R's 21 and 20 W., with local relief approximating 200 feet; in T. 20 N., R. 23 W., with local relief of 240 feet; and in T's 5 and 4 N., R's 24 and 25 ECM, with local reliefs of 100, 80, and 140 feet.

A discussion of geologic history and sedimentation of the Morrow formation would be incomplete if unaccompanied by a map showing the present attitude of the Mississippian surface. An obvious feature of the structure of the Mississippian unconformity surface (Plate II) is its lack of structural closures. Equally apparent is the fact that there has been down-to-basin (southward) tilting of the Mississippian surface in post-Morrowan time. The present structural slope of the Mississippian surface varies from 83 feet per mile in the northern part of the study area to 170 in the southern part. This post-Morrow tilting explains why the structure map of the Mississippian unconformity resembles a subdued replica of the pre-Morrowan topography shown on Plate I. This is evident from the lessening of sinuosity of the contour lines on the structure map of Plate II (actually a topo-structural map).

The structural configuration of the top of the Morrow formation (Plate III) is more subdued than that on the Mississippian surface with respect to channels and interchannel areas of the pre-Pennsylvanian land surface. This further reduction in intensity of structures shown on the structure map on top of the Morrow is due, first, to differential rates of sedimentation in the paleotopographic lows; second, to down-to-basin divergence of the Morrow formation; and, third, to differential compaction of Morrowan shales with respect to associated lenticular sandstone bodies. Post-Morrowan structural activity was not an influential factor because such activity equally affected both the top and bottom of the Morrow formation.

Despite reduced sinuosity of the structural contours on the Mississippian surface and the further reduction of sinuosity of the structural contours on top of the Morrow, the major valley axes, shown on the paleotopographic map (Plate I), could be ascertained from the structure maps.

A few interesting features considered as results of differential compaction are shown on the structure map on top of the Morrow formation. On the contiguous line of T's 24 and 23 N., R. 23 W. (Plate III), a southward reversal in sinuosity along a valley axis is shown, indicating a thick channel sand accumulation. This basinward bulge of contours is due to differential compaction of shales bounding either side of the sand-filled channel.

The closure shown in T's 5 and 6 N., R's 24 and 25 ECM is due to draping over the buried hills shown in the same area on the paleotopographic map (Plate I). This draping is shown also for the same area on Plate II.

In T. 20 N., R. 23 W., a topographic high with acute sinuosity is shown on Plate I. This topographic high has been subdued and shifted slightly westward as a result of tilting and structural movements, as shown on Plate II. On Plate III the structure contours are further subdued as a result of differential compaction associated with a buried hill, in addition to tilting and structural movements.

The structure of the top of the Morrow (Plate III) reveals a slope approximating 63 feet per mile in the middle of the area, that increased southward to 125 feet per mile. These figures compared with 83 and 170 feet per mile, respectively, for the Mississippian unconformity surface. This decrease in rate of dip is due to the gradual south-southwestward thickening of the Morrow section.

Interesting comparisons between depositional and structural strikes may be made by comparing Plates I, II, III. On Plate I, the direction of depositional strike is west-northwestward. On Plates II and III the structural strike is east-westward. This difference in depositional versus structural strike is due to a greater amount of basinward tilting in the eastern portion of the study area.

Gas production is obtained from both permeable and tight Morrowan sandstones. Due to the salinity of drilling mud, both permeable sandstone and siltstone display low order self potential "kick" and, for this reason, are difficult to distinguish on the electric logs. Therefore, the landward wedgeouts against the old Mississippian surface (Plate IV) appear the same for both sandstone and siltstone members of the Morrow genetic sequence.

In constructing the map shown on Plate V, scout tickets were utilized in cases involving associated siltstone and productive tight sandstone members.

Because of the irregular surface of the Mississippian unconformity, the cyclic shoreline trends were equally irregular; hence, the sinuosity of the *en échelon* "stairstep" sandstones (Plate IV). This conclusion was presented previously by Busch (1959).

Because of extensive overlap of several sandstone and siltstone members, it is impossible to show the geographic extent of all members on a single map. A graphic portrayal of all Morrow sandstone and siltstone members would require several overlays; it is possible, however, to illustrate the successive updip limits of sandstone and siltstone members 25 to 40 on a single map (Plate IV).

Sandstone members 29, 36, and 38 are graphically portrayed (Plate V) as typical examples of the numbered sandstones of the Morrow formation. Sandstone 29 exhibits a set of subparallel offshore bars separated from the sandstone of the barrier island by beach and shallow neritic deposits. Barrier island 29, in turn, is separated from the mainland by lagoonal deposits. Sandstone members 36 and 38, of Plate V, also display offshore bars that developed southward, but they are not illustrated in the interest of simplicity.

Beach sediments of the successive Morrow shorelines are considered to be similar to those of the present strand zone of Texas, as described by LeBlanc and Hodgson (1959). Features of the Texas Gulf Coast consist of alluvial valleys and deltaic plains, estuaries, barrier islands and offshore bars, and lagoons, all resembling those deposited during Morrowan time.

The Morrow shorelines of the northeastern shelf of the Anadarko Basin, following the terminology of LeBlanc and Hodgson (1959), consisted of a basin shoreline and a bay shoreline. A basin shoreline is the seaward edge of barrier islands and deltaic plains, and it is characterized by a regular and arcuate boundary with well-developed beach sand. The bay shoreline, on the other hand, lies at the edge of the mainland behind the barrier islands in association with low-lying marshes and lagoons, and it is characterized by an irregular boundary devoid of beach sand.

Cross sections reveal that southeastward strand zone 29 (and several other Morrow strand zones) is a barrier island with bay and basin shorelines. Northwestward, however, sandstone 29 impinges against the Mississippian unconformity; i.e., it rests upon the edge of the mainland as a beach sandstone without a bay shoreline behind it.

The basin shorelines, shown on Plate V, for the three sandstone members are characterized by arcuate, smooth lobes. These lobes apparently represent deltaic deposition, their positions strikingly coinciding with channel courses shown on the isopachous map (Plate I). Minor irregularities in outline may be due to such variable factors as unevenness of sea floor, direction of wave motion, longshore currents, and delta positions.

Miller (1962) described the depositional pattern of the Atlantic Coastal Plain adjoining Middle Sound, North Carolina, noted that associated barrier islands are constituted of a series of narrow, arcuate islands of eolian-dune and strandline sands. The islands average 1,050 feet in width and are separated by tidal inlets 500 to 1,000 feet wide; the inlets are devoid of materials of sand size.

A comparison of modern barrier islands of both the Gulf Coast of Texas and the Middle Sound area on the North Carolina coast with those of Morrowan time reveals many similarities, not only in origin (as shown later), but also in dimensions, trend, and other characteristics. Insofar as length is concerned, all Morrowan barrier islands shown on Plate V approximate 60 miles in length. With well control of only one well per section (or less) it cannot be established herein that this, is a continuous 60-mile barrier island; it may involve several coalescing barrier islands or several separate barrier islands with clay-filled inlet channels. Much closer well spacing would be necessary to determine whether possible tidal inlets interrupted such elongated stretches of sandstone. It is known that some of the inlet channels associated with Morrow barrier islands were sites of deltaic deposition, although now integral parts of the islands. The barrier islands average 2.5 miles in width, comparable to the width of Galveston Island, except where deltaic lobes or thin barrier island aprons widened them seaward. Successive Morrow deltas are extremely localized and of the arcuate "classical" type.

## Interpretation of the Morrow Formation

The Morrow formation represents a genetic sequence resting unconformably upon tilted and truncated Mississippian strata. Cross sections constructed normal to the depositional strike reveal that the Morrow formation is a south-to-northward transgressive lithic unit. Individual Morrowan beds impinge against the Mississippian unconformity, and each, in turn, is transgressed by the succeeding overlying unit. Time lines, essentially parallel with the base of the "Thirteen Finger" limestone, impinge against the underlying truncated Mississippian surface.

The paleodrainage pattern depicted on the isopachous map of the Morrow formation (Plate I) indicates that fluvial conditions existed during much of the time. Distinct valleys and ridges, with relief in excess of 100 feet, may be recognized in the study area. Those ridges which later became buried hills and the valleys which later were filled with sand are considered to be prospective paleogeomorphological traps. Buried erosional land forms below the Mississippian unconformity in the area of study are known to be productive of gas. Hydrocarbon accumulation in weathered carbonates has been reported from Devonian, Mississippian, and Jurassic Systems in the provinces of Alberta, Saskatchewan, and Manitoba, Canada (Martin, 1960). Siever (1951) reported similar occurrences of hydrocarbon on the Mississippian surface in the Illinois Basin.

Paleogeomorphology, the study of ancient landforms (including those developed under marine conditions), is becoming a practical exploration tool. Martin (1966) described the different types of paleogeomorphological traps, and demonstrated their application to exploration for oil and gas in Western Canada. In fact, the practicality of paleogeomorphological studies can be made from existing data to explain the erratic behavior of certain reservoirs. Busch (1959) introduced a unique type of paleogeomorphological trap and coined the term "strike-valley sands" for basal Cherokee reservoir sandstones deposited in low areas separating cuestas at the time the land surface was inundated by a transgressive sea.

An attempt was made to outline the paleogeomorphological traps associated with buried landforms of the Mississippian erosional surface. This would require a paleostructure map of the pre-unconformity formations. The paleostructure map can be shown by an isopachous map of the stratigraphic interval between the base of the "Thirteen Finger" limestone and a formation boundary below the unconformity, as outlined by Levorsen (1960). The only factor that made such an interesting appraisal impractical was the lack of a reliable, consistent formation boundary close to and below the unconformity surface.

The Anadarko Basin began to form in Early Pennsylvanian time, and subsidence persisted throughout the Pennsylvanian and well into the Permian period. With submergence, the dominant process in the valleys, beginning in the lower reaches, changed progressively from erosion to deposition. With continued submergence, the valleys were gradually filled with sediments by aggrading streams and this slow filling probably extended headward.

With continued cyclic submergence, the sea transgressed the mainland. As a result of both thinning and overlap (onlap), the Morrow formation thins to featheredge eastward and northward. Thus, it defines successive shorelines that lie east and north of the more rapidly subsiding, and now structurally deeper, portion of the Anadarko Basin. The Morrow was deposited upon an irregular pre-Pennsylvanian erosional surface carved by a dendritic pattern of south-southwesterly-flowing streams. The shore zone was that of a low-lying coast.

Marine transgression results from either rise of sea level or submergence of the land. This leads to the drowning of a region of hills and valleys already molded by subaerial agents. An indented coastline of bays, estuaries, gulfs, etc., separated by headlands, begins to develop. Such a shoreline is typically a shoreline of submergence. It was during successive stillstands of an escalloped shoreline that relatively thick shore and nearshore Morrow sands were deposited. In other words, the Morrow sandstone members were deposited along temporarily stationary shorelines, whose positions were stabilized for variable periods of time; the sandstones are the result of cyclic marine transgression. Inasmuch as each sandstone member was deposited during a stillstand of the shoreline, each should approximate an isochron. It is interesting to note that the "Gulf shoreline" of the Texas Gulf Coast, formed by the barrier islands and deltaic plains, originated during the recent standing sea level stage (Fisk, 1959; LeBlanc and Hodgson, 1959). This explains the critical thickness intervals of the different sandstone members within the genetic sequence to which they are related.

A remarkably similar study has been reported by Hollenshead and Pritchard (1961) of the sandstone "benchos" of the Point Lookout and Cliff House formations (Middle Cretaceous-Mesaverde group) within the San Juan basin, New Mexico. The writers demonstrated that the marine sediments of the Mesaverde group were deposited under conditions of cyclic regression and transgression. Seven pronounced fluctuations in the position of the shoreline took place. Regression resulted when the rate of sedimentation exceeded the rate of subsidence; transgression resulted when the rate of subsidence exceeded the rate of sedimentation; and a stationary shoreline occurred when the two rates were in equilibrium. The Point Lookout formation was formed during regression, and the Cliff House formation, during transgression. Thick, relatively well-sorted sandstone "benches" in each formation were deposited along stationary shorelines. The framework of Morrow deposition bears some similarities to the Cliff House formation.

Most of the sand which accumulated on the shore and nearshore in Morrow time was apparently introduced into the basin by numerous streams which were flowing into it (Plate I). The sand, upon arrival at the shore, was picked up by longshore currents and redistributed along the successive shorelines. Another possible source of sand would be the scouring of the sediments on the basin bottom within the depth of wave base.

Each stream on the present Texas Gulf Coast flows within its alluviated valley, and each alluviated valley merges with a deltaic plain near the coast, in fashion similar to Morrowan streams on the northeastern flank of the Anadarko Basin.

The barrier islands of the western Texas Gulf Coast (LeBlanc and Hodgson, 1959) vary in length from 15 (St. Joseph Island) to 110 miles (Padre Island). Their origin is associated with deltaic sedimentation. The latter, rather than marine processes, plays the dominant role in shaping the shoreline and in forming many of the physiographic features of the coast. This segment of the Gulf Coast is considered the modern analog of the ancient Morrow shorelines during stillstand positions.

The configuration of the upper segment of the Texas Gulf Coast, i.e., the shape and formation of physiographic features, was ascribed by LeBlanc and Hodgson (1959) primarily to marine processes. They stated that seaward growth of barrier islands, such as Galveston Island and Bolivar Peninsula (offset by a tidal inlet), is maintained by continued addition of sand contributed by longshore currents, as indicated by abandoned beach ridges and intervening low swales on the islands. Galveston Island, approximating 30 miles in length, is 2.5 miles wide near its eastern end, and gradually tapers to a point southwestward.

Diagrammatic cross sections (Figure 6) illustrate the different types of Morrow shore and nearshore sand deposits.

Thus far only a geological framework of Morrow sedimentation has been presented. Systematic samplings

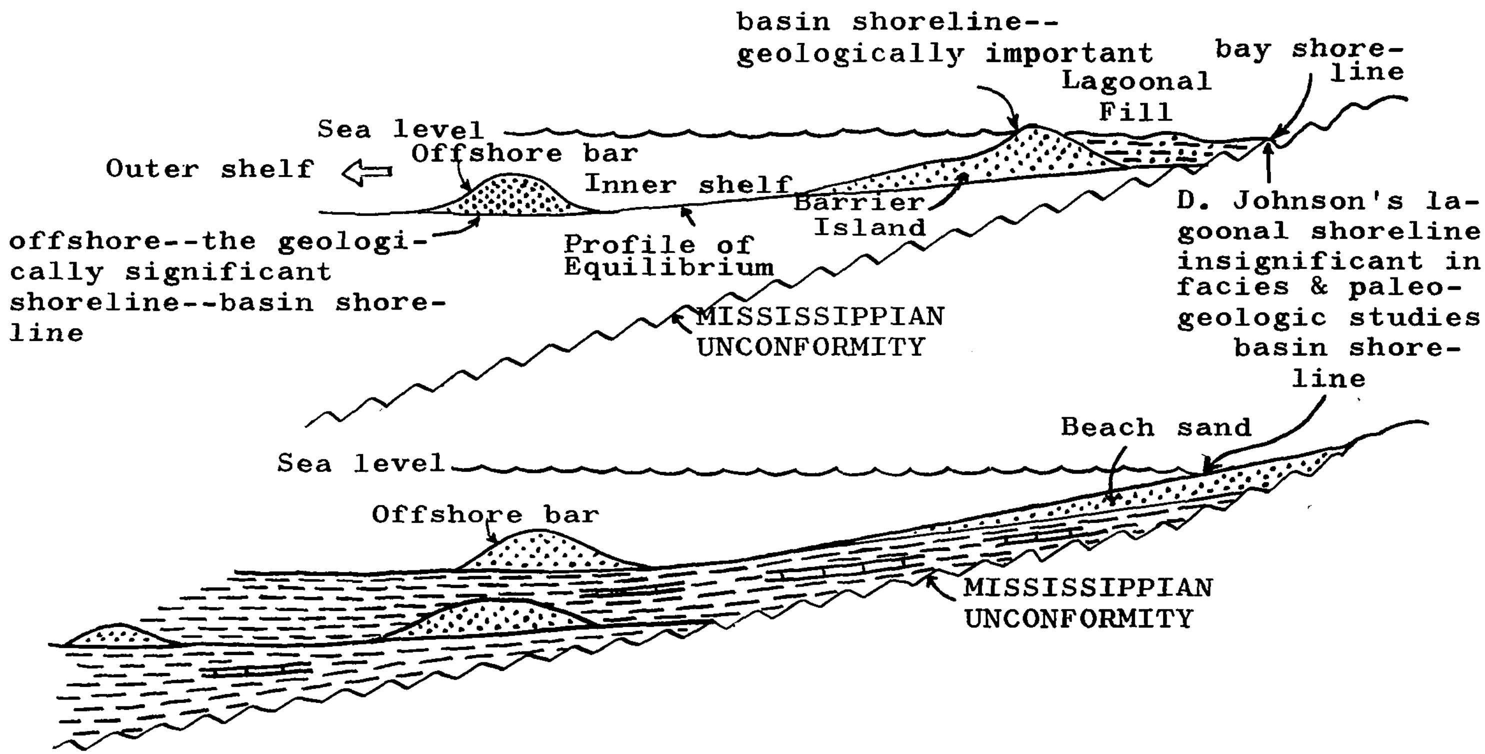



Figure 6- Diagrammatic cross sections illustrating *en échelon* arrangement of beach sand-stones.

and petrographic analyses should serve as an independent line of evidence to substantiate current theories and supplement understanding of various Morrowan environments. These should emphasize physical factors, which controlled and brought about the formation of fringing beach sandstones, barrier islands and offshore bars, channel sandstones, and deltas, all of which are present in Morrowan time. The petrographic work done in association with this report is treated elsewhere under a separate heading.

## TONKAWA SANDSTONE

### General Statement

The Tonkawa sandstone grades progressively updip into shale and carbonates; it produces both oil and gas. Pate (1959) published a structure map of the Tonkawa sandstone revealing a southward regional dip and geographic extent of four "bars." Pate also depicted two gas-water levels separated by a 100-foot interval. In using the term "bar," Pate included no discussion of sandstone distribution, geometry, and environment of deposition.

In this study, the Tonkawa sandstone is subdivided into upper, middle, and lower members, as identified on electric logs (Figure 7).

The upper member of the Tonkawa sandstone is encountered only in Beaver County, where it produces gas. The middle and lower members extend across the study area from a position near the middle of T. 26 N. (or its extension across the Oklahoma Panhandle in T. 3 N.) into and beyond the southern boundary of the study area. The middle member produces oil and gas; the lower member produces gas only.

Sec. 27, T. 3 N., R. 27 ECM.

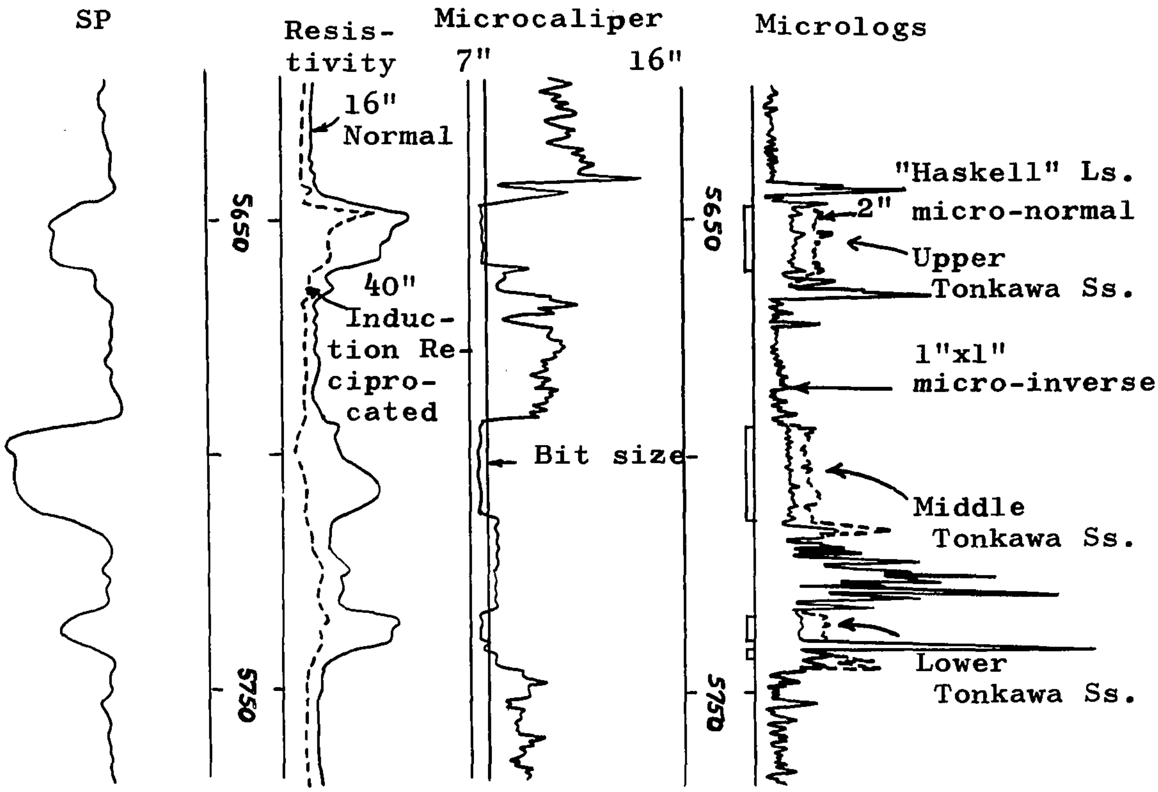



Figure 7- Electric logs showing the three members of the Tonkawa sandstone.

The upper member of the Tonkawa sandstone is overlain by the thin, persistent, and readily recognizable "Haskell" limestone, with average thickness of 3 feet. Locally, the "Haskell" limestone changes facies into calcareous shale. It is considered to be a marker bed in the subsurface of northwestern Oklahoma (Jordan, 1957). Pate (1959) noted that this "Haskell" is not the equivalent of the surface Haskell limestone.

The upper member of the Tonkawa sandstone occurs directly below the "Haskell," whereas the middle member occurs 35 to 50 feet below the "Haskell." Figure 7 shows the lower member at a depth of 94 feet below the "Haskell." The interval of the lower member below the "Haskell" cannot be ascertained elsewhere (see Figure 10) because the middle and lower members apparently merge vertically into a single sandstone body along and below the contiguous boundary of T's 25 and 26 N. It is here that the Tonkawa produces oil rather than gas. The geometry, distribution, and environment of deposition of the middle and lower members could not be evaluated because there is no consistent, natural shale break separating the two members. Consequently, only the upper member of the Tonkawa sandstone was analyzed in this investigation.

## Correlations

Two isopachous maps were prepared to determine the geometry, distribution pattern, and environment of deposition of the upper member of the Tonkawa sandstone. One of the isopachous maps involves the genetic sequence between the base of the sandstone and the top of the "Haskell" limestone (Plate VI); the other isopachous map involves the sandstone proper (Plate VII). A structure map on top of the upper Tonkawa sandstone was drawn also.

Upper and lower boundaries of the upper Tonkawa sandstone and the "Haskell" limestone are determined readily on all mechanical logs. In logs that reveal the "Haskell" to be shaly, a stratigraphically higher, unnamed marker bed serves as precaution against miscorrelation (see Figure 8).

## Upper Tonkawa Cross Sections

Several cross sections were constructed but only two, DD' and EE' (Figure 8), are included. Their locations are shown on Plate VI. They illustrate a relatively abrupt facies change and local thickening at the base of the upper member of the Tonkawa sandstone.

The upper member is biconvex on several of these cross sections. This is due to differential compaction of the laterally adjacent shale due to the weight of overburden.

An erosional unconformity at the base of thick sandstone trends is postulated, but this cannot be demonstrated from electric logs alone.

## Upper Tonkawa Maps

The cross sections reveal that sand thickening occurs at the expense of the underlying shale, accordingly, channel-type deposition is interpreted for this sandstone.

It is assumed that the "Haskell" limestone was deposited with negligible depositional slope. A meaningful picture of the relief of the surface upon which the upper Tonkawa sandstone was deposited can be shown by an

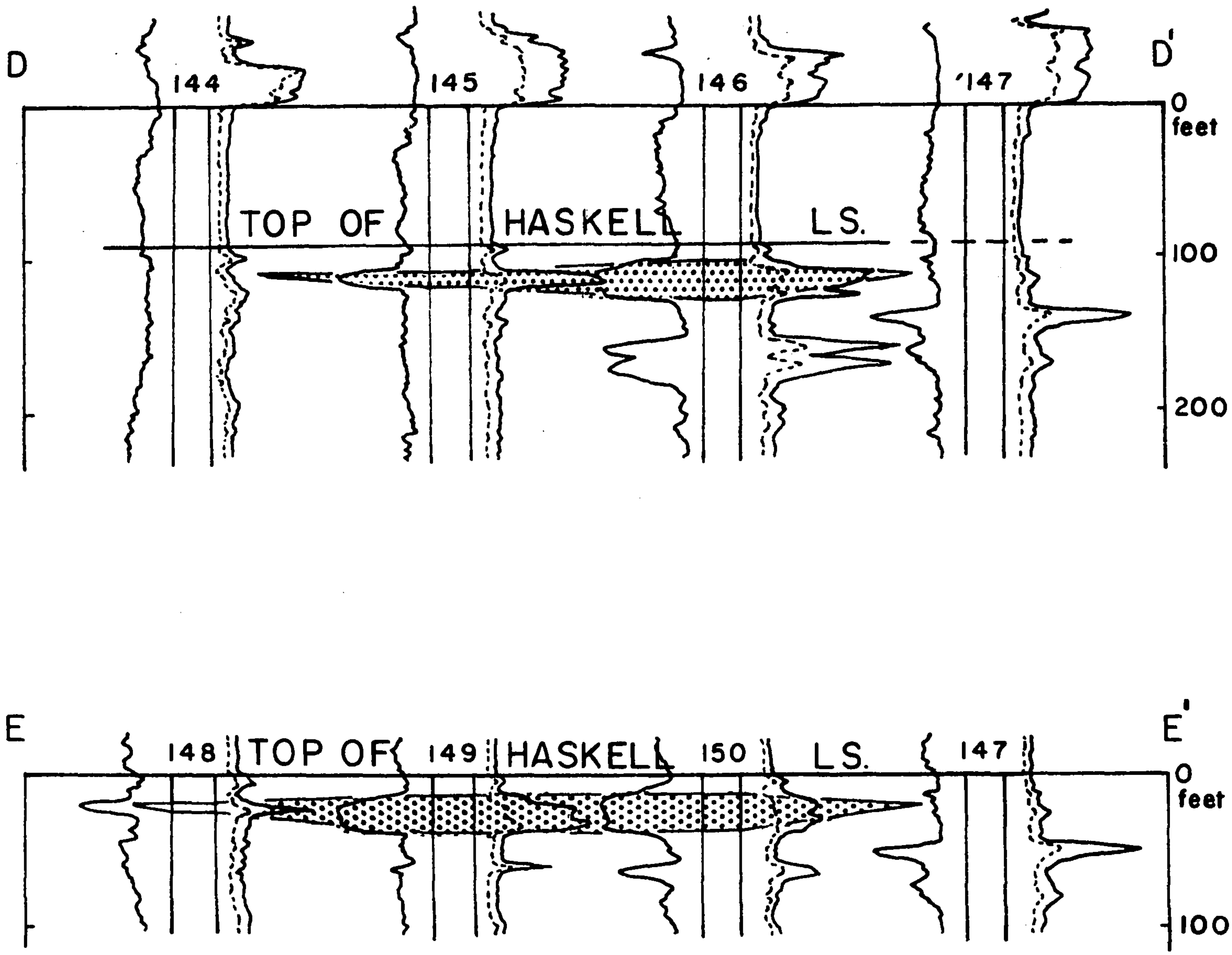



**FIGURE 8**

CROSS SECTIONS DD' & EE'

(no horizontal scale)

isopachous map of the genetic sequence between the top of the "Haskell" limestone and the base of the upper Tonkawa sandstone (Plate VI). This map is essentially a submarine paleotopographic map showing a deltaic distributary system of channels constructed by the "datum plane-valley floor isopach method" of Andresen (1962).

The isopached interval is thickest where down-cutting was at a maximum; the respective valley axes are drawn along these trends of maximum down-cutting (greatest thickness) (Plate VI).

Plate VII is an isopachous map of the upper Tonkawa sandstone and clearly supplements the deltaic distribution pattern shown on Plate VI. It was constructed by the "valley-fill isopach method" of Andresen (1962). Locally deltaic distributaries migrated laterally, such as in the "four-corner area" of T's 3 and 4 N., R's 24 and 25 ECM; southwestern corner of T. 4 N., R. 26 ECM; T. 3 N., R. 27 ECM; and T. 2 N., R's 24 and 25 ECM. Divergent trends of maximum sand deposition are indicated by dashed lines. Although the trends of these dashed lines are similar to those shown on Plate VI, they do not represent necessarily areas of maximum down-cutting where distributaries had migrated laterally. Divergent trends of maximum down-cutting are indicated by dashed lines as shown on Plate VI. The thickness of distributary sandstone varies from zero to more than 35 feet. Down-cutting was not profound and the upper portion of the sandstone was probably sheet-like.

The structure map on top of the upper Tonkawa sandstone (Plate VIII) reveals southeastward homoclinal regional dip which is interrupted locally by ridges and troughs. The approximate gas-water contact is at subsea depth of -3270 feet. Structure and abrupt facies change apparently influenced gas entrapment. Structure contours do not exhibit downward convexity along deltaic distributaries, i.e., local porous and permeable distributary sandstones are not developed upon structural noses. Structure merely tilted the upper surface of the upper Tonkawa southeastward.

## Interpretation of the Tonkawa Sandstone

The Tonkawa sandstone appears to be quite similar to the Lower Cretaceous Fall River sandstone of the Dakota oil fields on the eastern flank of the Powder River Basin (described in several papers in the Wyoming Association Guidebooks). Barkley and Gosman (1958), in a study of the Donkey Creek field, show a north-southward trending anticline with 50-foot closure on a structure map constructed on a marker bed located stratigraphically 50 feet above the producing Dakota sandstone. However, this structure is of only minor significance in trapping the oil, as suggested by the fact that productive wells are located upon the flanks, while non-productive wells are located higher upon the structure. Also, this reservoir sandstone is known to "shale out" on the eastern side of the oil field. Consequently, the writers concluded that the production from the Dakota sandstone in this field is controlled primarily by stratigraphic variations within the sandstone body. Similarly, a structure map (not included in this report) of the top of the "Haskell" limestone, which occurs from zero to 50 feet above the Tonkawa, reveals regional southward dip.

Barkley and Gosman, however, apparently identified three members within the Dakota Sandstone. Although their approach seems to be most practical in explaining the production of sandstone bodies such as the Dakota or the Tonkawa, the interpretation is difficult at best when relying primarily on electric logs. Miller (1962) confirmed the tripartite distribution pattern of the Fall River sandstone. Trotter (1962), in a study of the Fall River sandstone in the nearby Coyote oil field, subdivided the Dakota sandstone in some wells into three members with separating shale breaks; he stressed the stratigraphic control of the Dakota sandstone oil trap.

The upper Tonkawa sandstone represents a brief, regressive, prograding deposition. The isopachous pattern is one of bifurcation with interbranch areas increasing in width seaward. The pattern consists of two small distributary systems of two laterally coalescing deltas; they may be classified as an arcuate type of delta. The abrupt lateral and vertical sand facies change, the sand-depositional pattern, and the sand-thickness trends all point to the deltaic origin of this sandstone. Its development is confined to the shelf area, or undaform, along the northern side of the Anadarko Basin.

# ENDICOTT SANDSTONE

## General Statement

The Endicott sandstone is part of the Oread Formation, which consists of the following members (descending): Oread limestone, Heebner shale, Endicott sandstone, and Toronto limestone (Figure 2). The Oread Formation is in the lower Shawnee Group of the Virgil Series.

The thickest parts of the Endicott sandstone are characterized by an erosional unconformity at the base, either part or all of the underlying Toronto limestone having been removed by erosion. The unconformable contact is sharp and well-defined.

A genetic sequence was selected to determine the shoreline trend, basin configuration, and possible differential subsidence. Because of the aforementioned localized erosional surfaces at the base of the Endicott sandstone in areas of Endicott thickening, the depositional breaks are not considered significant and, consequently, the interval from the top of the Oread Formation to the top of "Haskell" limestone is interpreted as a genetic sequence. An isopachous map of this interval (not included herein) reveals west-northwestward depositional strike and south-southwestward dip. This isopachous map also reveals thickening in the direction of depositional dip, and an obvious deltaic distribution pattern. An isopachous map of the interval between the top of the Oread Formation and Toronto limestone was abandoned because the Toronto limestone is partly or absent _in toto_ in many wells. Such an isopachous map, however, also shows a fairly uniform rate of thickening in the depositional direction. The rate of thickening was expected to increase basinward from a line separating the undaform from the clinoform domain, where an abrupt change in facies is anticipated. (The writer hesitates to refer to this as a "line of flexure" or "hinge-line" since the latter carries a tectonic connotation, in the sense of differential subsidence, which has not been established in this instance). Capps (1959) presented an isopachous map of the interval between the top of the Oread Formation and the top of the Marmaton Group (see Figure 2) in the map area as far south as the southern boundary of T. 19 N. Uniform south-southwestward increase in thickness was depicted by Capps, with an increase in the rate of thickening occurring along the boundary line between T. 21 N. and T. 20 N.; this marks the undaform edge.

Since cross sections reveal a channel-type for the Endicott sandstone, an isopachous map of the interval between the top of the Oread Formation and the valley floor (base of the Endicott sandstone) was constructed (Plate IX). A deltaic distributary pattern results in using the "datum plane-valley floor isopach method" of Andresen (1962). An isopachous map of the Endicott sandstone also was constructed (not included herein) using the "valley-fill isopach method" of Andresen (1962). This map presents an average paleodrainage pattern for the interval of valley filling and is useful in determining any possible lateral channel migration from true valley axes.

In a north-southward diagrammatic cross section, Capps (1959), and later Winter (1963), depicted the Endicott as a blanket-type sandstone. In this study, evidence for the deltaic nature of this sandstone is presented.

To date there has been no commercial hydrocarbon production from the Endicott sandstone. Pate (1959), although not having studied the Endicott sandstone, alluded to its oil and gas potential. The only Endicott production to date is from several wells in the Oklahoma Panhandle and in Northeastern Texas.

Many of the world's oil and gas fields produce from deltaic sandstones (Rainwater, 1966); the deltaic environment is characterized by abundant organic materials. Organic shales associated with deltas are readily buried and preserved because of rapid sedimentation. Conditions are ideal for hydrocarbons to migrate into neighboring porous and permeable lenticular sands of the deltaic distributaries. In the area, oil stain and porosity were noted in microscopic examination of cuttings, and effective porosity is clearly indicated by electric logs. Further study, however, would be necessary to evaluate the oil and gas potential of this sandstone.

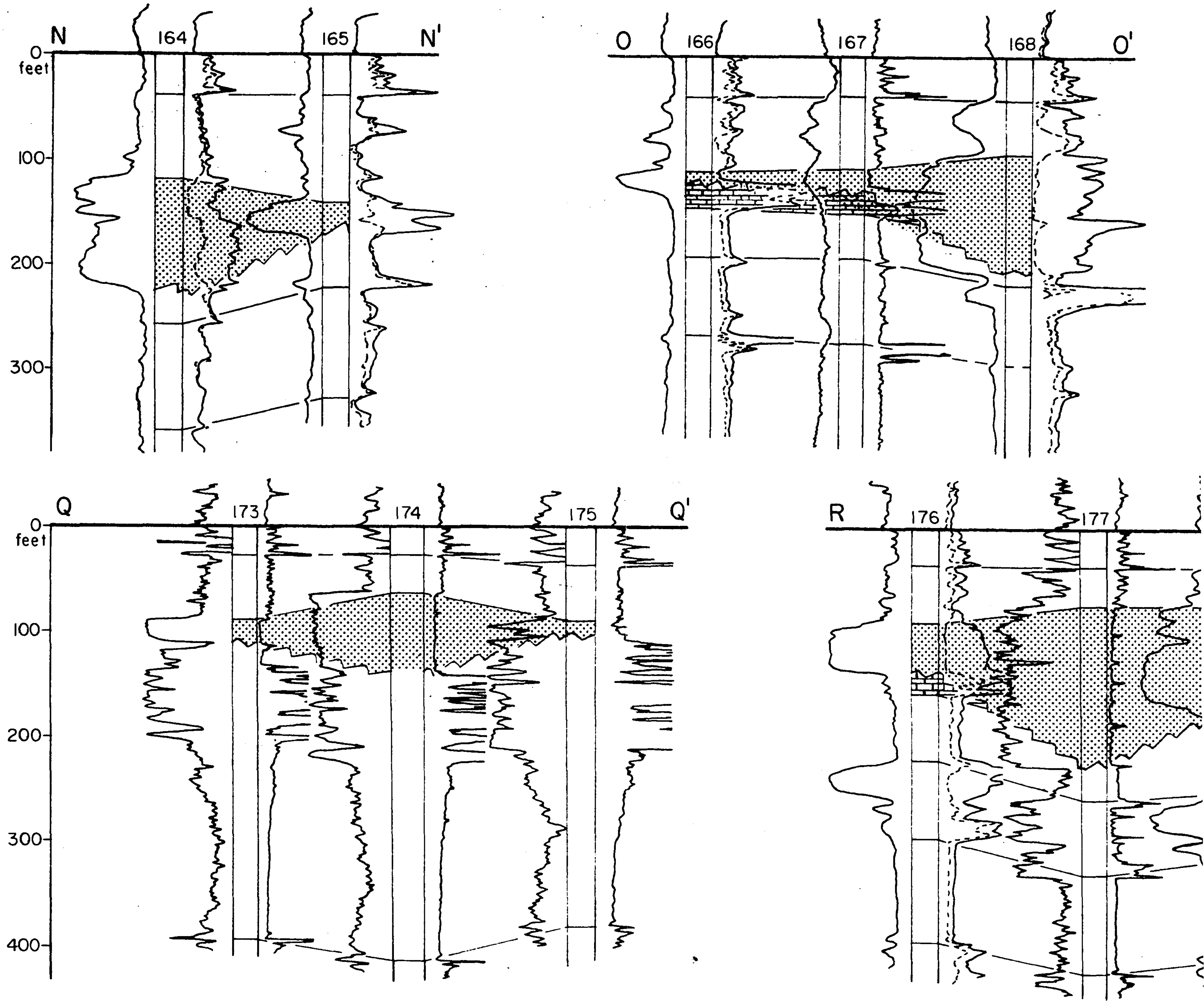
## Correlations

The top of the Oread Formation is a distinctive, reliable, and easily recognizable marker horizon. The valley fill is sufficiently porous for ready recognition of its top and bottom on electric logs.

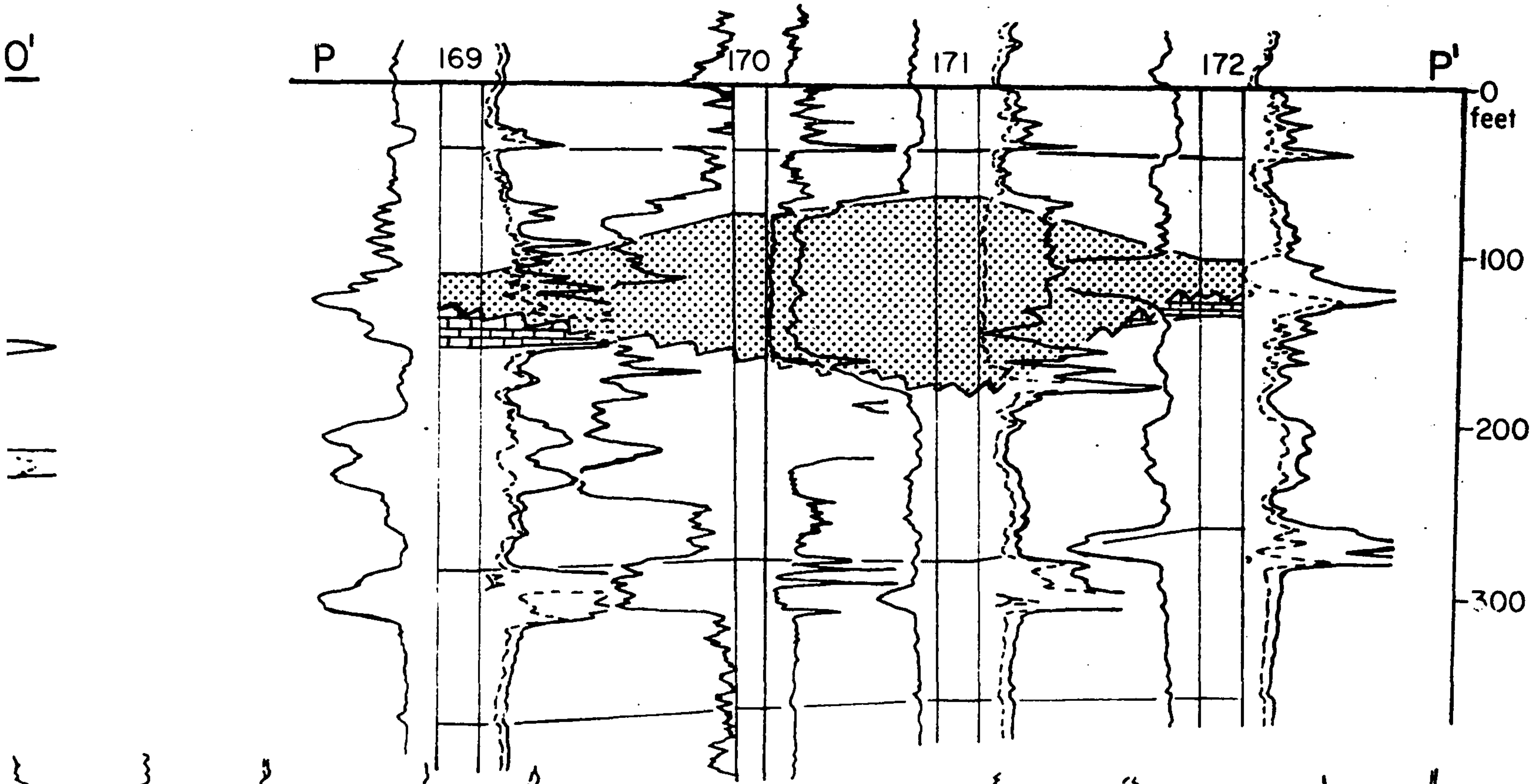
## Endicott Cross Sections

The location of the six cross sections (NN', OO', PP', QQ', RR', and SS'), shown in Figure 9, are indicated on Plate IX. They reveal channel-type deposition of the Endicott sandstone, including the following features:

1. Local thickening at the base.
2. Differential compaction of laterally adjacent shale. This is due to the weight of the overburden which caused the margins of the sandstone to bow downward. Local thinning of the shale and siltstone over the thickest portion of the channel sandstone is apparent.
3. Local abrupt facies change. Within a mile on both sides of a thick channel sandstone, thickness diminishes by an average of 50 to 70 feet.



N
164
165
N'
0
feet
100
200
300
O
166
167
168
O'
Q
173
174
175
Q'
0
feet
100
200
300
400
R
176
177



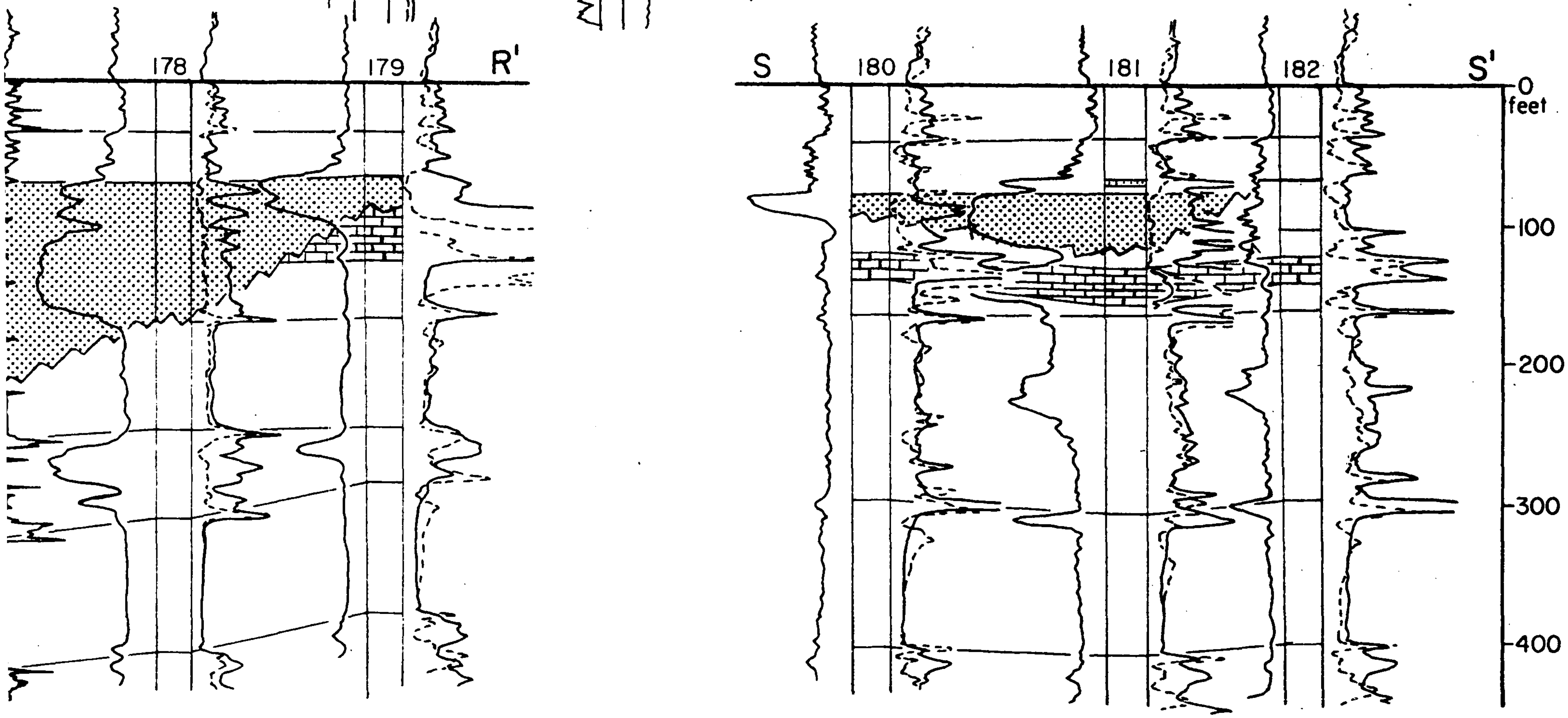




**FIGURE 9**

CROSS SECTIONS
N-N', O-O', P-P', Q-Q',
R-R', S-S'

DATUM: TOP OF OREAD
FORMATION

(no horizontal scale)

4. Down-cutting is well demonstrated by the removal of part or all of the underlying marker bed, the Toronto limestone. Were it not for the presence of the Toronto limestone in places, the erosional unconformity at the base of the thick portions of the sandstone could not be defined so readily.

5. In most instances, the basal contact of the Endicott sandstone is abrupt and well-defined.

## Endicott Maps

The isopachous map (Plate IX) of the interval between the top of the Oread Formation and the base of Endicott sandstone presents a deltaic distributary pattern with valley axes in their true positions, unaffected by lateral river channel migration. The top of the Oread Formation is so near the Endicott sandstone that any contemporaneous structural movement occurring during the time of valley carving and the deposition of the upper datum horizon was probably minimal. The isopachous map closely reflects a cast of the pre-Endicott surface as it appeared immediately prior to Endicott deposition.

The effect of differential compaction of shales laterally adjacent to the Endicott sandstone may be observed in a stratigraphic profile that utilizes a reference marker bed above the sandstone. Any marker bed below the elongate sandstone body is bowed downward beneath the thickest part of the sandstone; this is well illustrated on most of the profiles shown in Figure 9. Conversely, were the underlying marker bed utilized as reference datum in profiling, then the top of the Oread Formation would be bowed upward in the area of maximum sandstone thickness, as shown in Figure 10.

Plate IX shows two coalescing deltas. These deltas have formed by deposition of sediments at the mouths of two major rivers that debouched into the northern shelf area of the Anadarko Basin.

Another isopachous map was constructed to illustrate variations in thickness of the Endicott sandstone. This isopachous map is not included herein because it reveals a paleodrainage pattern quite similar to that of Plate IX. This similarity indicates that there was little or no lateral migration of the deltaic distributaries. The thalwegs of the individual distributaries, with their bifurcating pattern, almost coincide on the two isopachous maps.

The thickness of the Endicott varies from zero to more than 180 feet. The thickness of the permeable sandstone may increase from 40 feet to more than 140 feet in a lateral distance of one mile, as shown on cross section RR' (Figure 9).

A structure map (not included herein) of the Endicott sandstone in a selective nine-township area in the southwestern portion of the area of investigation was

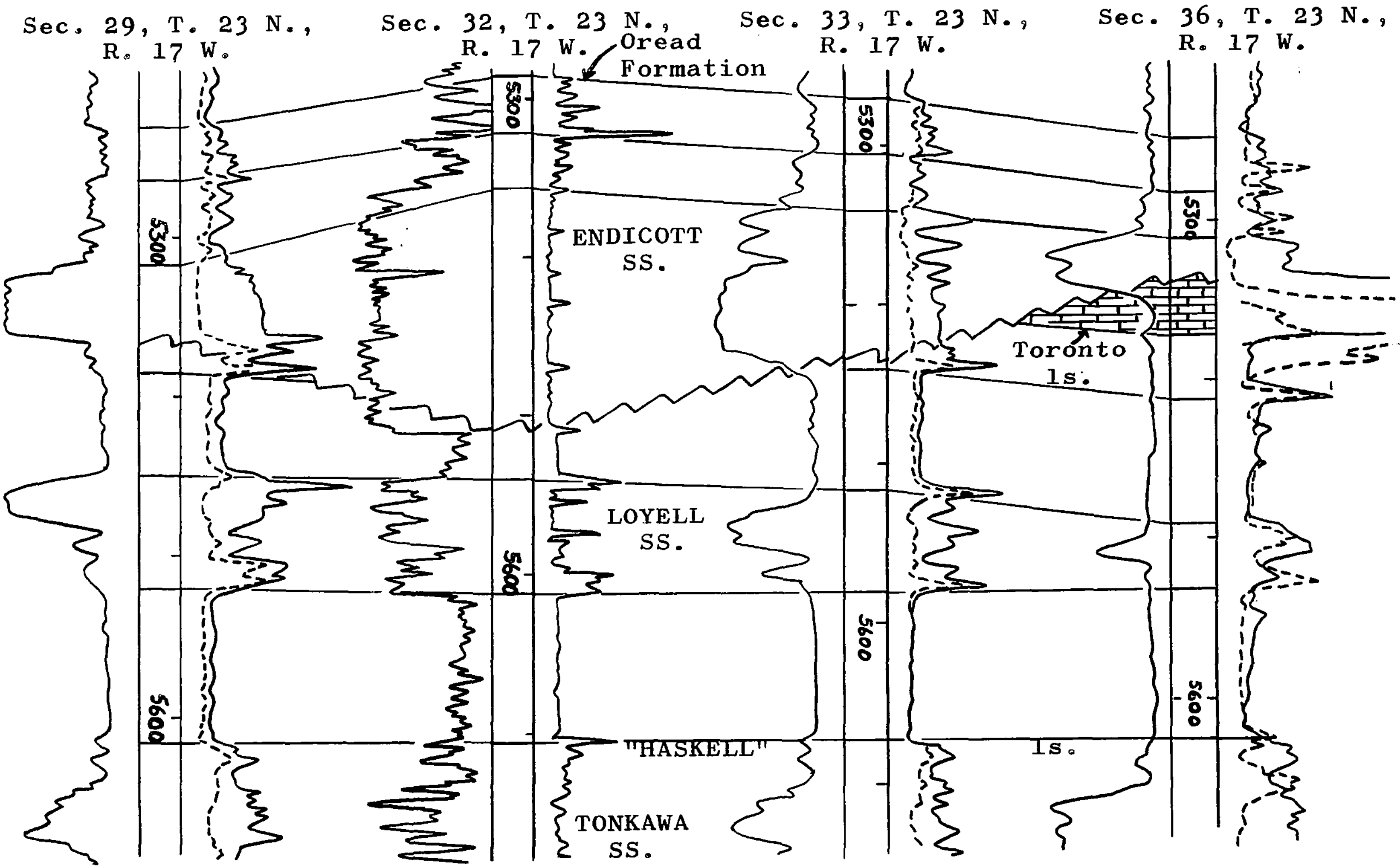



Figure 10- Differential compaction illustrated by a cross section of mechanical logs through the Endicott deltaic sandstone.

constructed to evaluate the effects of structural control in the formation of Endicott traps. The map reveals southward dipping homoclinal regional slope, with no apparent structural closures or noses.

## Interpretation of the Endicott Sandstone

The Endicott sandstone is deltaic in origin and confined to the shelf area along the northern side of the Anadarko Basin. On the isopachous map (Plate IX), the deltaic distributary arrangement of the thick portions of the Endicott is noteworthy, and areas of no sand deposition may be noted. In other areas, the Endicott sandstone is sheet-like among distributaries. The channel portion of the sandstone attains a maximum thickness of 180 feet.

The edge of the depositional shelf is located along the contiguous boundary of T's 21 and 20 N. Directly south of this line lies the less stable part of the depositional basin, as indicated by more rapid rate of divergence of the sediments. It was on the shelf that clays, thin limestones, coal, other carbonaceous materials, and sands were deposited. The sands vary considerably in thickness and geographic extent.

Both modern and ancient deltas have been studied and well documented. A noteworthy source of information is the Houston Geological Society publication "Deltas in their Geologic Framework" (Shirley, 1966). Busch (1953) mapped the subsurface Booch sandstone of the McAlester formation (Lower Pennsylvanian) in the Seminole District, Arkoma Basin of Eastern Oklahoma. He showed a detailed distributary system of the Booch delta and pointed out that the thick Booch sandstone is of the channel-fill type, the upper part of which is connected by a blanket of silty, fine-grained sandstone. The southern half of the delta is overlain by a thin coal bed (Busch, 1954). Fisk (1961) presented a detailed study of the bar-finger sands of the Mississippi delta. He interpreted the aforementioned Booch channel sandstones of the Seminole District as bar-fingers, a point with which Busch is in disagreement, except for the largest of the numerous distributaries (personal communication, 1967). Fisk emphasized that accurate interpretation requires much detailed lithologic and faunal information. Without detailed information, the Endicott sandstone is herein interpreted as a channel-filled, distributary, deltaic system. In support of this interpretation, it is noted that the Endicott sandstone is overlain locally by thin coal beds; furthermore, depositional bar-finger sands, as Fisk emphasized, result largely from displacement of water-rich delta-platform fine-grained sediments by the mass of accumulating bar sands. In the writer's opinion, a process of displacement cannot account for the removal of part or all of the Toronto limestone below the Endicott trends of maximum thickness. Accordingly, then the Endicott sandstone is a "filling-in" of erosional channels.

The Endicott delta probably was deposited adjacent to a coastal plain of relatively high relief because sand bodies form major parts of its framework. By contrast, the Mississippi Delta (and most other modern deltas) adjoins a coastal plain of low relief, and receives but a minor amount of sand-size fraction.

## HOOVER SANDSTONE

### General Statement

Upper Virgilian stratigraphy in this area is dependent on two different, although related, principles of sedimentation. The first concerns three critical environments of deposition as defined by Rich (1951, p. 2).

> On the floor of any body of standing water in which appreciable wave action occurs, three physiographic units or environments can be recognized, in each of which the physical and biological conditions are distinctive. These, in order outward from the shore, are: (1) that part of the floor which lies in the zone of wave action and in which, therefore, the bottom is repeatedly stirred and reworked by storm waves; this the writer proposes to call the unda environment ... (2) the sloping part of the floor which extends from wave base down to the more or less level deeper parts; this the writer calls the clino environment. (3) all of the floor not compassed by the other two; for it the term fondo ... environment is suggested.

The submarine topographic terms of Rich are coined by adding the suffix "-form" to the prefixes, unda, clino, and fondo. The resulting rock units associated with each of the three environments are referred to by adding the suffix "-them," as the undathem, clinothem, and fondothem. The three environments, topographic units, and resulting lithologic types exist contemporaneously. This depositional topography is presented diagrammatically in

Figure 11, showing terms used and sediment characteristics.

The second related principle of sedimentation pertains to basinward thinning of stratigraphically equivalent facies. This principle was first discussed by Adams, et al., (1951, p. 2605) as follows: "Unfilled basins ... surrounded by broad sediment-hoarding epicontinental shelves may well be called starved basins." Adams, et al., studied the sediments and structures in and about the Midland Basin of West Texas, a well-known and thoroughly explored Late Paleozoic basin. Starvation of the Midland Basin, among other basins in the same region, was due to the fact that it was an active sag in an extensive foreland. This foreland included much of West Texas and Southeastern New Mexico, an area ringed by local basins which trapped most of the detritus from bordering active tectonic belts, leaving the actively subsiding major basins too far from source rocks to receive an adequate supply of clastics. Carbonate deposition in these major basins also ceased, as shallow water conditions could no longer be maintained during rapid sinking of these basins.

The Hoover sandstone presents some striking similarities to other sandstones associated with depositional topography. Jackson (1964), Rall and Rall (1958), and Van Siclen (1958) have called attention to depositional topography, in accordance with Rich's concept, of Pennsylvanian-Permian deposits in West and West-central Texas.

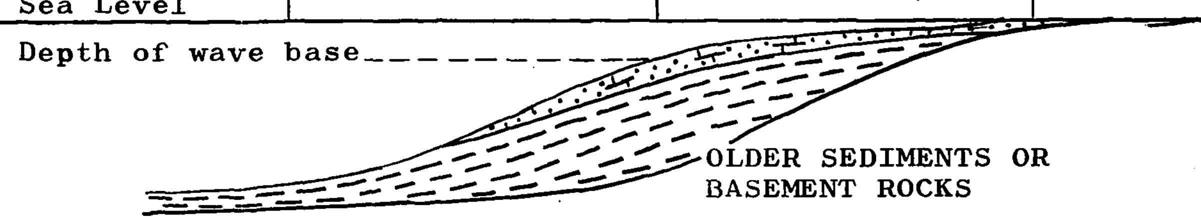
| TOPOGRAPHIC FORMS | FONDOFORM | CLINOFORM | UNDAFORM | LAND |
|---|---|---|---|---|
| SEDIMENTARY UNITS | FONDOTHEM | CLINOTHEM | UNDATHEM | COASTAL PLAIN (sediment source) |
| ROCK CHARACTERISTICS<br>Type | shale, clay, calc. oozes | shale, siltstone, & calc. equivalent | conglomerate, sand, limestone & oolites | Sediments with characteristics of undathem; in addition to coals, channel sands, conglomerate, and red beds |
| Texture | fine, ls, may be lith., fossils are pelagic or bottom dwellers | fine, mainly silt or clay | generally sand size; varying from silt to gravel | |
| Bedding | even, tending to massive<br><br>Sea Level | thin, regular, even, persistent, intrastratal flowage features | thin, wavy, irregular, may be ripple marked, cross bedded, lenticular, erratic | |
| PROFILE |  | | | |



Figure 11- Diagrammatic presentation of Rich's model of depositional topography; showing terms used and sediment characteristics (after Jackson, 1964, adapted from Rich, 1951).

Owen (1962), after mapping several of the most spectacular depositional features in West Texas, was impressed by the ubiquity of the undaform-clinoform-fondoform pattern. A noteworthy publication by Oliver and Cowper (1963) describes the depositional topography within the Ireton formation, upper Woodbend Group (Late Devonian), in Central Alberta, Canada.

## Correlations

Correlations within the rocks of the upper Virgilian Series were made on several electric log cross sections, only two of which are presented herein (Figures 12 and 13). Cross section TT' (Figure 12) trends east-westward, and cross section UU' (Figure 13) trends northeast-southwestward.

The interval between the top of the Pennsylvanian System and the top of an unnamed marker bed, herein termed "Marker A" (see Figures 2, 12, and 13), shows basinward divergence and constitutes a genetic sequence. On the other hand, the underlying genetic sequence, comprising the interval between "Marker A" and the stratigraphically lower Elgin limestone (see Figures 2, 12, and 13), displays a basinward convergence. This is attributed to basin starvation during the time represented by this interval.

The top of the Pennsylvanian System (top of the Brownville limestone) and "Marker A" limestone are considered time marker beds. Both are readily recognizable on most of the electric logs in the area of investigation. The top of the Pennsylvanian System (Brownville limestone) disappears westward, and "Marker A" disappears east of the mapped area. The eastward disappearance of "Marker A" created some difficulty in sharply outlining its undaform edge.

Other electrical markers in the area represent either relatively insignificant argillaceous limestone beds or a slight increase in calcareous content of the shales. The Topeka limestone and Elgin limestone apparently change facies basinward to become argillaceous limestones of relatively doubtful correlative value.

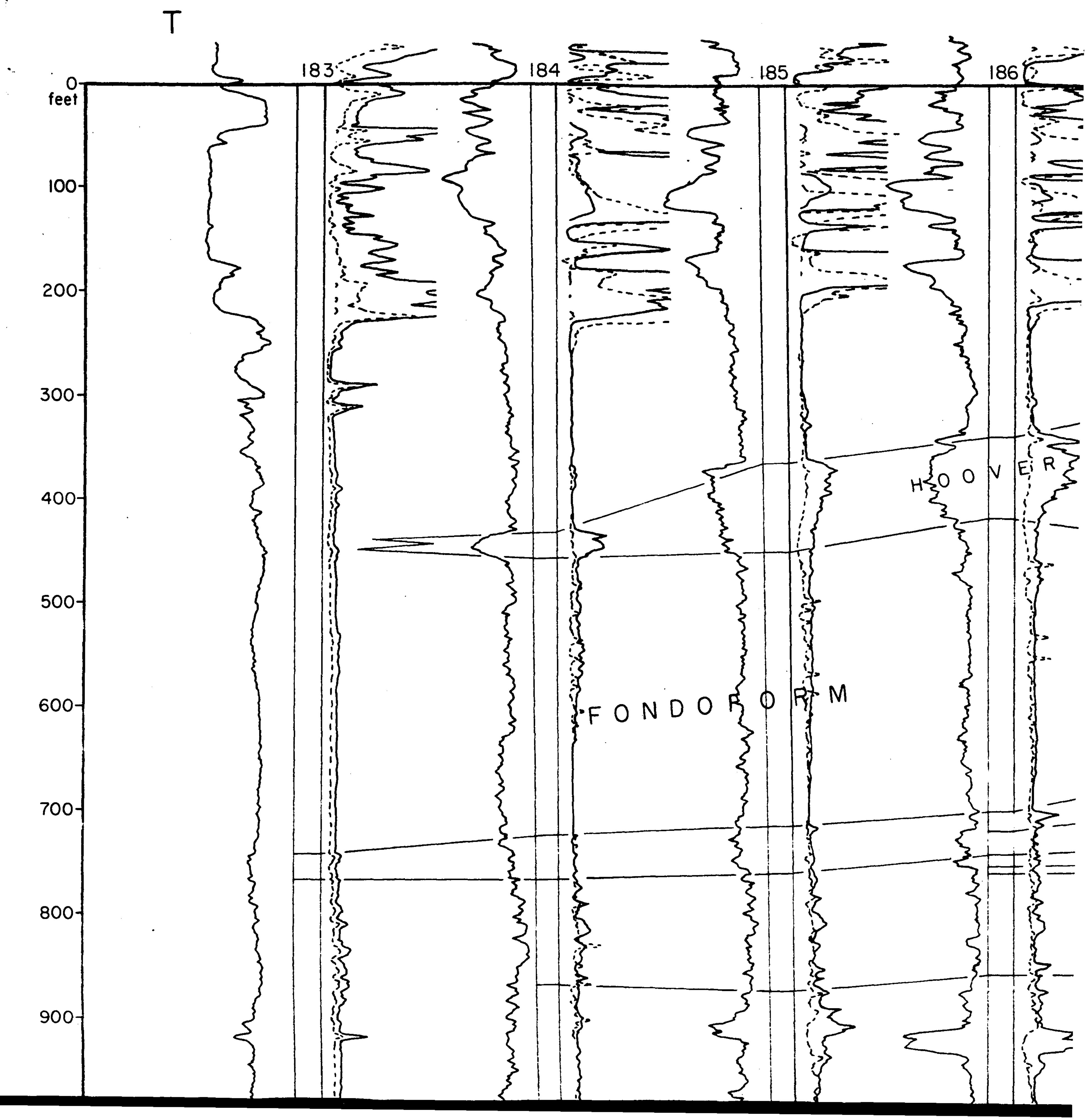
The margins of the Hoover sandstone are shaly, and locally, even the main body of the sandstone is shaly. Persistent shale breaks are lacking in the Hoover sequence. The cumulative thickness of the sandstone members within a given shaly Hoover zone, with a reasonably dependable SP or Gamma build-up, is considered as constituting 50 per cent of the total thickness of the zone. Because of the fact that the Hoover sandstone displays a slanted lower boundary on the majority of electric logs in the area, the mid-point of this gradient is selected as the base of the sandstone.

In constructing a structure map on top of the Hoover sandstone, precise position of the top is somewhat problematical in a shaly Hoover sequence or when the only log available is of the Gamma-Neutron type. The Hoover zone, however, is readily recognizable on all mechanical logs, the top of a uniformly shaly Hoover sequence being selected as the top of that zone.

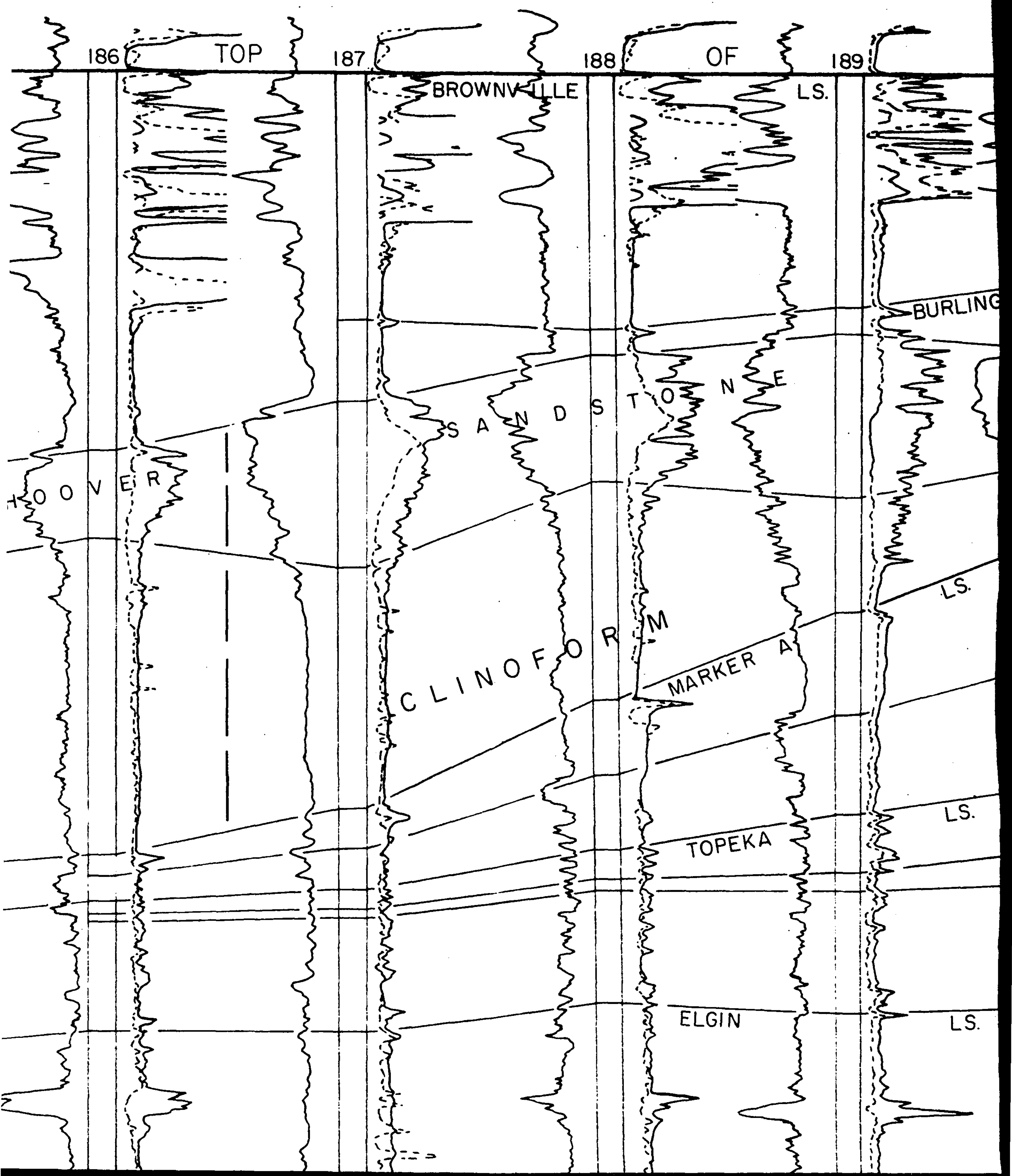
## Hoover Cross Sections

Two electric log cross sections involving the Hoover, TT' and UU' (Figures 12 and 13), are included herein, their locations are shown on Plate X. Both of the sections are in the direction of depositional dip of the genetic sequence between the top of the Pennsylvanian System and the top of "Marker A." These sections, as well as several others not included, display the following features related to Rich's concept of depositional topography and Adams' concept of basin starvation:

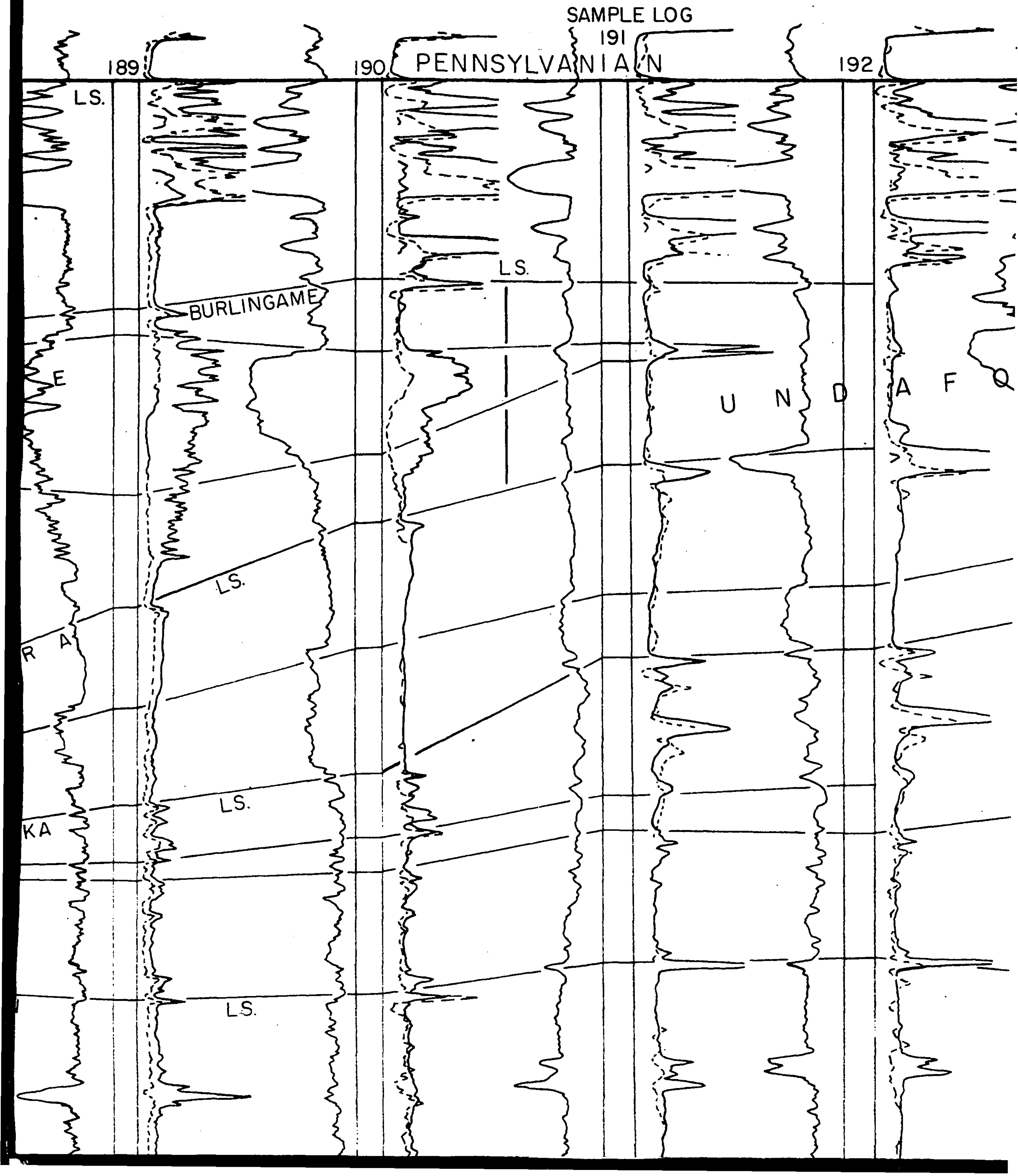
1. A striking feature of each cross section is a number of thin limestone beds within the interval between "Marker A" limestone and the Elgin limestone that dip westward at an average slope of 30 feet per mile, a much lesser regional dip than in the subsurface farther eastward.
2. Westward, these limestones cross diagonally through a dark shale section, in which they thin, disappear, or change facies to black shale and flatten out to the same average dip of underlying strata.
3. Post-Elgin limestone deposition demonstrates repeated two-phase cycles, a carbonate-black shale phase and a



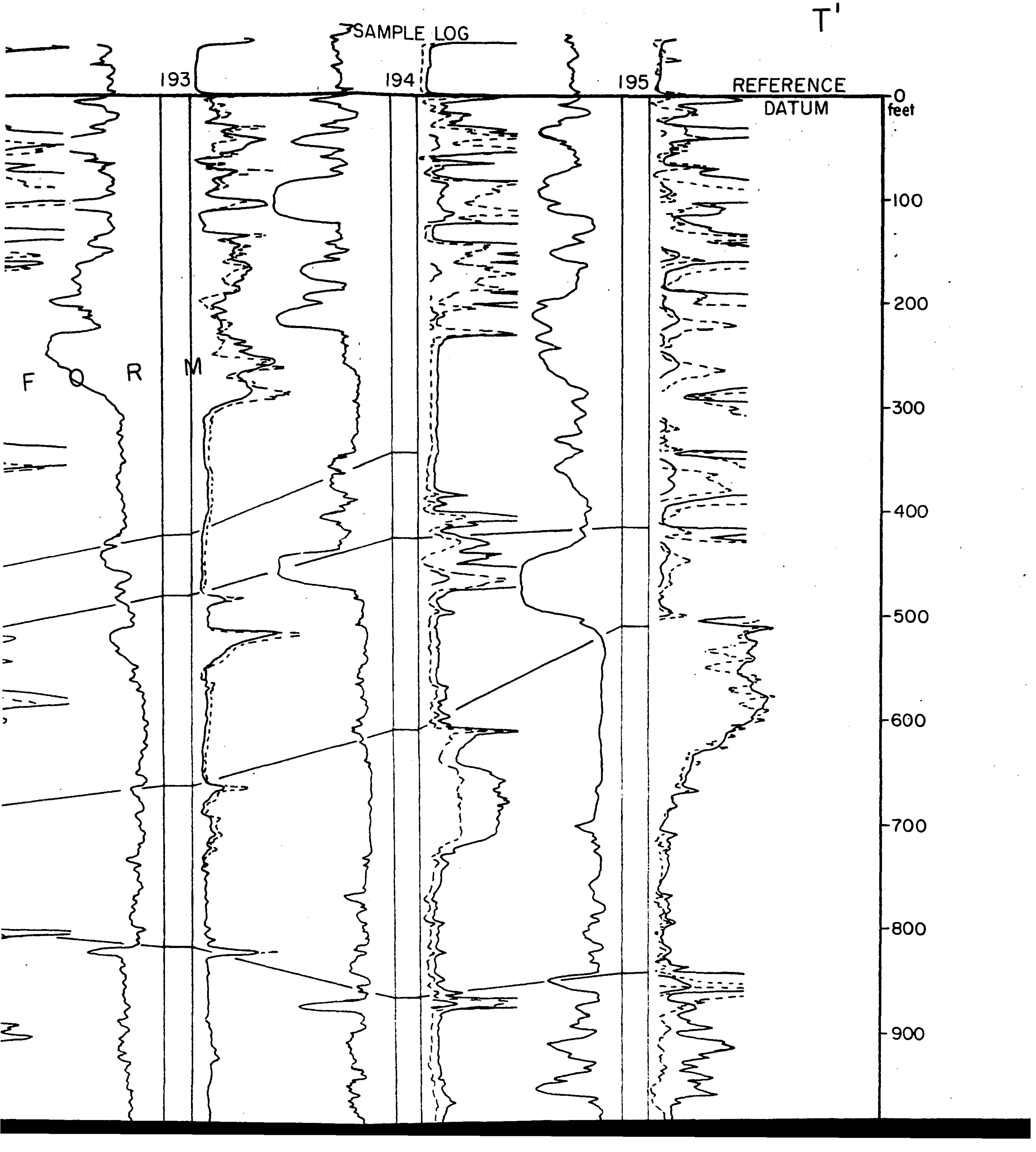
T
183
184
185
186
0
feet
100
200
300
400
500
600
700
800
900
HOOVER
FONDOROP ORM

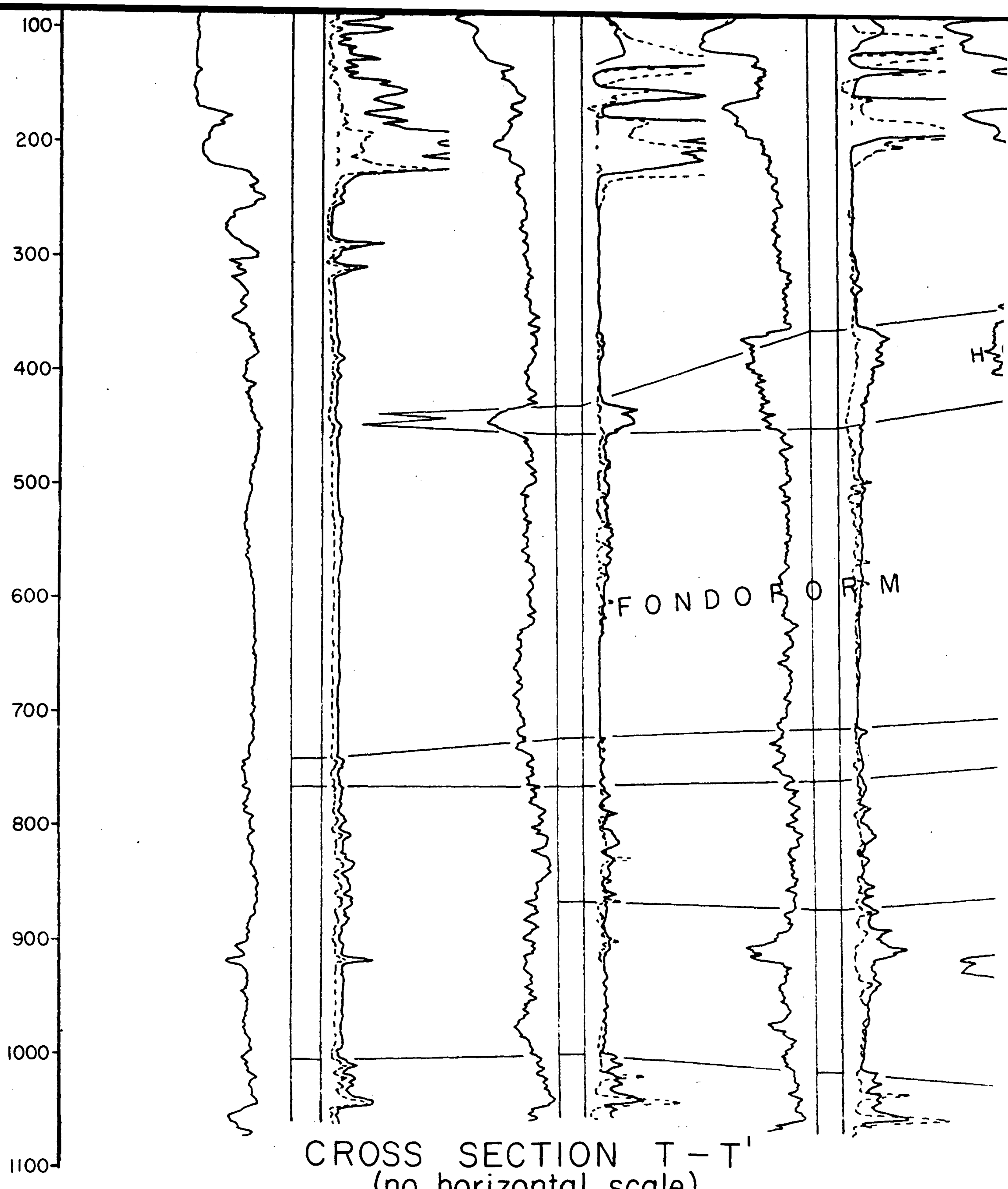


186
TOP
187
188
OF
189
BROWNVILLE
LS.
BURLING
SANDSTONE
HOOVER
CLINOFORM
MARKER A
LS.
LS.
TOPEKA
ELGIN
LS.



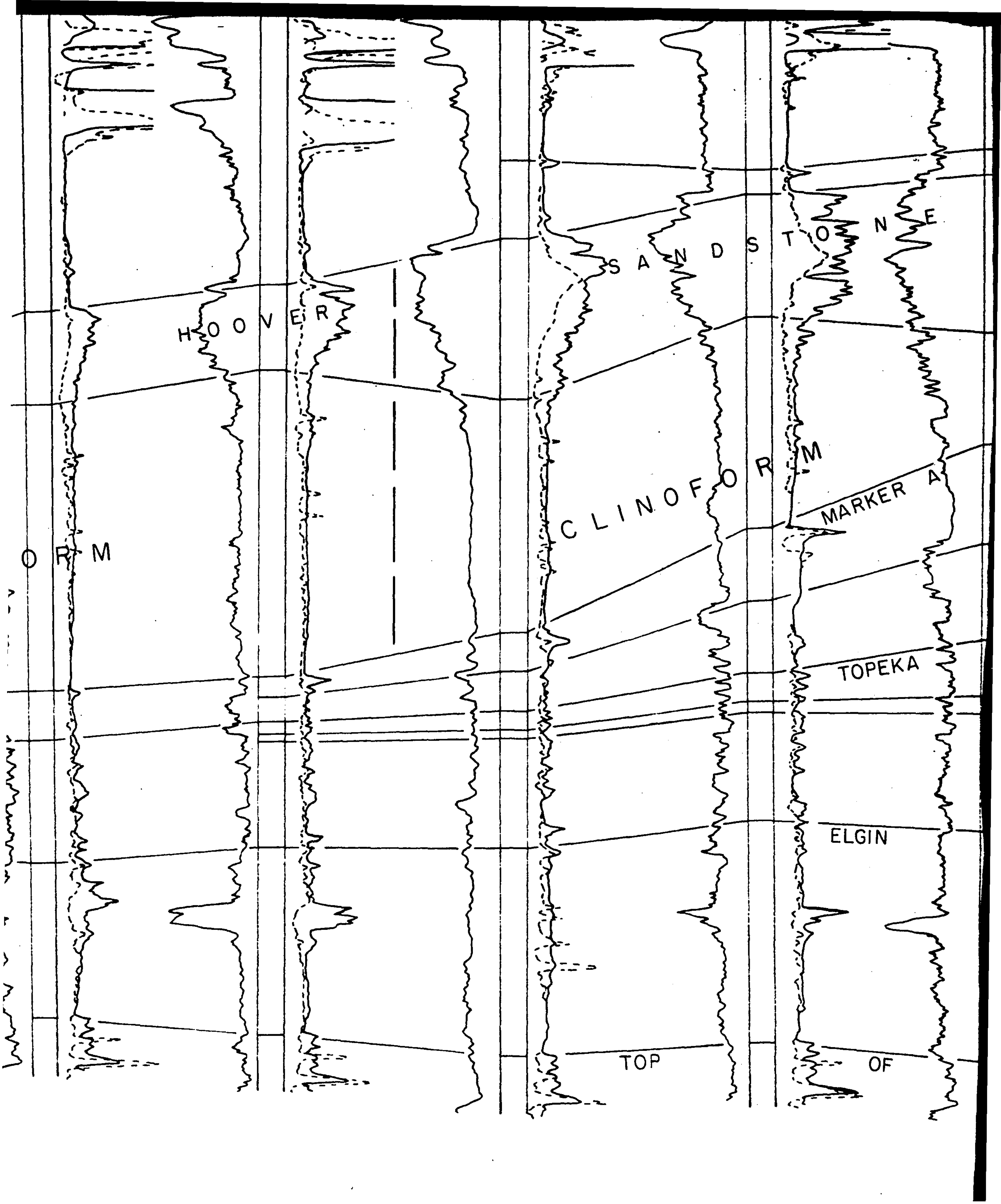
SAMPLE LOG
189
190
191
192
PENNSYLVANIAN
LS.
BURLINGAME
LS.
E
U N D A F
R A
LS.
KA
LS.
LS.

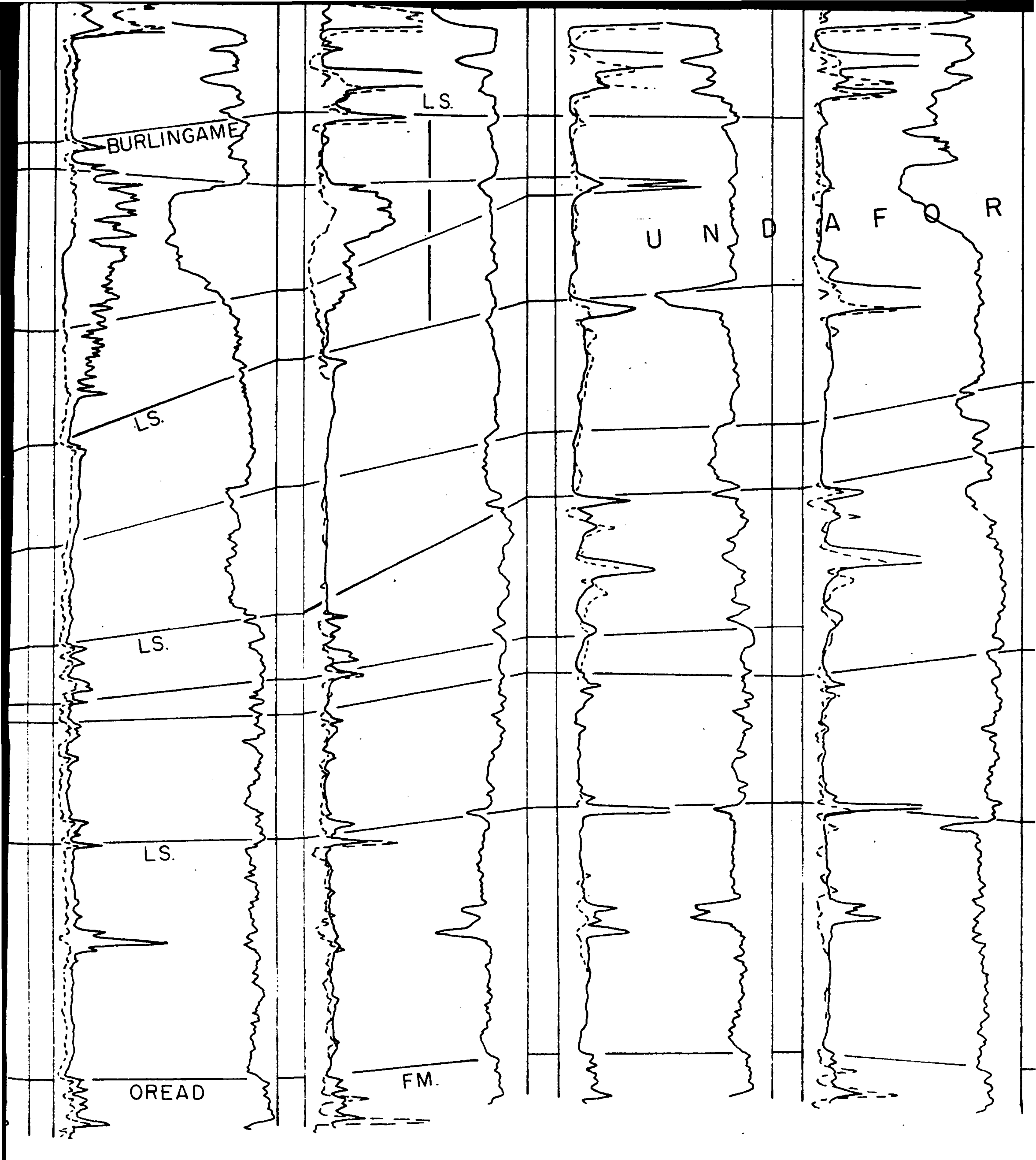

T'
SAMPLE LOG
193
194
195
REFERENCE
DATUM
0
feet
100
200
300
400
500
600
700
800
900
F O R M




CROSS SECTION T – T'
(no horizontal scale)

**FIGURE 12**


HOOVER SANDSTONE
CLINOFORM
ORM
MARKER A
TOPEKA
ELGIN
TOP OF


BURLINGAME
L.S.
LS.
LS.
LS.
LS.
U N D A F O R
OREAD
FM.

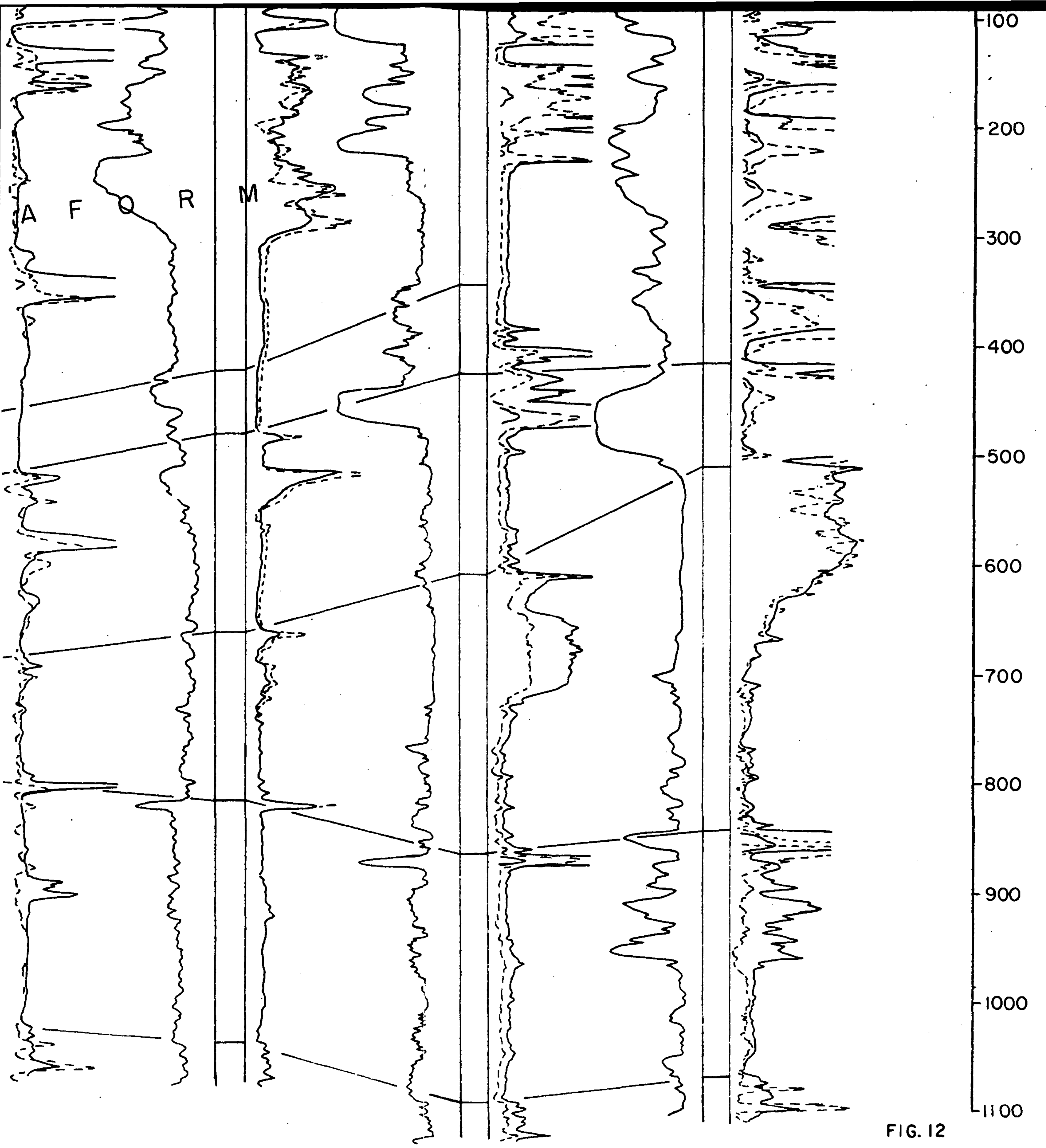
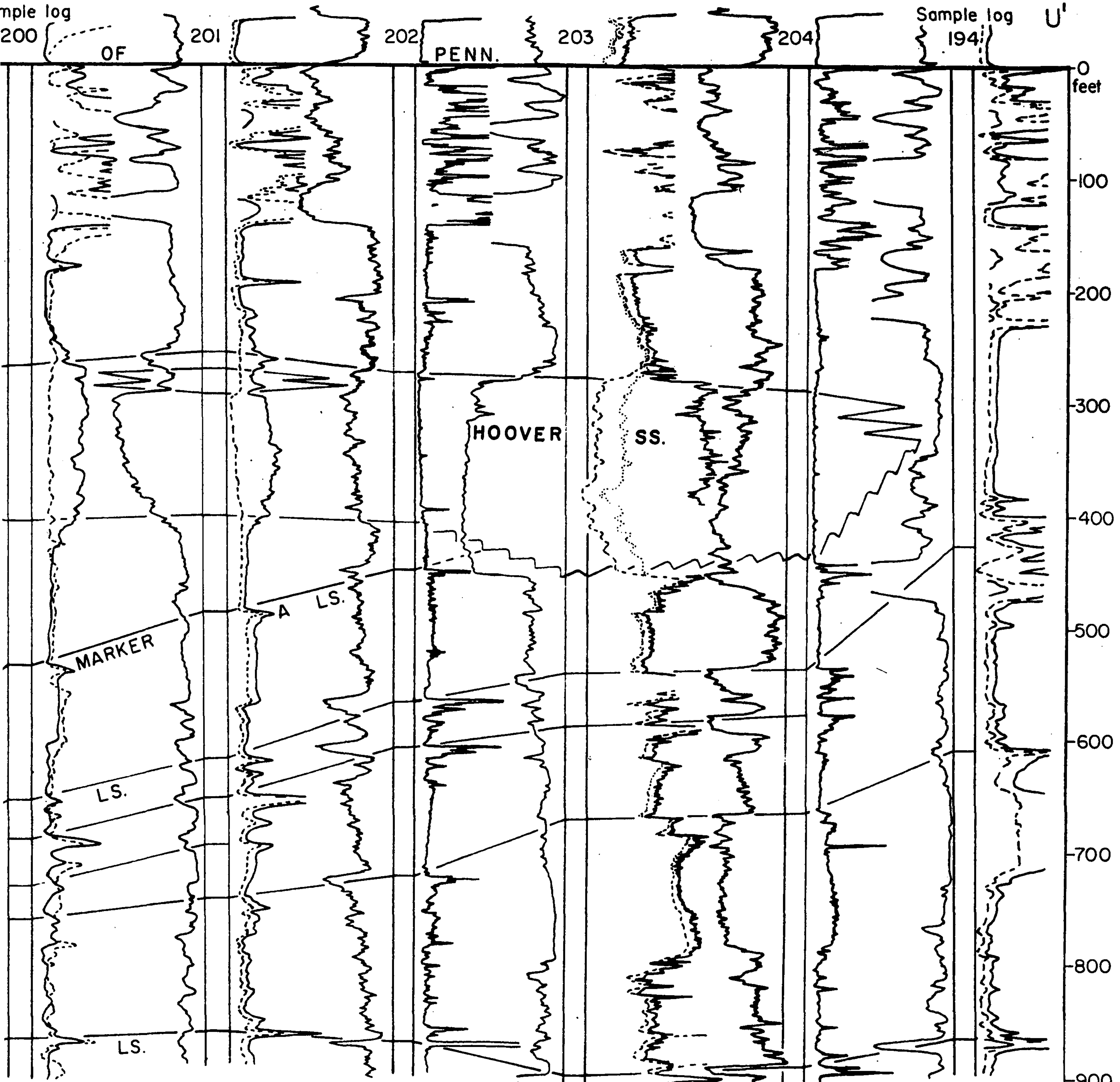



FIG. 12


CROSS SECTION
(no horizontal sca

**FIGURE 13**




ROSS SECTION U-U'
(no horizontal scale)
**FIGURE 13**

FIG. 13

clastic phase.

4. Within the Elgin-"Marker A" interval, the clastic phase of each cycle thickens slightly westward (basinward) relative to thickening of the clastic phase of the preceding cycle. This is due to the west-southwestward migration of the undaform edge from lower to upper markers. This interval (Elgin-"Marker A") converges basinward and is attributed to an epoch of basin starvation. Elgin-"Marker A" interval and the overlying genetic sequence, comprising the interval between "Marker A" and higher consistent markers, such as the Burlingame limestone (Figures 2 and 12), or the top of the Pennsylvanian, constitutes a genetic sequence. This genetic sequence resembles the classic delta deposits suggested by Van Siclen (1958) for the Late Pennsylvanian and Early Permian of West Texas.

5. The stratigraphic interval is fairly uniform from the top of the Oread Formation (or the Elgin limestone) to some higher consistent marker, such as the Burlingame limestone, or the top of the Pennsylvanian System (Brownville limestone). An isopachous map of such an interval, although not prepared, would probably reveal a thickness variation of no more than 100 feet over the entire map area.

6. The Hoover sandstone indicates development at the expense of both overlying and underlying units. It represents a tongue-shaped body of sandstone that "shales

out" radially.

7. Cross Section UU' (Figure 13) shows channel sand development in wells 203 and 204 (for location see Plate X), where the stratigraphically lower "Marker A" limestone has been removed by erosion.

8. Many of the electric logs show the Hoover sandstone with sharp upper boundary and gradationally slanting lower boundary.

## Hoover Maps

An isopachous map (Plate X) of the "Marker A"-Brownville interval presents a simulated reconstruction of the configuration of the sea floor at the end of deposition of "Marker A" limestone. Post-Pennsylvanian structural movements are effectively eliminated in such a map. Post-depositional compaction of the shales within this interval must have changed slope values of the depositional surface, but just how much is not known. However, such compaction effects could not be considered responsible for the undaform-clinoform-fondoform depositional topography shown prominently at the horizon of "Marker A" limestone and, to a lesser degree, by the underlying, less significant time markers, such as the Topeka limestone.

This map (Plate X) reveals evident changes in stratigraphic positions of "Marker A." In the eastern part of the map area, "Marker A," although losing its identity, apparently grades into a thick carbonate section.

The "Marker A" depositional surface is 1) eastward, a gently sloping, essentially flattened shelf; 2) a relatively sharp west-southwestward slope beyond the shelf edge; and 3) a more gently sloping basinal area. These three areas are the unda-, clino-, and fondoform, respectively.

However, the western edge of "Marker A" undaform is outlined with some difficulties. Although "Marker A" limestone consistently reflects its clinoform slope in being traceable continuously up the slope, yet as it approaches the undaform edge, it loses its identity. Control wells in this area are more widely spaced and erratically distributed. A few channels, particularly that in T. 25 N., R. 23 W. (Plate X and Figure 13), obliterate the undaform edge. Similar difficulties were reported by Van Siclen (1958) in outlining the undaform edges of the Early Cretaceous Edwards limestone and associated strata in South Texas, the Late Jurassic Smackover limestone in northwestern Louisiana, and the Early Miocene *Heterostegina* limestone in the subsurface area east of New Orleans, Louisiana.

It is emphasized herein that "Marker A" limestone merely conformed to the pre-existing submarine topographic surface; it was not a product of tectonic activity. The near parallelism of the Elgin limestone with the top of the Pennsylvanian System is the evidence for such conclusion. There is no indication of differential subsidence during the growth of the carbonate bank along the "Marker A" undaform of the map area. The change in stratigraphic positions of the marker beds, therefore, is related to sedimentary processes, and not to differential subsidence.

The Hoover sandstone is part of the clastic phase of the "Marker A"-Burlingame cycle. An isopachous map of this sandstone body (Plate XI) shows some relation to the paleodepositional topography of "Marker A." Thick Hoover sandstone was deposited over the lows of the "Marker A" surface, whereas the Hoover is thin over the highs.

The Hoover sandstone attains maximum thickness of 180 feet on the clinoform. Much of this thickest part is above the gas-water contact (Plate XII). Upon approaching the fondoform to the west, starting approximately along the boundary line of Beaver and Harper Counties, the Hoover thins to maximum thickness of 90 feet. Thick Hoover sandstone trends are observable in the center of T. 25 N., R. 23 W. and in areas extending westward (thickening is augmented by channel deposition); another area of Hoover thickening centers in the middle part of the map area along the boundary line of T's 25 and 26 N., R's 24, 25, and 26 W.; minor local thickening is observable in T. 24 N., R. 23 W.

The structure map of the top of Hoover sandstone (Plate XII) shows an average southward regional dip of 17 feet per mile, although depositional dip at the time of Hoover deposition was to the west-southwestward. Post-Pennsylvanian structural movements tilted the Marker A-Brownville genetic sequence, of which the Hoover is a part, toward the south. The gas-water contact is at a subsea depth of -2,120 feet.

Gas accumulation in the area north of the gas-water contact is controlled by a combination of structure and stratigraphy (facies changes). The northern margin of the pool is determined by "shaleout" of the sandstone, whereas the southern margin is controlled by the structural position of the gas-water contact.

## Interpretation of the Hoover Sandstone

Cyclic deposition of Middle and Late Virgilian, the interval from the Elgin limestone to the Burlingame limestone (Figures 2, 12, and 13), seems to be similar to that of the Pennsylvanian-Permian deposition in West-central Texas (Jackson, 1964; Ralls, 1958; and Van Siclen, 1958), and to Late Devonian deposition in central Alberta (Oliver and Cowper, 1963).

The rock units represented by the three environments, unda, clino, and fondo, are analogous to the topset, foreset, and bottomset rock units of a delta. In fact, when "Marker A" limestone deposition began, the underlying mud and silt was probably already overlain by topset, foreset, and bottomset distribution.

Jackson (1964) proposed the term "cyclo-phase" in describing cyclic deposition of the Upper Pennsylvanian-Lower Permian strata in West-central Texas. The term denotes a repeated, or cyclic, alternation of two phases of deposition, a clastic or sand-shale phase and a carbonate-black shale phase. This term is meant to distinguish the cyclic deposition of West-central Texas from the cyclothem type of deposition of the Illinois Basin and elsewhere. The Middle and Late Virgilian deposition of the Laverne district of northwestern Oklahoma represents a "cyclo-phase" of the type described by Jackson.

The cross sections clearly reveal that basin filling was accomplished during a series of successive cycles. The filling progressed west-southwestward, as indicated by the westward advance of the undaform edges of individual marker beds (Figures 12 and 13). Also, the repetition of these successive cycles suggests a repetition of similar environmental conditions. This repetition is due either to cyclic subsidence or cyclic rise in sea level under conditions of steady supply of sediment. Van Siclen (1958), in a study of the Pennsylvanian-Permian depositional framework in West and West-central Texas, postulated that since the undaform edge of individual limestone bed migrates basinward beyond earlier beds, a situation comparable to that involving Late Virgilian rocks of northwestern Oklahoma (Figure 14). In both instances, sea level must have experienced net rise despite fluctuations.

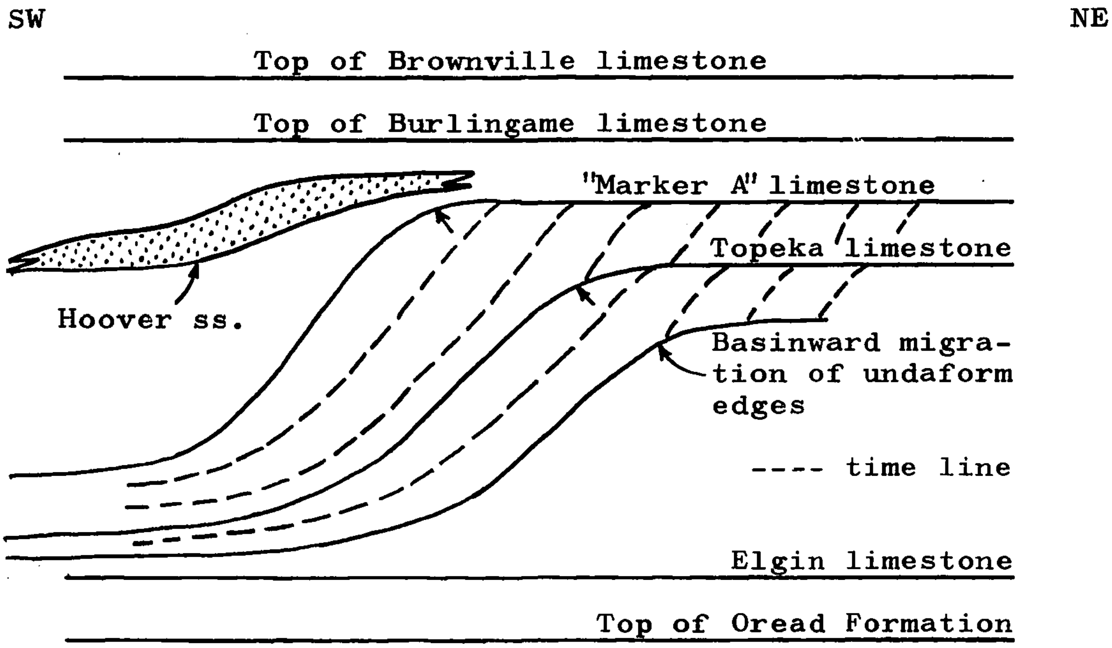



Figure 14- Diagrammatic cross section showing idealized cycles of deposition of unda, clino, and fondo beds of upper Virgilian Series (modified after Oliver and Cowper, 1963).

The clastic phase of each cycle must have been deposited at times which preceded cyclic rises of sea level. During those epochs of clastic accumulation, much detritus was flushed rapidly into the sea to extend the coastal plain seaward. As sea level rose, the influx of detritus essentially ceased, and carbonate deposits accumulated with but a modicum of contamination. Carbonate deposition progressed eastward and some limy debris was washed down the clino slope formed by the preceding clastic unit to form a continuous bed with the unda marker.

A diagrammatic cross section (Figure 14) shows the stratigraphic relationships of the Late Pennsylvanian "cyclophase" deposition in the Laverne district of northwestern Oklahoma.

The clastic phase (top of "Marker A" limestone to base of Burlingame limestone) of the final cycle formed prior to the return of steady rise of sea level. The undaform of "Marker A" limestone was subjected to scouring, or channeling, as in T. 25 N., R. 23 W., causing the clino beds to develop at an accelerated rate. Sand, silt, and clay were carried seaward by numerous streams.

Normally, the Hoover sandstone would be characteristic of the unda environment in the high-energy zone above wave base. This sandstone should be well-sorted in its high energy environment, and all clay material was winnowed out. This sandstone could have been part of the undathem had it not been transported toward the undaform edge. As turbulence decreased markedly, the sand remained at depths favorable for development of turbidity currents. The Hoover is considered to have been transported by such currents basinward from the seaward edge of the undaform. The turbidity currents probably followed existing lows on "Marker A" paleodepositional surface (Plate X). With loss of current energy, the sand settled out on the clino- and fondoform.

The formation of unda and clino beds continues simultaneously. Clay-sized material was winnowed out of the carbonate shelf or undaform and carried down the clinoform below wave base, thus, forming a slightly inclined platform. Across this platform individual marker beds advanced and changed facies basinward into black shale. This black shale is composed essentially of carbonate rock flour, as reflected by relatively high electric log resistivity.

Time lines cross rock units of the clastic phase of each cycle, although they parallel the carbonate-black shale phase (Figure 14). Along the unda and fondo beds, time lines are subparallel to rock unit boundaries. Those of the clino beds exhibit distinct divergence because within a given time interval the clinoform apparently received a greater quantity of sediment than received by the undaform or fondoform. Assuming relatively uniform compaction, isochrons in the undathem and fondothem, therefore, would be compressed. This is understandable because only part of the section will be preserved in a stable undaform, and because of the lower rate of sedimentation on the fondoform. Such conditions would by-pass the clinothem, to exhibit relative divergence of the isochrons.

Were it not for the presence of the time markers, the deposition of the Middle and Late Virgilian rocks in this area (and in other similar stratigraphic sections) would no doubt have been interpreted as a normally layered stratigraphic sequence.

Several possible causes of cyclic fluctuations of sea level may be suggested. A local minor change in the size of the Anadarko Basin, and/or the melting of Southern Hemisphere Carboniferous glaciers, or any of several other considerations advanced by Wanless and Shepard (1936) could account for the fluctuations. Van Siclen (1958) theorized that the cyclic fluctuations of sea level during Pennsylvanian-Permian time in West-central Texas were caused by continental glaciation. Swann (1964) proposed climatic fluctuations in the source area, rather than fluctuations of the boundary of continental ice in the Southern Hemisphere, as the direct control of the sedimentary rhythms of the upper part of the Mississippian column of the Illinois Basin.

In general, the sedimentary rock characteristics, advanced by Rich in 1951, and outlined on Figure 11, are reasonably comparable with rocks of the unda, clino, and fondo in the Upper Pennsylvanian of the Laverne district of northwest Oklahoma. The black shale is typical of a fondo environment and, in fact, the change from limestone to black shale may be utilized arbitrarily in defining the boundary between the fondoform and the clinoform. This criterion was employed by Jackson (1964) in a study of the Upper Pennsylvanian-Lower Permian rocks in an area east of the eastern shelf of the Midland Basin of West-central Texas.

## MINERALOGICAL, PHYSICAL, AND RESERVOIR CHARACTERISTICS OF THE MORROW, TONKAWA, ENDICOTT, AND HOOVER SANDSTONES

Sixty thin sections and approximately 45 sets of samples supplied information from which general observations are presented herein.

### Morrow Sandstones

The geological framework of Morrow deposition in the study area has been discussed elsewhere. This analysis is supplemented with detailed microscopic study of cores and rotary cuttings from individual Morrow sandstone members. Diagnostic microscopic differences characterize the fringing beach sandstones, barrier islands, offshore bars, channel sandstones (fluvial and deltaic) of the Morrow formation.

An adequate microscopic study requires systematic sampling of different Morrow sandstones at numerous localities. Such an approach should offer an independent line of evidence to substantiate findings based on conventional mapping techniques. The limited microscopic analyses of these different Morrow sandstone bodies provides only tentative conclusions regarding the environment and the geomorphology of their sites of deposition.

In general, the Morrow sandstones are compositionally mature, in the sense that only the more stable components survived. They consist predominantly of sand-size quartz grains. Textural maturity varies from one sandstone body to another, depending on whether the sandstone be deltaic, fluvial, barrier island, offshore bar, or fringing beach. Variation may obtain also within a given sandstone body of a barrier island, an offshore bar, or a beach, depending on the geographic location of the sample, i.e., whether it be on the landward or seaward margin of the given body.

The beach sandstone 35 (Figure 15A) and the barrier island sandstone 34 (Figures 15 B and C) represent mature to supermature orthoquartzitic sandstones obtained from the landward side of the sandstone bodies. Their seaward extensions are represented by lower stages of maturity. The grain size in landward samples and in their seaward extensions varies from fine to medium.

Sandstone developed in a lagoonal environment, behind barrier island 33 (Figures 15 D and E), demonstrates what Folk (1961) termed textural inversion; i.e., relatively well-rounded, and essentially unsorted grains display two predominant degrees of roundness. This sandstone was deposited along the bay shoreline where current energy was insufficient for effective sorting. The sand

Fig. 15- Thin sections illustrating the mineralogy and texture of Morrow sandstones. (All X 112, with polars crossed unless otherwise indicated).

A. Sandstone member 35.

Fine sandstone: siliceous mature (or supermature) orthoquartzite.
95% quartz- shows secondary quartz overgrowths in optical continuity with sand grains whose original outlines are marked by "dusty inclusions" line; the angularity is mainly the result of overgrowth; almost all grains are riddled with minute bubbles and inclusions; most grains show sutured contacts indicating pressure-solution creating a clay-coated stylolitic seam; and few grains show undulatory extinction. 4% chert. 1% mica. A trace of sphene. Treated with Epoxy resin and alizarine red-S. Porosity fair (13%).
(Gulf, McClung #1, sec. 23, T. 26 N., R. 25 W., 6949').

B. Sandstone member 34.

Fine to medium sandstone: siliceous (partly dolomitic with some calcite) supermature fossiliferous orthoquartzite.
93% quartz- same as 15A. 5% chert; figure shows a silicified oolite. 1% pyrite. 1% collophane. A trace of plagioclase. Many calcitic and dolomitic (or calcitic and later dolomitized) fossil fragments (mainly Foraminifera). Some fossils are filled with detrital quartz grains cemented with dolomite. Few fossils are coated with pyrite. Treated with Epoxy resin and alizarine red-S. Porosity poor (5%).
(Same location as 15A, 6970').

C. Same slide as 15B.

D. Sandstone member 33.

Fine sandstone: dolomitic (calcitic and phosphatic in part) bimodal submature intraclast- and fossil-bearing orthoquartzite.
100% quartz- poorly sorted with two predominant roundness classes. Cement is almost 50% of the total rock volume with floating grains of calcite common. Dolomitic, calcitic, and phosphatic fossil

(continued on p. 90)

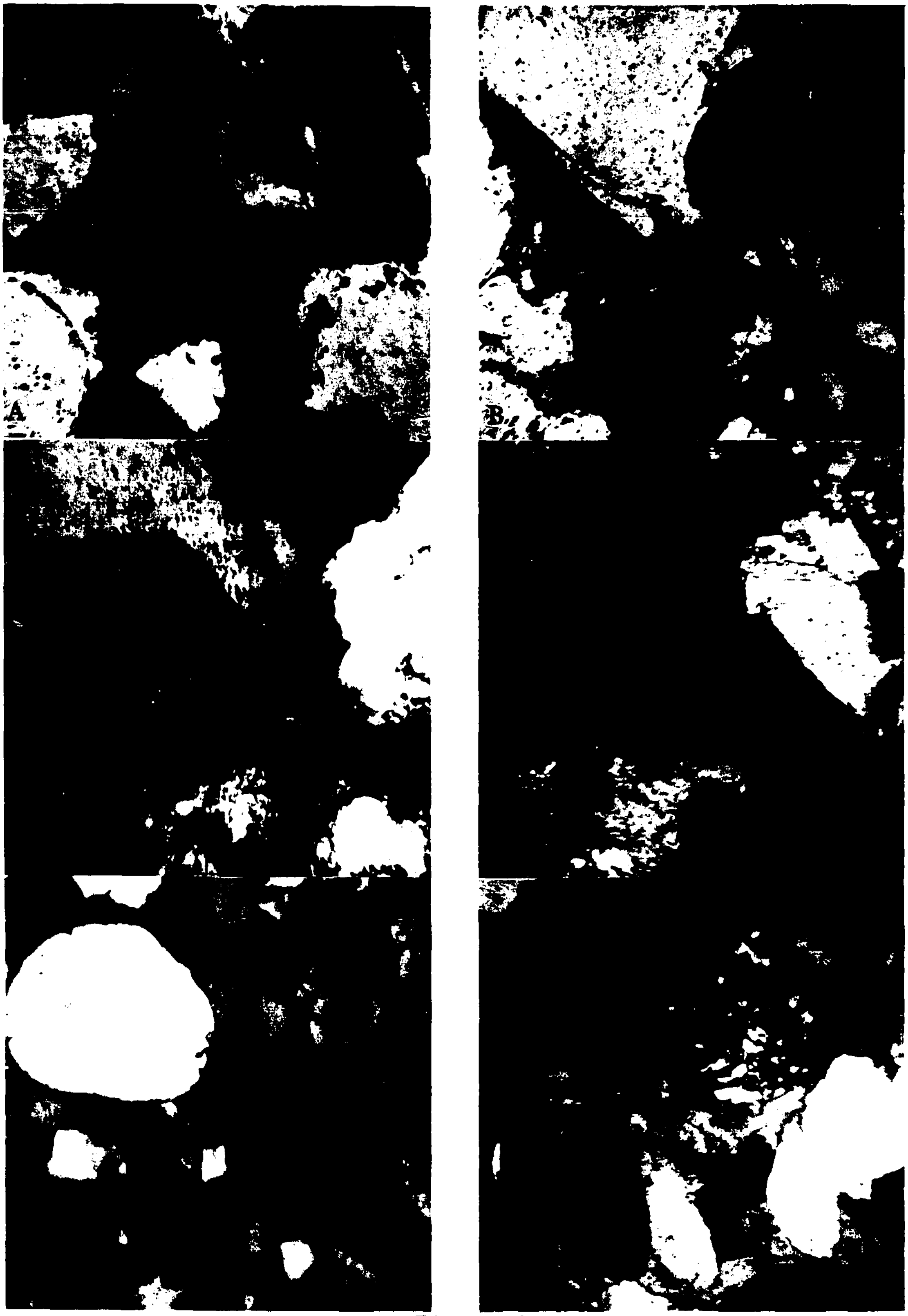



Figure 15

grains illustrated in slides 15 D and E represent mixing of products of two energy levels; i.e., rounded sand grains were blown from the barrier island environment into a low energy environment which was too weak for effective sorting.

Figure 15F represents a supermature sandstone with calcite being the predominant cement. The specimen was obtained from the landward side of barrier island 29. Figure 15G is a submature sandstone obtained from the seaward extension of an offshore bar associated with barrier island 29.

Figures 15H and 15L illustrate fluvial sandstones associated with paleoshorelines 28 and 29, respectively. They are both submature and but partially sorted, calcite cement constituting 40 to 50 per cent of the total rock volume.

Figures 15 I, J, and K illustrate three slides of mature to supermature, exceedingly fine- to medium-grained sandstones; calcite cement constitutes as much as 20 per cent of the total rock volume. The three slides were obtained from sandstone members 26, 25, and 24, respectively.

Most individual quartz grains of Morrow sandstones show straight extinction; a few show slightly undulatory extinction. They are characterized by abundant inclusions, primarily bubbles and vacuoles. Using Folk's (1961)

fragments common. Carbonaceous material present. Treated with Epoxy resin and alizarine red-S. Porosity nil.
(Same location as 15A, 6987').

E. Same slide as 15D (X 56).

F. Sandstone member 29.

Medium sandstone: calcitic supermature orthoquartzite.
80% quartz- inclusions, bubbles, secondary overgrowths, and sutured grain contacts common. Some grains fractured after calcite cementation; 20% chert- some detrital and some authigenic. Calcite cement approaches 45% of total rock volume. Porosity nil.
(Lynn Drilling, Wisner #1, sec. 12, T. 23 N., R. 23 W., 7920-30').

G. Sandstone member 29.

Very fine sandstone: calcitic submature orthoquartzite.
100% quartz- inclusions and vacuoles. Grains floating in calcitic matrix approaching 50% of total rock volume; traces of muscovite, limonite, and accessories. Porosity fair (12%).
(Skelly Oil, Bell #1, sec. 23, T. 24 N., R. 26 W., 7945-50').

H. Sandstone member 28.

Fine sandstone: calcitic (partly chloritic) submature orthoquartzite.
98% quartz; 2% chert; trace of muscovite. Calcite cement is 50%, chlorite is 10% of total rock volume. Porosity fair (12%).
(Same location as 15F, 7940-50').

I. Sandstone member 26.

Medium sandstone: siliceous (scattered calcite patches) supermature orthoquartzite.
95% quartz- same as 15A, stylolytic seams absent. Inclusions in quartz are mostly muscovite; 5% chert and quartz rock fragments. Porosity good (18%).
(Same location as 15F, 7980-90').

J. Sandstone member 25.

Very fine sandstone: siliceous (calcitic in part) mature orthoquartzite.
100% quartz- some grains show inclusions, vacuoles, sutured grain contacts, and secondary overgrowths; trace of chert, muscovite, and phosphatic materials (collophane?). Calcite cement 15% of total rock volume. Porosity nil or very poor.
(Same location as 15G, 8075-85').

K. Sandstone member 24.

Fine sandstone: calcitic mature orthoquartzite.
95% quartz- many inclusions and vacuoles; 5% chert. Calcite cement approaches 20% of total rock volume. Porosity fair (12%).
(Same location as 15G, 8146-51').

L. Sandstone member 24.

Fine sandstone: calcitic (partly chloritic) submature glauconitic orthoquartzite.
99% quartz- vacuoles and inclusions; 1% glauconite; trace of chert. Calcite 40%, chlorite 3% of total rock volume. Porosity fair (12%).
(Pan American, Shattock #1, sec. 11, T. 22 N., R. 26 W., 8940-50').

Figure 15--Continued

empirical and genetic classifications of quartz by source area, these Morrow quartz grains indicate a sedimentary, hydrothermal, and/or pegmatitic source.

Furthermore, the clean, well-sorted, and well-rounded quartz grains show sutured contacts. This was effected by pressure in the presence of solutions, as postulated by Thomson (1959). As a result, such grains are flattened and broken, the stylolitic seams of many grains being coated with clays, with noticeable decrease in cement and porosity. Similar observations were noted by Adams (1964) for Lower Morrowan sandstones in the vicinity of Ellis County, Oklahoma.

The cementing materials consist of quartz, as secondary overgrowths, cement, and chalcedonic quartz (chert); calcite; dolomite; and chlorite. The texturally mature and supermature sandstones contain silica cement with or without patches of calcite; the texturally sub-mature sandstones are characterized by calcite, dolomite, and chlorite cements. In such sandstones, the calcite and/or dolomite cement may constitute as much as 50 per cent of the total rock volume. The source of the calcite cement may have been the extensive Mississippian carbonate erosional surface that was located north of the area.

A study by Siever (1959) regarding cementation of Pennsylvanian sandstones from several basins illustrates the sequence of cementation in relation to depth of burial.

In an exceptionally weak silica solution (as in present-day sedimentation waters), sandstone grains will be partially or wholly cemented by secondary quartz overgrowths or silica during shallow burial. The precipitation of silica is diagenetic rather than primary. With deeper burial, carbonate cement will fill the remaining pores. With increasing depth, carbonate cement tends to replace the original silica or secondary overgrowths, producing a sandstone in which carbonate cement constitutes 50 per cent of the total rock volume with floating quartz grains. This replacement process of silica by carbonate cement with depth is explained by the temperature dependence of solubility of carbonate and silica. Silica solubility increases steadily with increasing temperature. Conversely, calcite solubility decreases with increasing temperature.

## Tonkawa Sandstone

The Tonkawa sandstone is characteristically a white, fine-grained, angular to sub-angular, moderately sorted, slightly porous, micaceous sandstone with a trace of hydrocarbon stain.

Thin sections prepared from samples of the middle member of the Tonkawa sandstone are shown and described in Figures 16 A and B. Porosity and permeability of the three members of the Tonkawa sandstone are illustrated by the mechanical logs in Figure 7.

## Endicott Sandstone

The Endicott sandstone is characteristically light gray, exceedingly fine- to fine-grained, poorly sorted, calcareous, and micaceous, with fair to good porosity. This sandstone is laminated with light to dark-gray carbonaceous shales, and overlain by dark gray and black pyritic shales with coal streaks at the base. Thin sections of the Endicott sandstone are shown and described in Figures 17 **C** and **D**.

The Toronto limestone at the base of the Endicott sandstone, invariably eroded, displays a maximum thickness of 60 feet. It is typically light gray, tan, and buff, locally fragmental, and semi-dense, with traces of chert.

A porosity and permeability study of the Endicott sandstone by means of mechanical logs, including sonic logs, reveals fair to good porosity and permeability (Figure 18).

## Hoover Sandstone

The Hoover sandstone is characteristically light gray, fine-grained, poorly sorted, calcareous, with interbedded shale laminae. Thin sections of the Hoover sandstone are shown and described in Figures 19 **E**, **F**, and **G**.

The "Marker A" limestone is light to dark gray, finely crystalline and argillaceous.

A porosity and permeability study of the Hoover sandstone by means of mechanical logs reveals fair to good porosity and permeability (Figure 20).

Figure 16- Thin sections illustrating the mineralogy and texture of the middle member of the Tonkawa sandstone. (All X 112, with polars crossed unless otherwise indicated).

A. Very fine to fine sandstone: siliceous (partly dolomitic) mature orthoquartzite.
97% quartz- abundance of inclusions, bubbles, and vacuoles; secondary quartz overgrowth common. 1% chert. 1% plagioclase. 1% muscovite. Treated with Epoxy resin and alizarin red-S. Porosity good (15%).
(Gulf, McClung #1, sec. 23, T. 26 N., R. 25 W., 5450').

B. Fine sandstone: calcareous mature orthoquartzite.
94% quartz. 5% chert. 1% plagioclase. 1% muscovite. 1% biotite. Porosity good (15%).
(Lynn Drilling, Wisner #1, sec. 12, T. 23 N., R. 23 W., 5990'-6000').

Figure 17- Thin sections illustrating the mineralogy and texture of the Endicott sandstone. (All X 112 with polars crossed unless otherwise indicated).

C. Intinctly mottled clayey siltstone.
90% quartz. 10% muscovite and chlorite. Trace of accessory minerals. Calcareously cemented.
(Lynn Drilling, Wisner #1, sec. 12, T. 23 N., R. 23 W., 5550'-60').

D. Very fine sandstone: calcareous submature orthoquartzite.
85% quartz. 10% chert. 5% feldspars (mainly plagioclase). Porosity good (18%).
(Carter, Harrison #1, sec. 7, T. 23 N., R. 20 W., 5550'-60').

Figure 19- Thin sections illustrating the mineralogy and texture of Hoover sandstone. (All X 112, with polars crossed unless otherwise indicated).

E. Fine sandstone: calcareous immature subgraywacke.

55% quartz- loaded with vacuoles diagnositic of hydrothermal veins. 20% chert. 8% chlorite. 5% feldspars (mainly plagioclase). 5% metamorphic rock fragments. Cement is patchy and consists mainly of dolomite and trace of calcite. Treated with Epoxy resin and alizarin red-S. Porosity good (18%). (Gulf, McClung #1, sec. 23, T. 26 N., R. 25 W., 4284').

F. Very fine sandstone: siliceous immature Feldspathic subgraywacke.
40% quartz- often riddled with inclusions; grain contacts are occasionally sutured. 25% chert. 10% muscovite. 5% chlorite. 14% feldspars (mainly plagioclase). 5% rock fragments. 1% illmenite. Trace of rutile. Few patches of calcite cement. Treated with Epoxy resin and alizarin red-S. Porosity fair (12%). The slide is cut normal to bedding and shows clay strings along the edges. (Same location as 19A, 4187').

G. Same as 19B (X 28).


Figures 16, 17, and 19

Sec. 23, T. 24 N., R. 26 W.

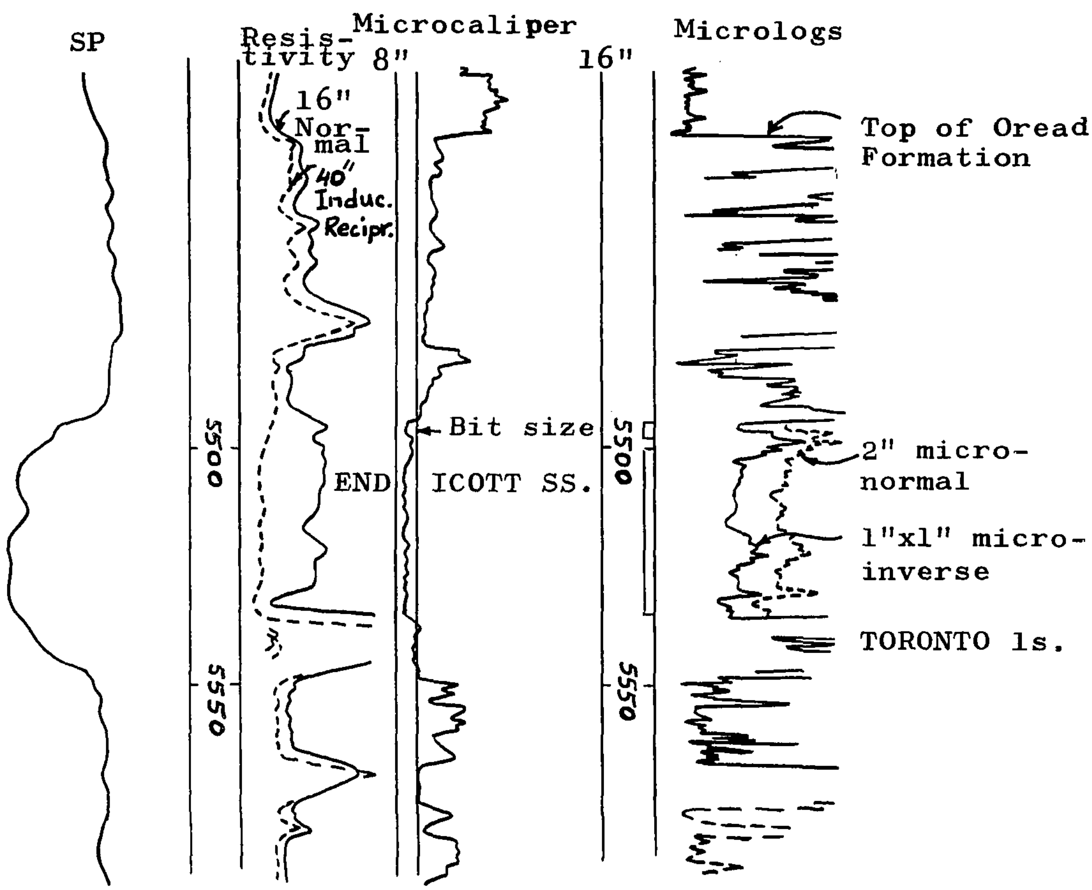



Fig. 18- Mechanical logs illustrating the porosity and permeability of the Endicott sandstone.

Sec. 9, T. 25 N., R. 25 W.

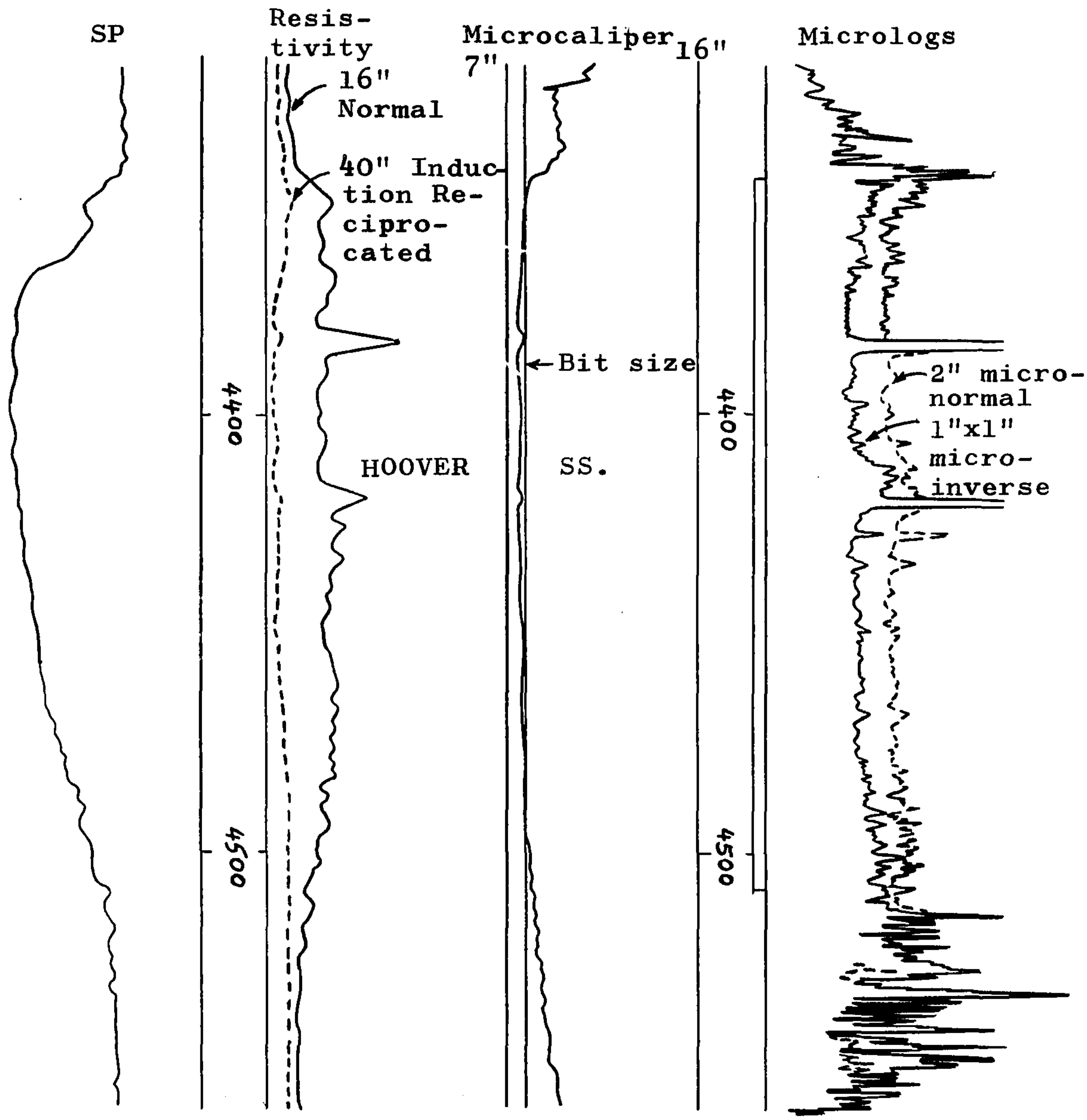



Fig. 20- Mechanical logs illustrating porosity and permeability of the Hoover sandstone.

## SEDIMENTATION AND PROVENANCE

Potter (1967, p. 340) defines a sedimentary environment ". . . by a set of values of physical and chemical variables that correspond to a geomorphic unit of stated size and shape." He visualized a geologist that reconstructed environments of ancient rocks as being a geomorphologist of the past. He grouped the properties utilized in environmental recognition into stratigraphic, internal sedimentary, petrographic, paleontologic, and geochemical.

Pennsylvanian environments of deposition are interpreted in this study primarily on stratigraphic and, to a lesser extent, petrographic observations. The latter have limitations and permit only tentative conclusions in terms of the geomorphology of the site of deposition.

Alluviation of Morrow channels is considered to be a result of change in sea level. Channel cutting upstream from deltas is subaerial, but infilling of such channels may be either subaerial or submarine. Point bars are deposited under conditions of subaerial fill, whereas submarine deposition results in response to marine transgression.

As previously pointed out, the Morrow sandstone members occur as a series of *en échelon* sandstones deposited during stillstands of the shoreline under conditions of cyclic subsidence. Coincident with a given stillstand, a barrier island system and beach sandstones were formed along a paleoshoreline, a pattern repeated several times during Morrowan deposition. A barrier island "pinches out" two to three miles before encountering the unconformity surface whereas a beach sand impinges directly against the unconformity surface. In general, Morrowan shorelines of the northwestern part of the area of investigation are characterized by beach sandstones, whereas those in the southeastern part are characterized by barrier islands. Both beach sandstones and barrier islands are widened seaward by deltaic distributary sandstones, and both are associated with offshore bars several miles seaward. The resulting depositional sequence for each stillstand reflects five distinct depositional environments: fluvial, deltaic, swamp, lagoonal, and littoral.

A cross section normal to the shoreline of a given stillstand sequence within the transgressive Morrow formation would show either swamp and lagoonal fill (see Figure 15 D and E) on and seaward from the bay shoreline followed laterally and seaward by a set of barrier islands; or beach sandstone resting directly upon the bay shoreline.

Such shore sand bodies are delta-tied and associated seaward with several subparallel offshore bars. After a stillstand, the overall transgression would continue, resulting in removal of some of the sand from the top of the beach sand, barrier islands, and offshore bars; the trends may shift and a shale sequence would be deposited. During the next stillstand, a similar shore and nearshore sand section would develop, but with different size and scale.

The pre-Morrowan surface was eroded by a series of consequent streams which became dendritic near their headwaters. Exceptional amounts of terrigenous clastic material were deposited at the mouths, forming deltas. Much of this sand, silt, and clay were redistributed by waves and longshore currents. The resulting barrier islands and beach sands paralleled the ancient shorelines and were reworked by eolian action (see Figure 15 D and E), oscillatory wave motion, and tidal currents. Storms may have created washover fan sand deposits in the swampy and lagoonal areas behind the barrier islands.

Petrographically, the Morrow sandstones consist of orthoquartzites, with few, if any, feldspars, igneous or metamorphic rock fragments. This orthoquartzitic composition could have originated in diverse fashions. The lack of feldspars and metamorphic and igneous rock fragments indicates a long period of abrasion and/or weathering (or a brief period of weathering under humid conditions) that caused the removal of such less stable components. Again, there is a possibility that the source of these orthoquartzites was a feldspar-deficient, quartz-rich, older sedimentary unit in any tectonic framework and almost any environment.

The physical nature of the environment of deposition of the Morrow sandstones is reflected by the textural maturity of those sandstones. Indirectly maturity is the result of tectonism (Folk, 1961). The deltaic and fluvial sandstones exhibit a relatively low degree of sorting and roundness (both indicative of low textural maturity). This indicates a low energy level and is characteristic of all such modern and ancient equivalents. The beach sandstones, barrier islands, and offshore bars, on the other hand, reflect a higher energy level that results in a higher stage of textural maturity.

The sandstones of the beach, barrier islands, and offshore bars seem to show a gradational decrease in textural maturity seaward. Updip, these sandstone bodies contain more sorted and rounded grains, they lack glauconite and/or chlorite; they are cemented with silica. Downdip, the same sandstone body is finer-grained, less sorted, glauconitic and chloritic with a significant increase in carbonate cement. Locally, this carbonate cement may constitute 50 per cent of the total rock volume, and force apart the grains of quartz to develop the texture known as "floating" sand grains. Adams (1964), in studying the diagenetic aspects of Lower Morrowan sandstones in Ellis County, Oklahoma, termed the updip facies "type A," and the seaward facies, "type B" sandstones. Similar seaward decrease in textural maturity is revealed by petrographic study of the Mesaverde "bench" sandstones (Hollenshead and Pritchard, 1961). They discovered that the relatively best sorted and cleanest sandstones lie along the updip edge of each "bench," and that silt and clay content increases gradually seaward.

The Morrow shore and nearshore sandstones display mineralogical and physical characteristics similar to sands upon many present-day shores. In this respect, the Morrow sandstones may be considered as excellent ancient analogs. In contrast, the Mesaverde sandstones are not as well sorted as modern beach sands. Hollenshead and Pritchard (1961) attributed this dissimilarity to the possibility of more rapid rate of sedimentation during Mesaverde time than sedimentation along many of the present-day shorelines. A faster rate of sedimentation allowed little time for sorting and rounding of sand grains. By the same token, the rate of sedimentation during Morrowan time was similar to sedimentation along many of the present-day shorelines, particularly along the Texas Gulf Coast. It is to be noted that this similarity of the rate of sedimentation occurred only at the still-stand positions of the shorelines, otherwise sedimentation was transgressive. It is during times of stillstand positions of Morrowan shorelines that the rate of sedimentation is assumed to have been in equilibrium with the rate of subsidence. It was during these times of stabilized shorelines that the sands were washed clean and developed rounding of the grains.

With prolonged tectonic stability, a granite or granitic gneiss can supply orthoquartzitic sands in either a humid or an arid climate. A much shorter period of tectonic quiescence would be necessary in a humid climate, because abrasion would be aided by chemical decay. A period of tectonic quiescence of the order of one or two geologic periods is required under arid conditions, whereas one-eighth this period is sufficient under humid conditions (Folk, 1961).

Likewise, a long period of tectonic stability is required to obtain orthoquartzite from a metamorphic or vein-quartz source. An older sedimentary source rock, on the other hand, requires a relatively brief period of tectonic stability, because the source rock is already enriched in quartz. In fact, orthoquartzites are derived from reworked sediments following orogenies.

The lack of reworked carbonate fragments in Morrow sandstones precludes the underlying Mississippian rocks as the source area. However, this carbonate erosional surface supplied the streams upon it with calcium bicarbonate before they entered Morrowan seas; accordingly, the Mississippian surface is the logical source of calcite cements in the sandstones that exhibit low stages of maturity.

It seems reasonable to conclude that the Nemaha granite ridge was a source of sediments during Morrowan time. This conclusion is based on the assumption that the climate was humid and on the fact that tectonic conditions consisted of gradual epeirogenic upwarps and downwarps during pre-Morrowan time. The medium to fine grain size, mature-to-supermature sandstones with extreme roundness, the scarcity of heavy minerals, and the abundance of quartz overgrowths as cement in the clean, well-sorted, and well-rounded sand grains, all support this conclusion. The abundance of chert in association with two classes of predominant roundness suggest the Central Kansas Uplift as another possible source area.

The upper member of the Tonkawa sandstone and the Endicott sandstone represent deltaic deposits confined to the shelf area along the northern side of the Anadarko Basin. The depositional strike of both of these sandstones is east-westward. The two deltas are readily recognizable for they prograded abruptly into shallow marine water. Marine northward transgression drawned the deltas as sites of deltaic sedimentation. The upper Tonkawa and Endicott deltas undoubtedly each represents a composite of several stages of distributary development. A similar ancient example is the Booch delta of Oklahoma, described by Busch (1953).

Deltas are described as having developed through two phases, constructional and destructional (Scruton, 1960). During the constructional phase, the deltaic sedimentary unit from the bottom-set to top-set beds, develops under rapid rate of sedimentation. The build up of the sea floor continues subaqueously because of a "filling-in" process. The deltaic sequence contains deposits from many environments. Visher (1965) listed these as fluvial, flood plain, paludal, lacustrine, lagoonal, tidal flat, estuarine, bay, eolian, bar, delta fringe, and pro-delta. However, only three basic low energy environments are responsible for delta growth (Scruton, 1960; Visher, 1965). These are the transitional (save-agitated delta fringe sands), pro-delta, and distal. These environments are equivalent to those established on the undaform, clinoform, and fondoform, respectively. The seaward migration of these environments is responsible for delta growth.

The destructional phase of a delta begins with compaction and subsidence that permits transgression of the sea and deposition of a veneer of marine sediments that serves to preserve the delta.

Petrographically, the upper member of the Tonkawa and the Endicott sandstones are immature to submature deltaic sandstones, indicating deposition under low-energy conditions. In composition, they consist of quartz and chert, with little or no feldspar. The source of the upper member of the Tonkawa and of the Endicott sandstones was to the north, in the direction of the Central Kansas Uplift.

The Hoover sandstone was deposited as an extensive mass of deltaic sediments that accumulated at the edge of an undaform and in the heads of submarine canyons or trenches, such as in T. 25 N., R. 23 W. These canyons probably were eroded by turbidity currents. As Rainwater (1966) pointed out, the basic argument for the establishment of the theory of "turbidity currents" is the fact that Foraminifera in shales interbedded with nonfossiliferous sandstones are similar to recent Foraminifera living in more than 1,000 feet of water.

The high matrix content of the Hoover sandstone indicates lack of sorting or deposition in a low energy environment, where winnowing action was essentially lacking. The survival of some feldspars further substantiates the conclusion that the sandstone was deposited at a rapid rate and was derived from a relatively rugged source area.

Krumbein and Sloss (1963) stated that subgraywacke, Hoover type of sandstone, occurs under conditions of moderate subsidence in unstable depositional areas. Therefore, the Hoover mineralogical composition further supports the idea of repeated "cyclo-phase" deposition of the Upper Virgilian sequence, of which the Hoover is a part. The repetition of successive cycles, each of which is composed of a carbonate-black shale phase and a clastic phase, is due to either cyclic subsidence or cyclic rise in sea level under conditions of steady sediment supply. In fact, many of the sandstones associated with the Pennsylvanian cyclothem type of deposition are subgraywackes (Krumbein and Sloss, 1963).

The clastic phase of each cycle (the Hoover sandstone being part of the clastic phase of the final cycle) is interpreted as having been deposited in a regressive sea, as a result of either a lowering of sea level or because sedimentation proceeded faster than subsidence.

The depositional strike of the interval from "Marker A" to the top of the Pennsylvanian, of which the Hoover sandstone is a part, is north-southward. This strike, plus the mineralogic composition of the Hoover, suggests a source area to the east, in the direction of the Nemaha granite Ridge.

# GEOLOGIC HISTORY

The Anadarko Basin began to form in Early Pennsylvanian time, and continued to subside throughout Pennsylvanian and most of Permian time.

Mississippian strata are separated from Lower Pennsylvanian strata by pronounced unconformity. In Early Pennsylvanian time the weathered and eroded Mississippian surface was truncated progressively deeper northward, and inundated by cyclic marine transgression. At each still-stand of the shoreline, beach sands and barrier island complexes were deposited; some offshore bars were formed. Numerous, localized arcuate deltas were tied to the shore deposits. Pronounced embayments in the bay shoreline occurred at the debouchures of the numerous streams that eroded into the Mississippian surface. As marine transgression progressed, the base level of deposition of each of these drainage courses shifted upstream and, as a result, their channels became clogged with sand.

The upper Tonkawa and the Endicott deltas probably were deposited adjacent to coastal plains of relatively high relief, because sand bodies form major parts of their framework. In contrast, the present Mississippi delta, as a typical modern delta, adjoins a coastal plain of low relief, and receives only a minor fraction of sand-size material in its deposits.

Both the upper Tonkawa and Endicott deltas are confined to the northern shelf of the Anadarko Basin. Both deltas prograded fairly abruptly into shallow marine water as the rate of sedimentation exceeded that of subsidence; thus, deltaic conditions were terminated by marine transgression. These processes account for the constructional and destructional phases of delta development.

Late Pennsylvanian rocks upon the northern shelf of the Anadarko Basin are subdivisible into two genetic intervals. One of these comprises the rock interval between the Elgin limestone and "Marker A" (see Figures 2, 12, and 13). This genetic interval thins basinward and is ascribed to a period of basin starvation. It was a period during which the Anadarko Basin was subjected to subsidence at a rate far in excess of sedimentation. Supply of clastics was limited and, consequently, "Marker A" (top of this genetic interval) displayed striking changes in stratigraphic position, indicative of undaform, clinoform, and fondoform topographic units.

The other genetic interval comprises the rocks deposited between "Marker A" and the Burlingame limestone (see Figures 2, 12, and 13). This genetic interval thickens basinward and signifies a return to normal supply of sediments. The Hoover sandstone as part of this genetic interval is now contained within the rocks of the clino-fondo environment after having been transported down the undaform, and deprived of its natural association with the undathem.

This study indicates that the dominant paleoslope in the Anadarko Basin of northwestern Oklahoma rotated from the south to the west during Pennsylvanian time. This implies an increase in westward structural tilt in Late Pennsylvanian time.

## CONCLUSIONS

1. The Mississippian land surface at the outset of Pennsylvanian time was characterized by dendritic paleodrainage pattern.
2. The dominant direction of drainage during the time immediately preceding the Pennsylvanian was south-southwest.
3. The Morrow formation is a genetic sequence that includes numerous lenticular reservoir sandstones.
4. Northeastward, the Morrow formation thins to featheredge by onlap.
5. The Morrow channel sandstones represent stream deposition in valleys eroded into the uppermost part of the Mississippian System.
6. Successive Morrow deltas, which were formed during periods of stillstand of the shoreline, are localized and arcuate.
7. The Morrow deltas were the depocenters for the Morrow shore sand deposits, which were deposited along the margin of the northeastern shelf of the Anadarko Basin.
8. Porous and permeable linear Morrow sandstones of the beach and barrier islands display northwest-southeastward trend. The beach sandstones impinge directly

against the unconformable Mississippian land surface, whereas barrier islands "shale out" two to three miles before encountering the unconformity surface. In some instances, both the beach sandstones and the barrier islands are associated with offshore bars situated several miles seaward beyond the geologically critical basin shoreline.

9. The sandstones of Morrowan barrier islands grades updip northeastward into impermeable shales and sandstones that were deposited in swamp and lagoonal environments. These swampy and lagoonal sediments were deposited between the lagoonal shoreline of D. Johnson (1919), herein termed the bay shoreline, and the landward extent of the barrier islands.

10. Narrow tidal inlets through the Morrowan barrier islands were common. Mud filling of these inlets accounts for permeability barriers that occur occasionally along sandstone trends.

11. The Morrow shorelines during stillstand positions resembled the western segment of the present Texas Gulf Coast in physiographic features, and in the dominance of deltaic sedimentation processes responsible for the configuration.

12. Different levels of energy are deduced from petrographic studies of some Morrow sandstones. Fluvial and deltaic sandstones are submature, thus reflecting

low energy conditions. The shore and nearshore sand deposits reflect both high and low energy levels, fossils being fairly common. The landward segments contain clean, well sorted and rounded sand grains, which suggest a higher energy level than their seaward facies equivalents. The landward segments are siliceous, non-glauconitic, and further characterized by low porosity and permeability, due to diagenesis. The seaward sandstone facies are glauconitic, with calcareous to dolomitic and chloritic cement, and with fair porosity and permeability.

13. Morrow sandstones of swamp and lagoonal environments behind the barrier islands display textural inversion which probably is due to well-rounded grains having been blown off the barrier islands into a low energy environment.

14. Compositionally, the Morrow sandstones are classified as mature and orthoquartzitic.

15. The Morrow shore and nearshore sandstones have mineralogical and physical characteristics similar to sands upon many present-day shores; and accordingly, such sands may be considered excellent ancient analogs.

16. The Tonkawa sandstone body is composed of several reservoir sandstone members. The uppermost member represents an arcuate delta deposited as a single, regressive, prograding lithic unit during a "moment" of geologic time.

17. The upper member of the Tonkawa sandstone is fine-grained, angular to subangular, moderately sorted, porous, and micaceous.

18. The Endicott consists of interbedded sandstone, siltstone, and claystone fill of distributary channels of another arcuate delta.

19. The Endicott sandstone is a very fine-grained, calcareous, submature orthoquartzite.

20. The deltas of the upper member of the Tonkawa and the Endicott were deposited upon the northern shelf area, or undaform, of the Anadarko Basin.

21. The Upper Virgilian stratigraphy involves two different, but related, principles of sedimentation; the first relates rocks to their respective depositional environments, unda, clino, and fondo; the second pertains to basin starvation.

22. Upper Virgilian rocks exhibit "cyclophase" deposition. Each cycle consists of two phases: an argillaceous carbonate-black shale phase and a clastic, sand-shale, phase. The former was deposited during a rise of sea level, and the latter, during a fall or stillstand of sea level. A net rise of relative sea level occurred despite fluctuations.

23. The Hoover sandstone was transported by turbidity currents and deposited in a clino-fondo environment. Petrographically, the sandstone is an immature subgraywacke.

24. Post-Pennsylvanian structural tilt is southward.

25. Structure had little or no influence in localizing gas accumulation in the Morrow sandstones, whereas structure and stratigraphy (facies changes) were of equal significance in localizing gas accumulation in the Hoover and upper Tonkawa sandstones. The Endicott sandstone is water-bearing in the area considered.

26. The results of this study indicate that the dominant paleoslope in the Anadarko Basin of northwestern Oklahoma rotated from the south to the west during Pennsylvanian time.

27. Source areas for Pennsylvanian terrigenous sediments in the study area were the northwestward-trending Central Kansas Uplift to the north-northeast, and the northward-trending Nemaha granite Ridge to the east. These areas probably continued as dominant detrital sources throughout the Pennsylvanian Period.

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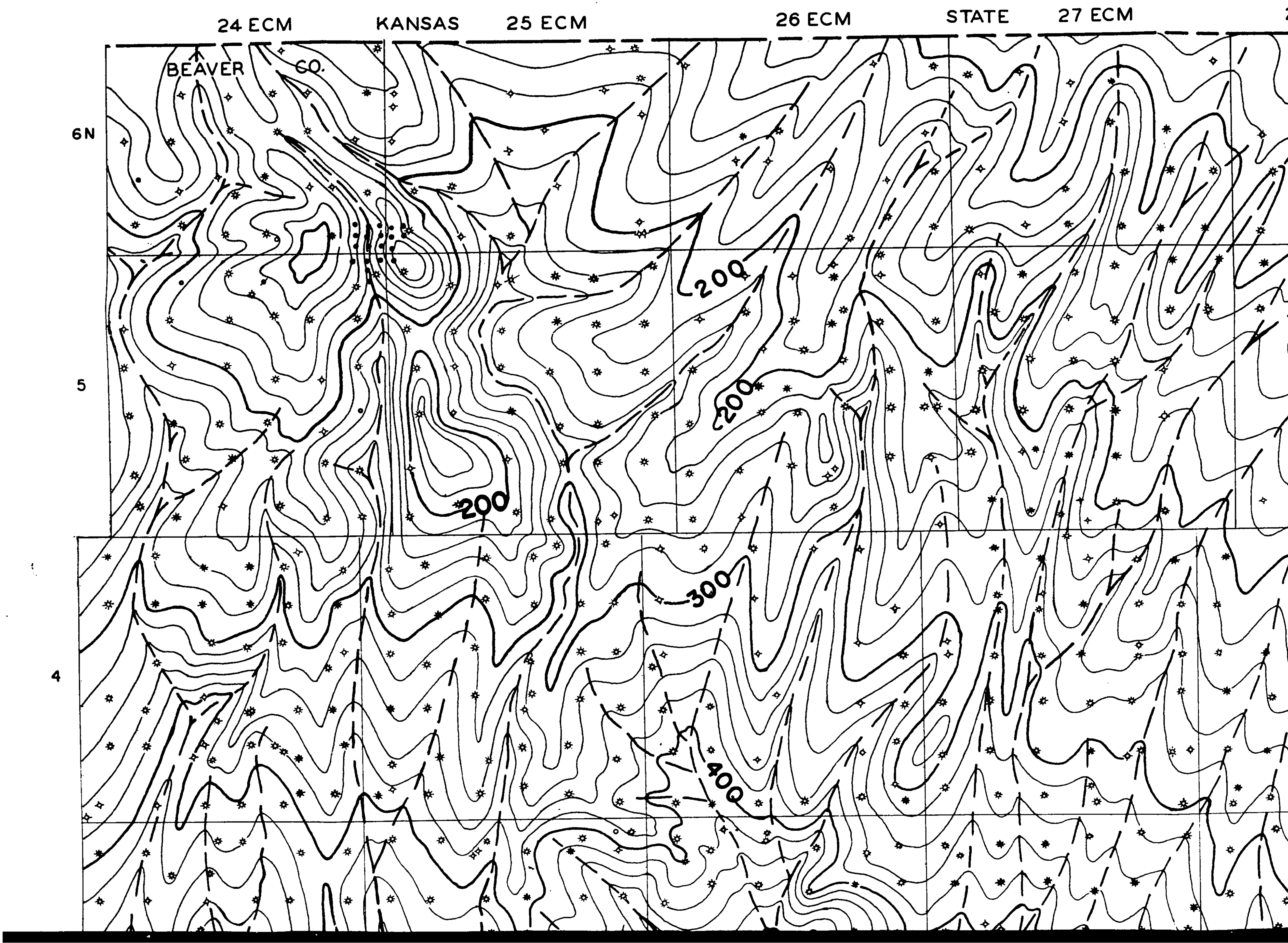
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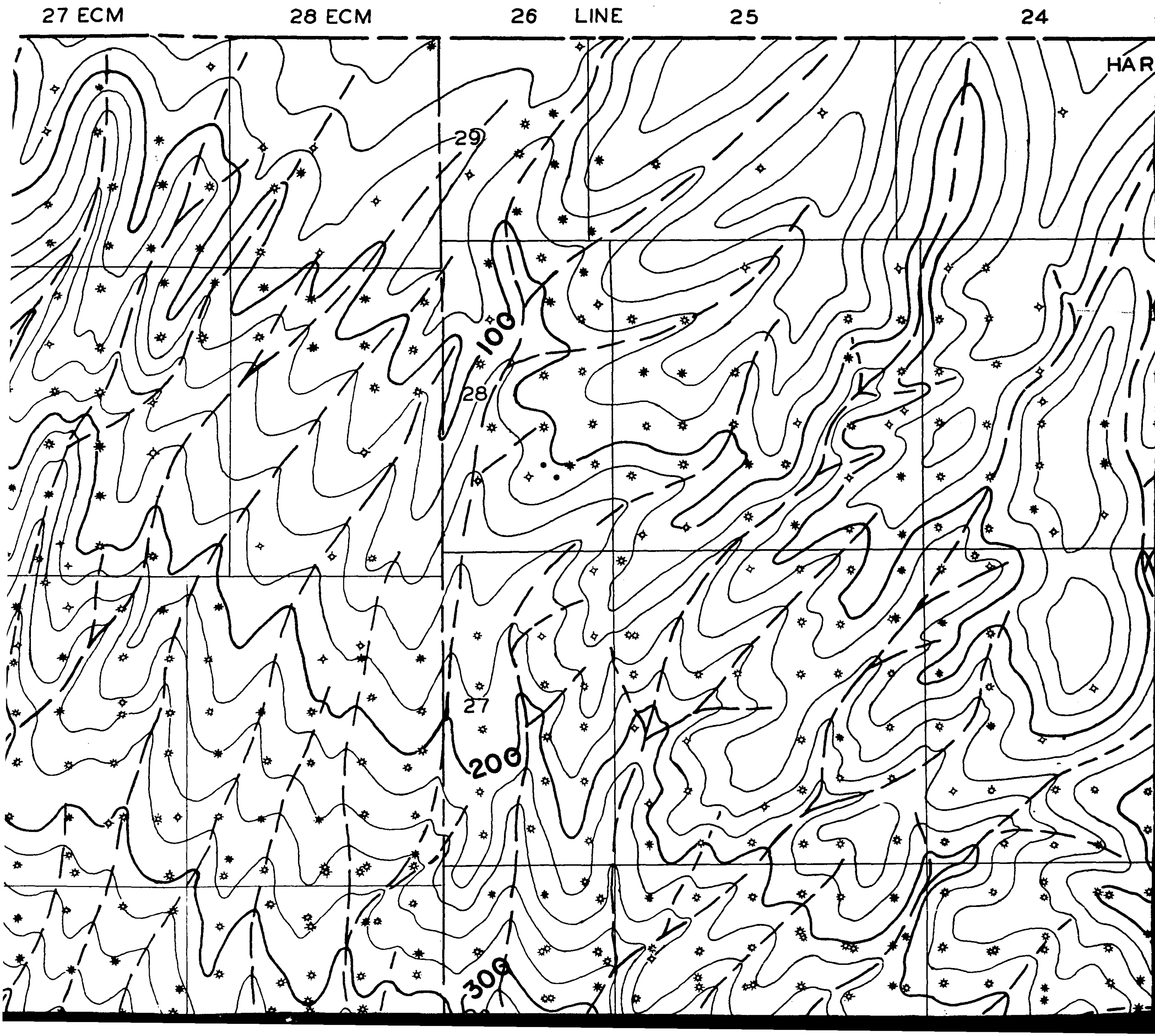
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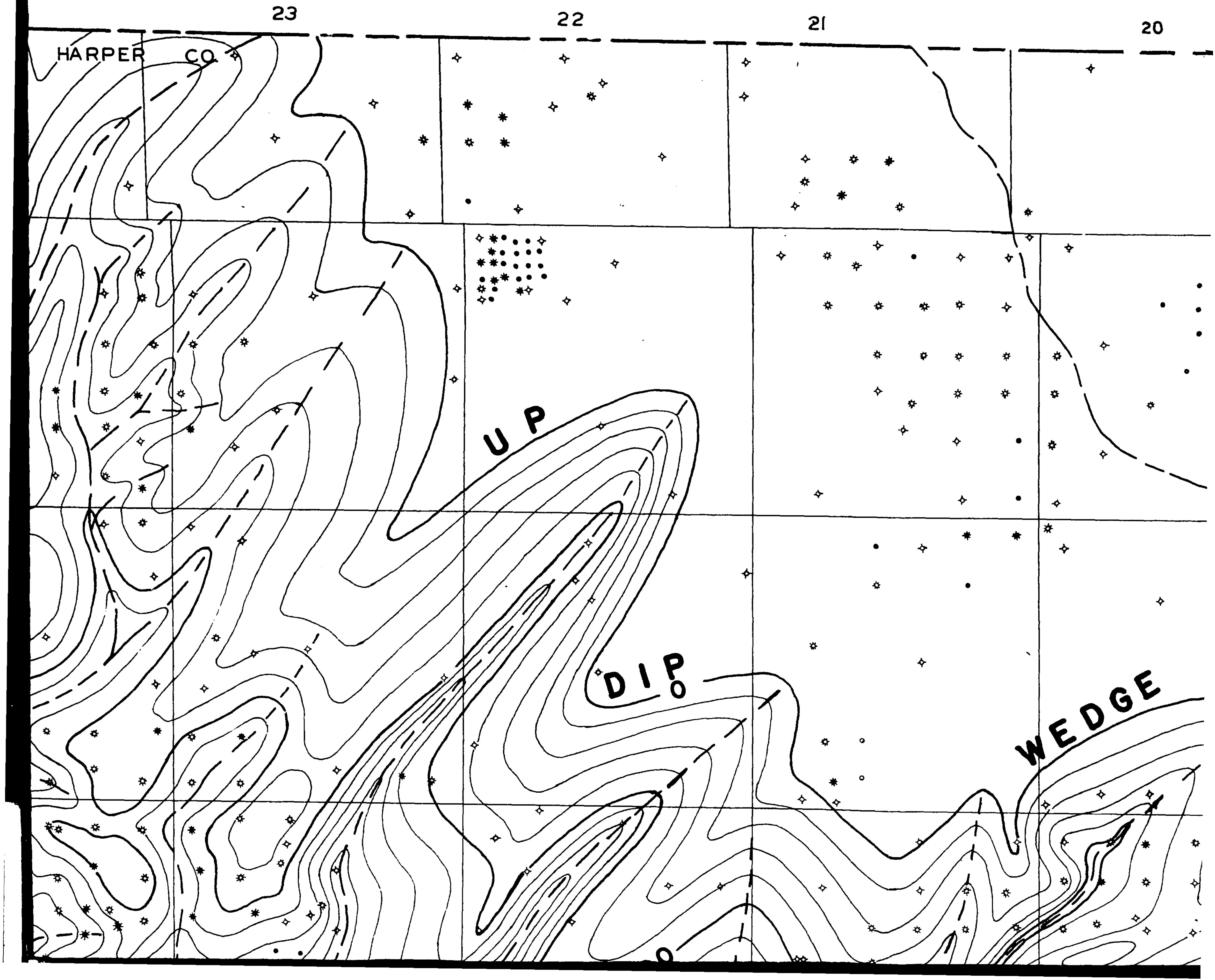

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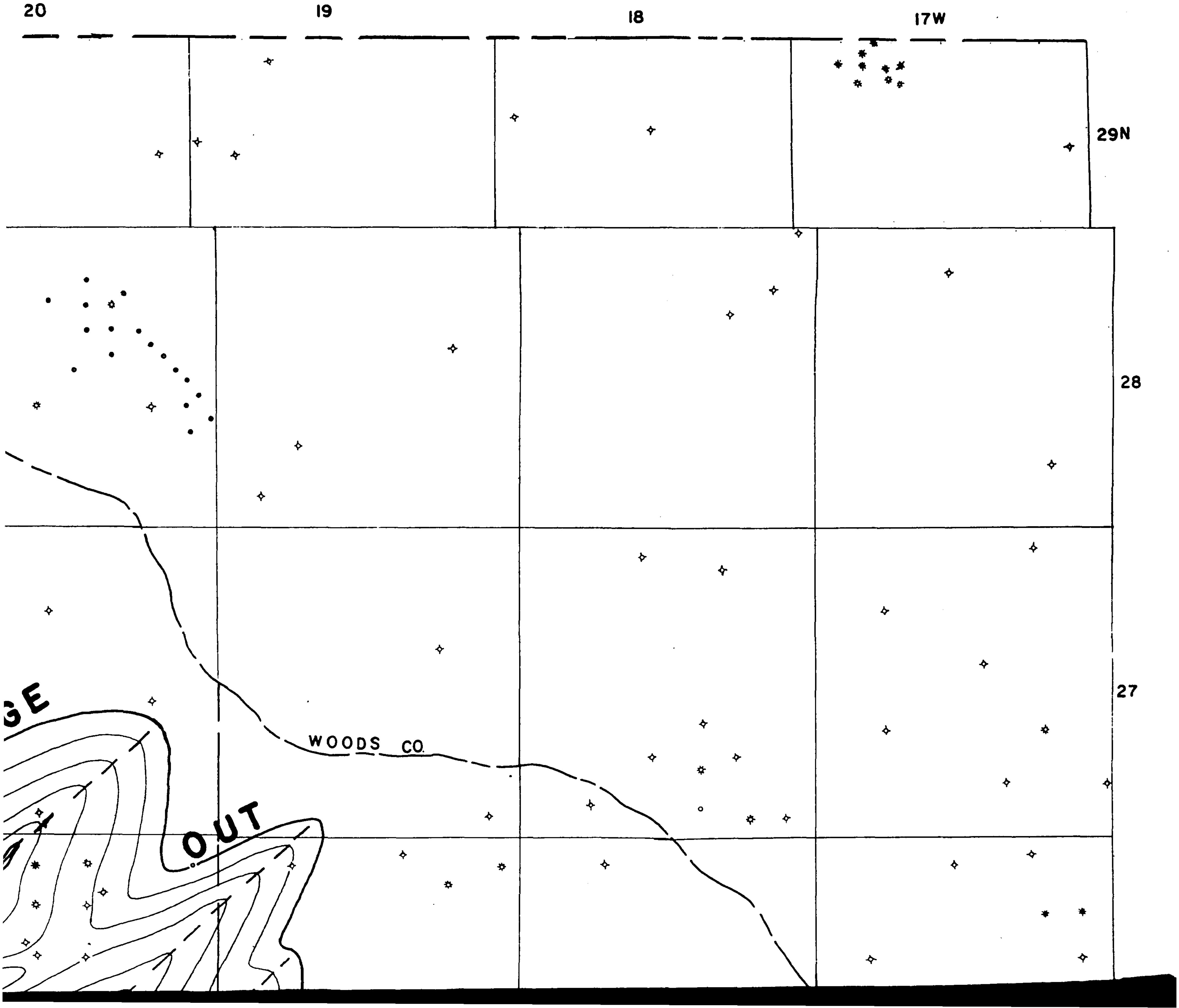

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WOODS CO.
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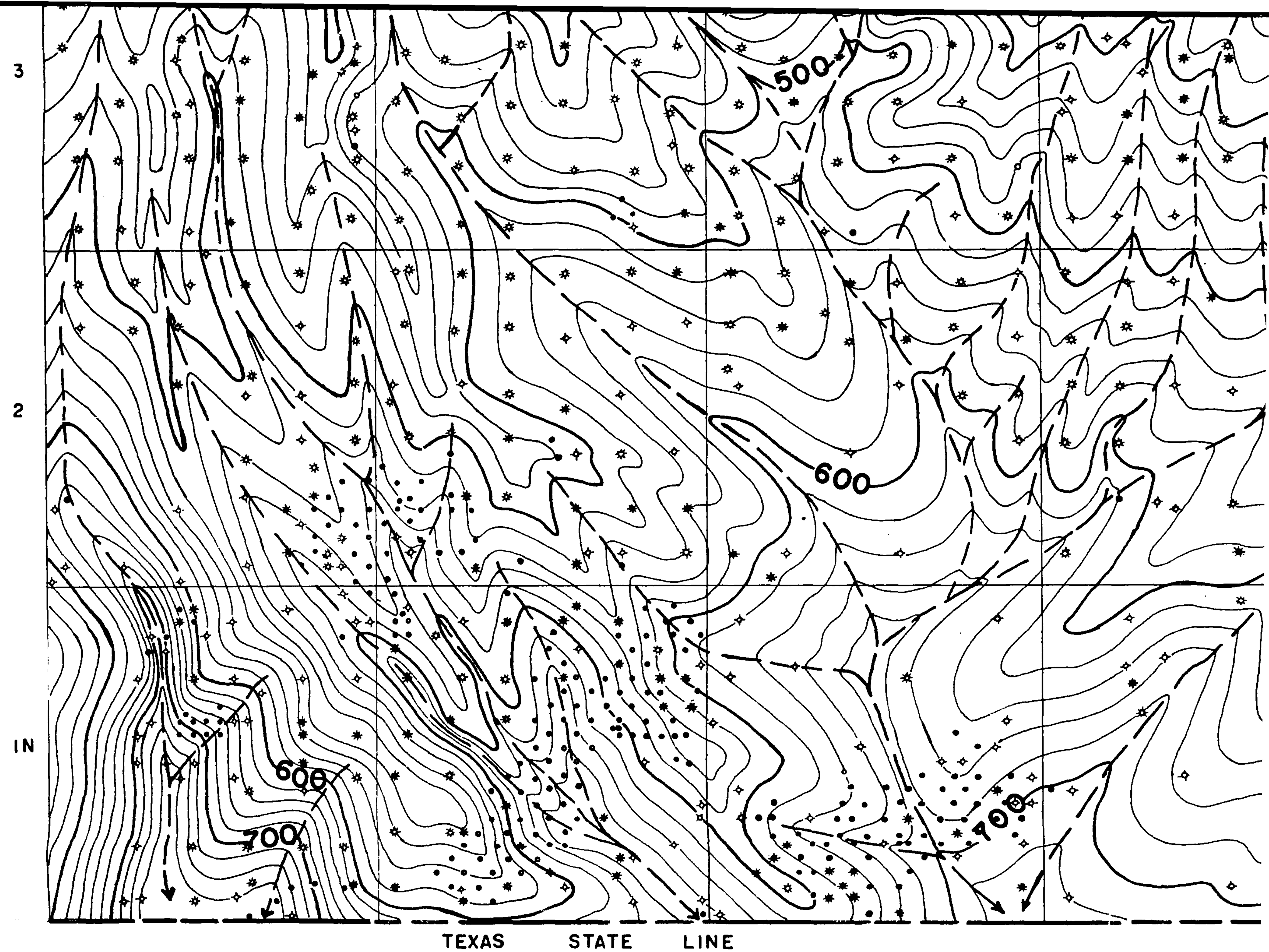
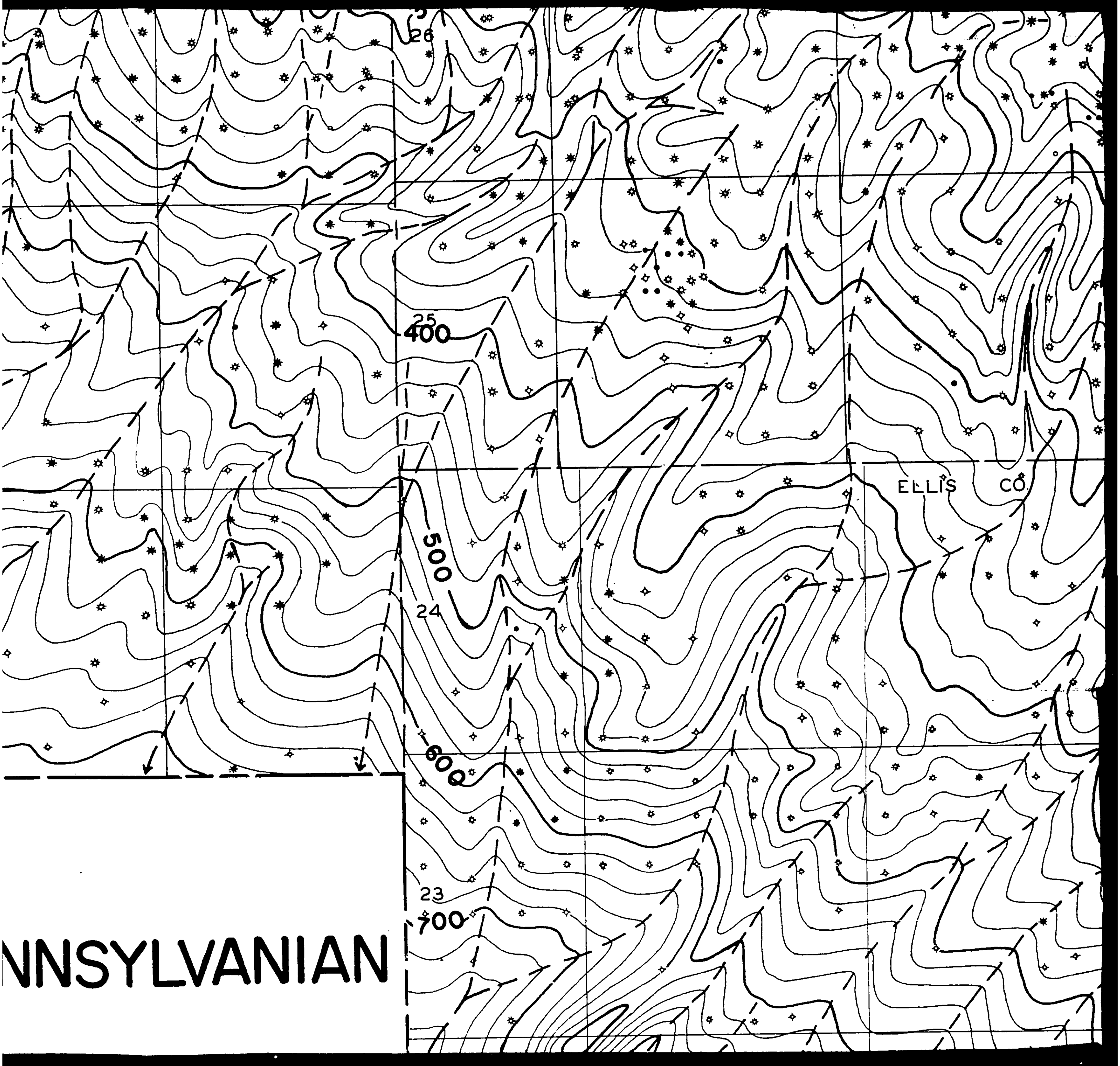



# PALEOTOPOGRAPHY OF PRE-PENN LAND SURFACE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ELLIS CO.
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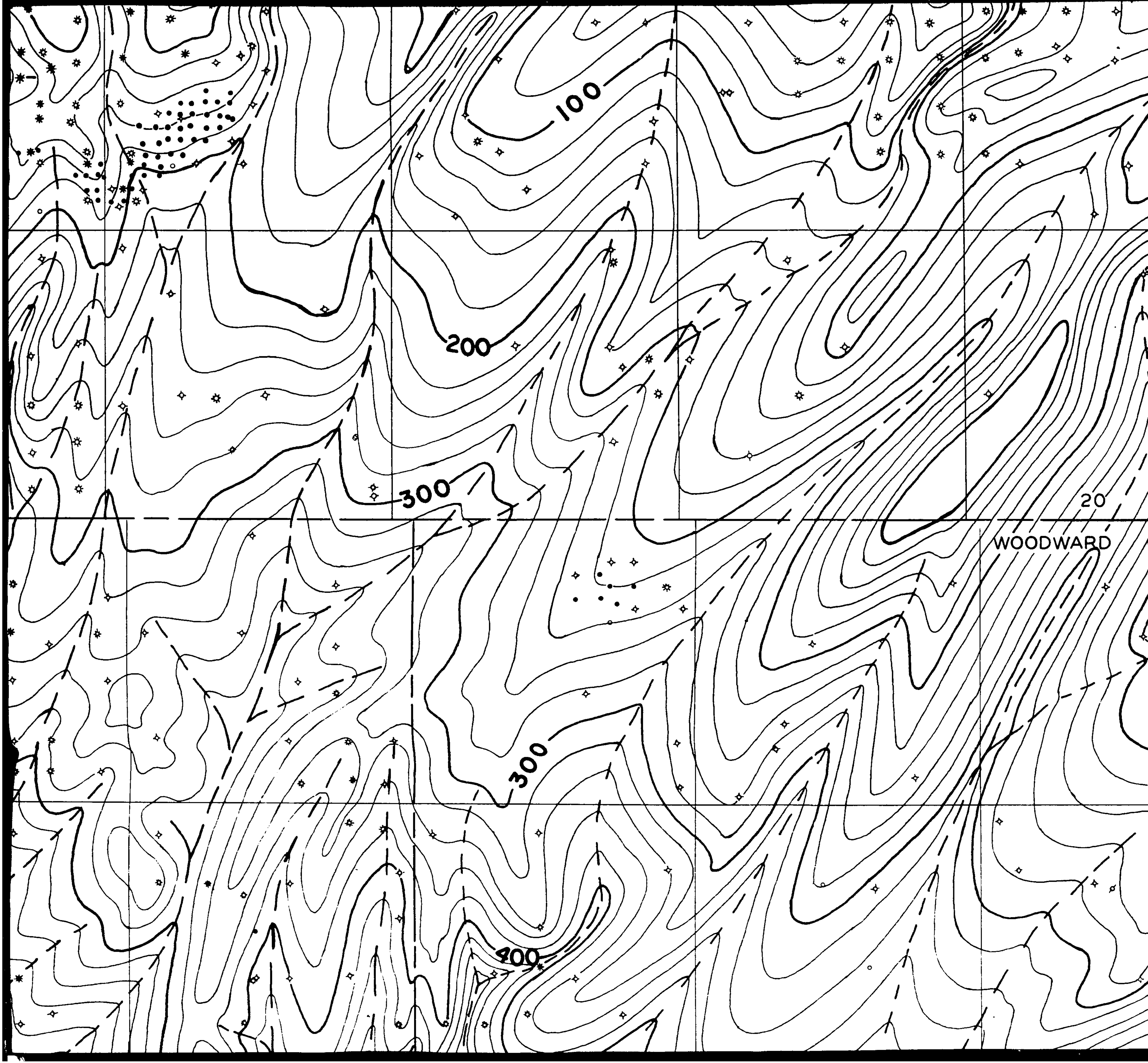
NNSYLVANIAN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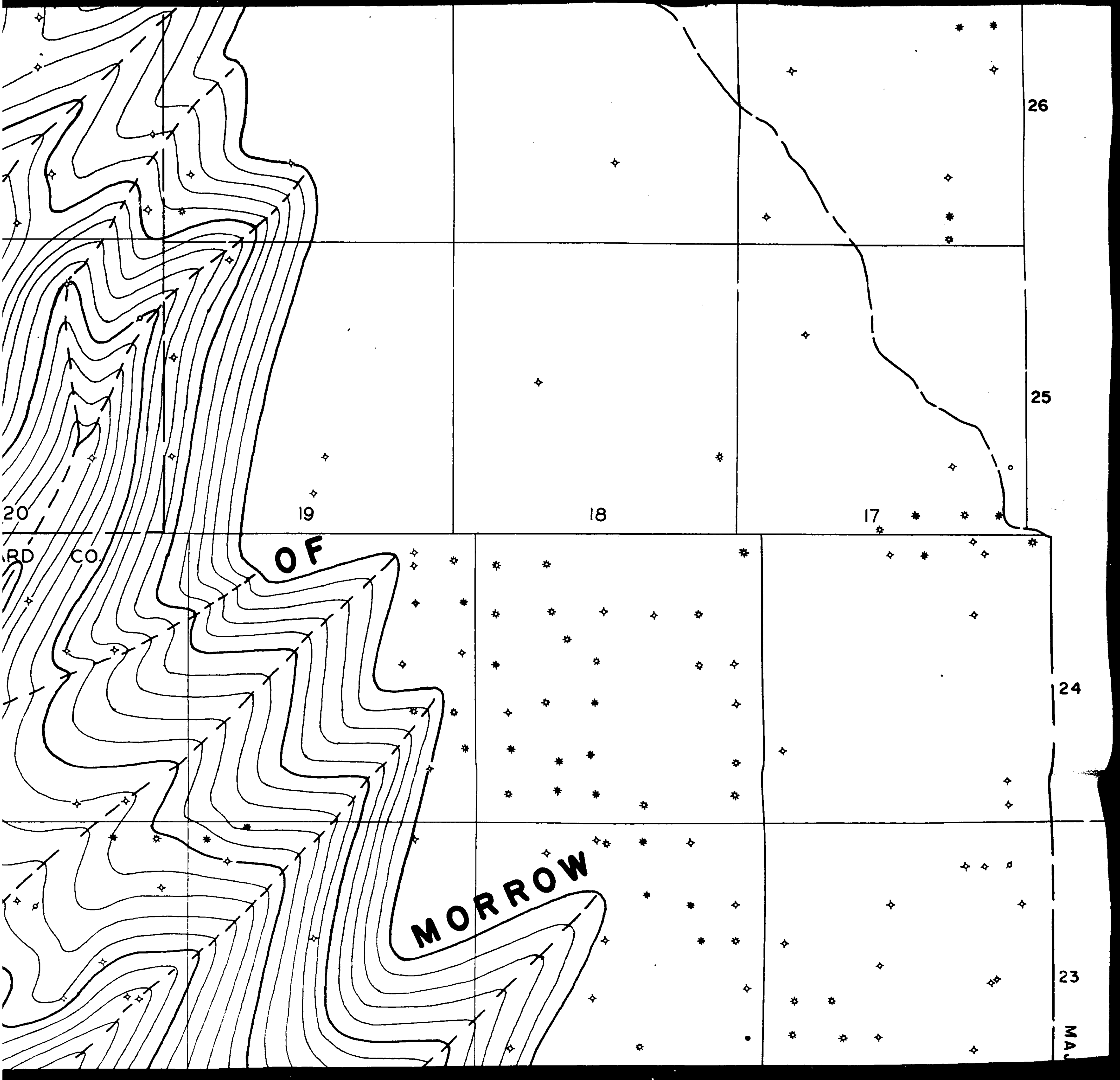
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CO.
OF
MORROW

# PALEOTOPOGRAPHY OF PRE-PENNSYL
# LAND SURFACE

## (ISOPACH, MORROW FORMATION)

## NORTHWESTERN OKLAHOMA

C. I. = 20 ft.

SCALE IN MILES:

0 1 2 4 6

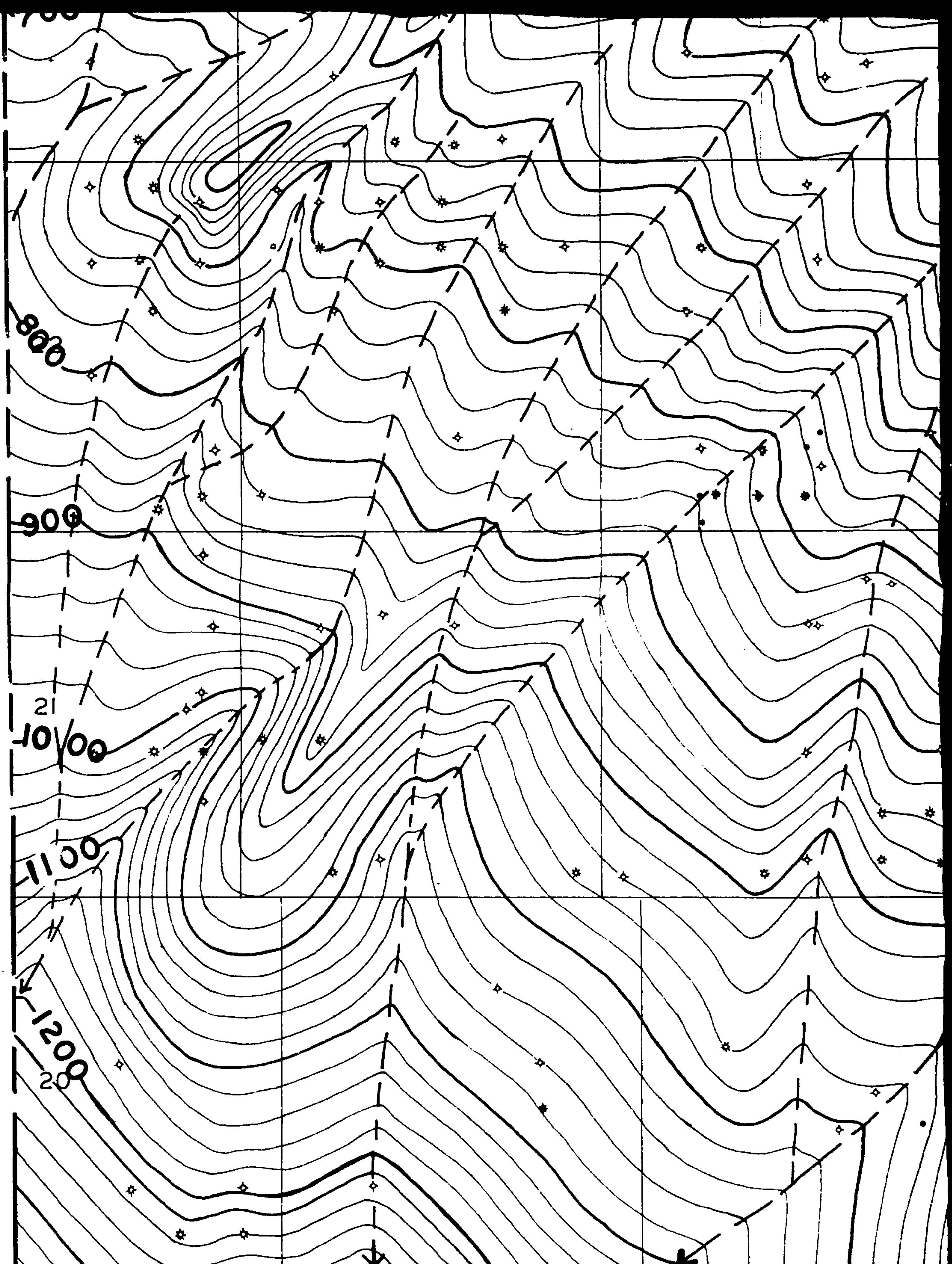
PLATE I

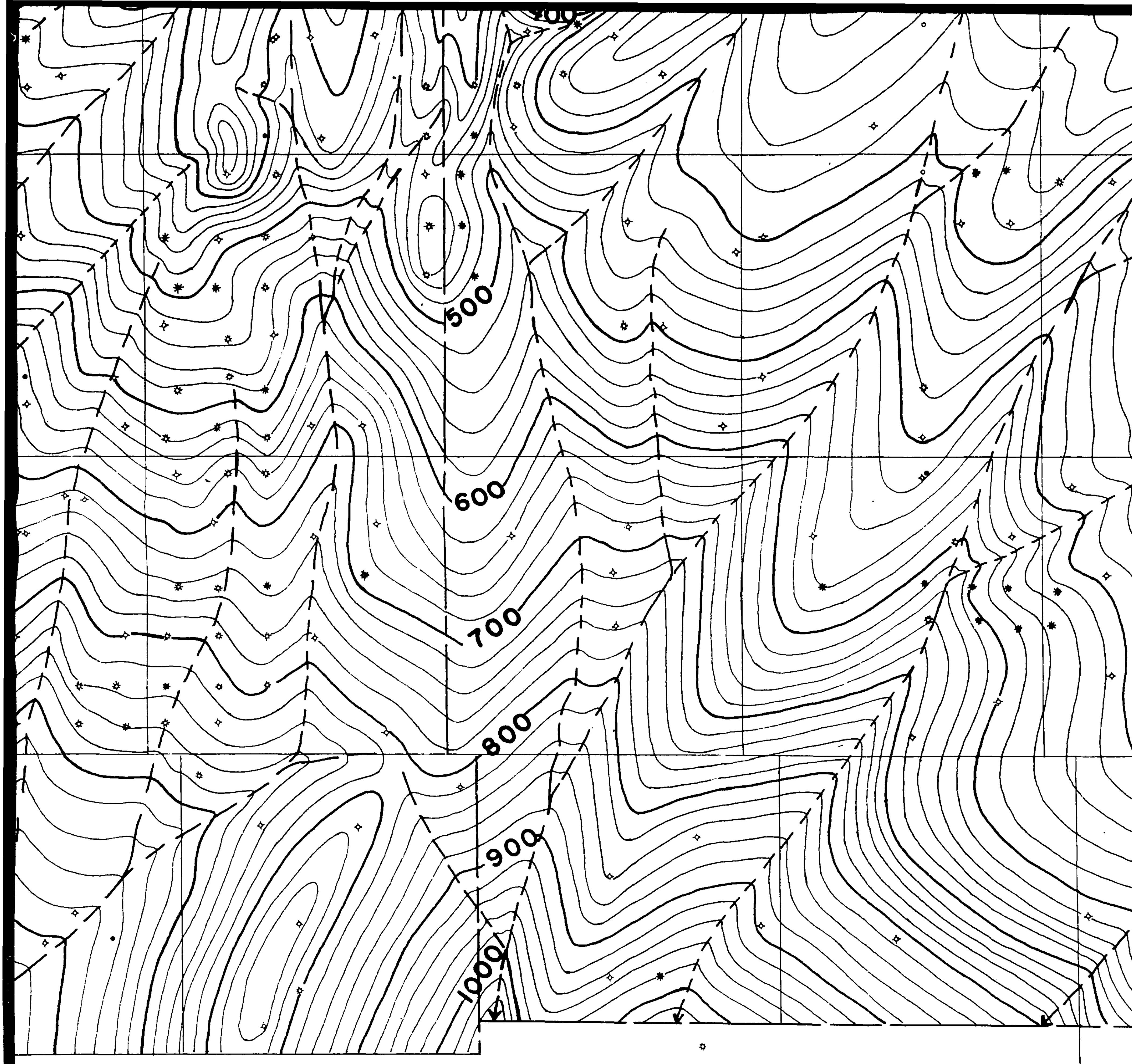
UNIVERSITY OF OKLAHOMA MOAYAD H. KHAIWKA Ph.D. 1968

SYLVANIAN

J)

68





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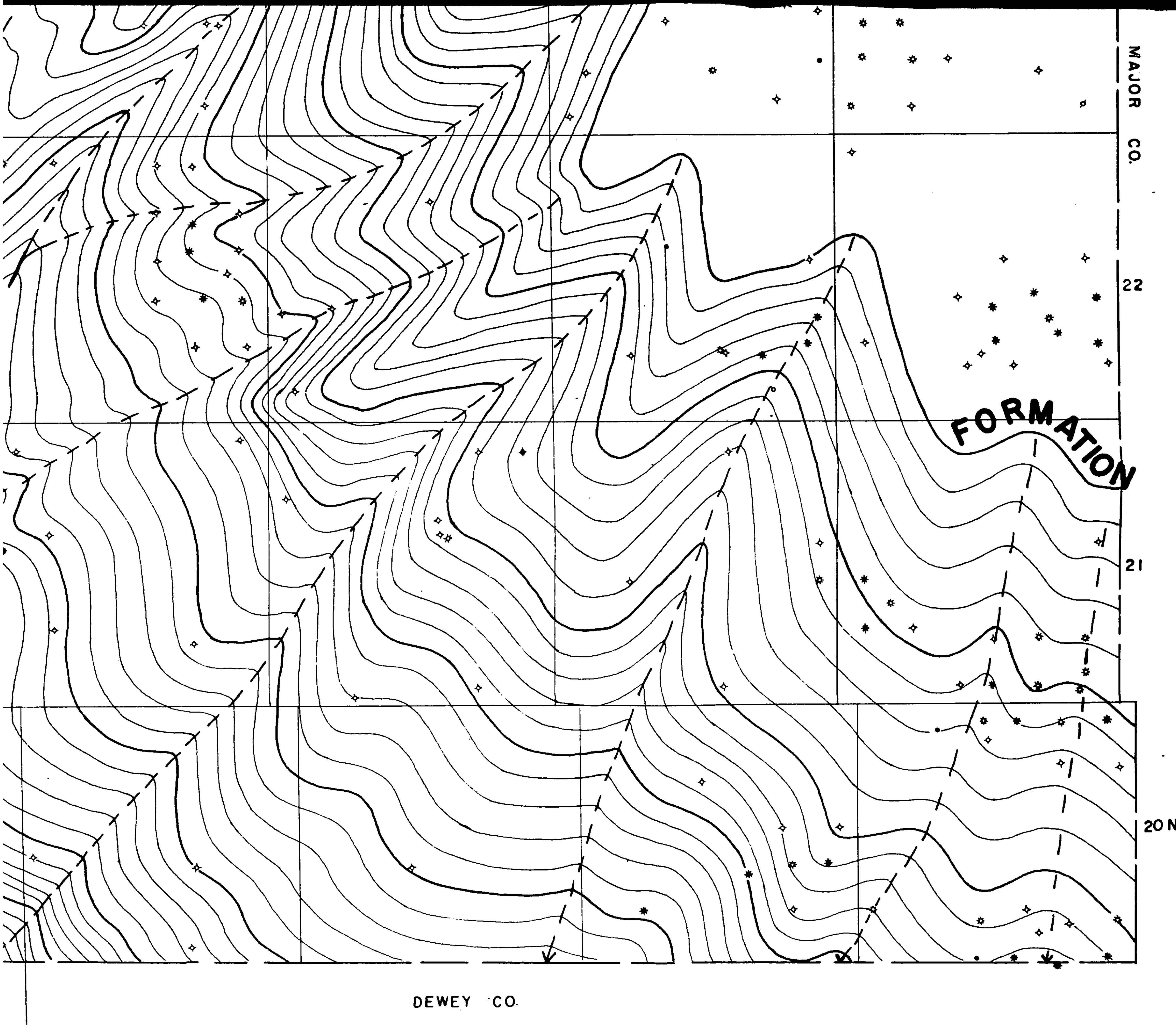
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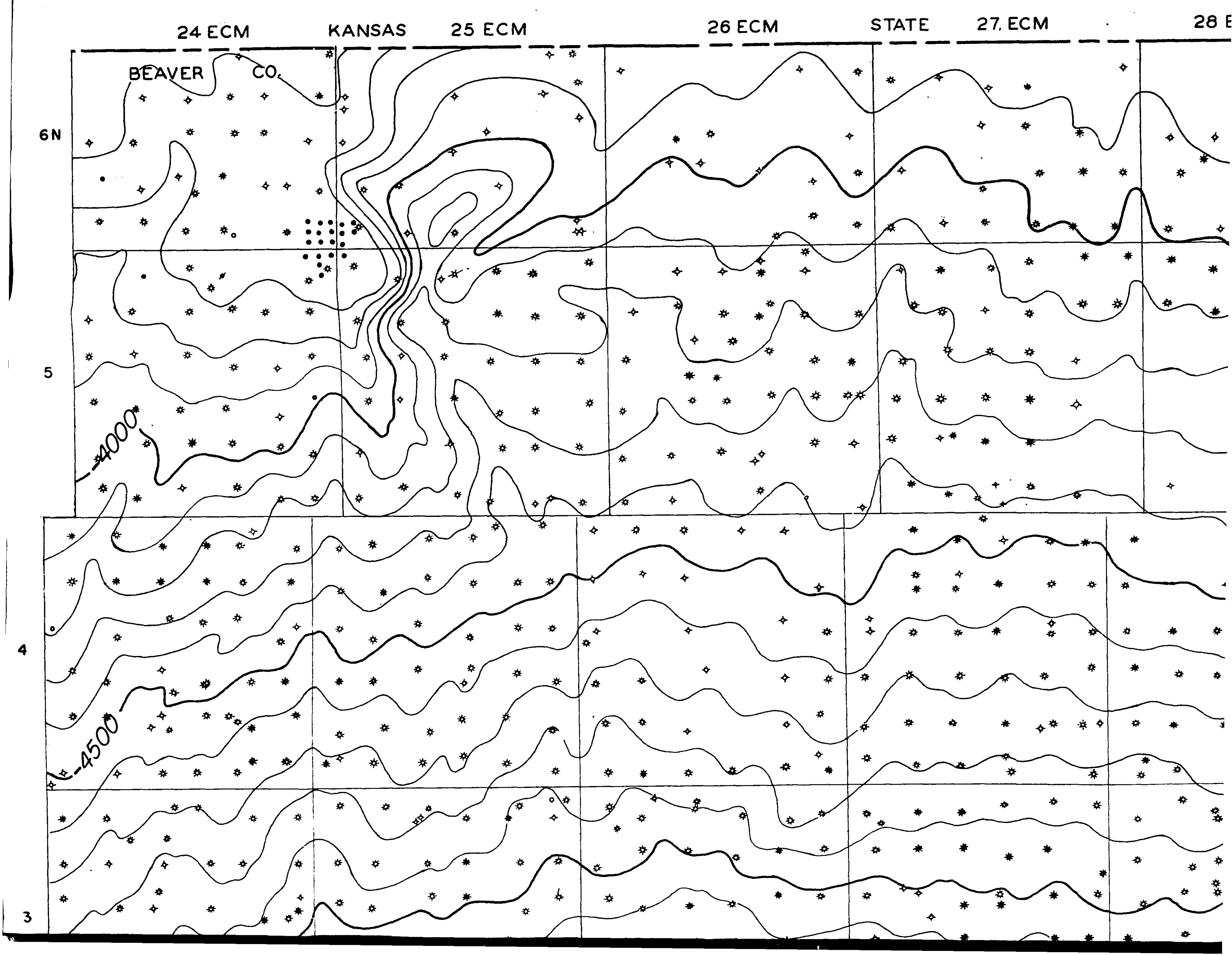
DEWEY CO.



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STATE
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BEAVER CO.
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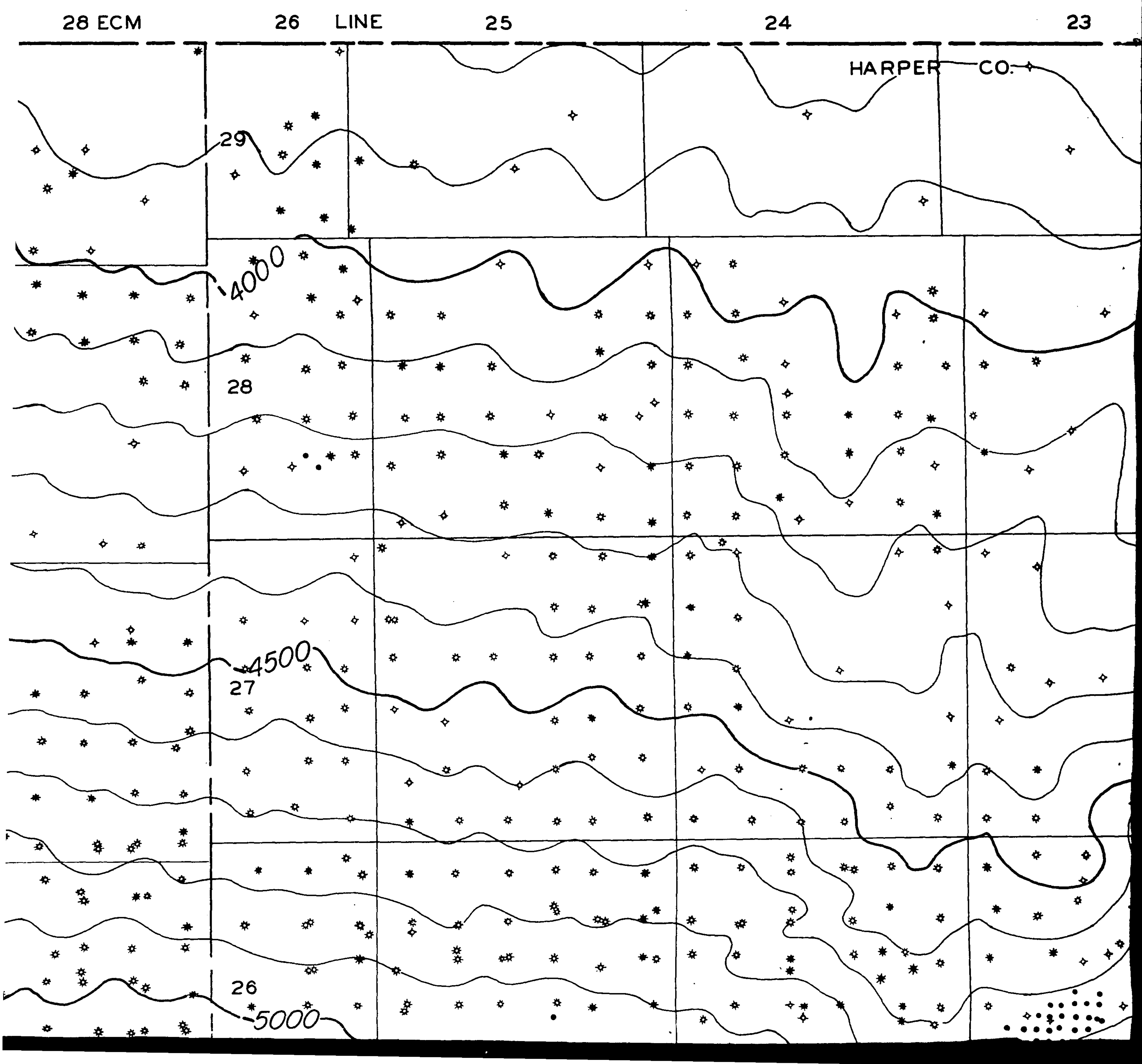
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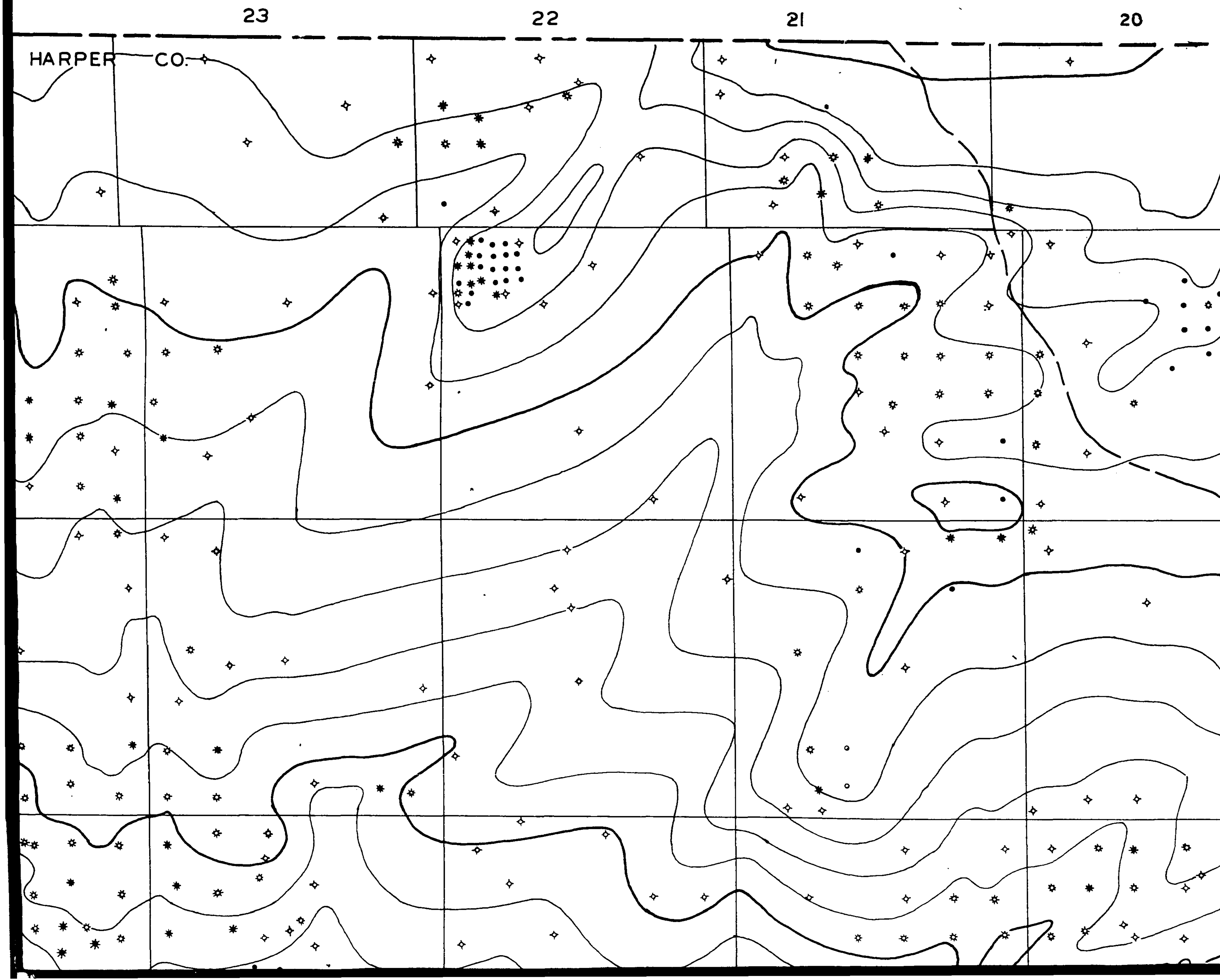

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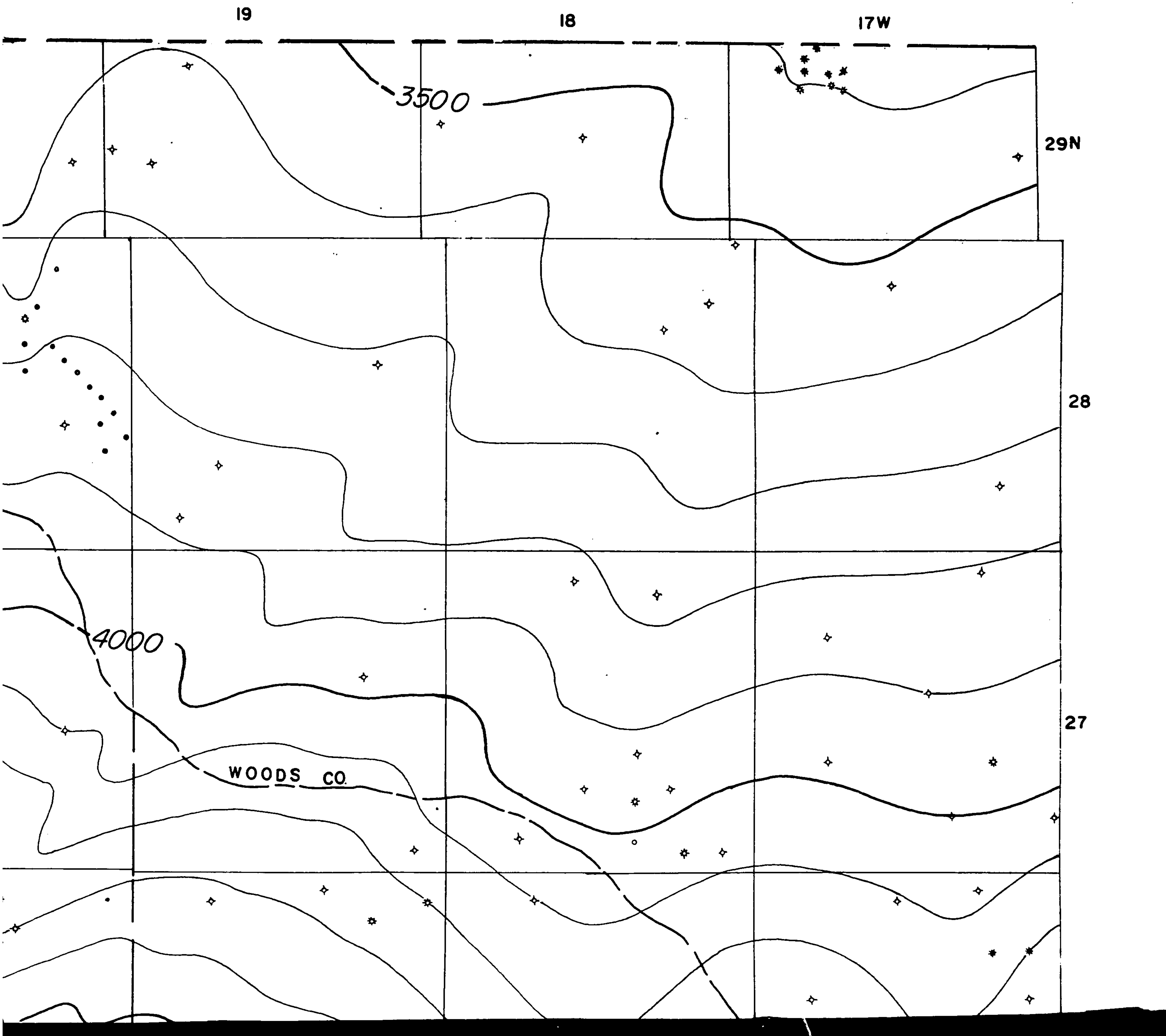
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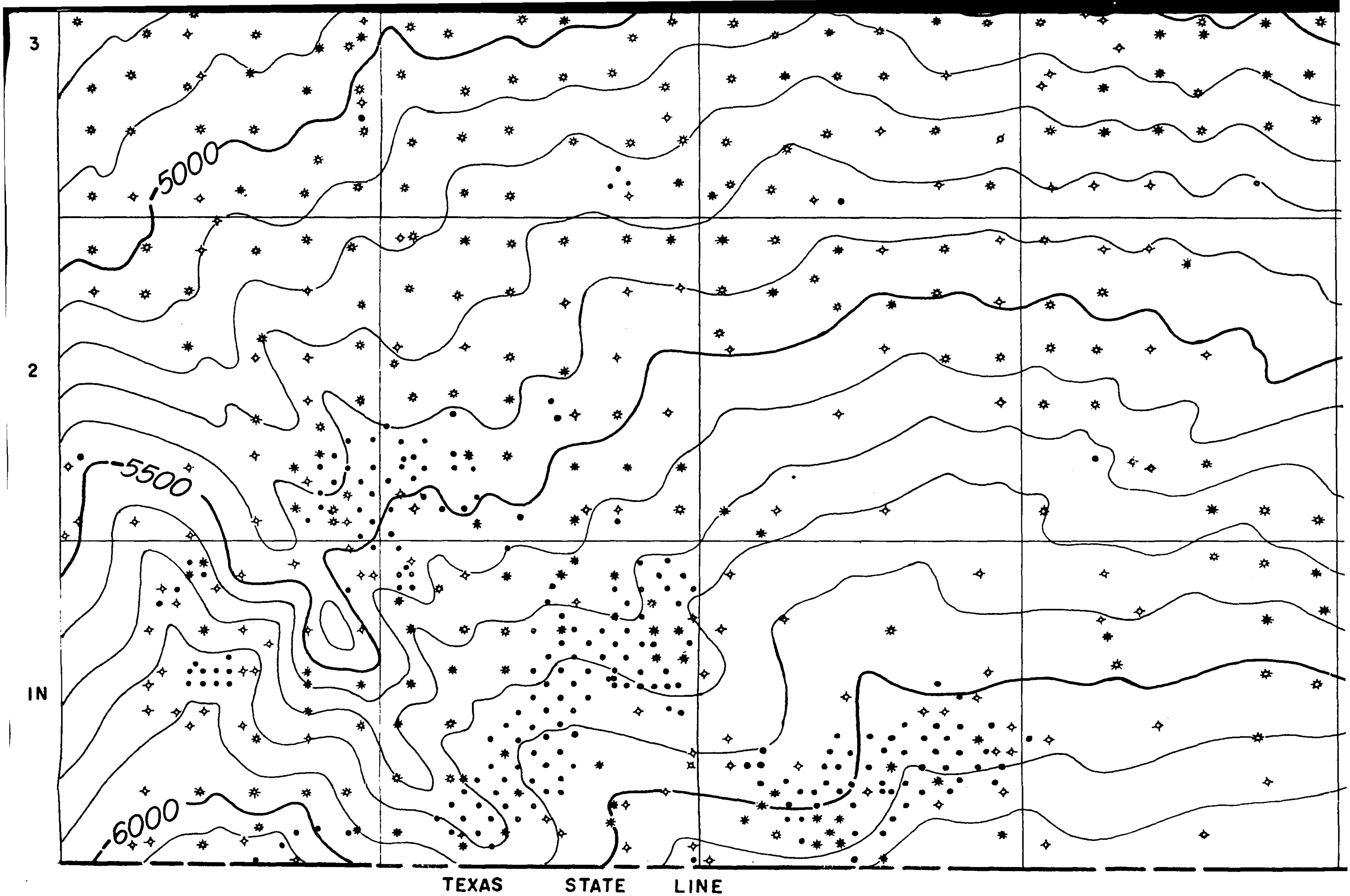
WOODS CO.



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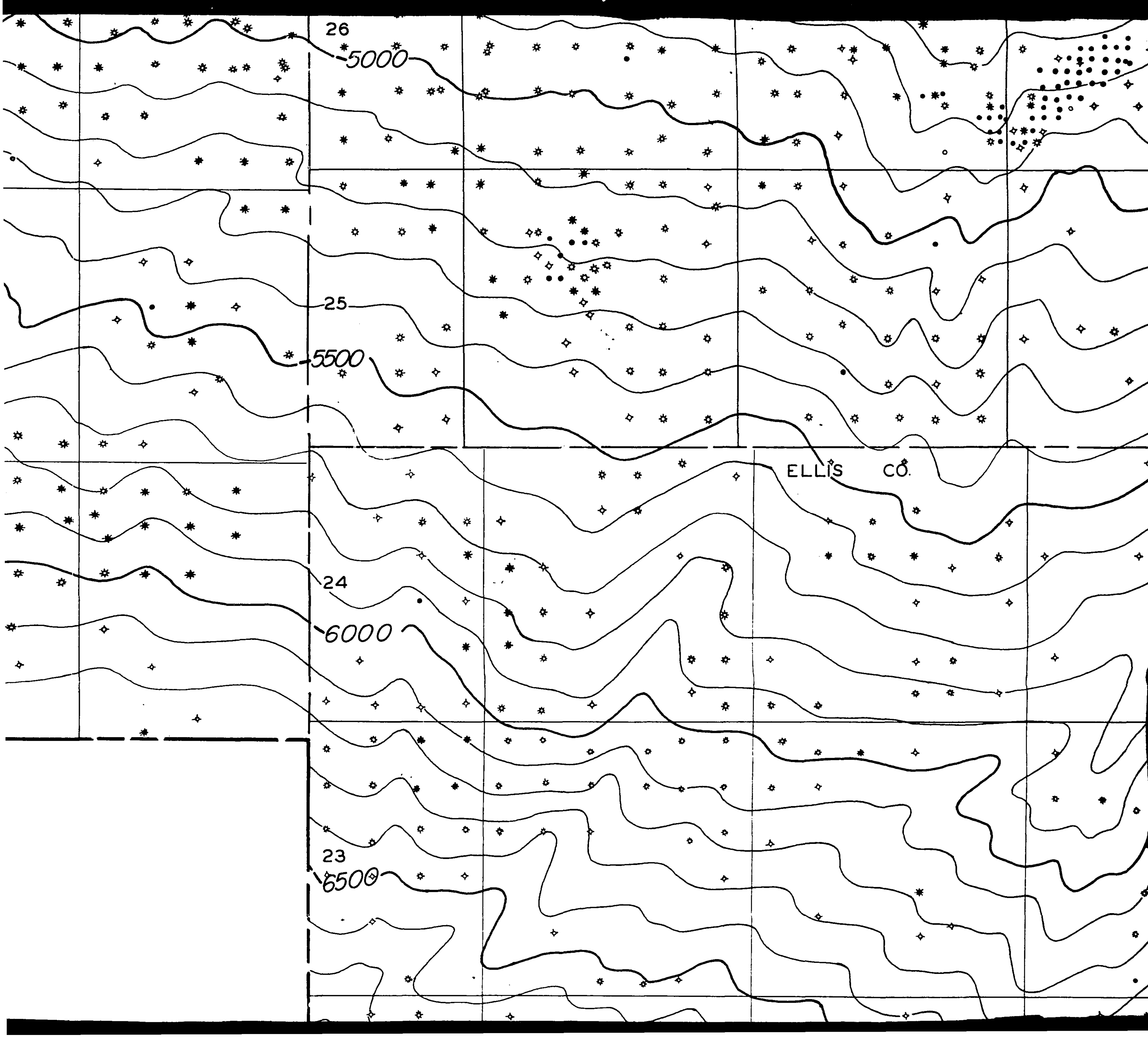

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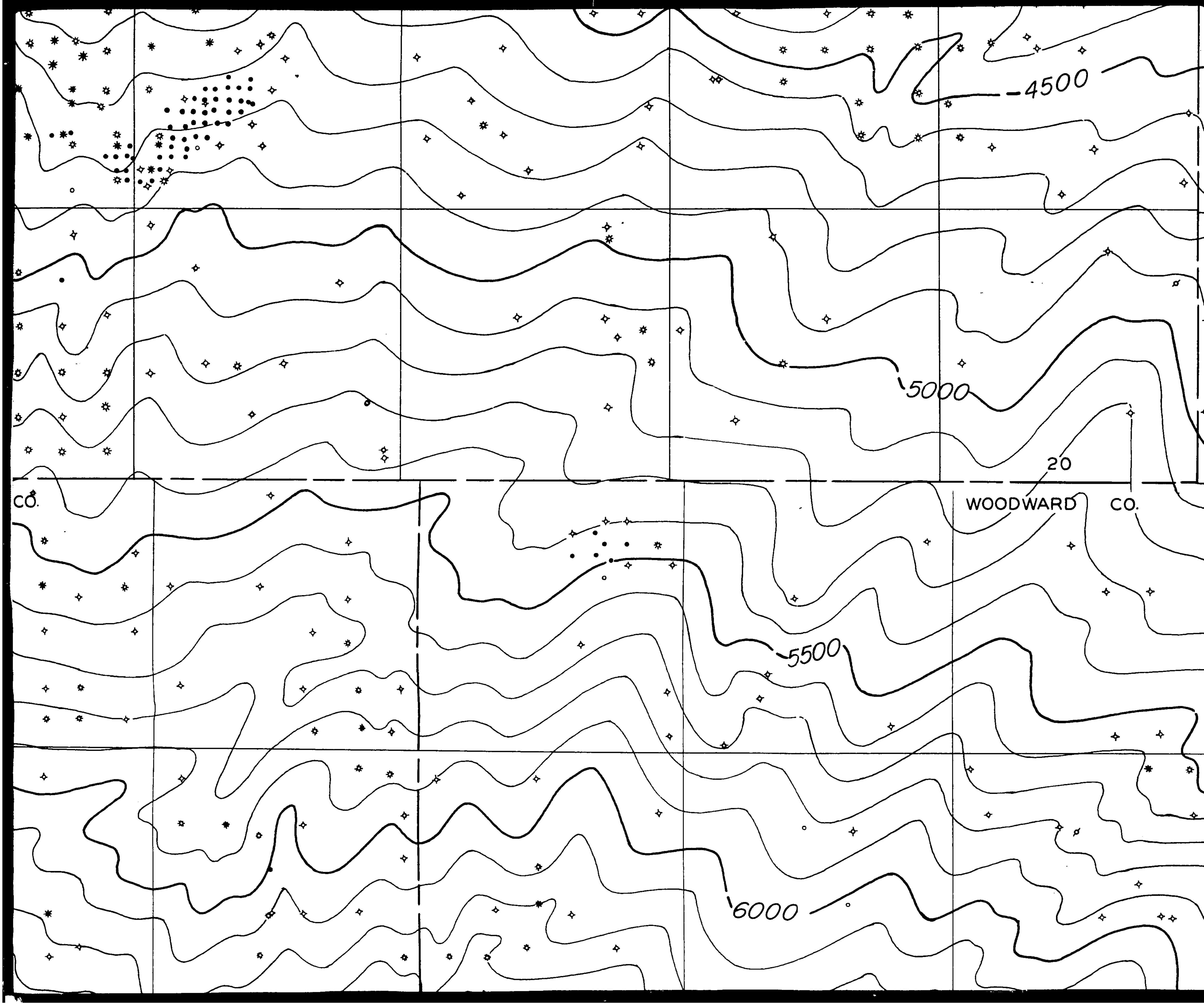
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WOODWARD
CO.
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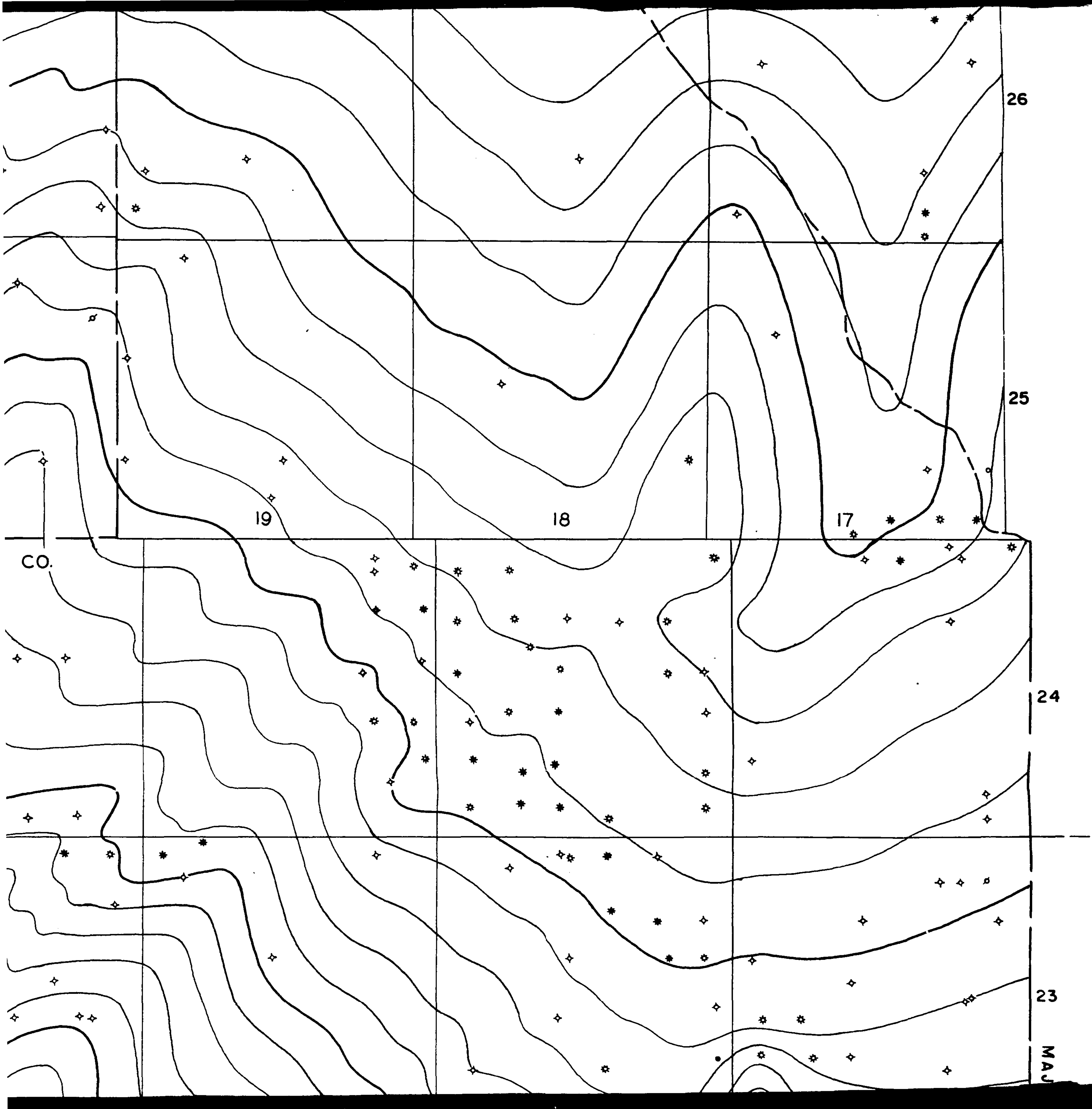
6000



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CO.
MAJ

# STRUCTURE OF THE MISSISSIPPIAN UNCONFORMITY SURFACE

NORTHWESTERN OKLAHOMA

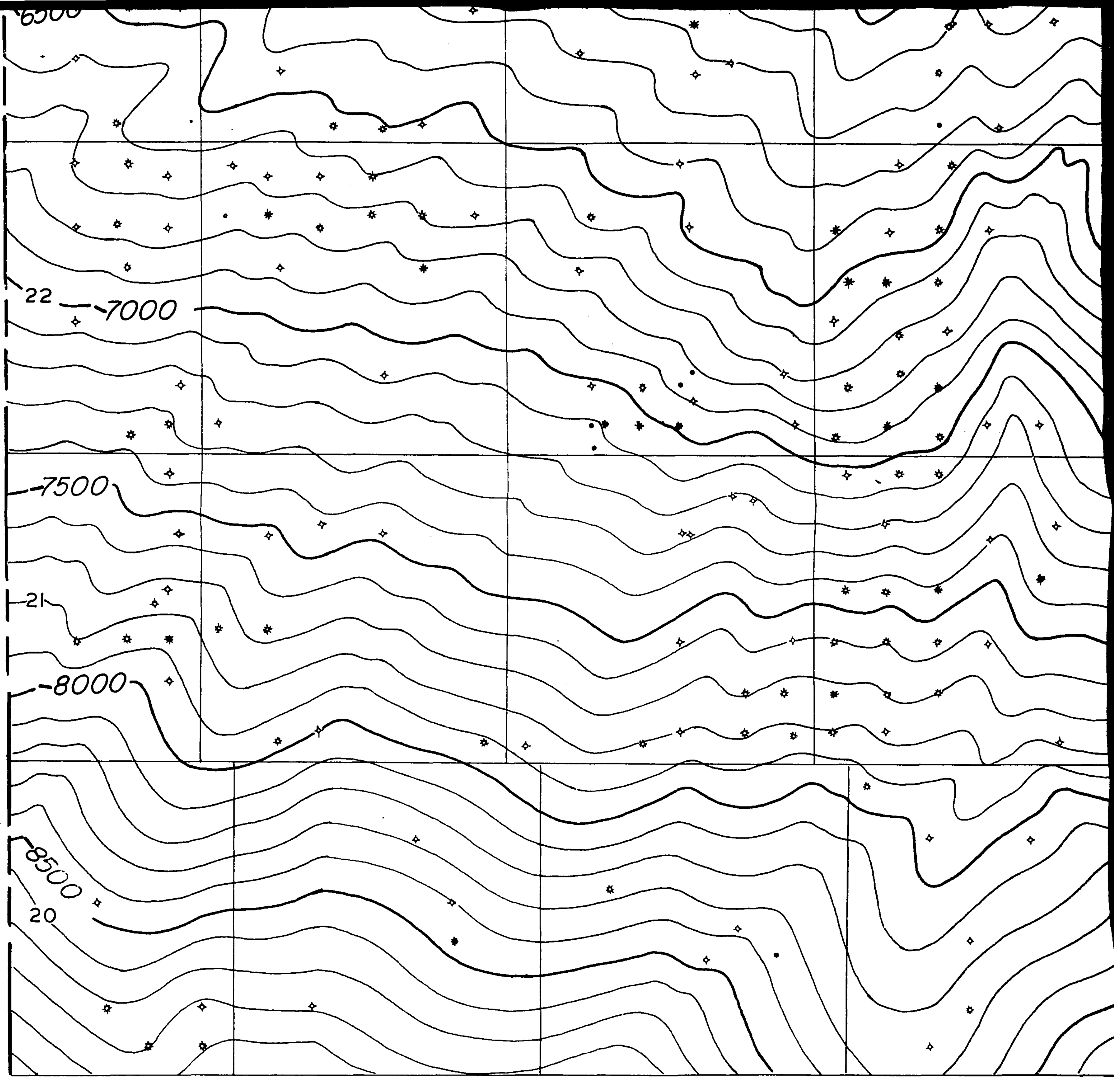
C. I. = 100 feet

SCALE IN MILES:

0 1 2 4 6

PLATE II

UNIVERSITY OF OKLAHOMA MOAYAD H. KHAIWKA Ph.D. 1968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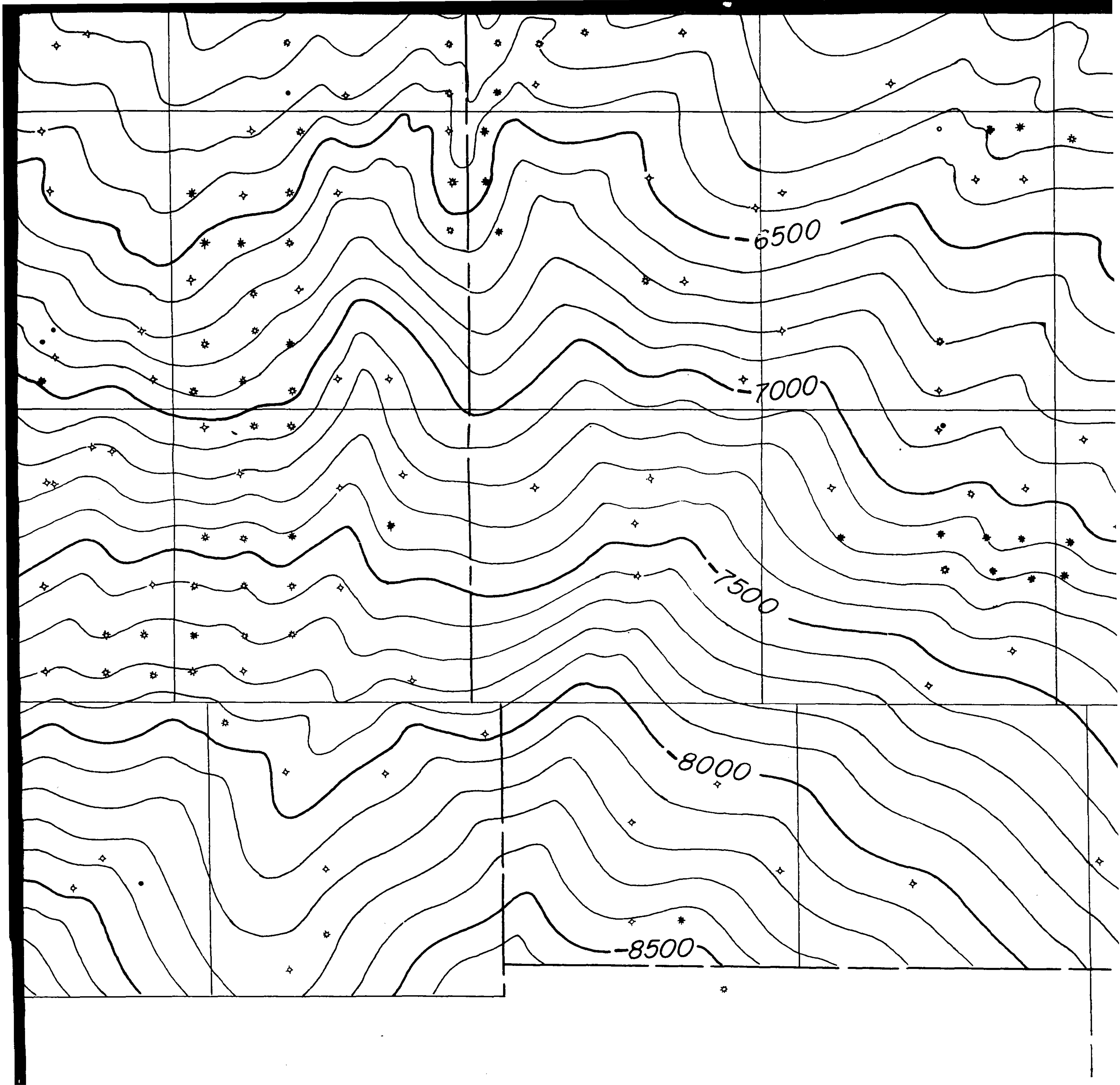
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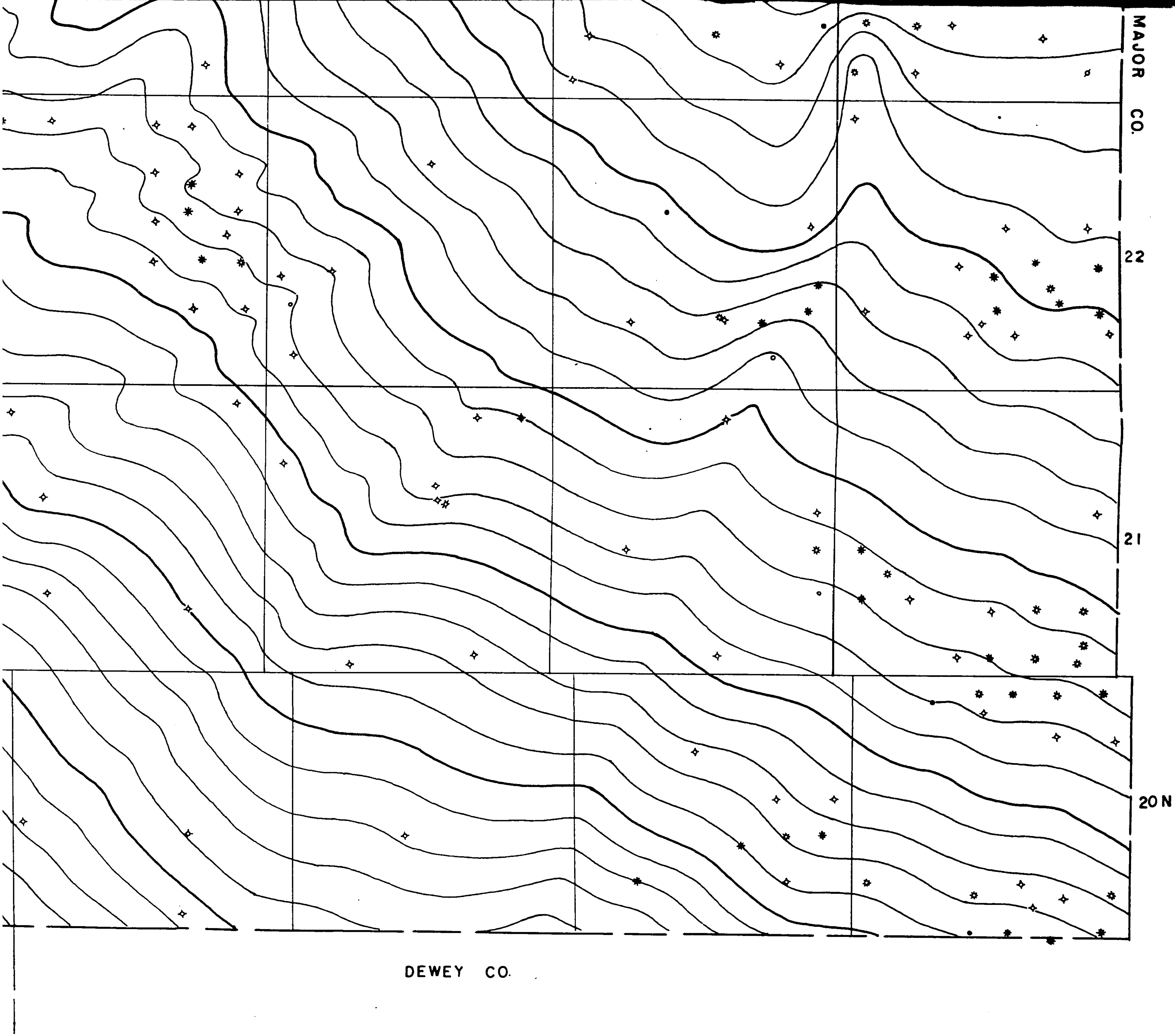

MAJOR CO.
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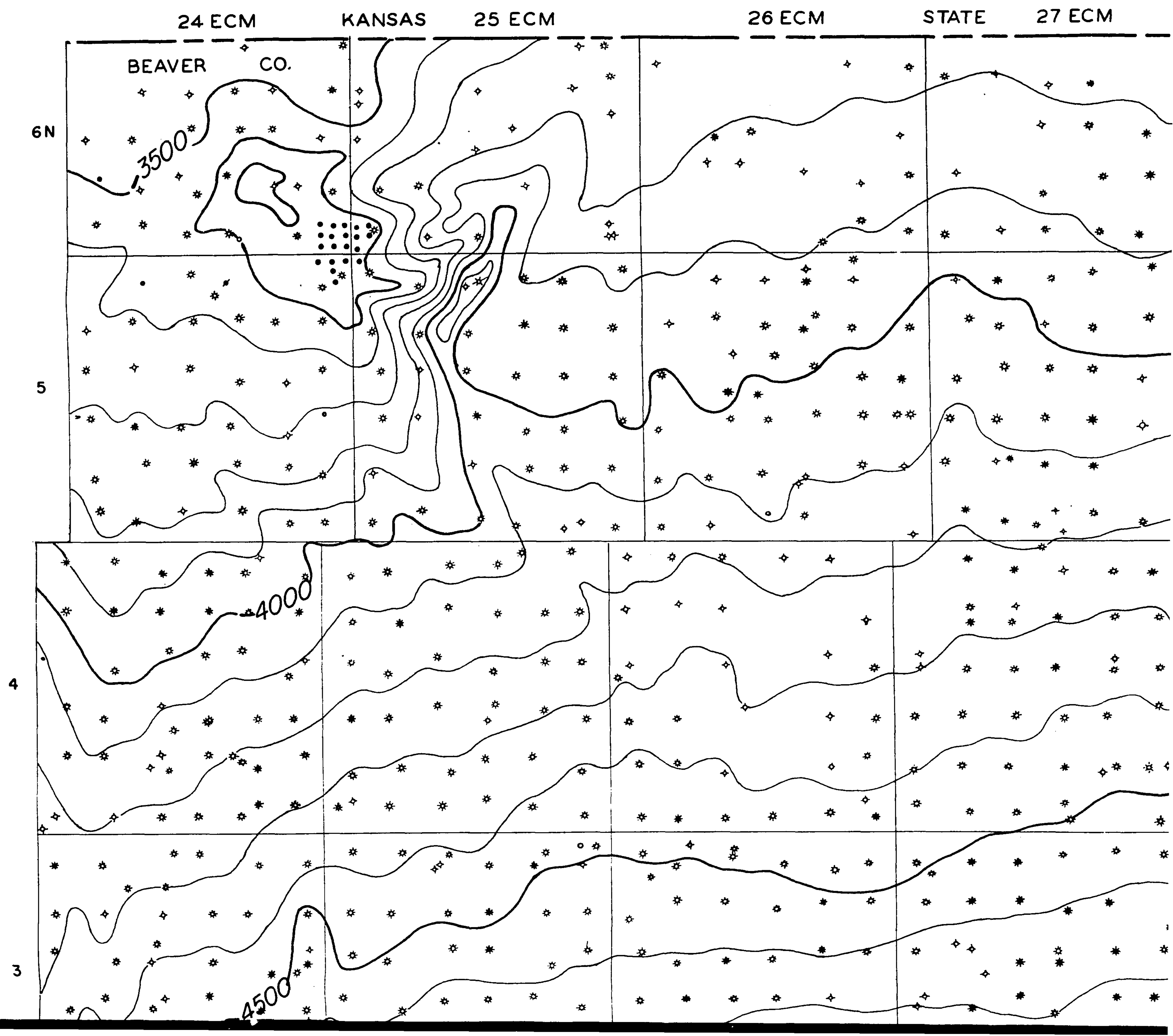
DEWEY CO.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KANSAS
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BEAVER CO.
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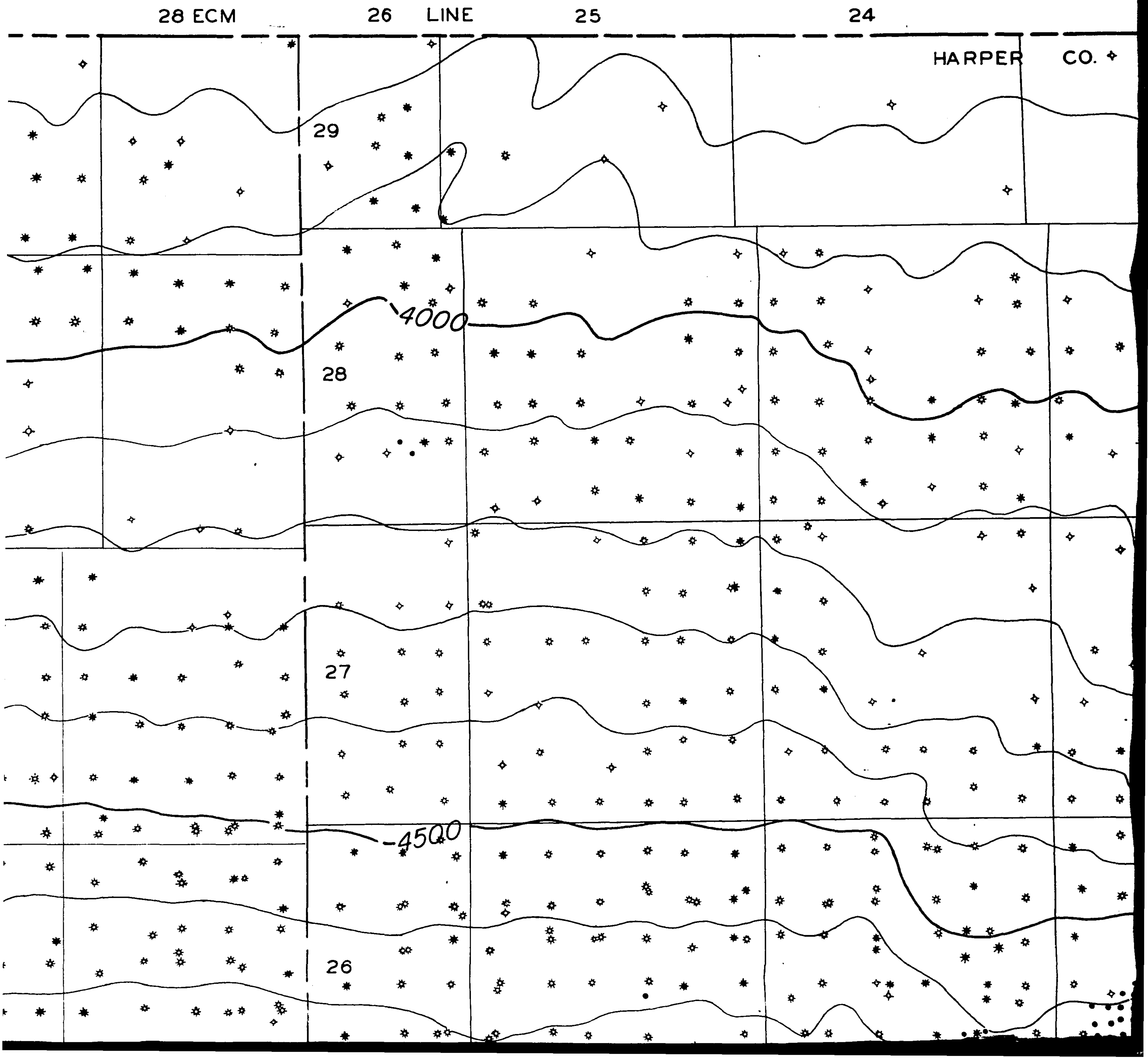

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HARPER CO.
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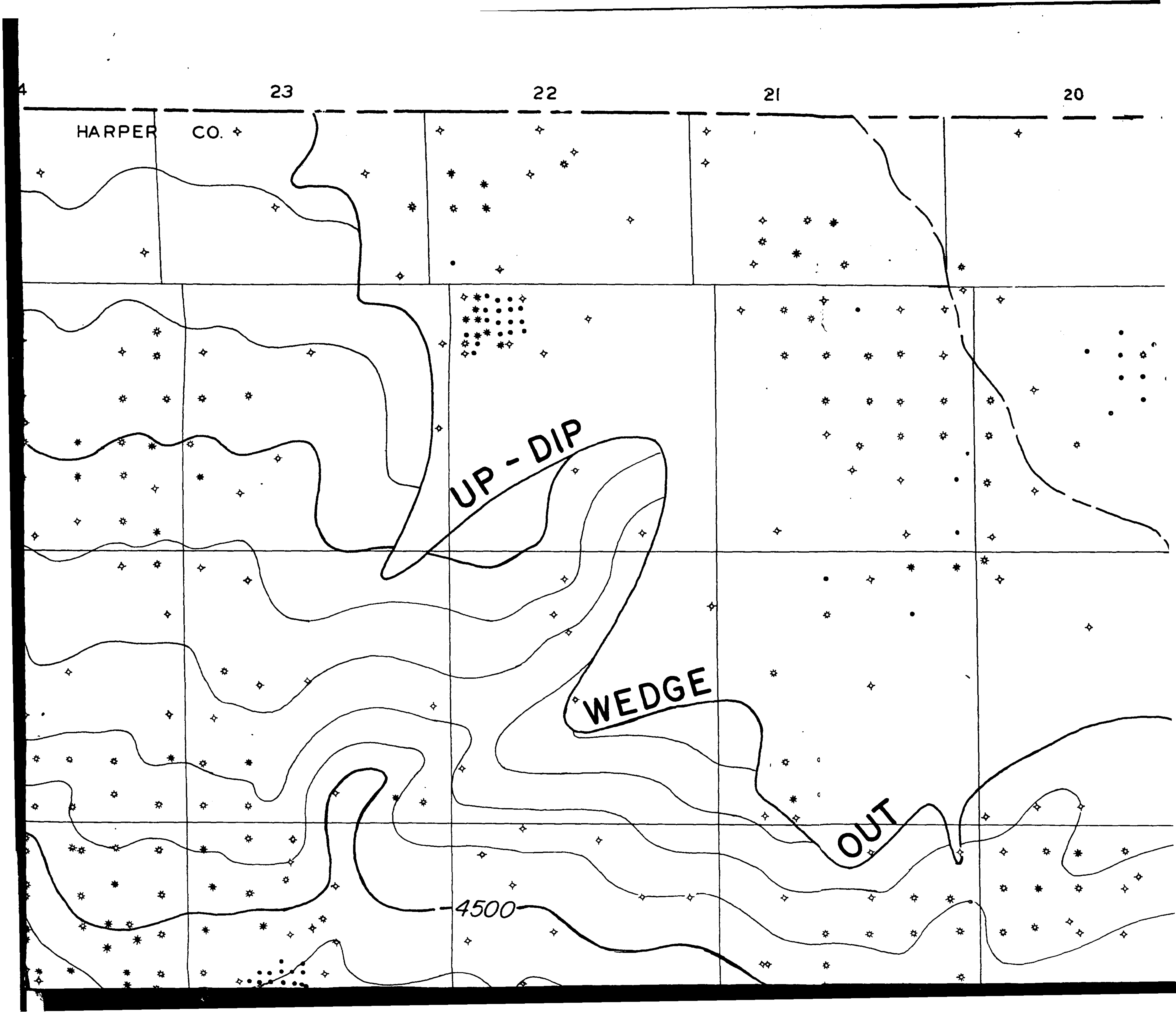

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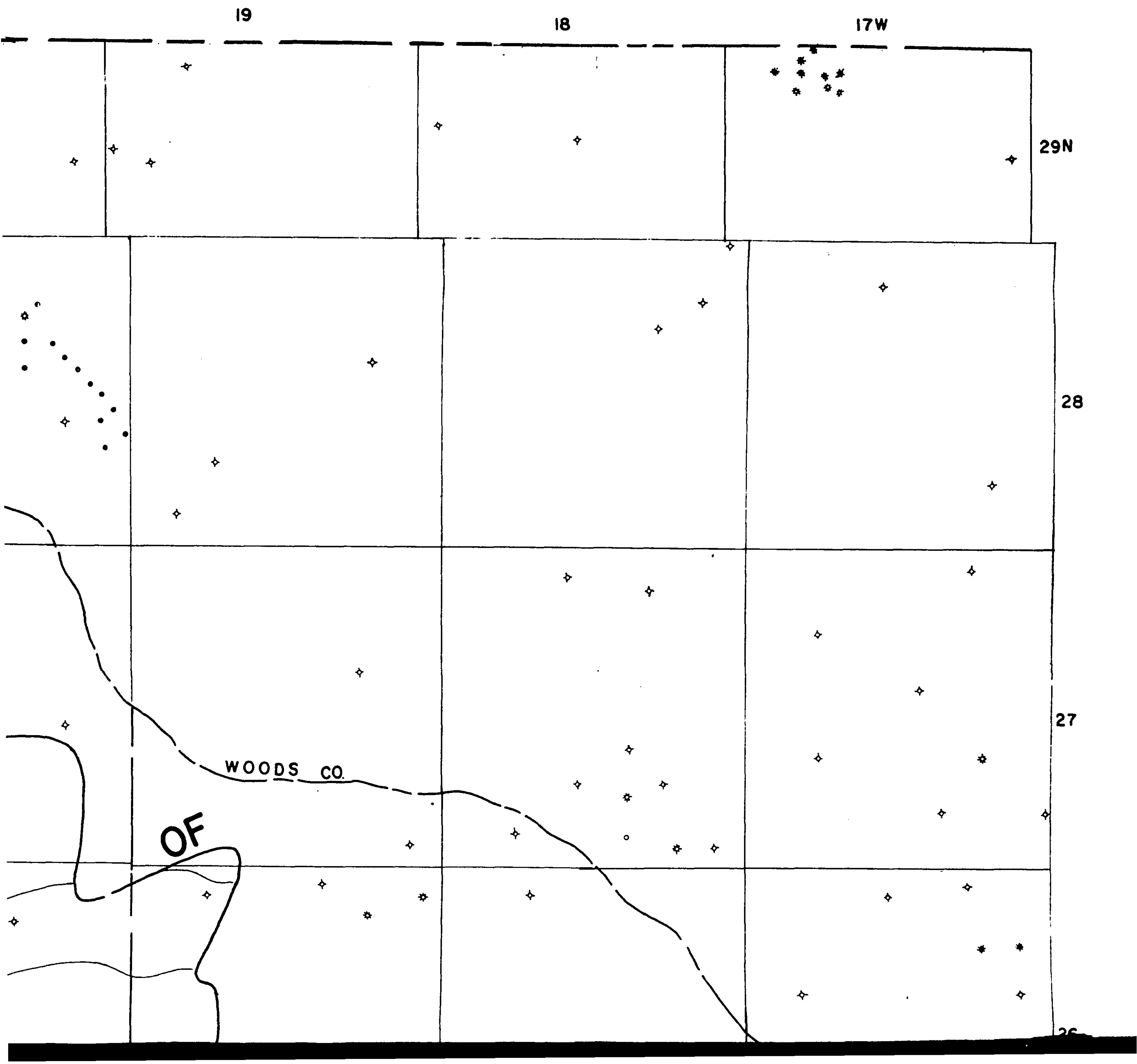
HARPER CO.
UP - DIP
WEDGE
OUT
4500



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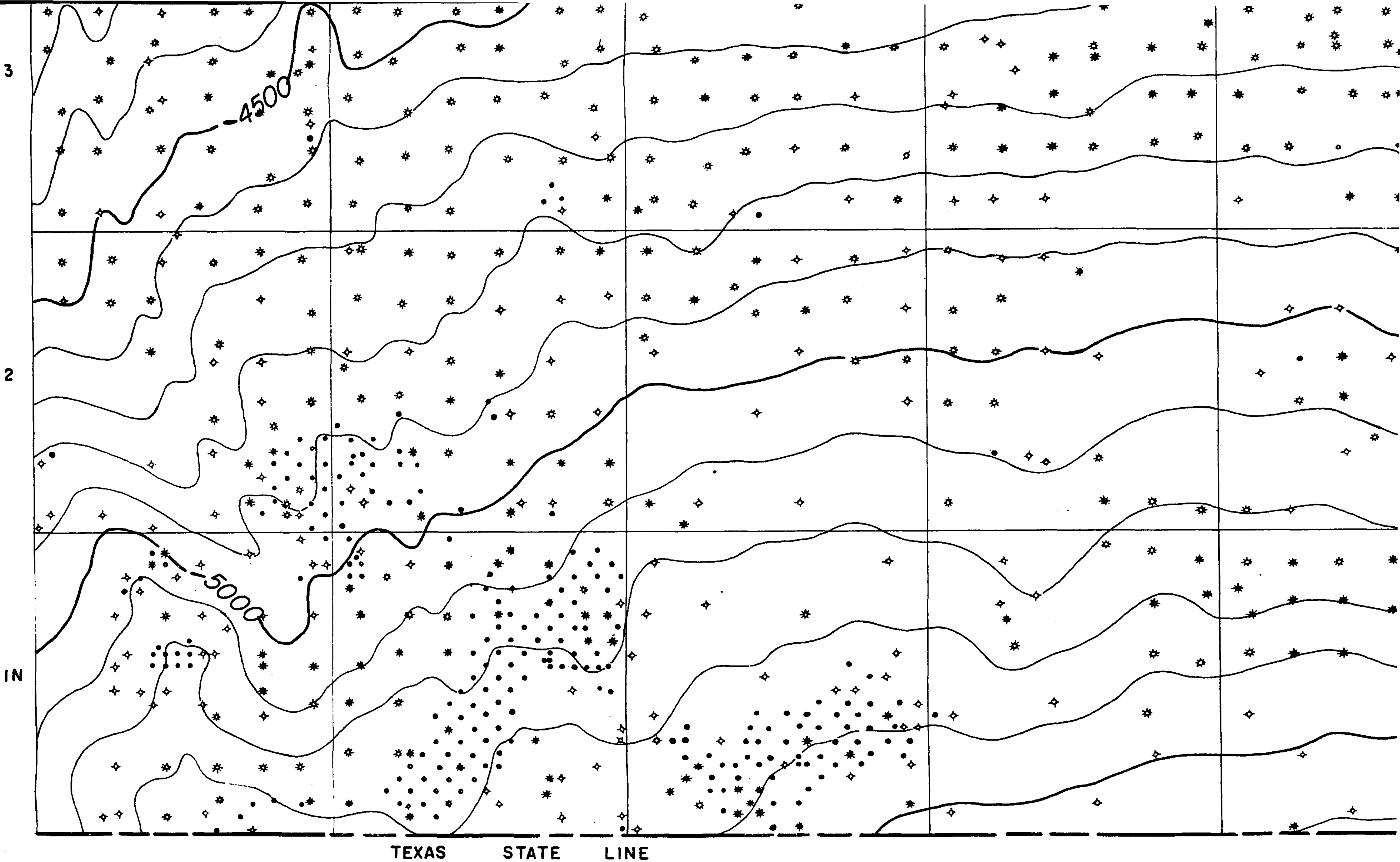
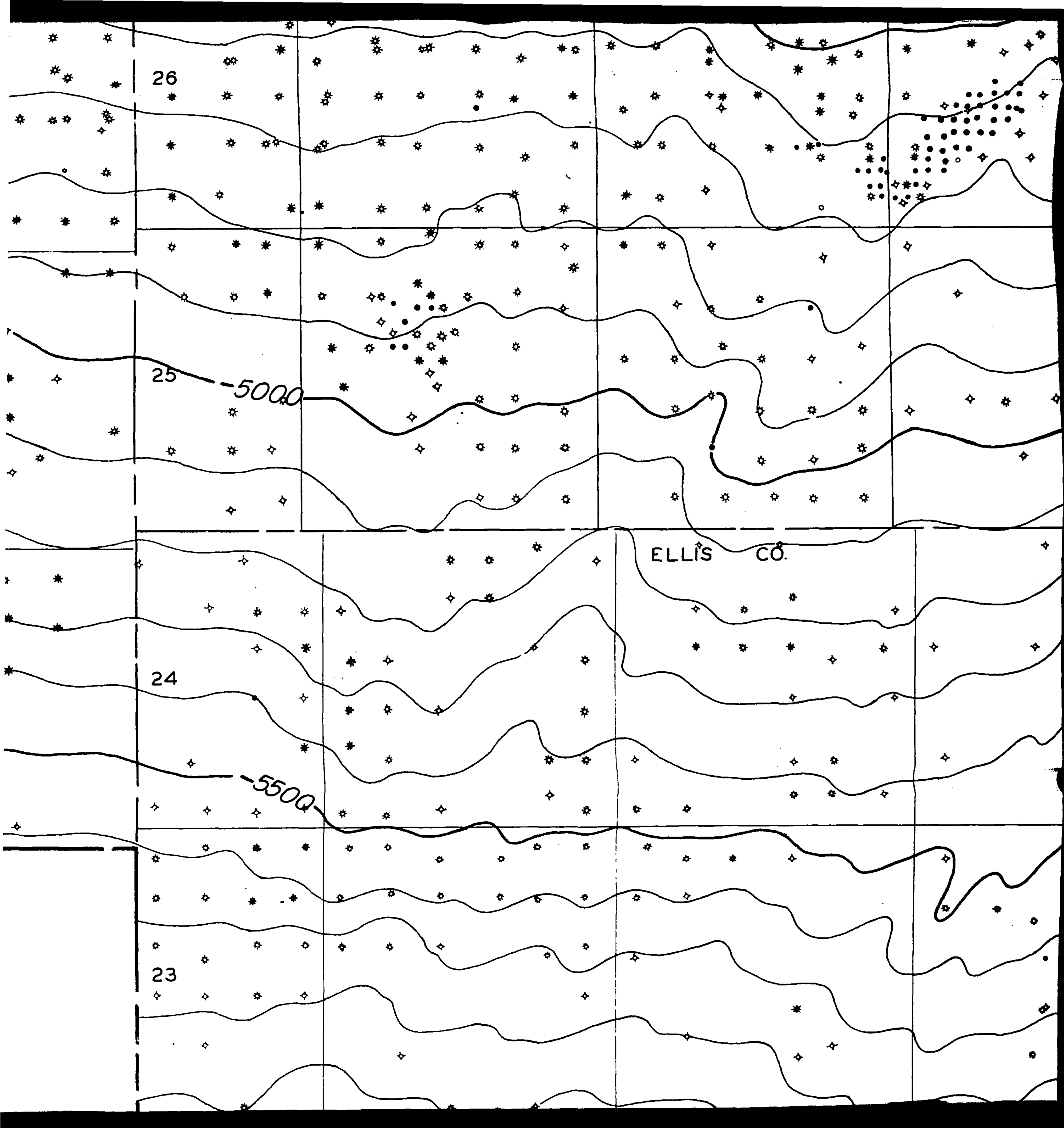
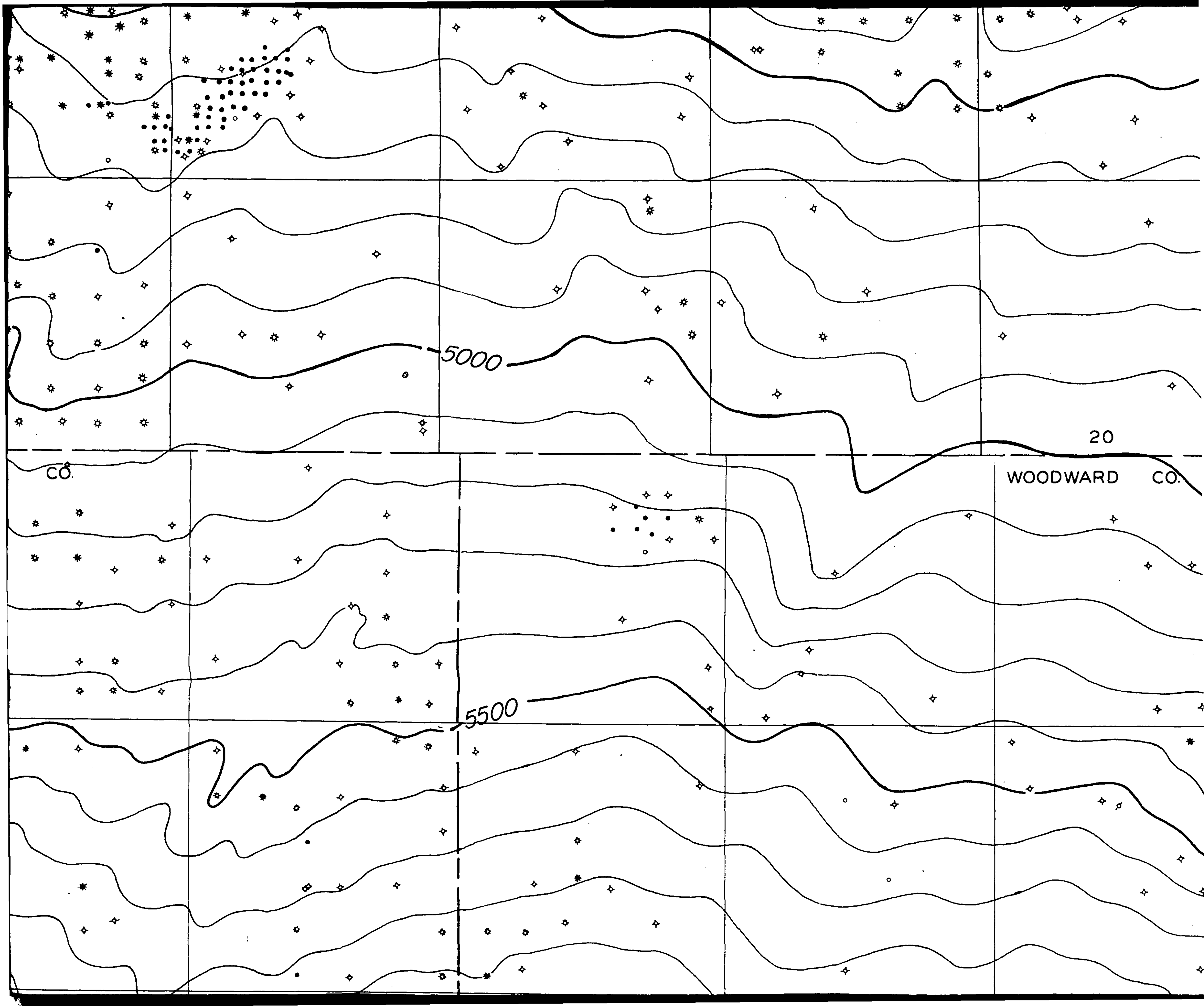
WOODS CO.
OF

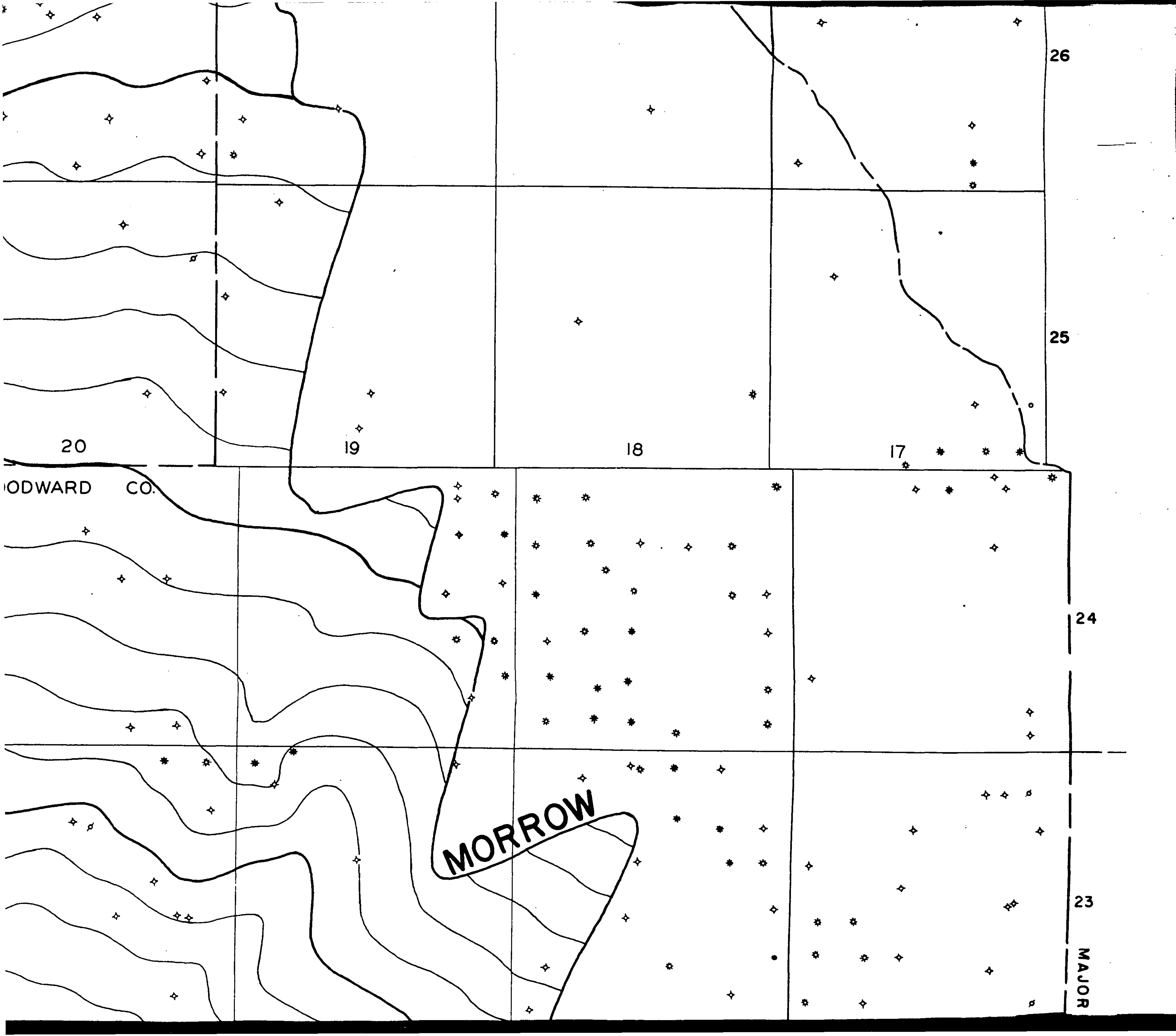



# STRUCTURE MAP

TOP OF MORROW FORMATION


26
25
-5000
24
-5500
23
ELLIS CO.


5000
20
CO.
WOODWARD CO.
5500



26
25
20
19
18
17
24
ODWARD CO.
MORROW
23
MAJOR

# STRUCTURE MAP
# TOP OF MORROW FORMATION
## (BASE OF THE THIRTEEN FINGER LIMESTONE)

NORTHWESTERN OKLAHOMA

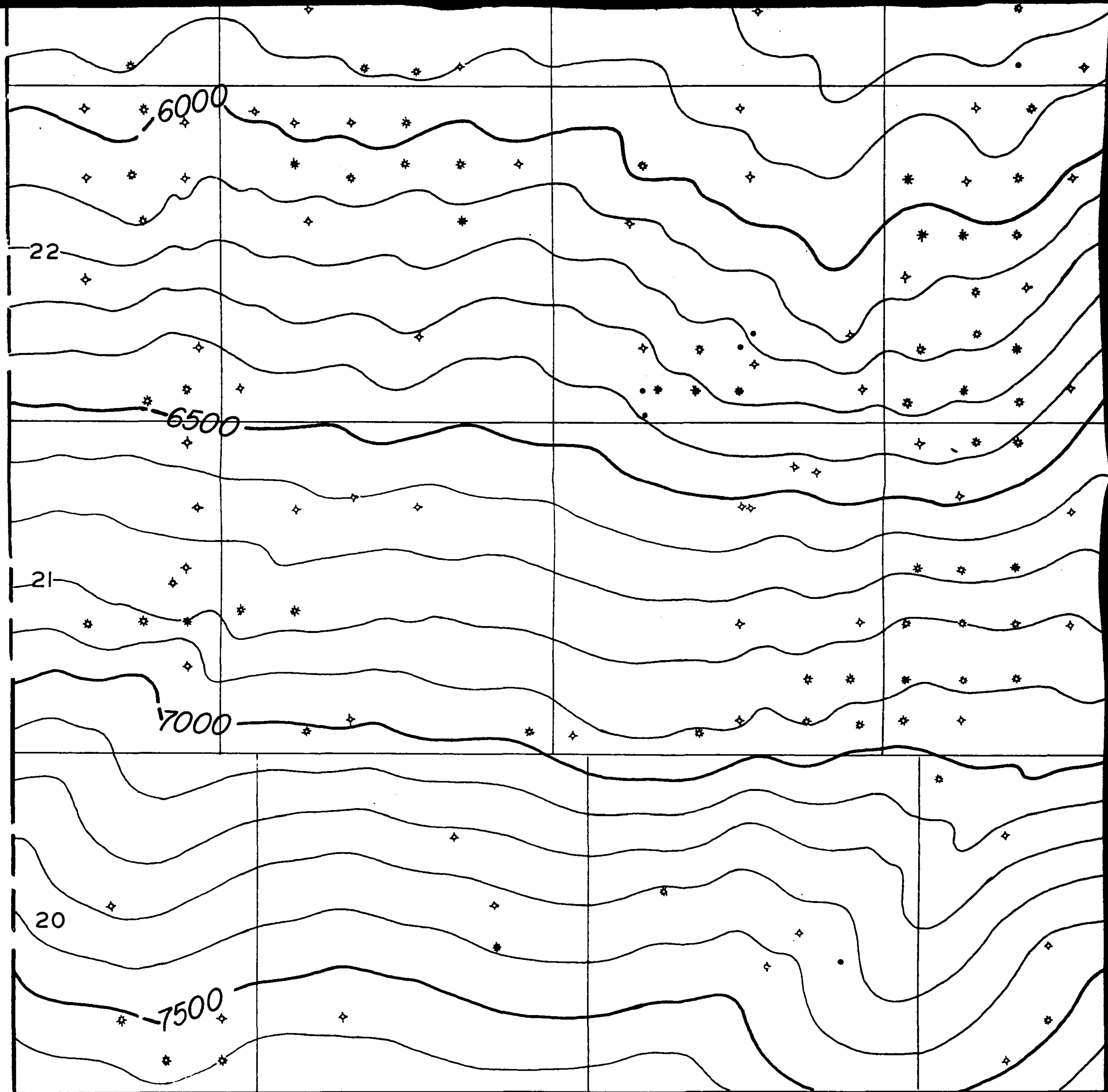
C. I. = 100 feet

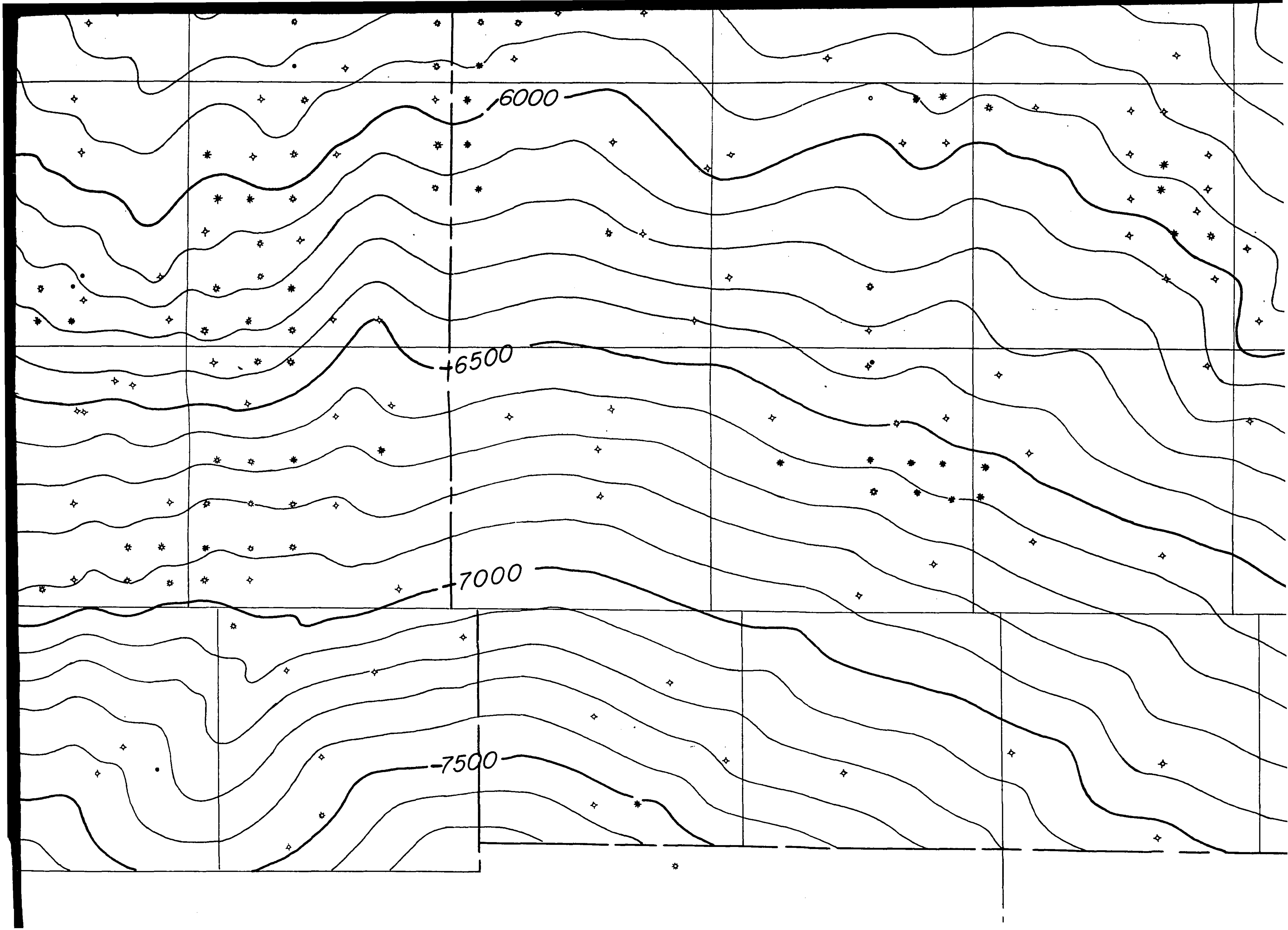
SCALE IN MILES:

0 1 2 4 6

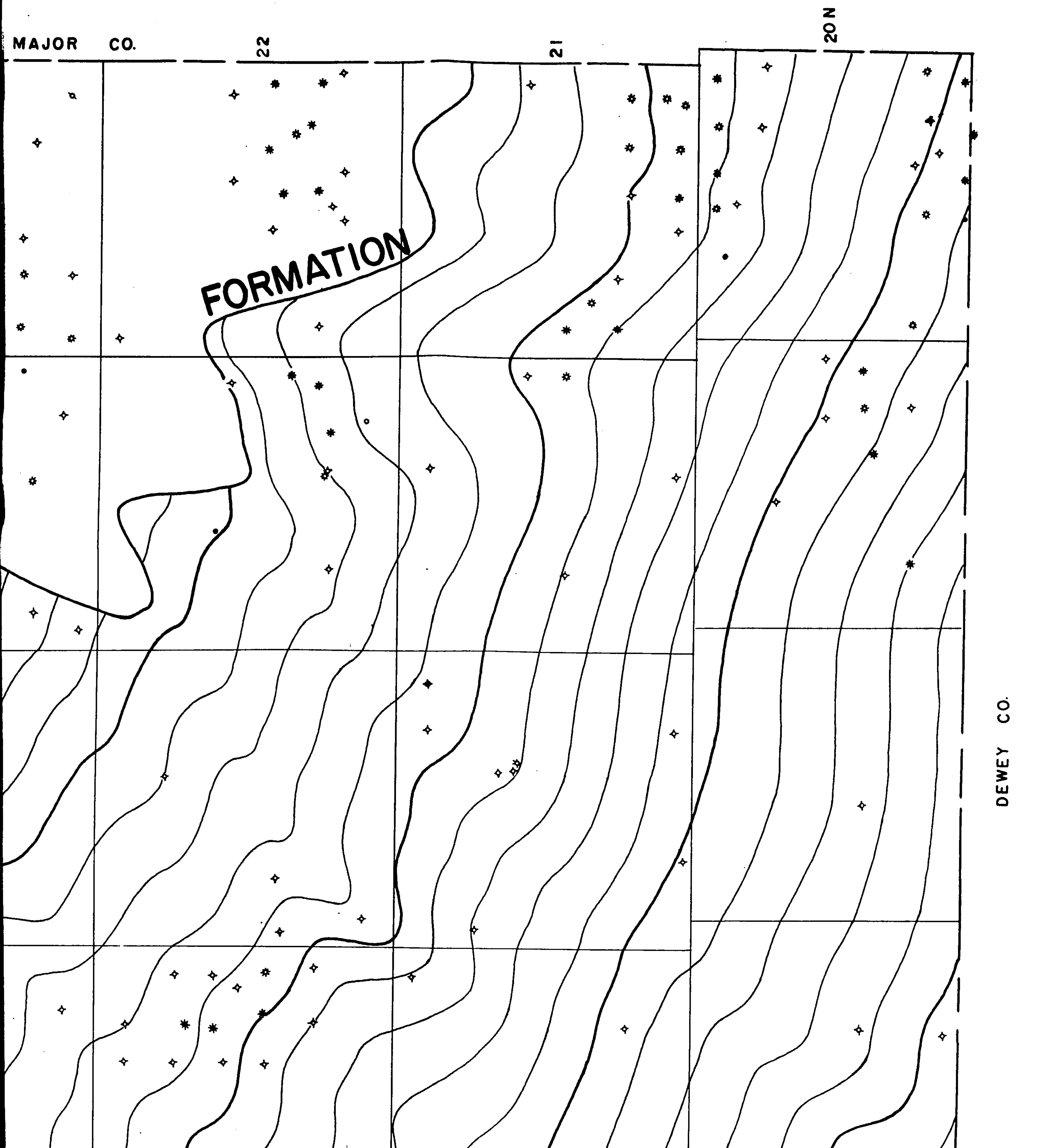
PLATE III

UNIVERSITY OF OKLAHOMA MOAYAD H. KHAIWKA Ph.D. 1968

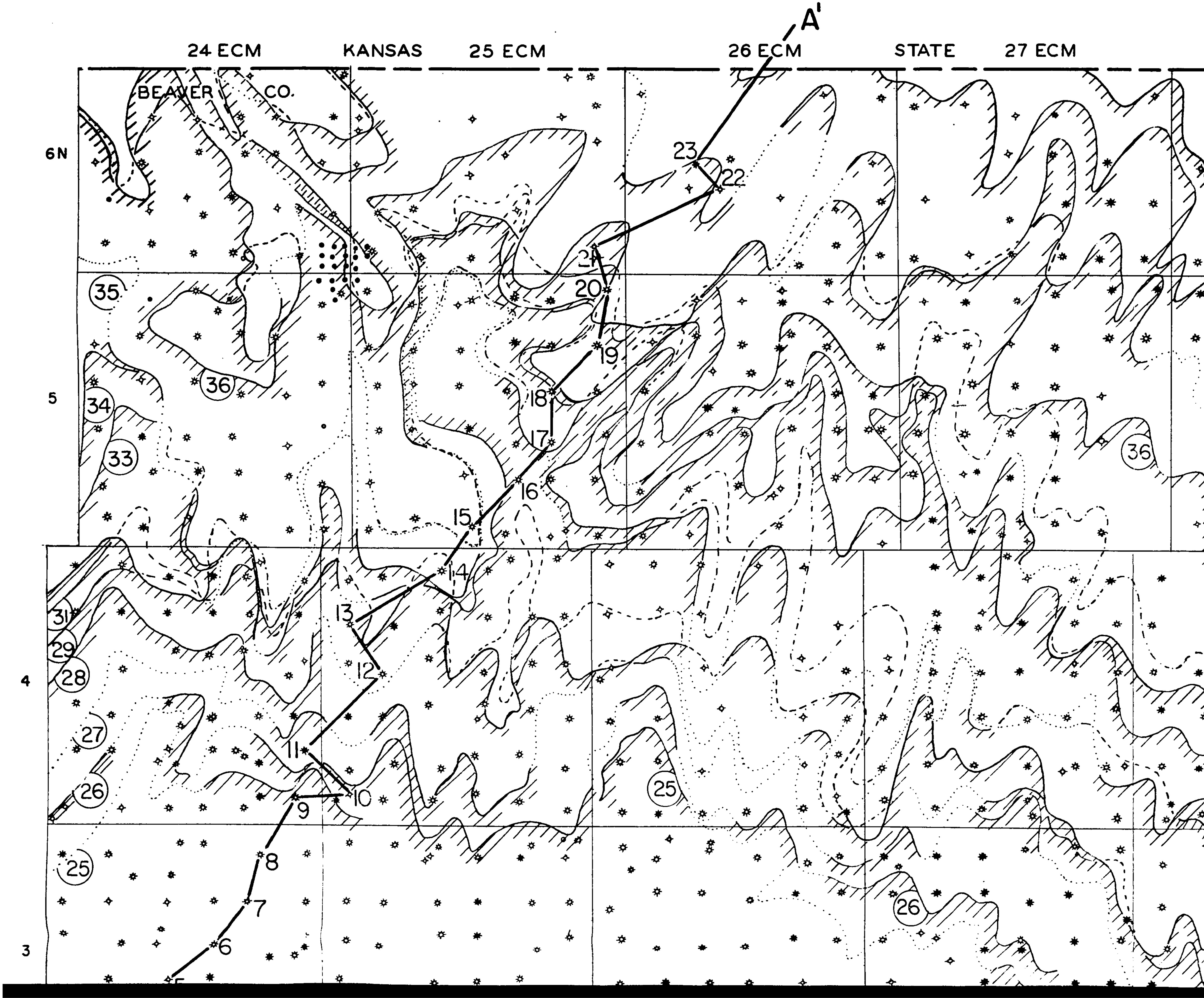

6000
6500
7000
7500
22
21
20



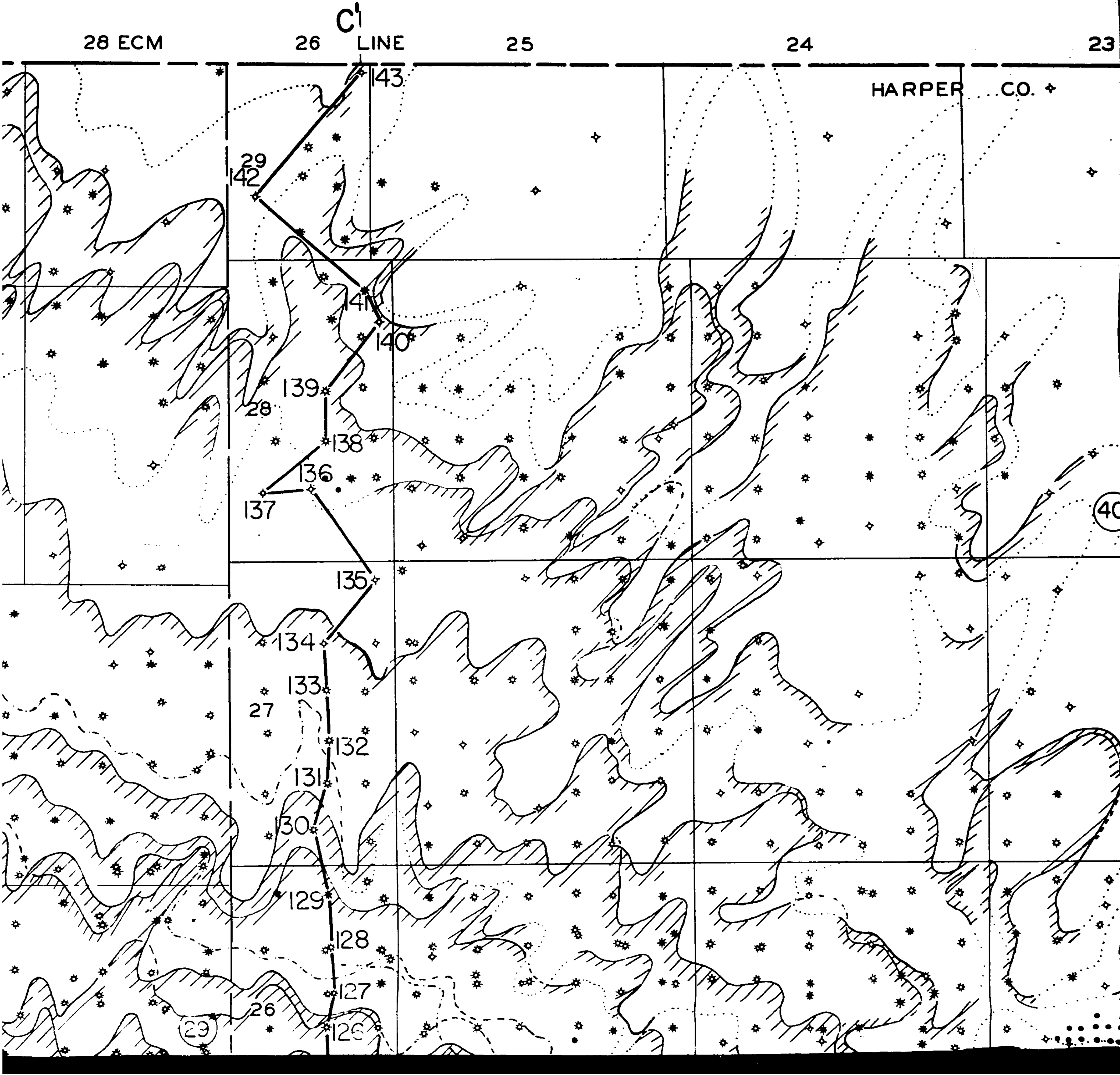
6000
6500
7000
7500



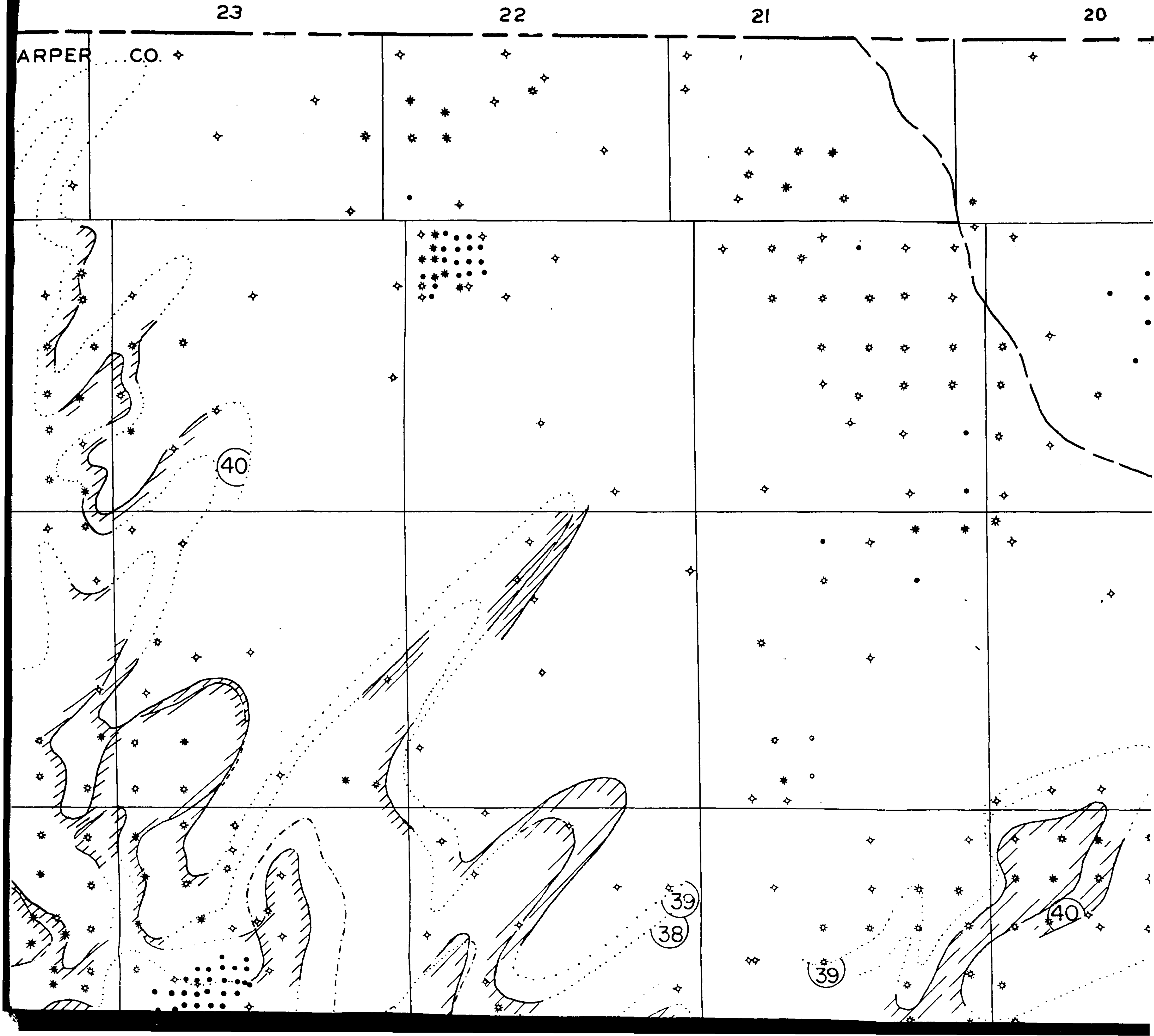
MAJOR CO.
22
21
20 N
FORMATION
DEWEY CO.



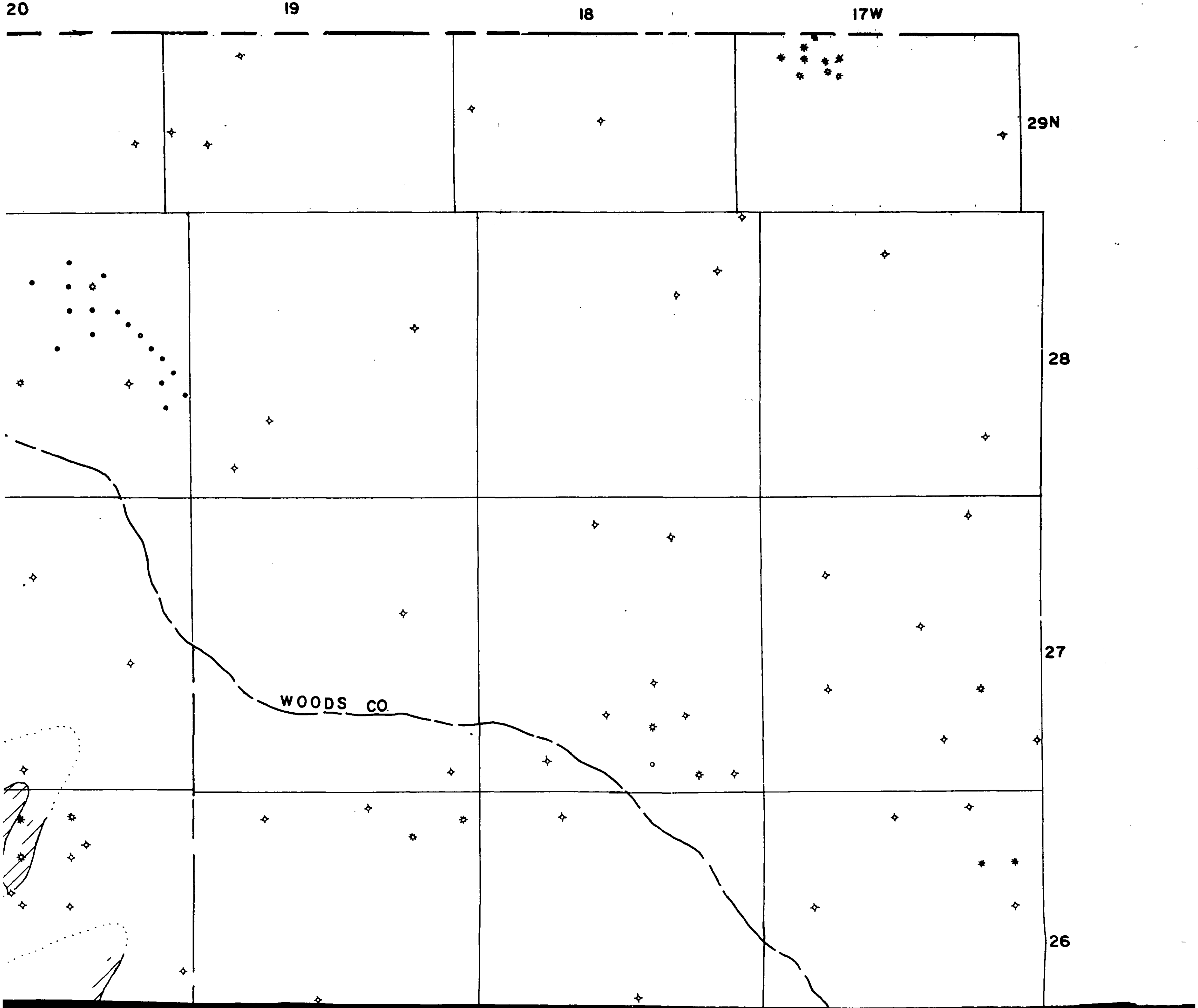
A'
24 ECM
KANSAS
25 ECM
26 ECM
STATE
27 ECM
BEAVER CO.
6N
5
4
3
35
36
34
33
31
29
28
27
26
25
36
25
26
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

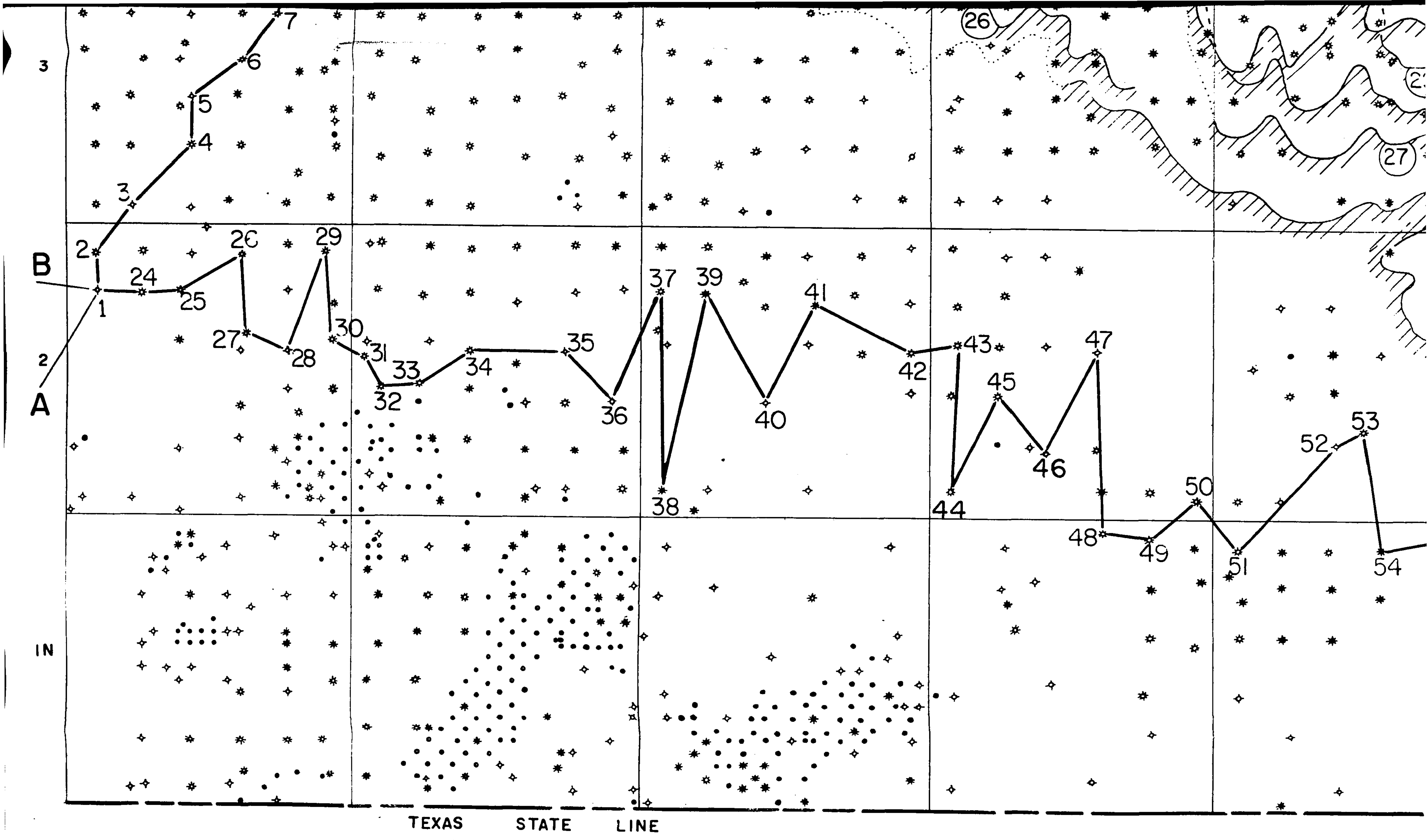


C'
28 ECM
26
LINE
25
24
23
HARPER CO.
143
29
142
141
140
139
28
138
136
137
135
134
133
27
132
131
130
129
128
127
26
126
29
40

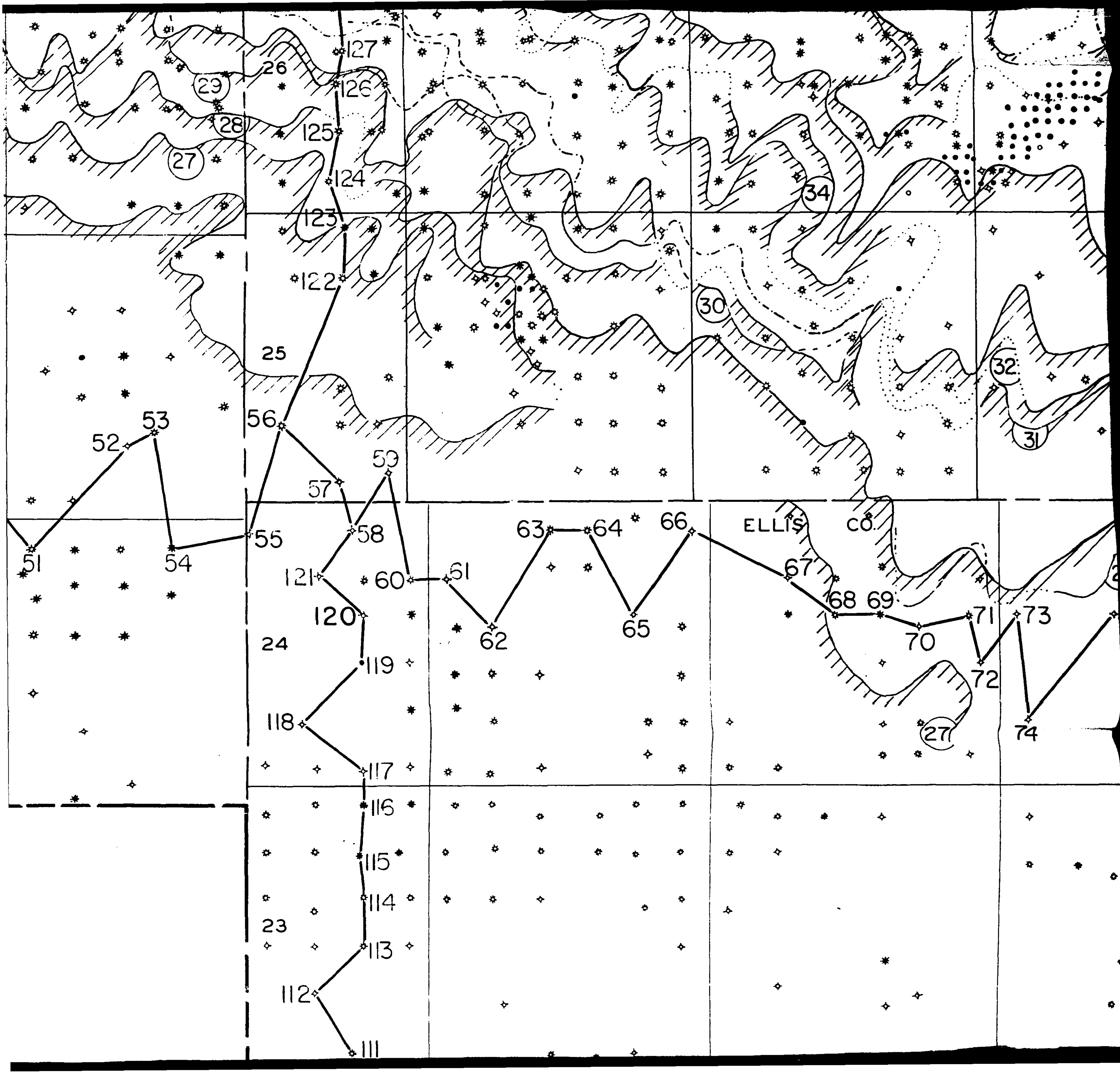


23
22
21
20
ARPER CO.
40
39
38
39
40

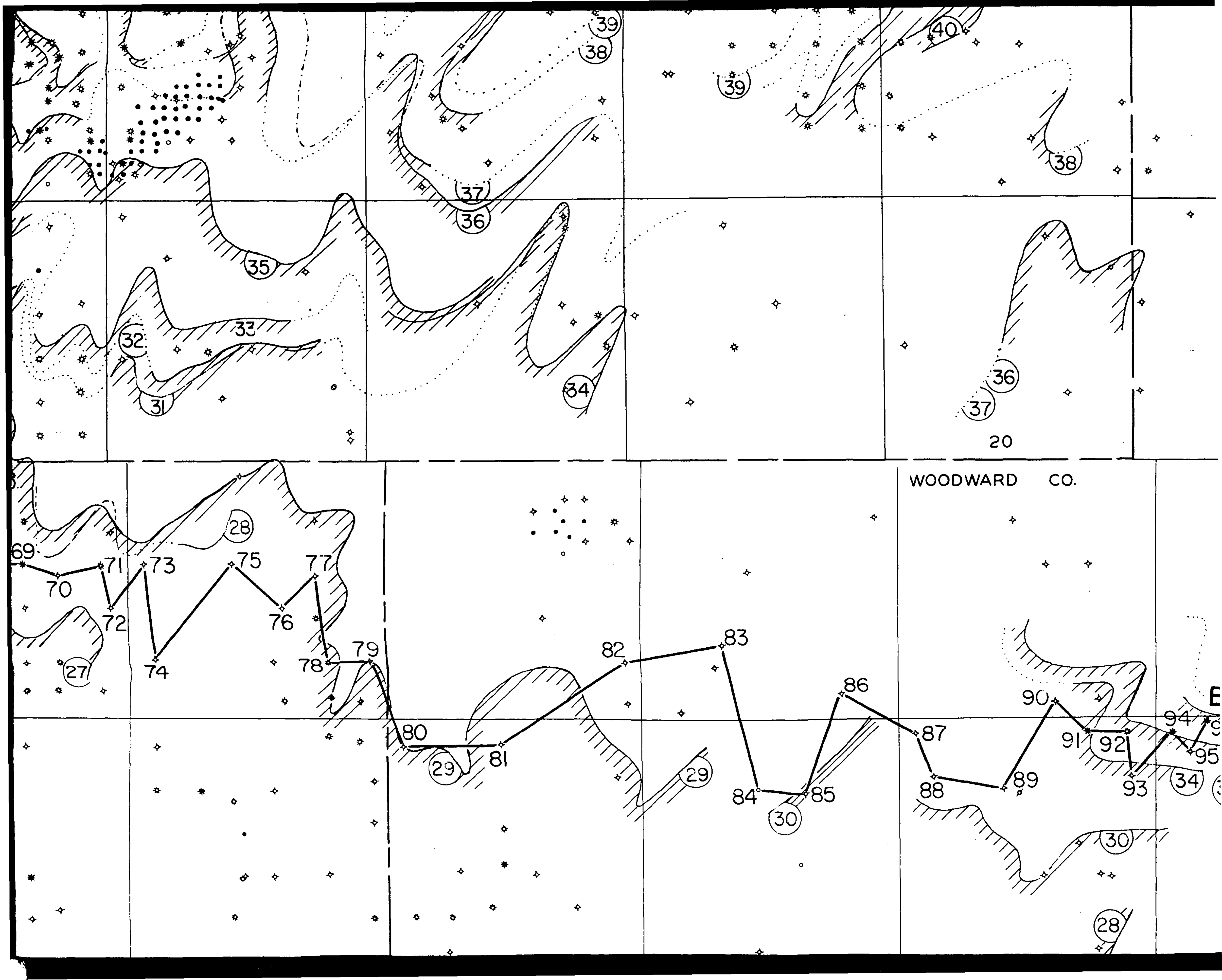

20
19
18
17W
29N
28
27
26
WOODS CO.



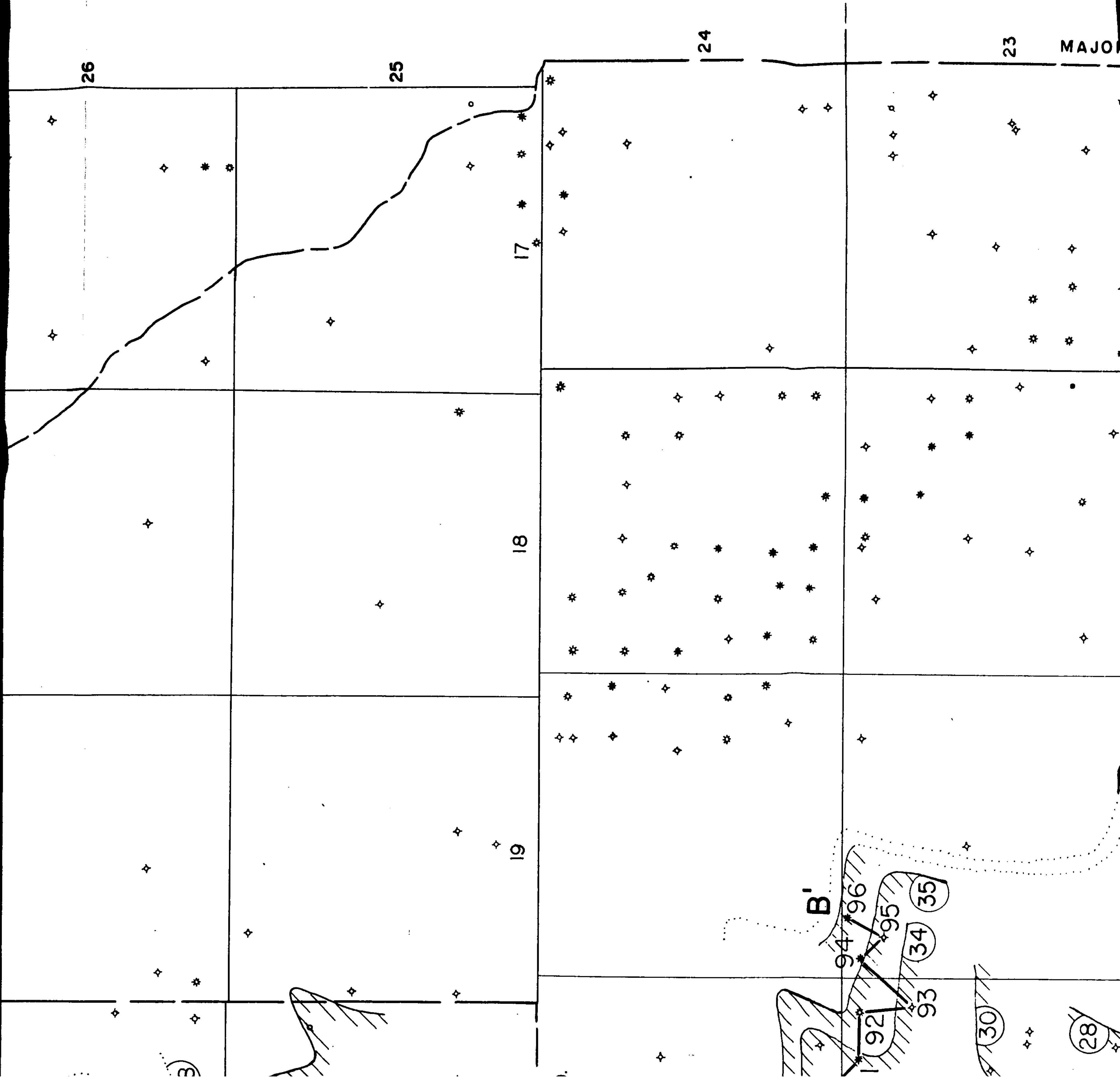
3
2
IN
A
B
1
2
3
4
5
6
7
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
26
27
TEXAS STATE LINE



127
126
125
124
123
122
26
29
28
27
34
30
32
31
25
56
53
52
57
59
58
55
51
54
121
60
61
63
64
66
ELLIS CO.
67
68
69
70
71
72
73
74
62
65
120
24
119
118
117
27
116
115
114
23
113
112
111



39
38
39
40
38
37
36
35
33
32
31
34
36
37
20
WOODWARD CO.
28
69
70
71
72
73
74
75
76
77
78
79
27
80
29
81
82
83
29
84
85
30
86
87
88
89
90
91
92
93
94
95
34
30
28


26
25
24
23
MAJO
17
18
19
B'
96
95
94
93
92
35
34
30
28

# PALEO-SHORELINES DURING MORROW TIME

## EXPLANATION

1 Shoreline with sand development

2 Possible shoreline with no sand development

3 Same as 1 - Overlain by younger shoreline(s)

4 Same as 2 - Overlain by younger shoreline(s)

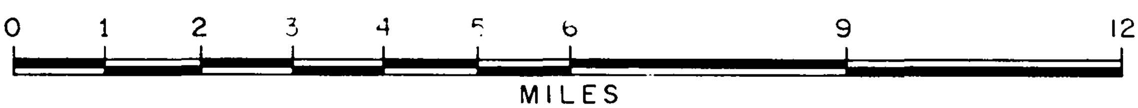
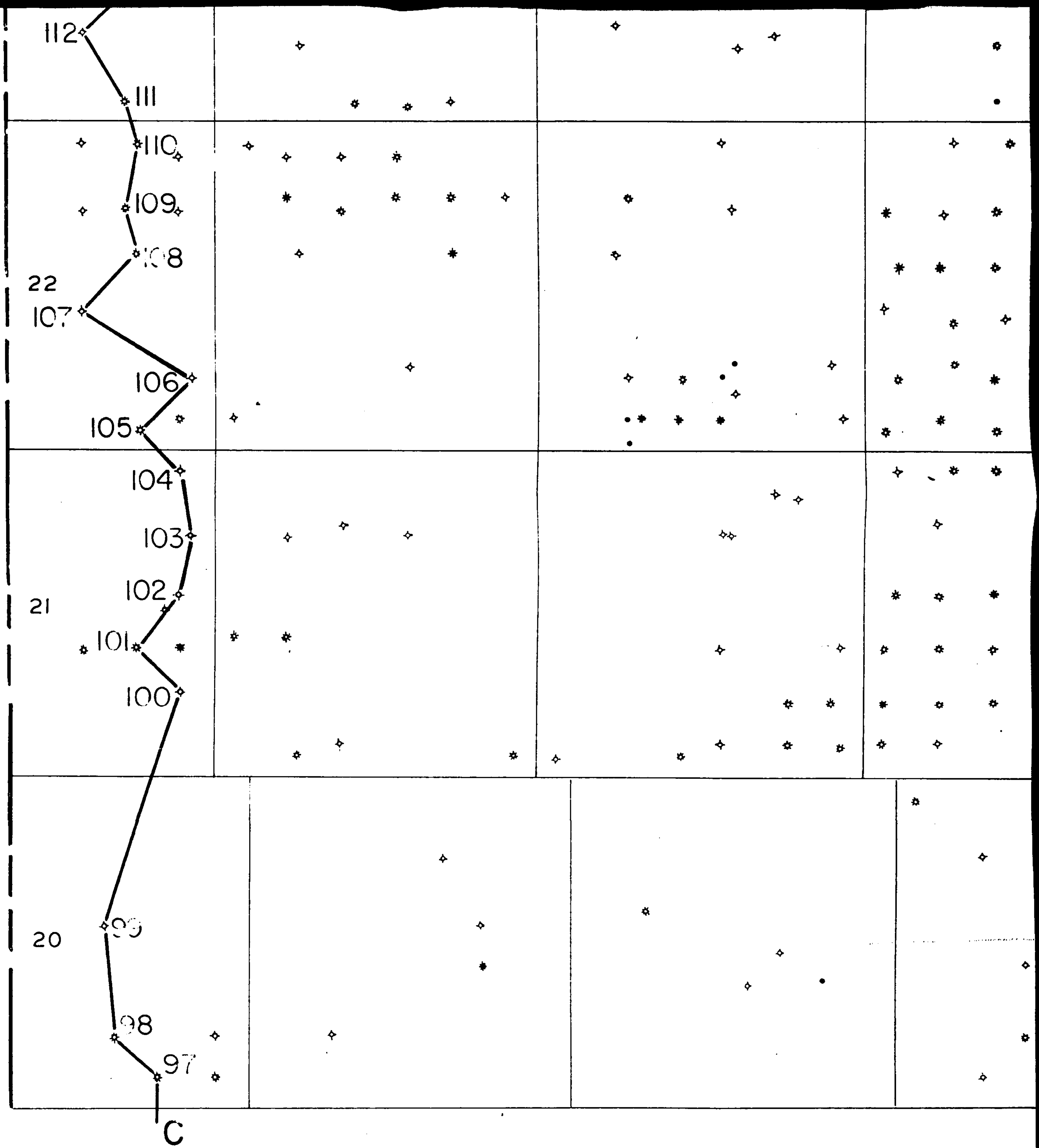
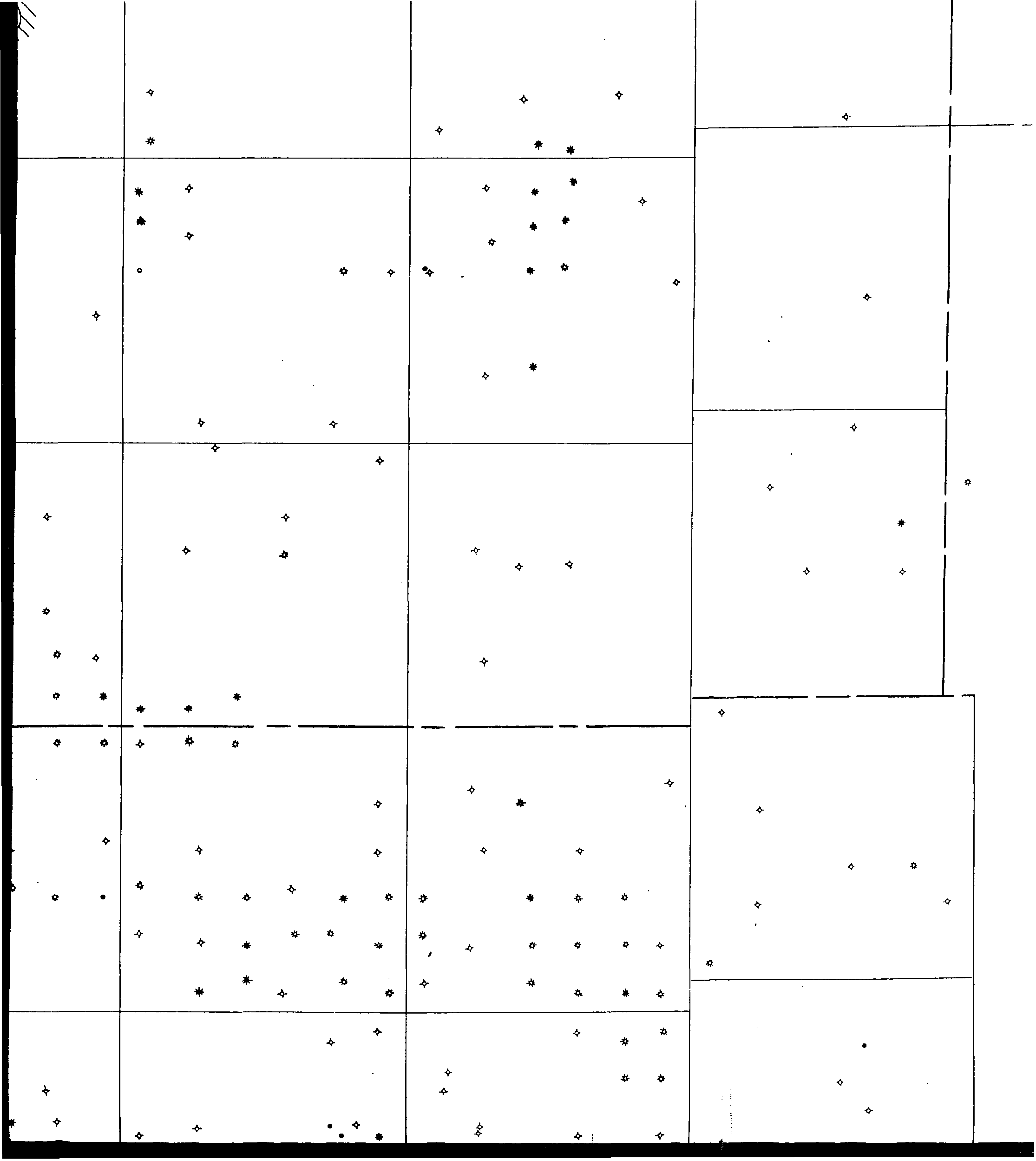


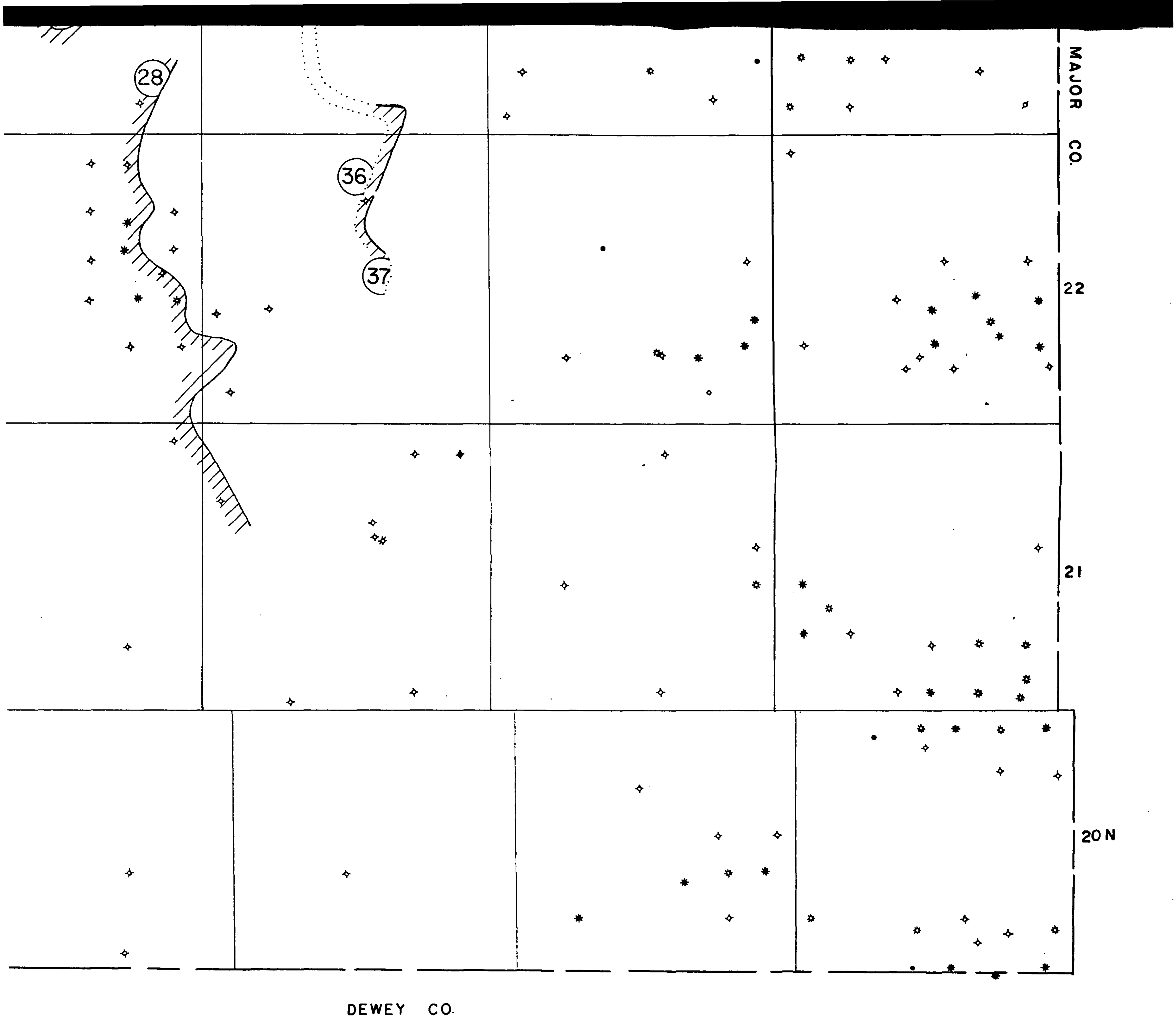

PLATE IV

UNIVERSITY OF OKLAHOMA MOAYAD H. KHAIWKA Ph.D. 1968

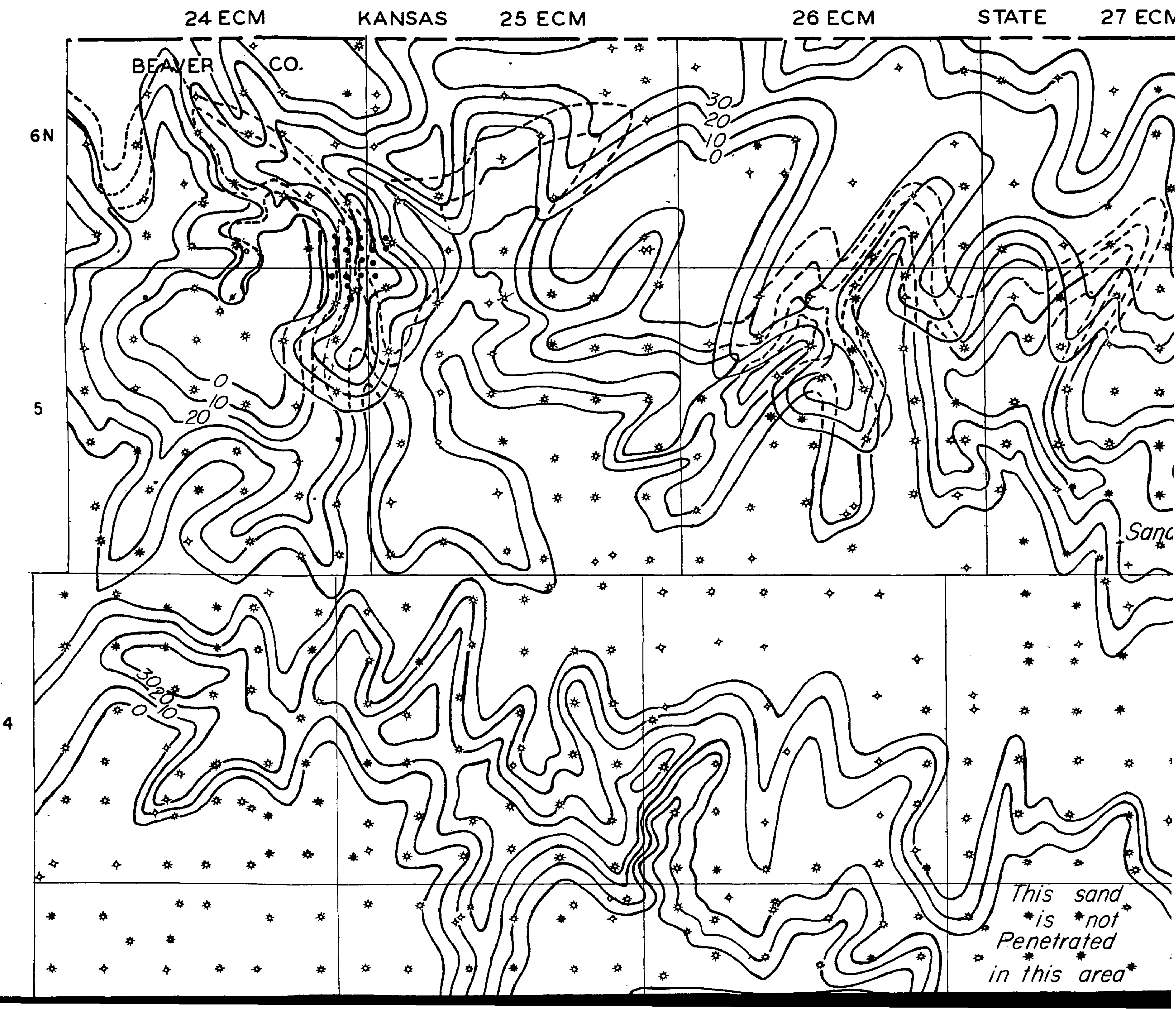


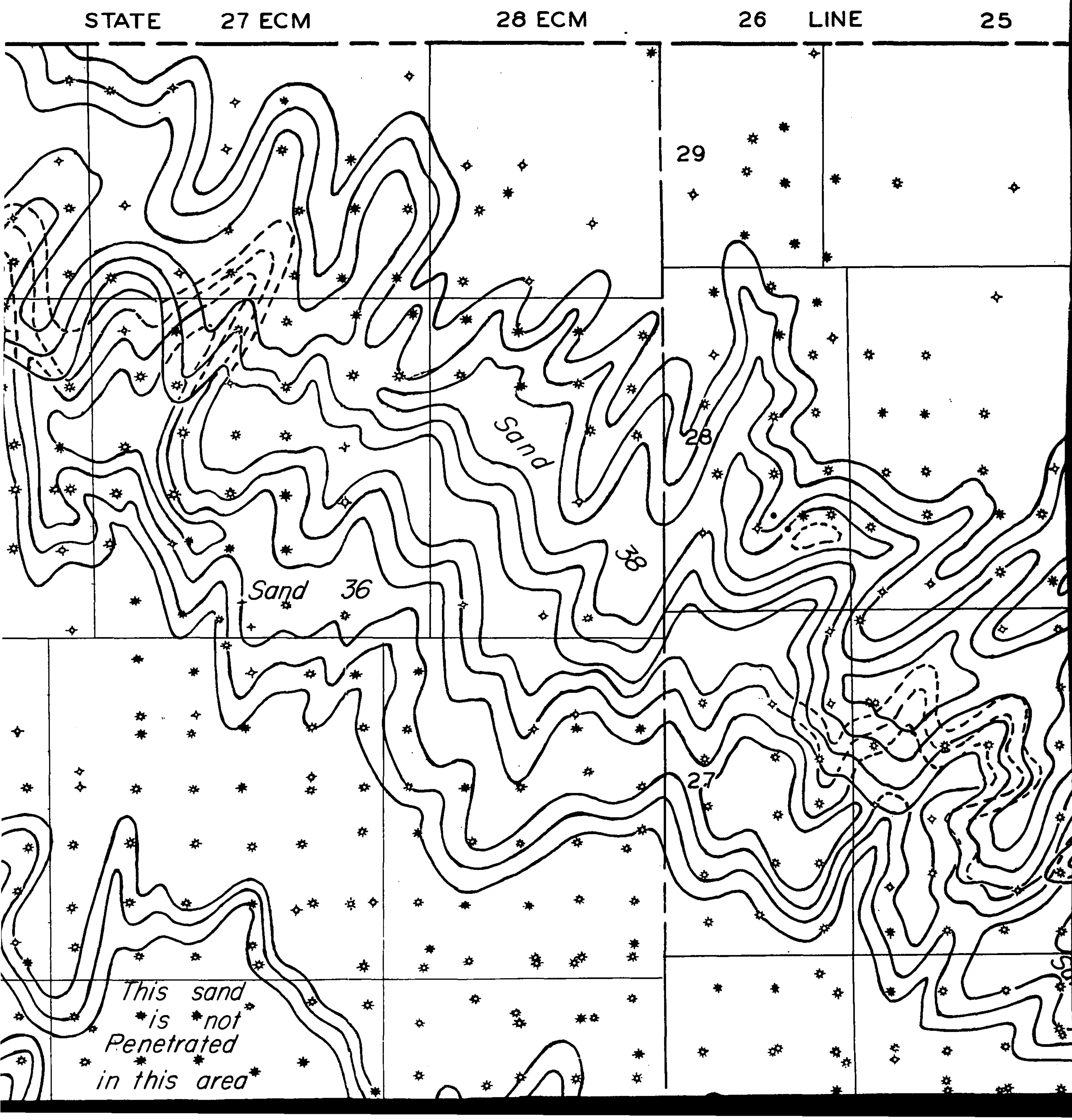
112
111
110
109
108
22
107
106
105
104
103
102
21
101
100
20
99
98
97
C

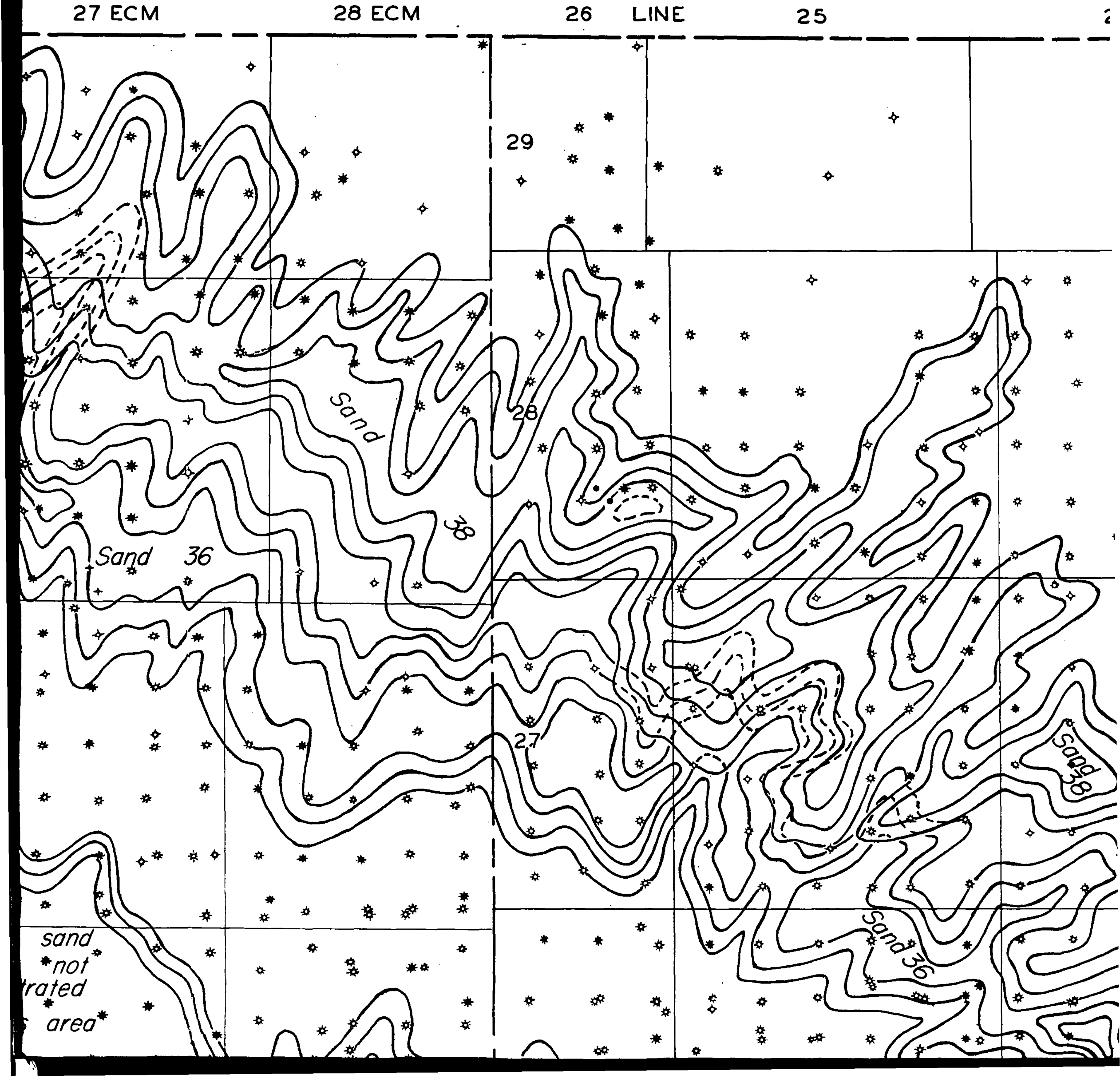


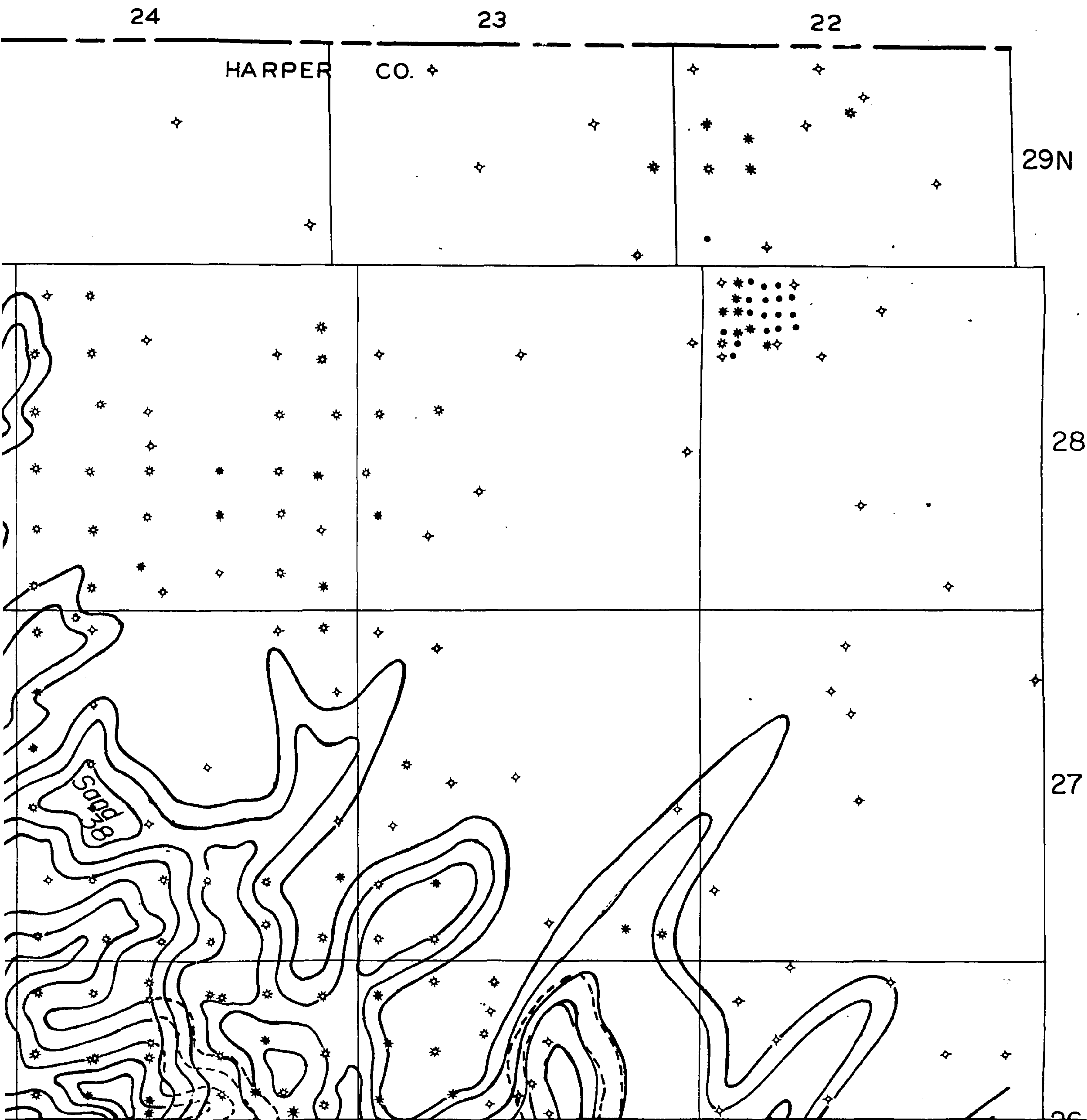


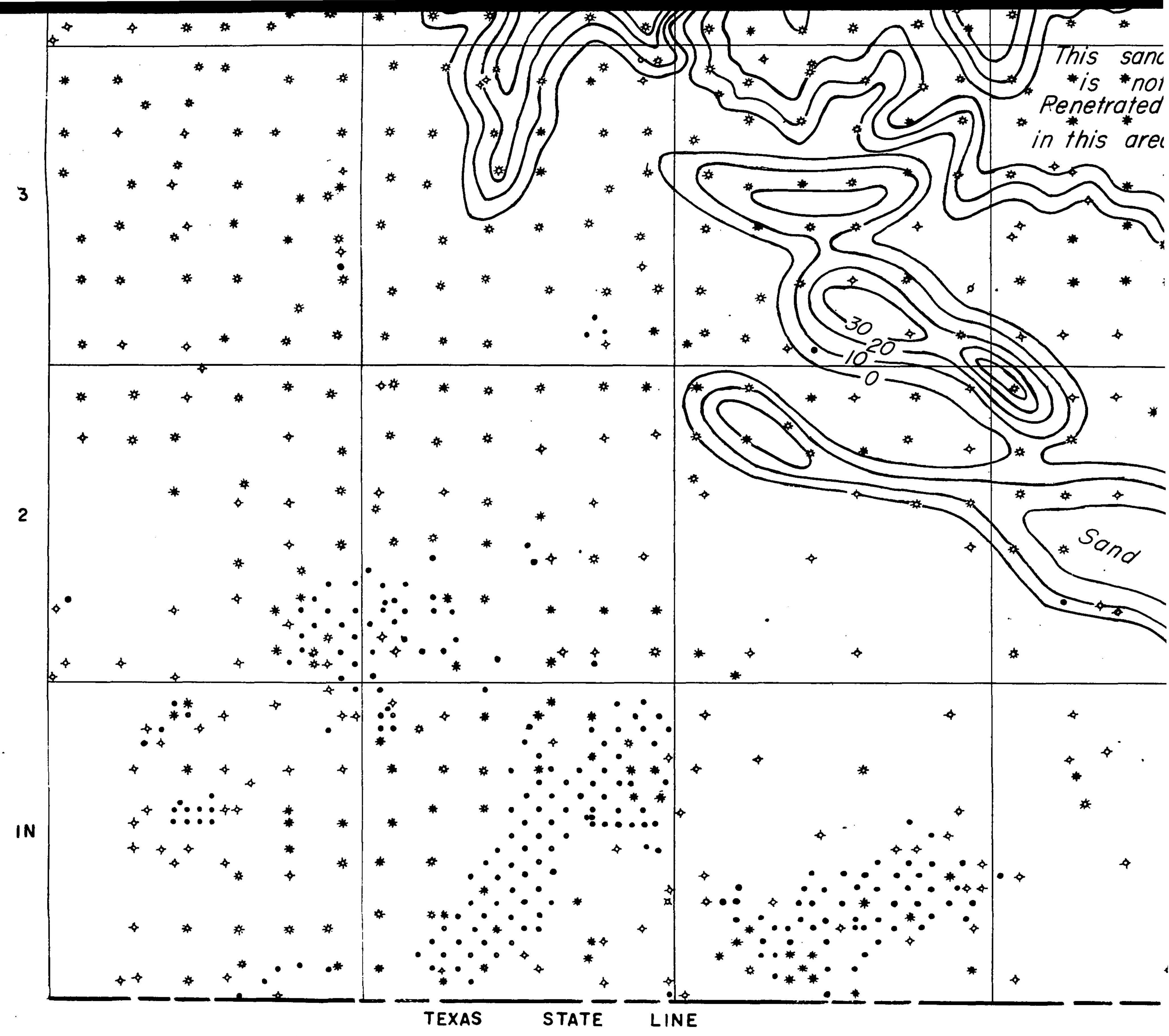
MAJOR CO.
28
36
37
22
21
20 N
DEWEY CO.


24 ECM
KANSAS
25 ECM
26 ECM
STATE
27 ECM
BEAVER
CO.
6N
5
4
30
20
10
0
Sand
This sand
is not
Penetrated
in this area


STATE
27 ECM
28 ECM
26
LINE
25
29
28
27
Sand
38
Sand 36
This sand is not Penetrated in this area

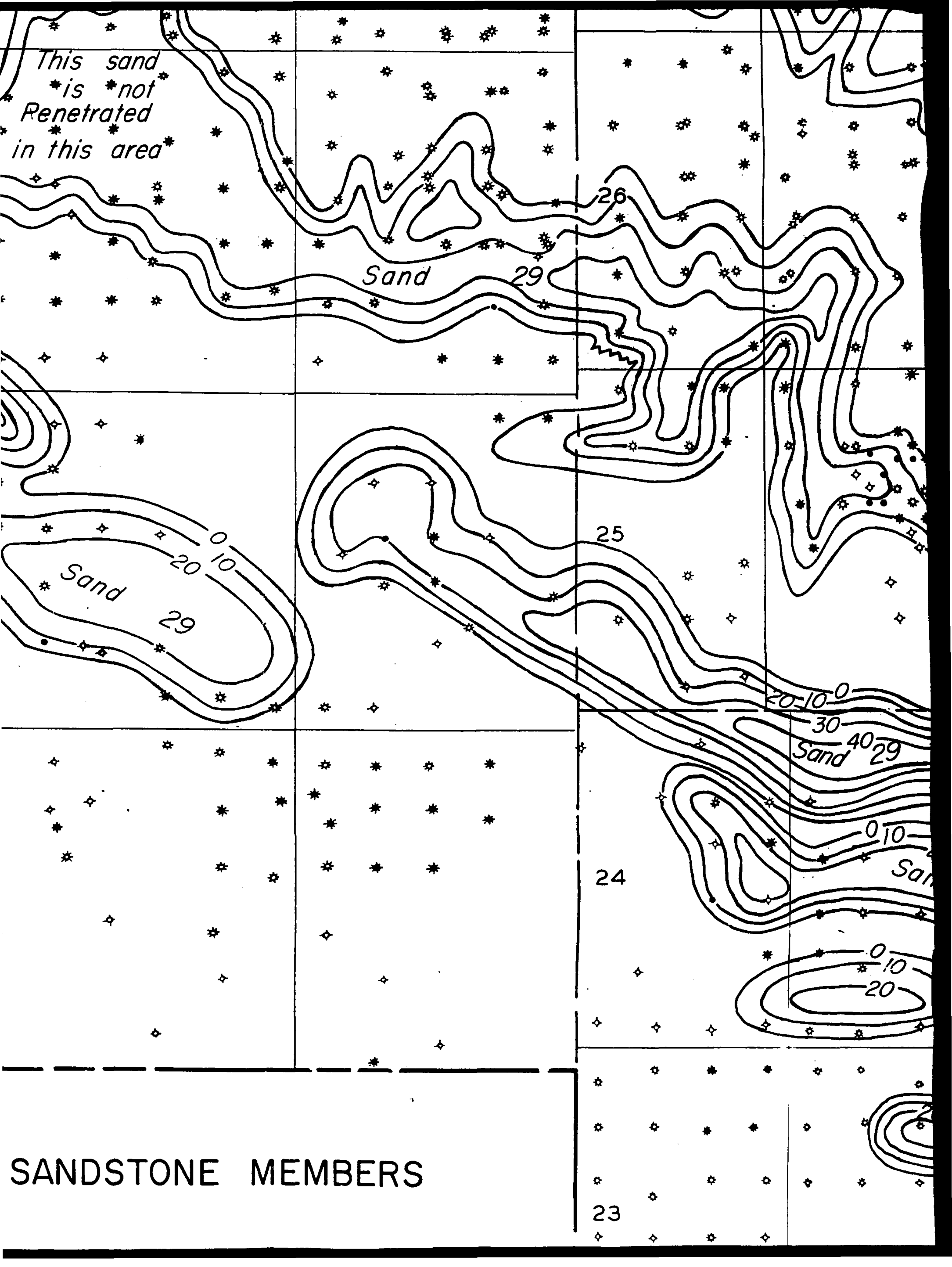

27 ECM
28 ECM
26
LINE
25
29
28
27
Sand
38
Sand 36
sand
not
trated
area
Sand
38
Sand 36

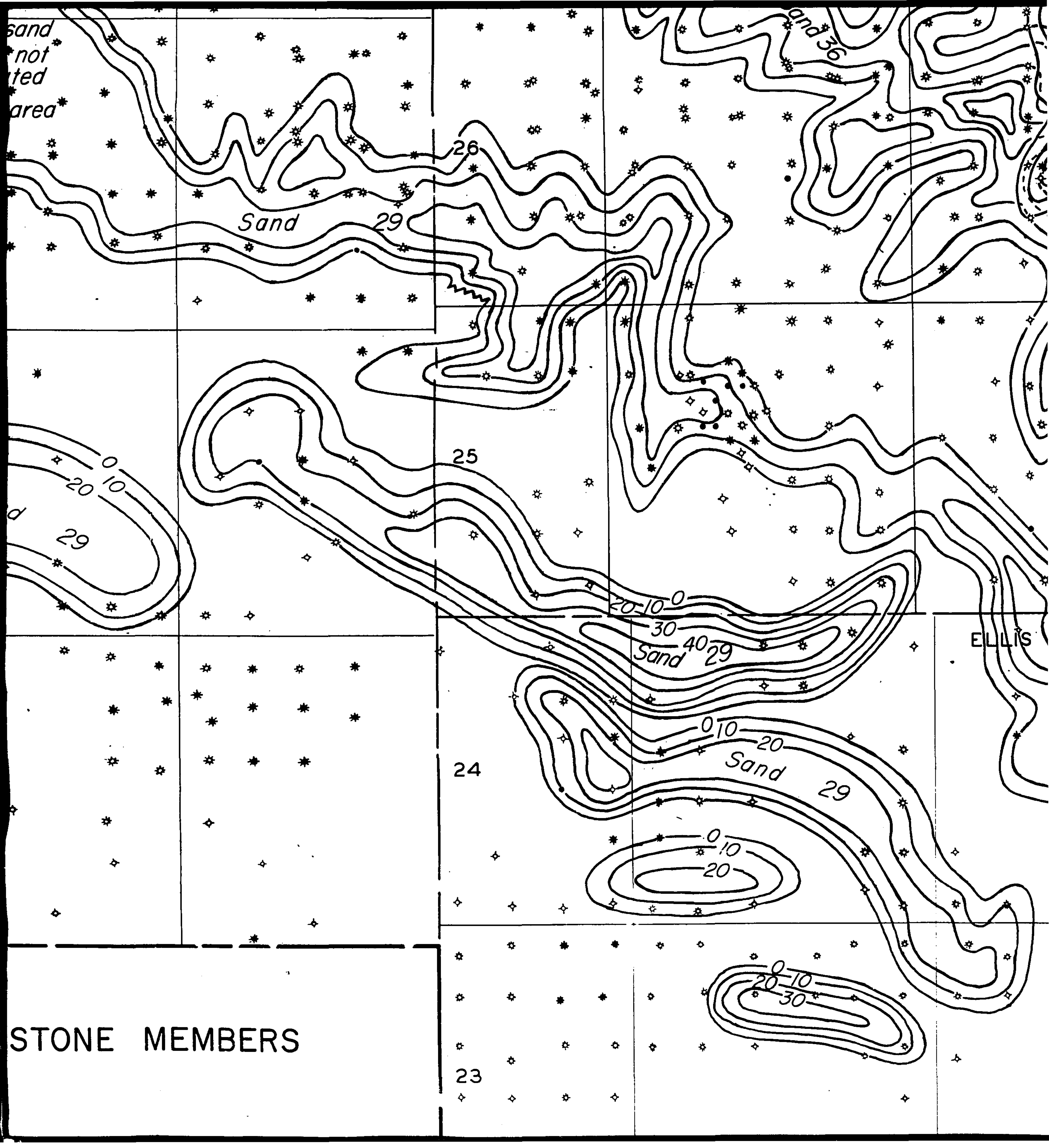

24
23
22
HARPER CO.
29N
28
27
Sand 38



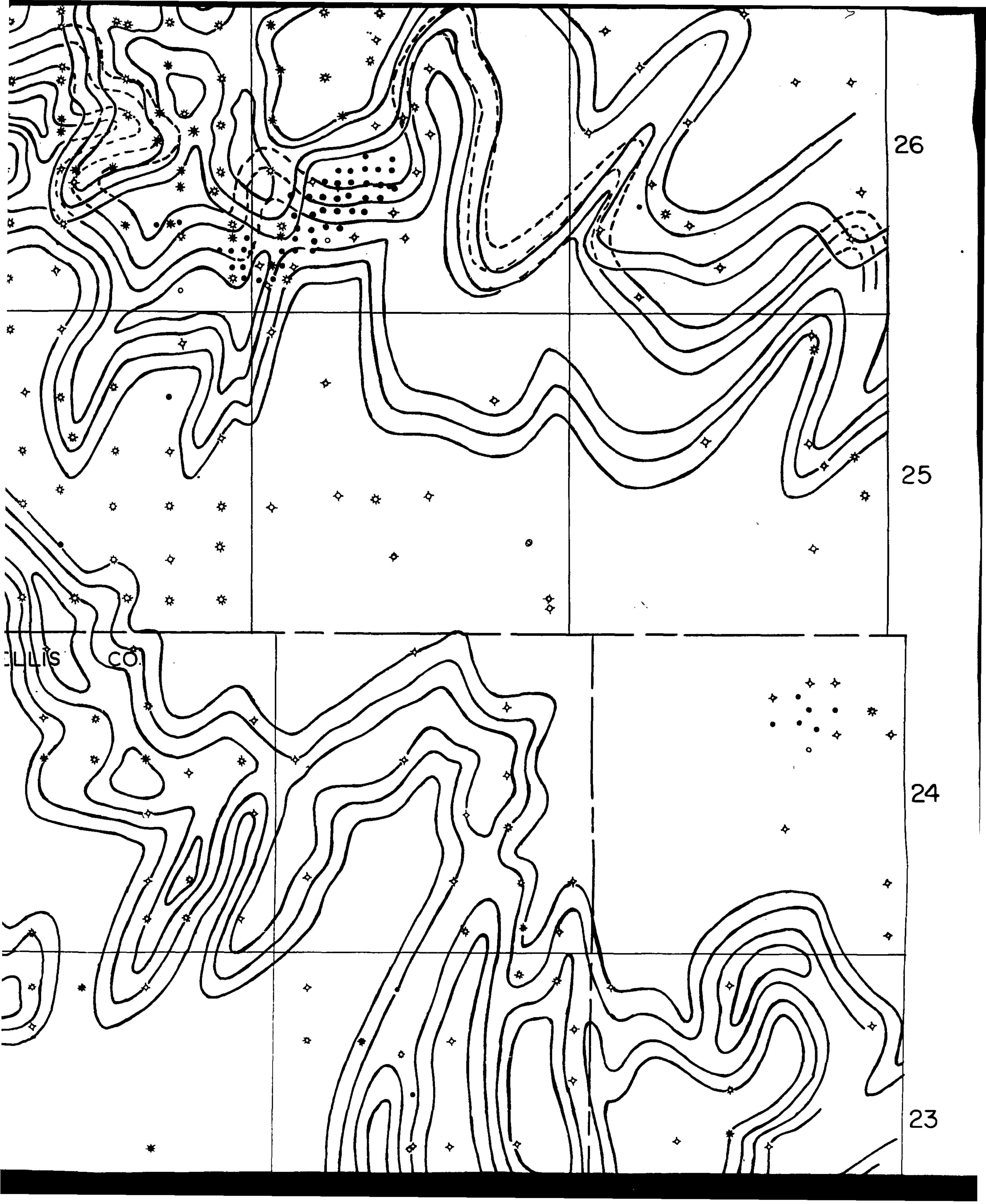

THICKNESS AND TRENDS OF THREE MORROW SANDSTO

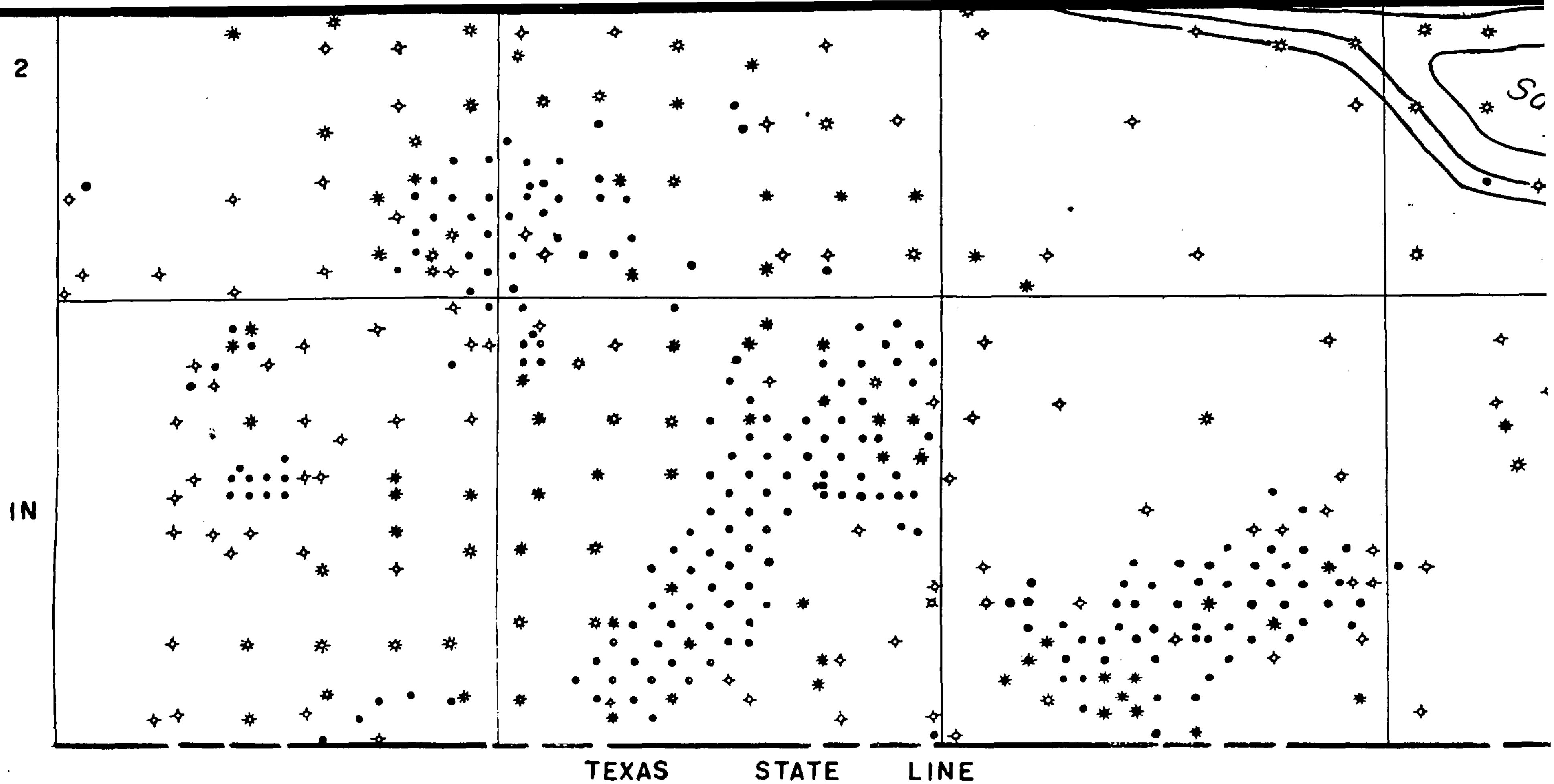
NORTHWESTERN, OKLAHOMA


This sand is not Penetrated in this area
26
Sand
29
25
0
10
20
Sand
29
20
10
0
30
40
Sand
29
0
10
Sa
24
0
10
20
23
SANDSTONE MEMBERS



sand not ...ted ...area
Sand 29
26
...and 36
25
0
10
20
...d 29
20 10 0
30
40
Sand 29
ELLIS
0 10 20
Sand 29
24
0
10
20
0 10
20 30
STONE MEMBERS
23


26
25
ELLIS CO.
24
23



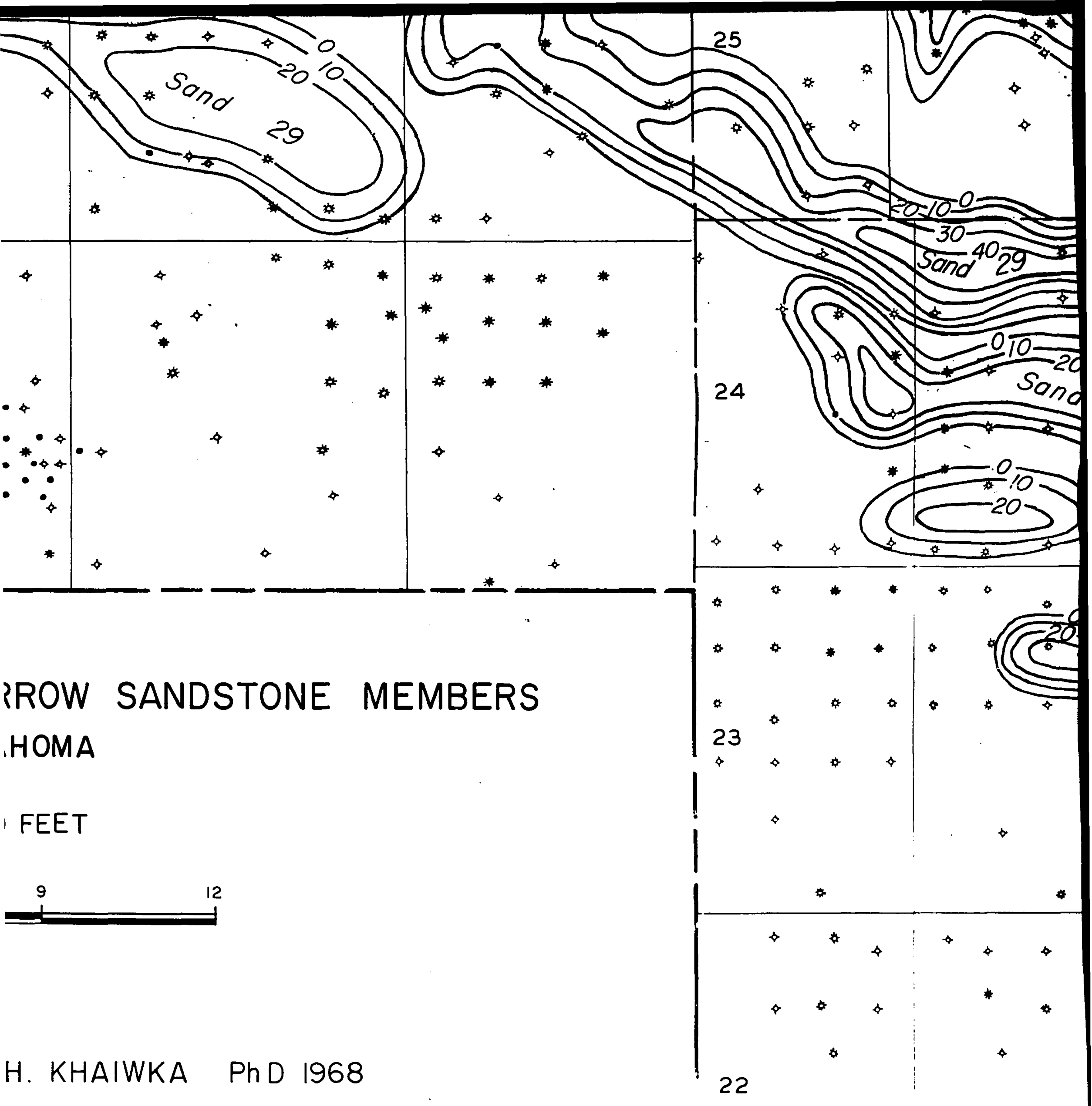

# THICKNESS AND TRENDS OF THREE MORROW SAND

## NORTHWESTERN, OKLAHOMA

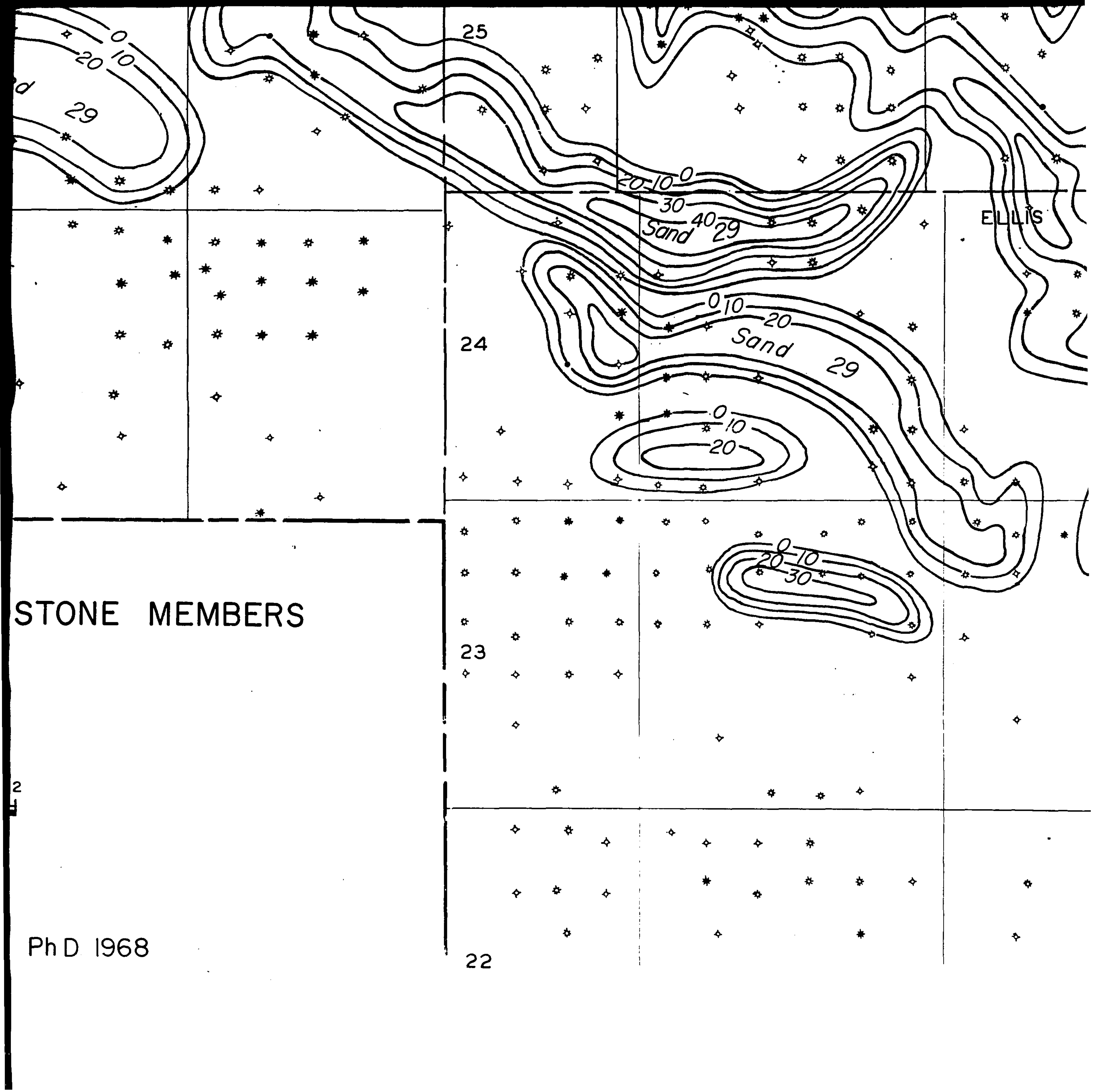
CONTOUR INTERVAL = 10 FEET


PLATE V

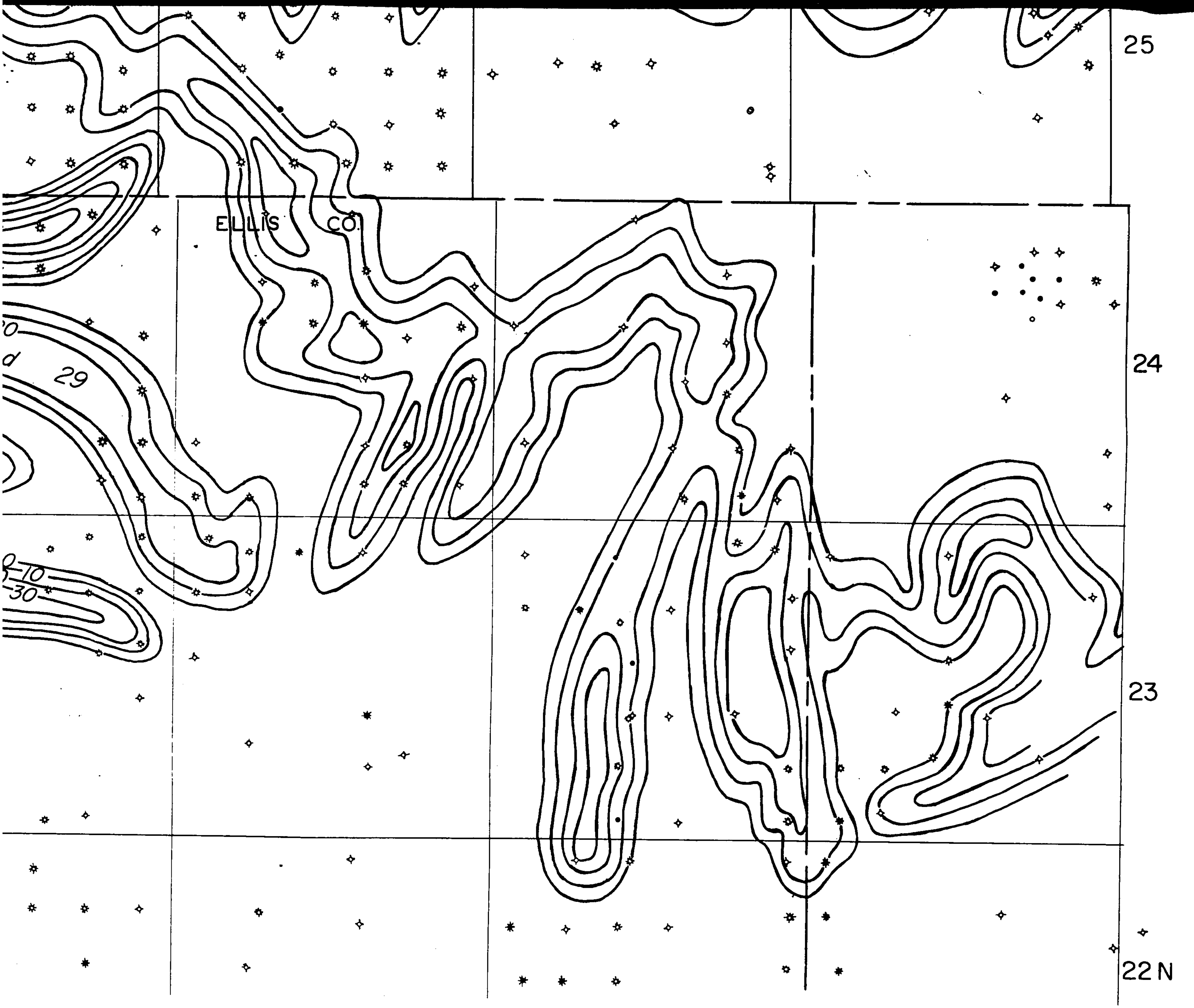
UNIVERSITY OF OKLAHOMA MOAYAD H. KHAIWKA



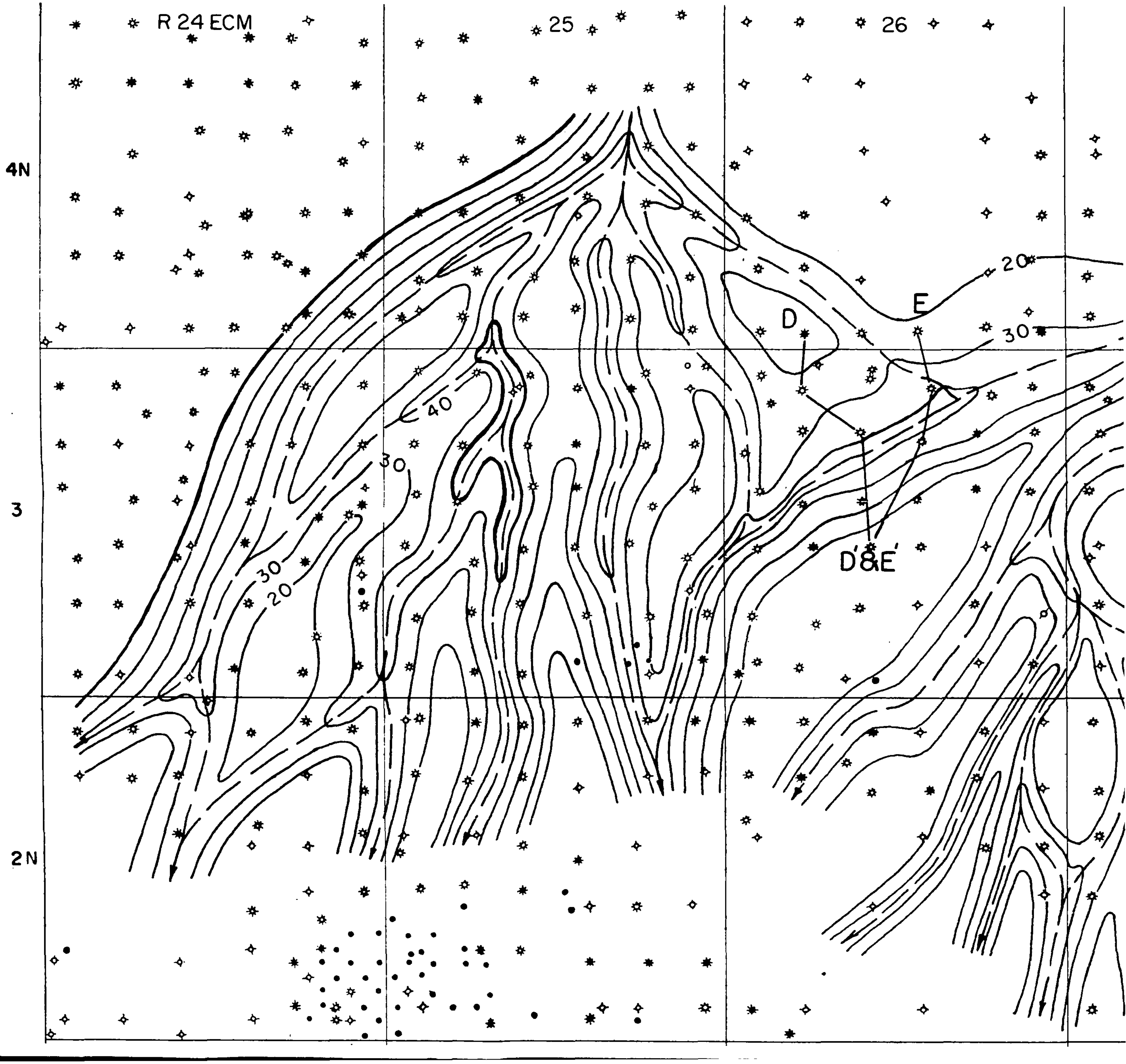
Sand
29
0
10
20
25
24
23
22
30
40
RROW SANDSTONE MEMBERS
HOMA
FEET
9
12
H. KHAIWKA PhD 1968



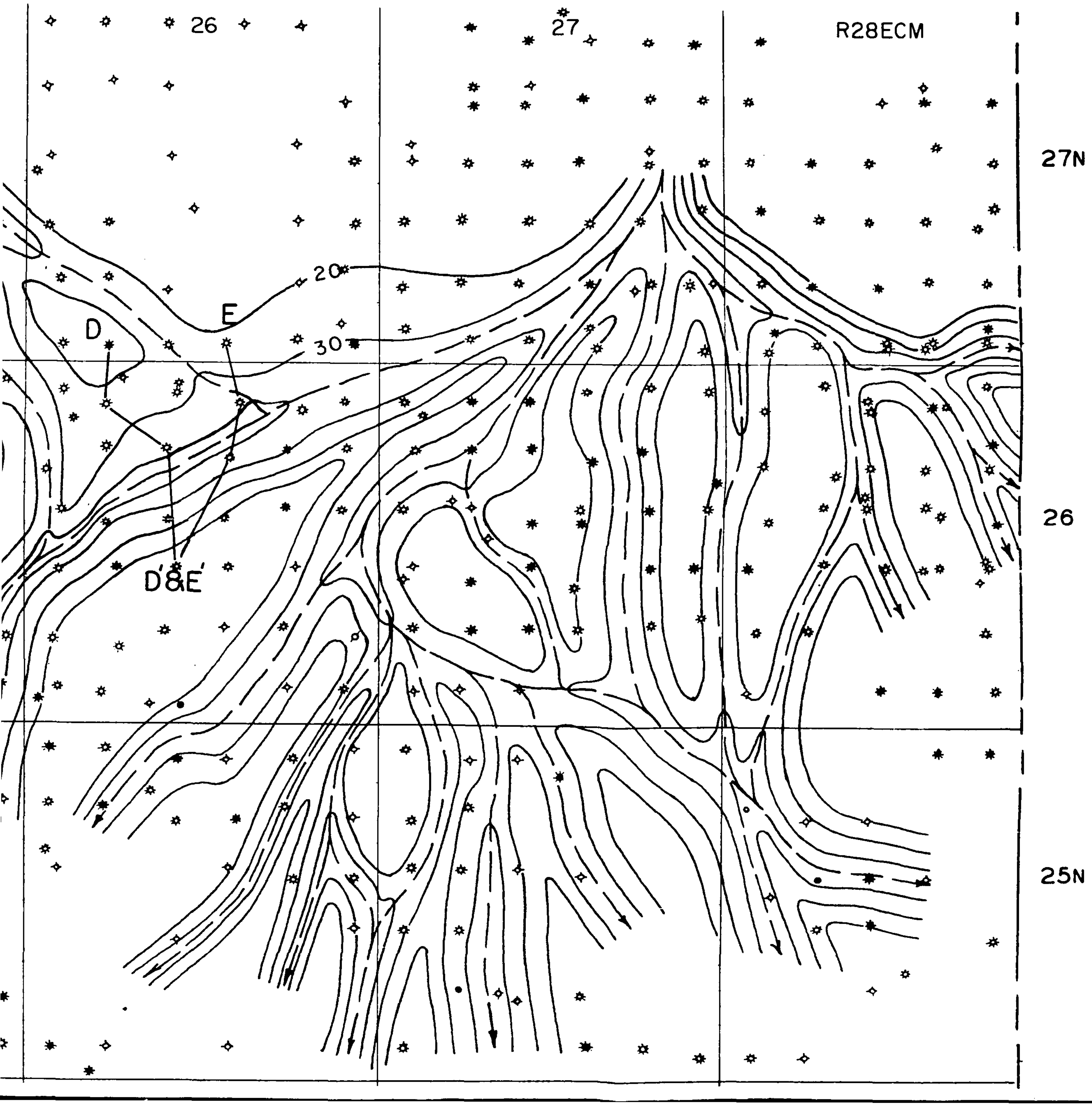
0
10
20
29
25
20
10
0
30
40
Sand
29
ELLIS
0
10
20
Sand
29
24
0
10
20
0
10
20
30
STONE MEMBERS
23
2
Ph D 1968
22



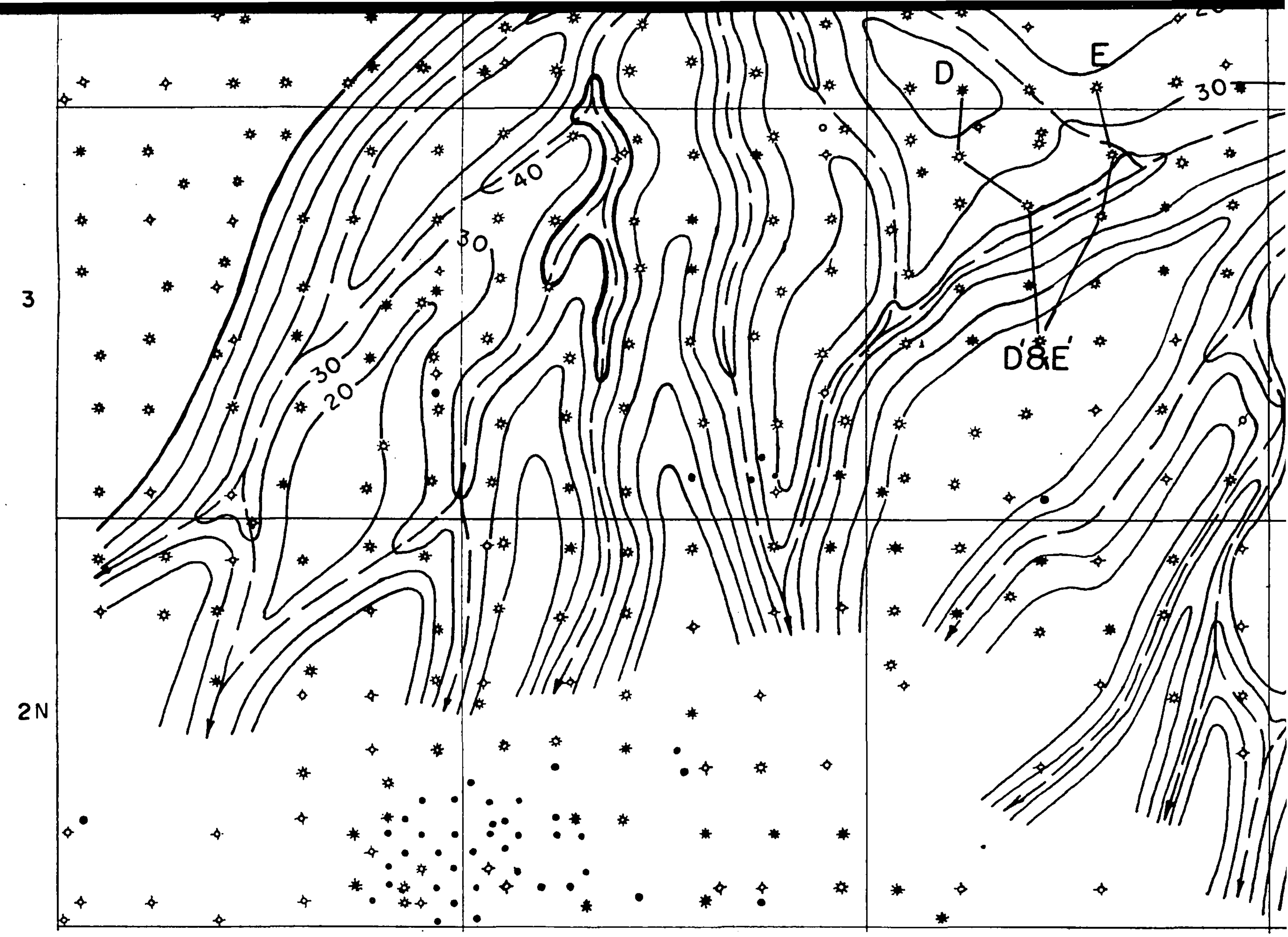
25
ELLIS CO.
24
20
d
29
10
30
23
22 N



R 24 ECM
25
26
4N
3
2N
40
30
30
20
20
30
D
E
D&E



26
27
R28ECM
27N
20
30
D
E
D&E
26
25N



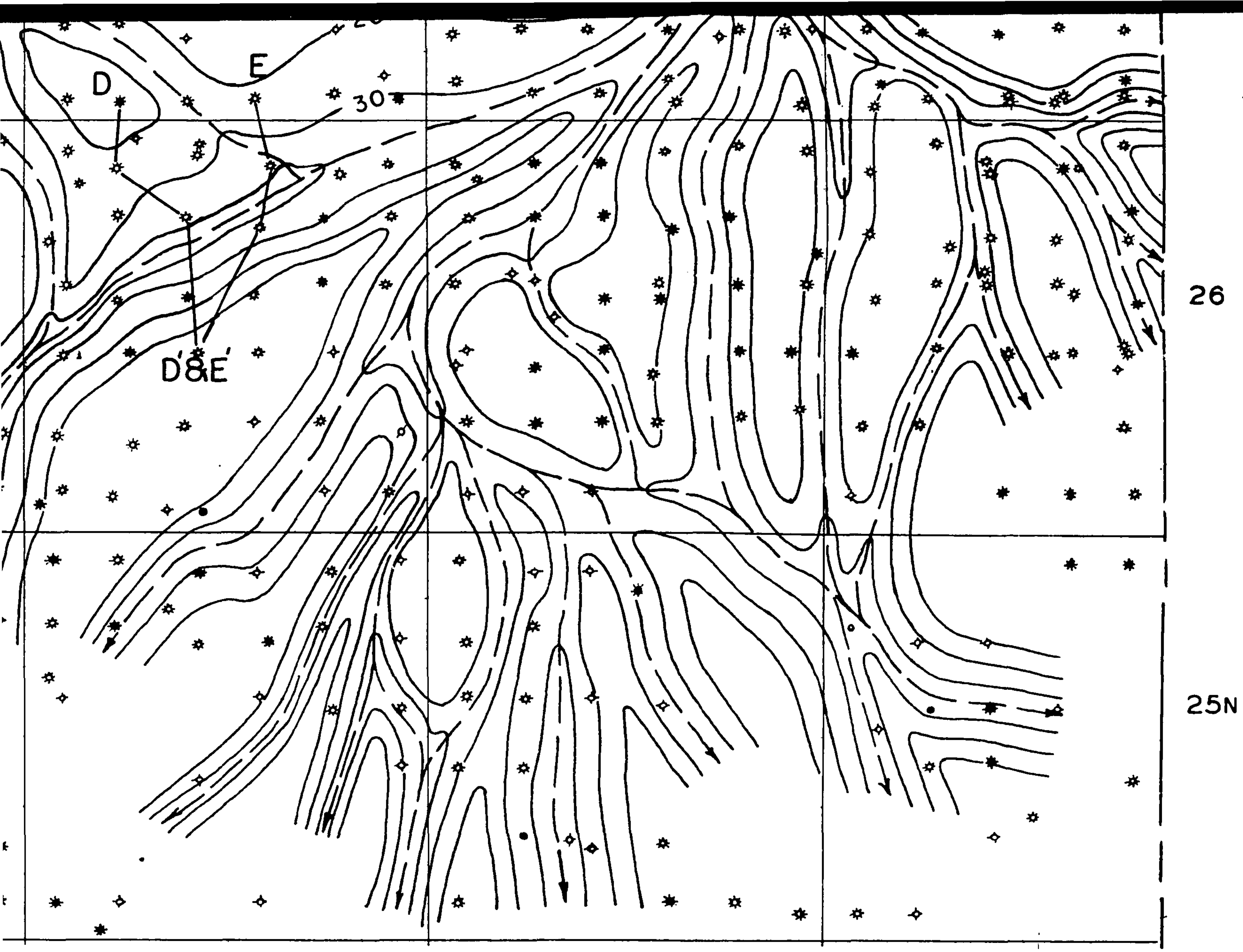

ISOPACH, TOP OF HASKELL L
BASE OF TONKAWA SANDSTONE
SHOWING DELTAIC DISTRIBUTI
BEAVER COUNTY, OKLAH

C. I. = 10 feet



PLATE VI

MOAYAD H. KHAIWKA UNIVERSITY OF OKLAHOMA




OF HASKELL LIMESTONE TO
AWA SANDSTONE UPPER MEMBER
LTAIC DISTRIBUTION PATTERN
.VER COUNTY, OKLAHOMA

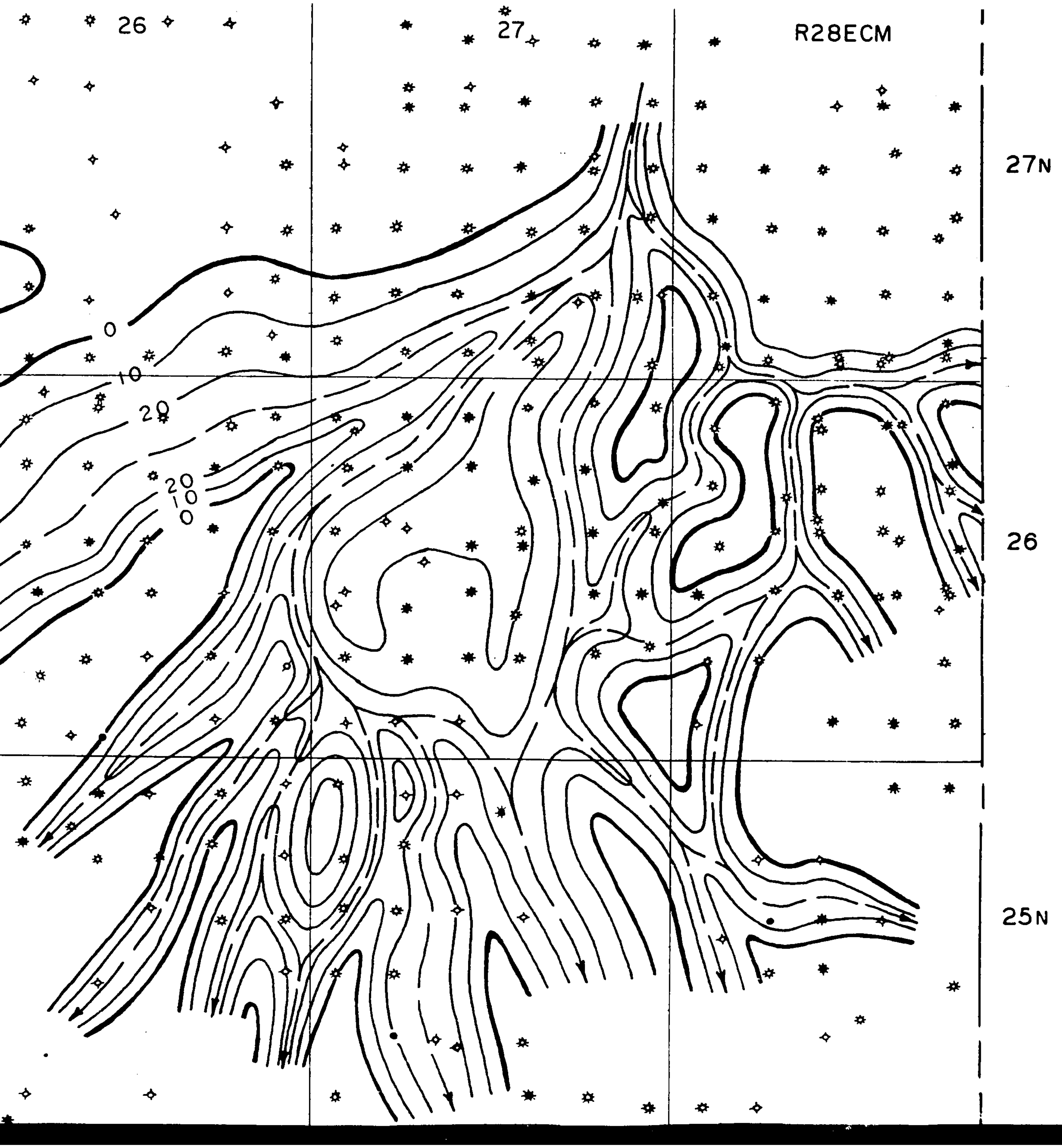
C. I. = 10 feet

0 1 2 3 4 5 6
MILES

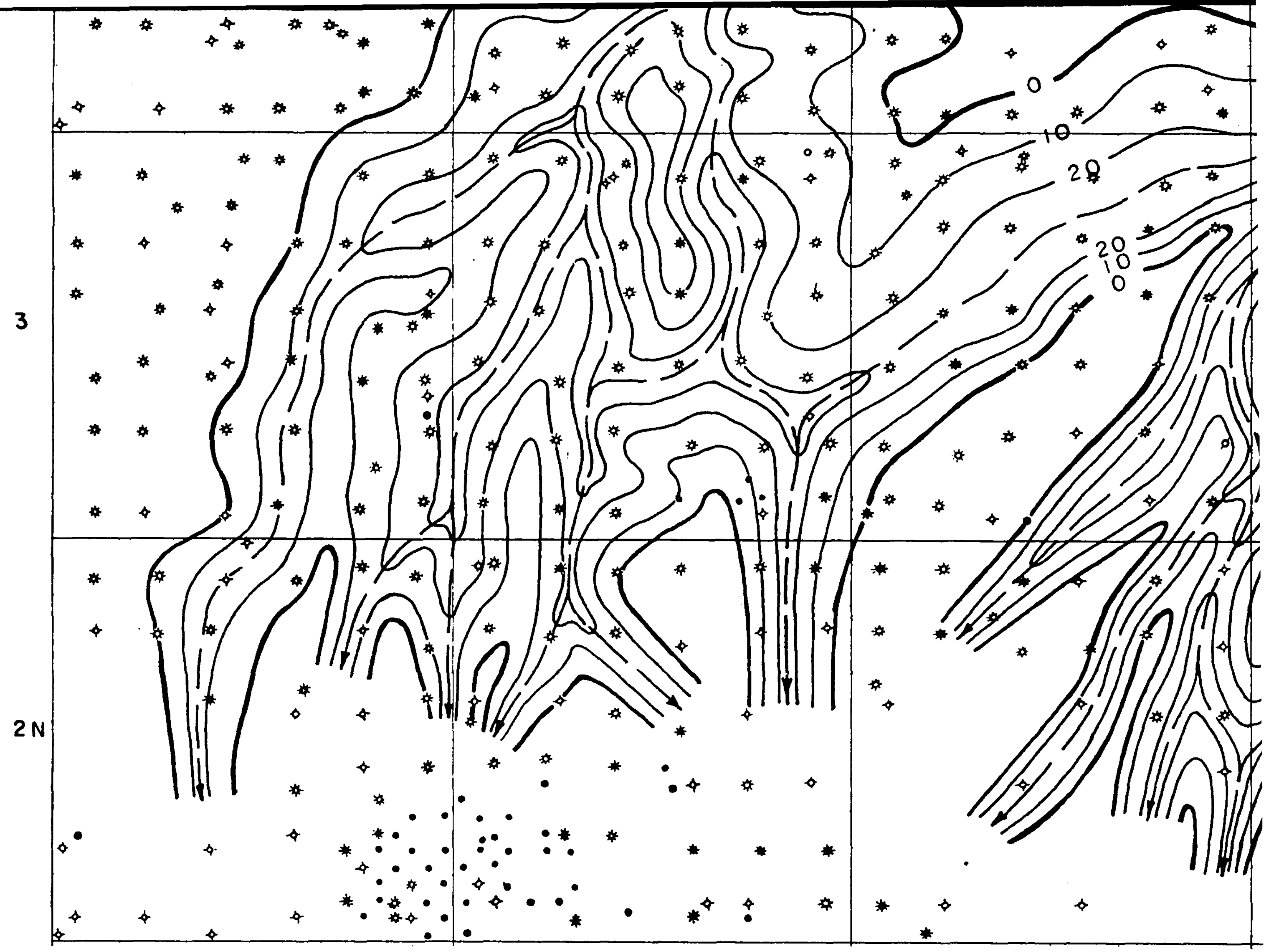
PLATE VI

HAIWKA UNIVERSITY OF OKLAHOMA Ph. D. 1968

R 24 ECM
25
26
4N
3
2N
0
10
20
20
10
0



26
27
R28ECM
27N
26
25N
0
10
20
20
10
0

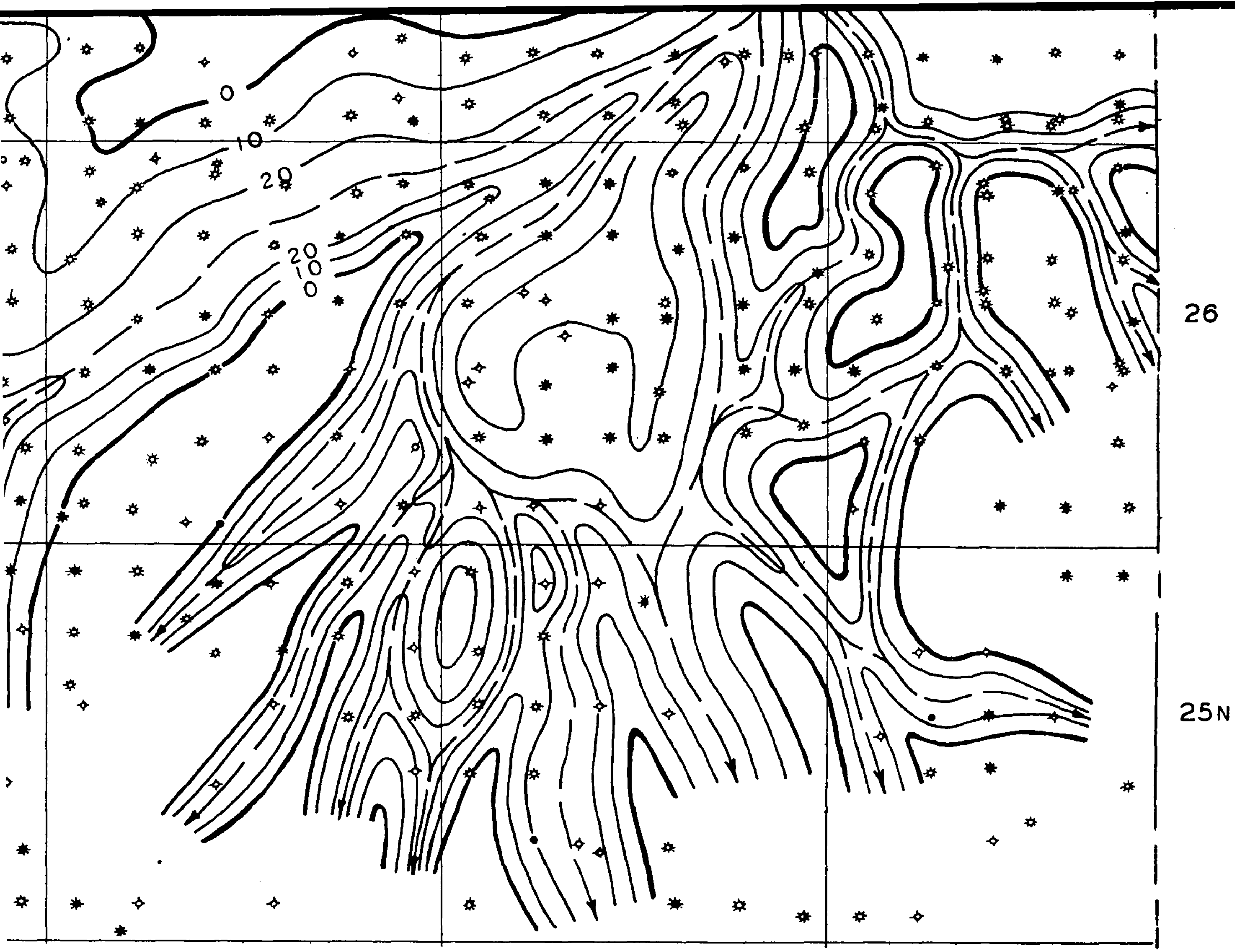



ISOPACH MAP
UPPER MEMBER OF TONKAWA
BEAVER COUNTY, OKLAH

C. I. = 10 feet


PLATE VII

MOAYAD H. KHAIWKA UNIVERSITY OF OKLAHOMA

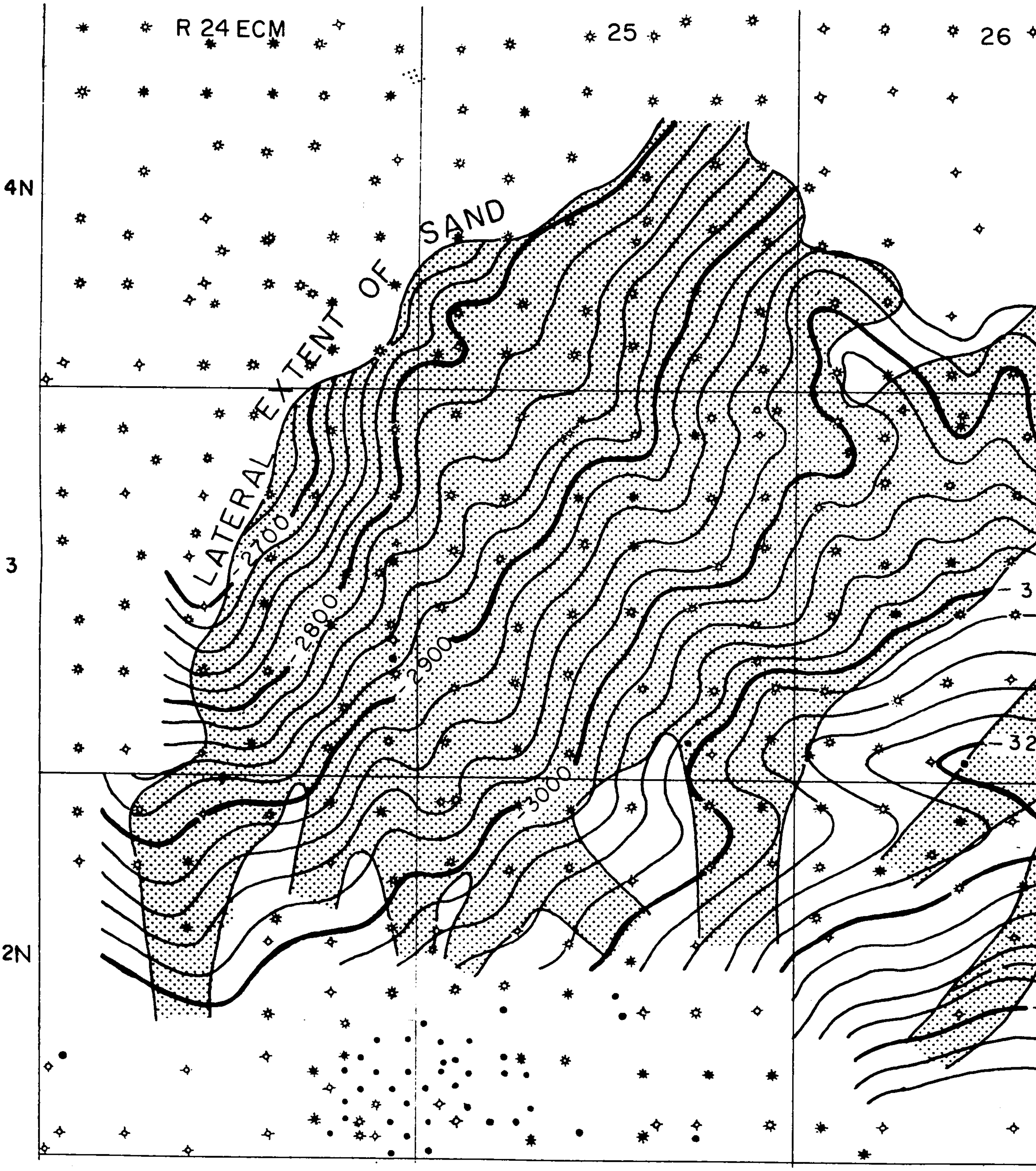



ISOPACH MAP
MBER OF TONKAWA SANDSTONE
AVER COUNTY, OKLAHOMA

C. I. = 10 feet

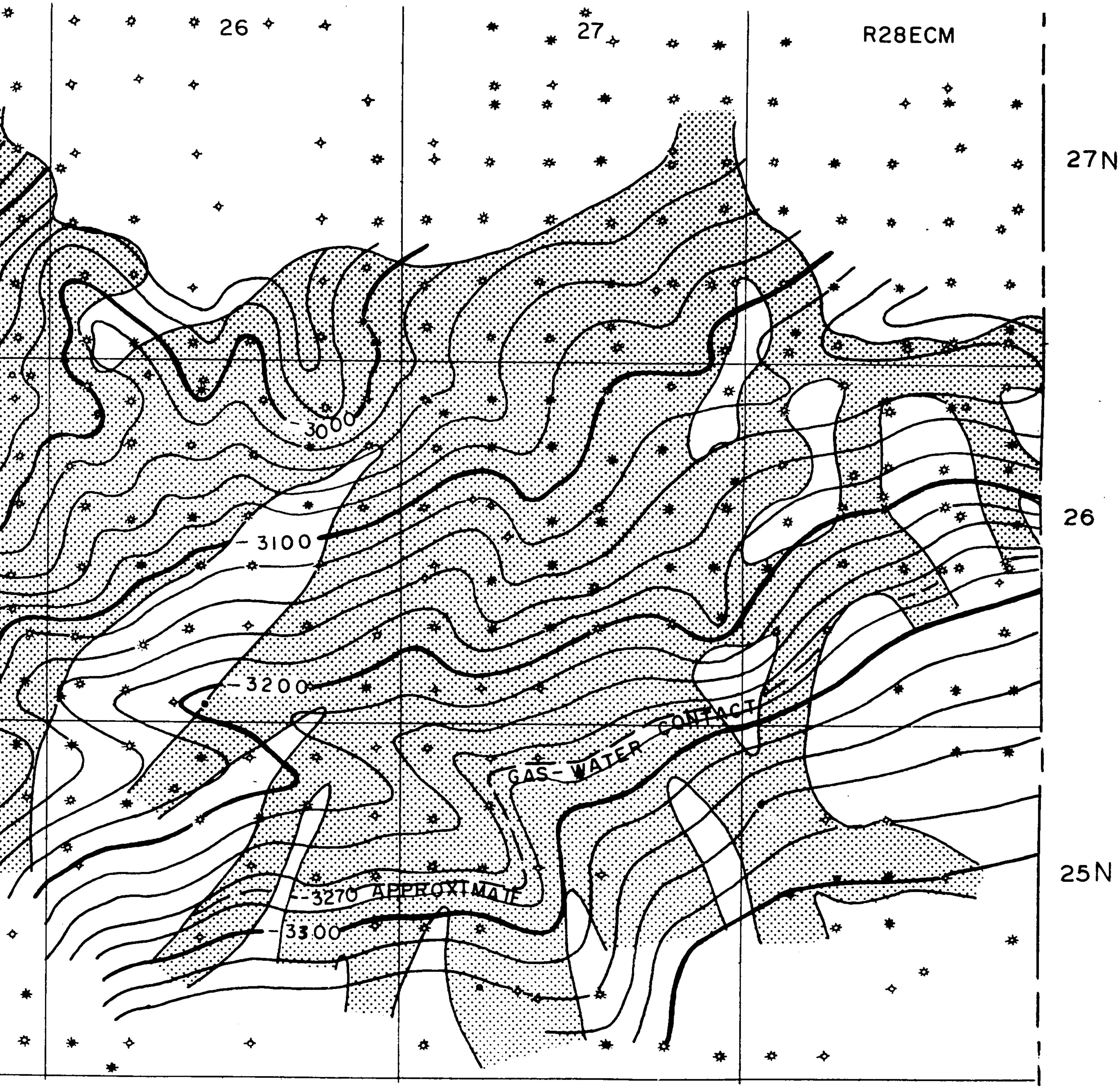

PLATE VII

:HAIWKA UNIVERSITY OF OKLAHOMA Ph. D. 1968

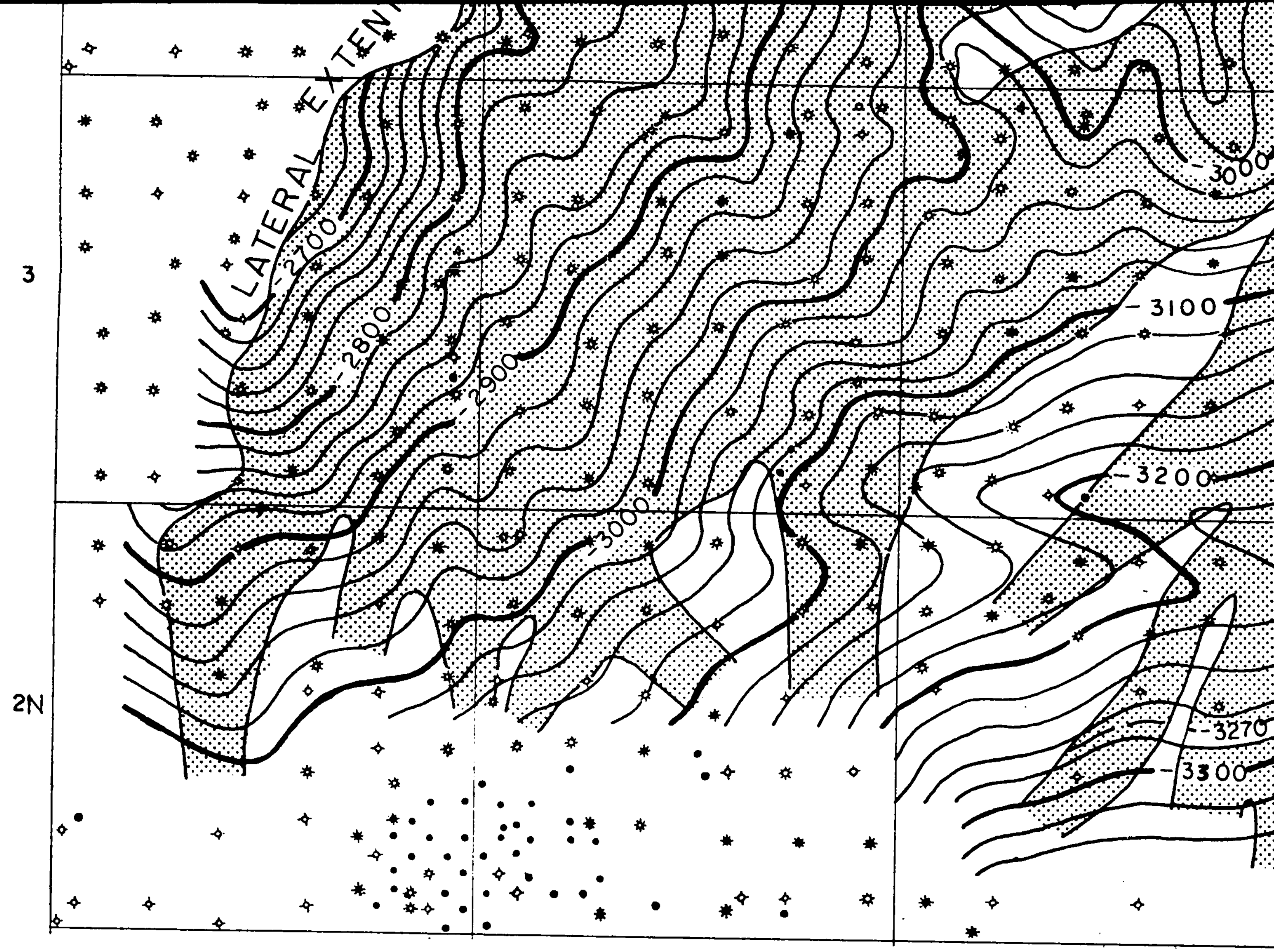


R 24 ECM
25
26
4N
3
2N
LATERAL EXTENT OF SAND
-2700
-2800
-2900
-3000


STRUCTURE




STRUCTURE MAP



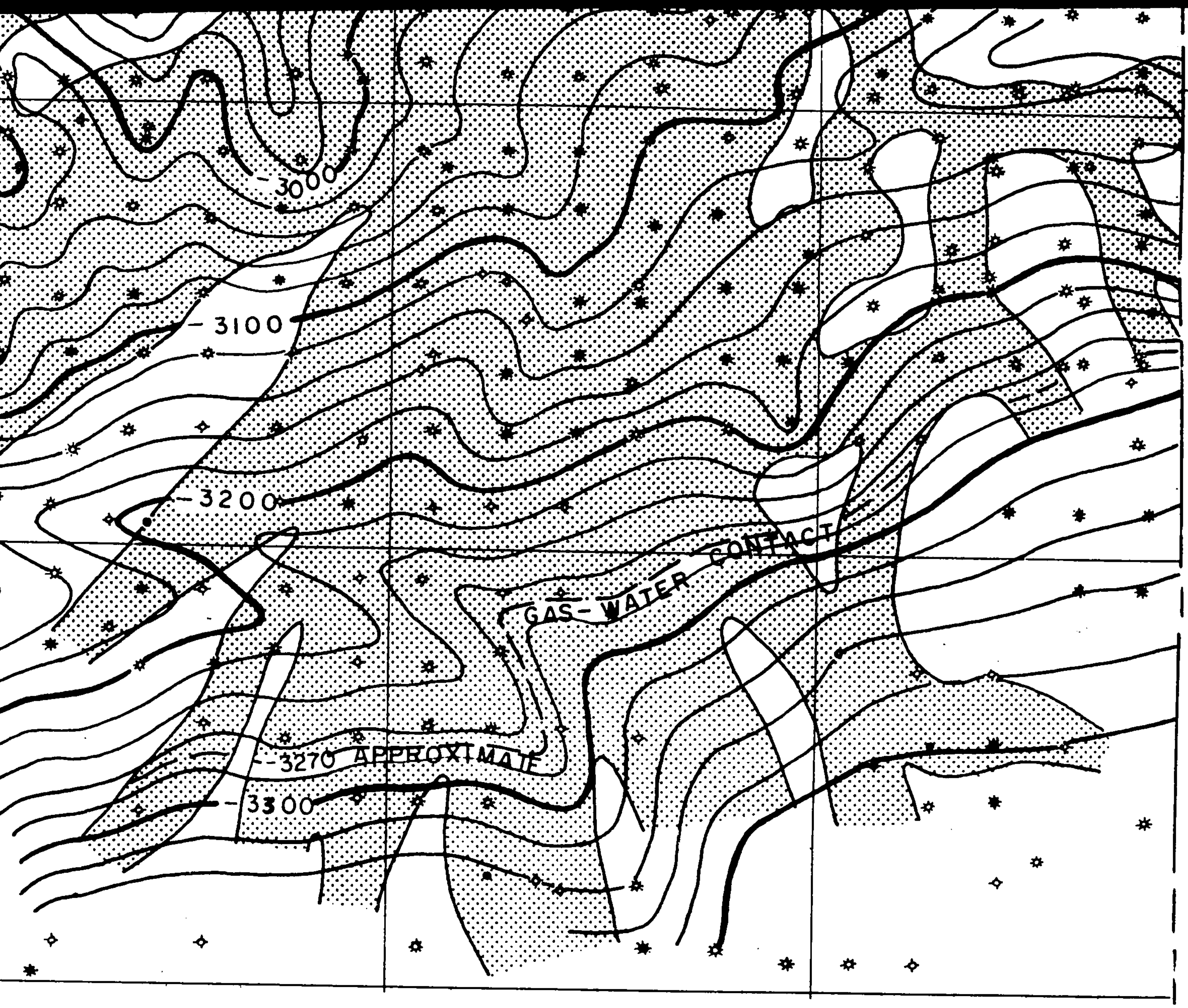

STRUCTURE MAP
TOP OF UPPER MEMBER OF TON
BEAVER COUNTY, OKLA

C. I. = 20 feet

0 1 2 3 4 5
MILES

PLATE VIII

MOAYAD H. KHAIWKA UNIVERSITY OF OKLAHO



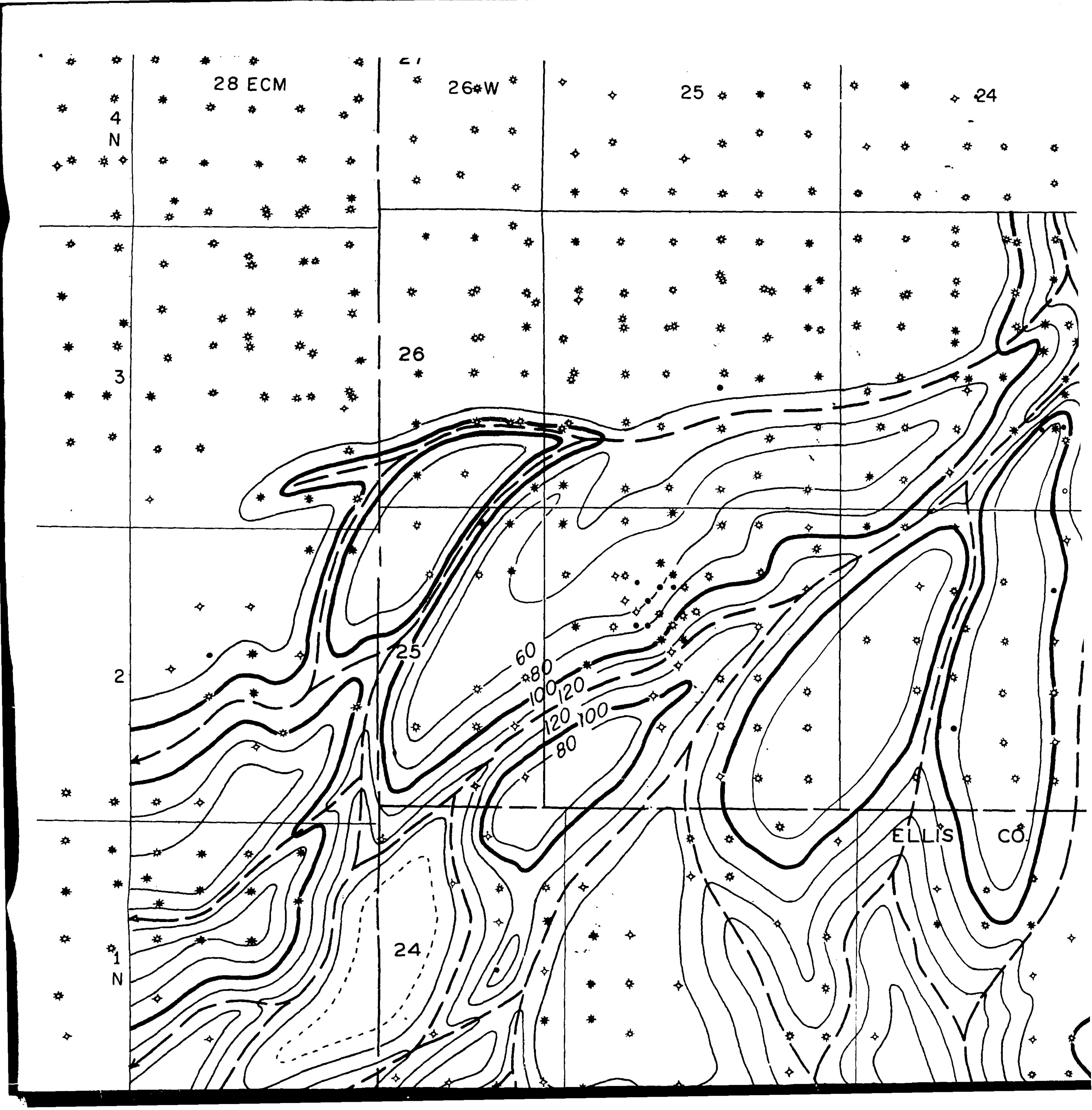

TRUCTURE MAP
EMBER OF TONKAWA SANDSTONE
R COUNTY, OKLAHOMA

C. I. = 20 feet

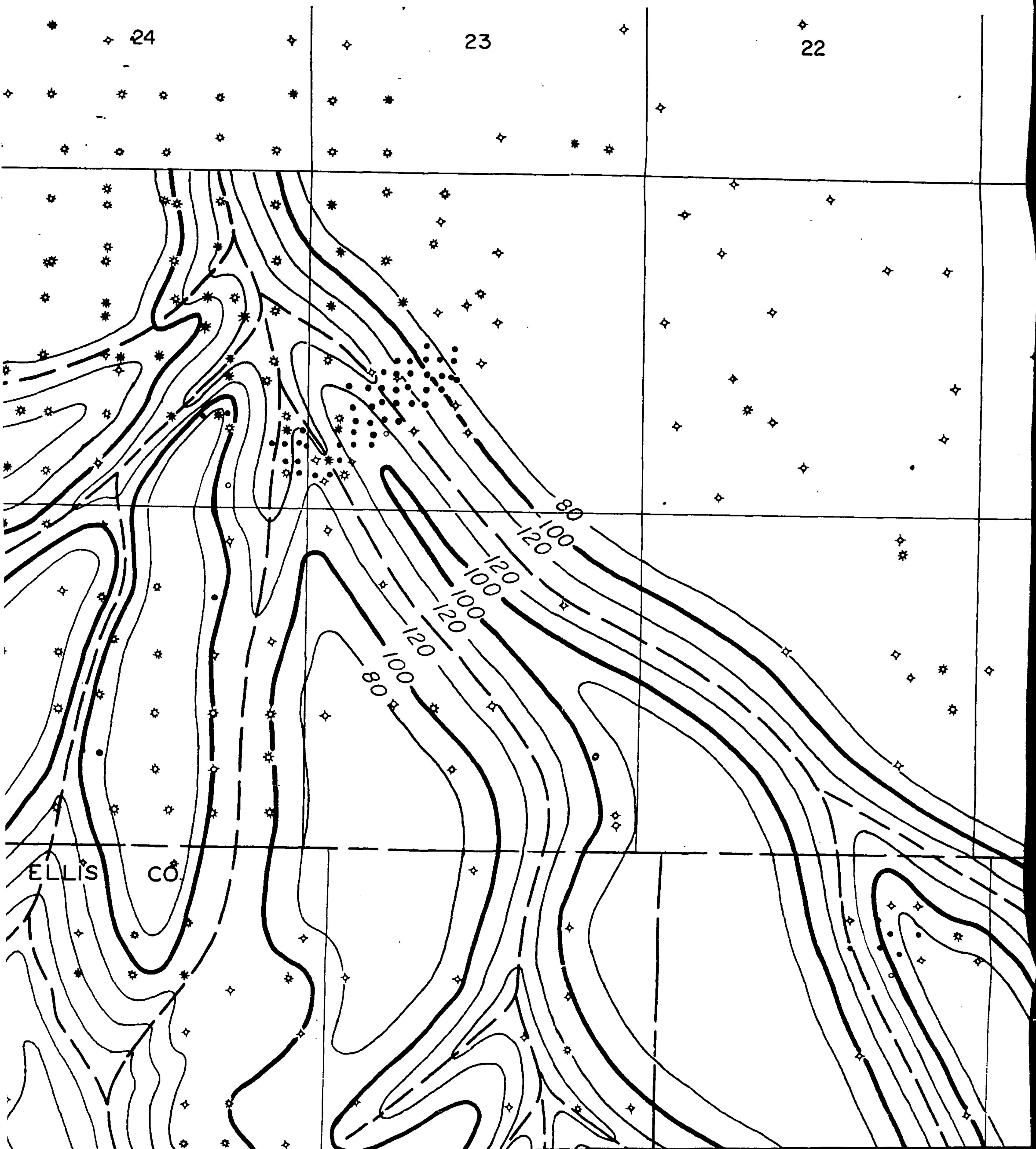
1 2 3 4 5 6
MILES

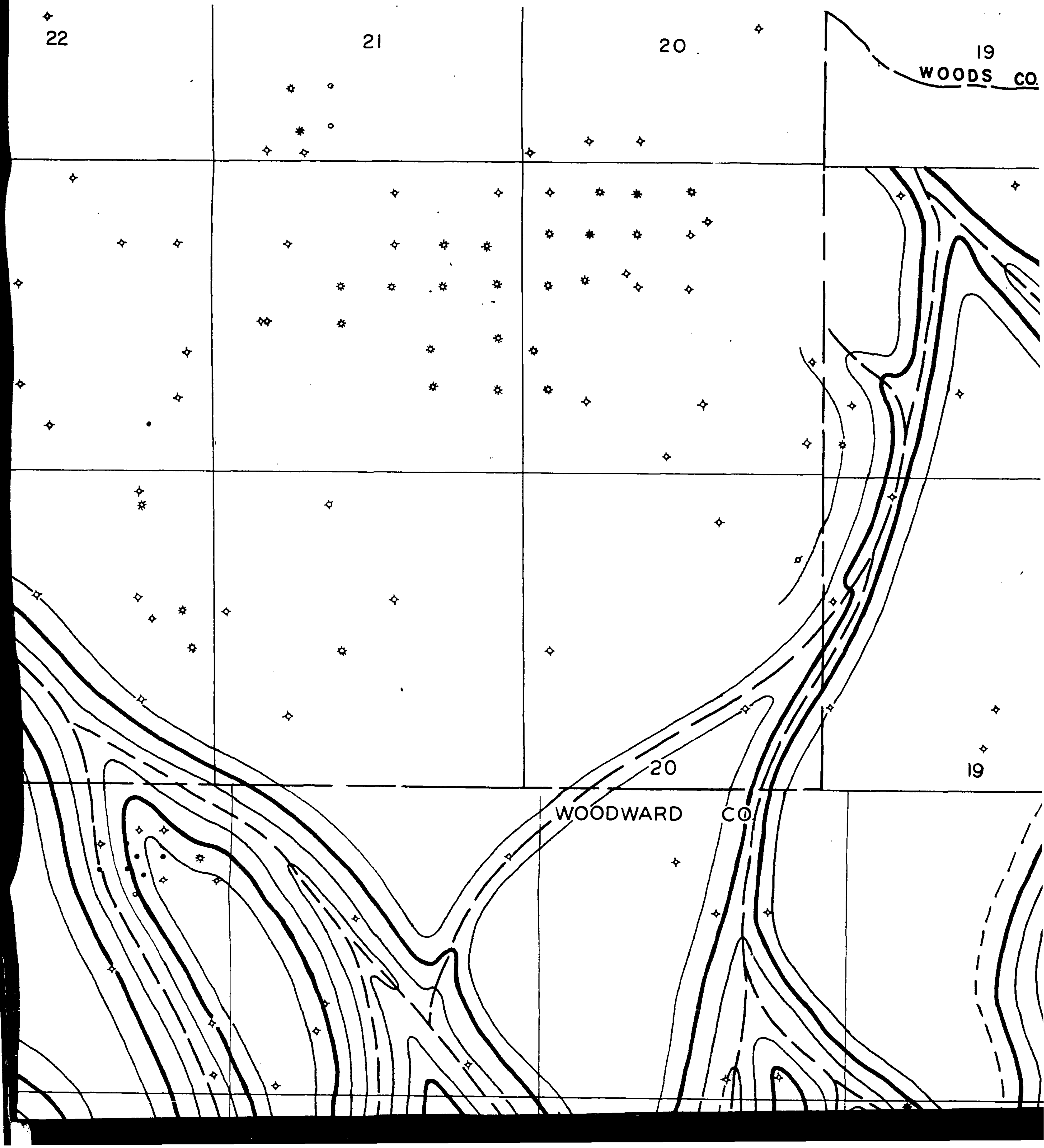
PLATE VIII

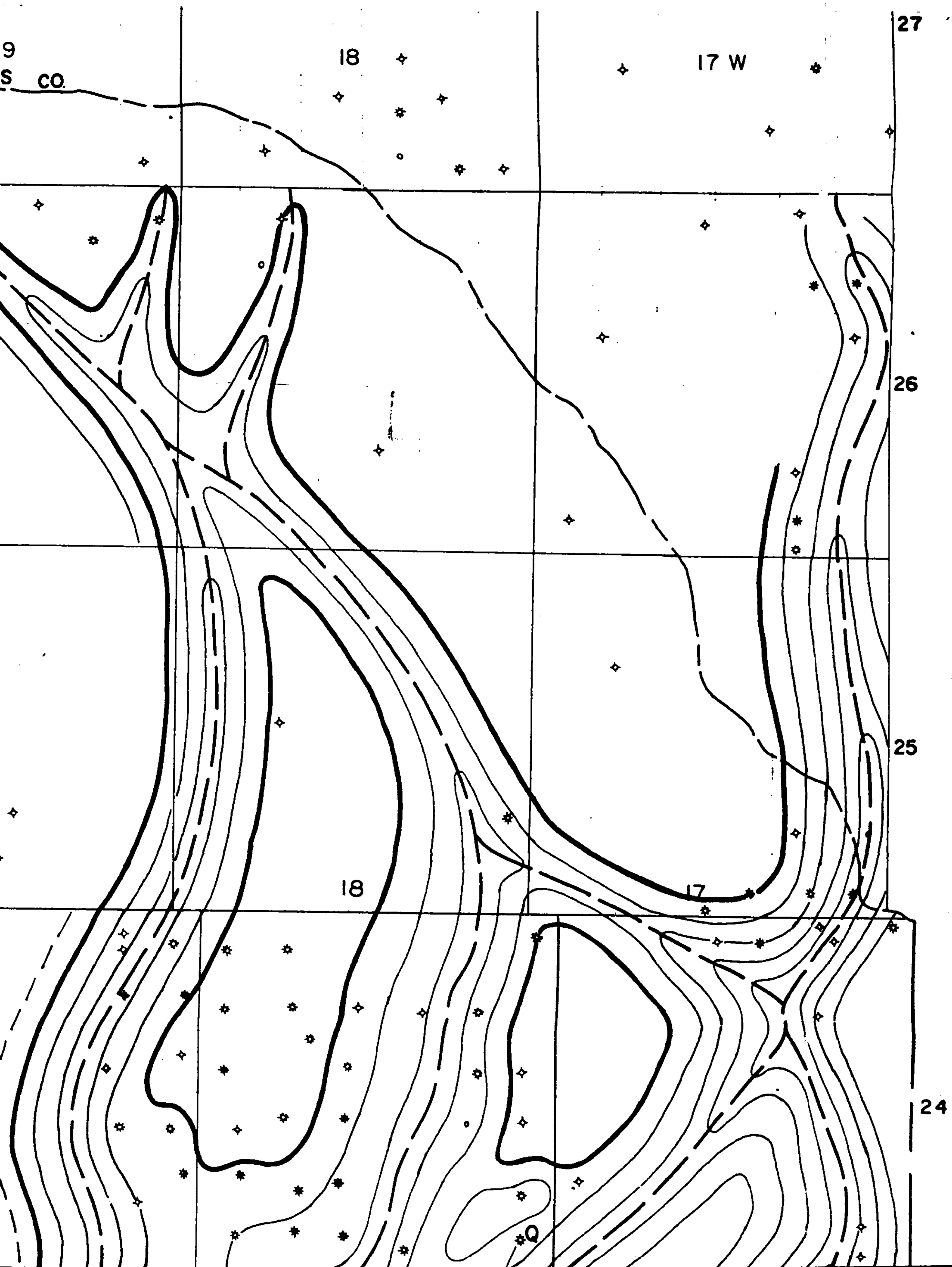
A UNIVERSITY OF OKLAHOMA Ph. D. 1968



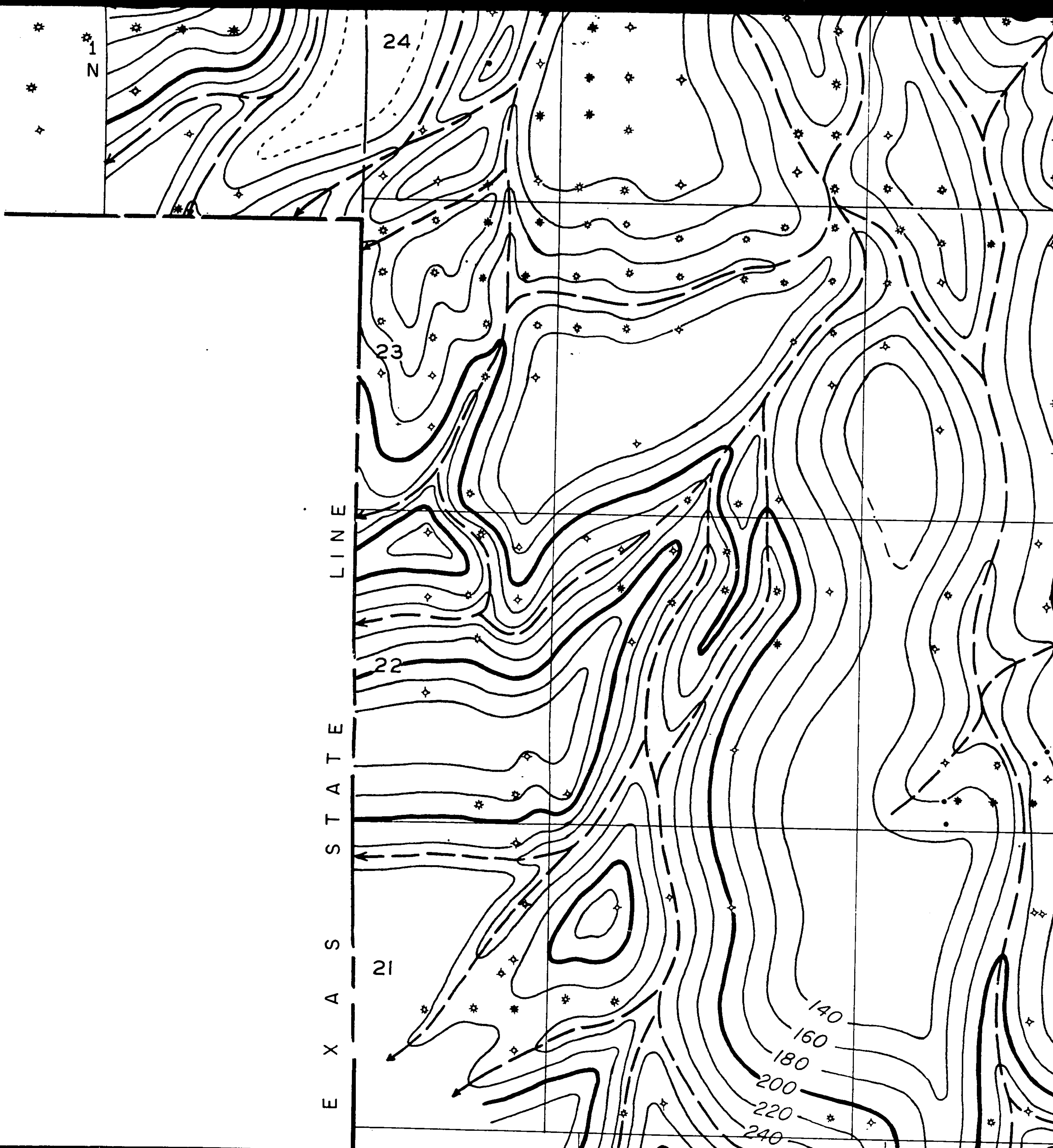
28 ECM
26 W
25
24
4
N
26
3
2
25
60
80
100
120
120
100
80
24
1
N
ELLIS CO.

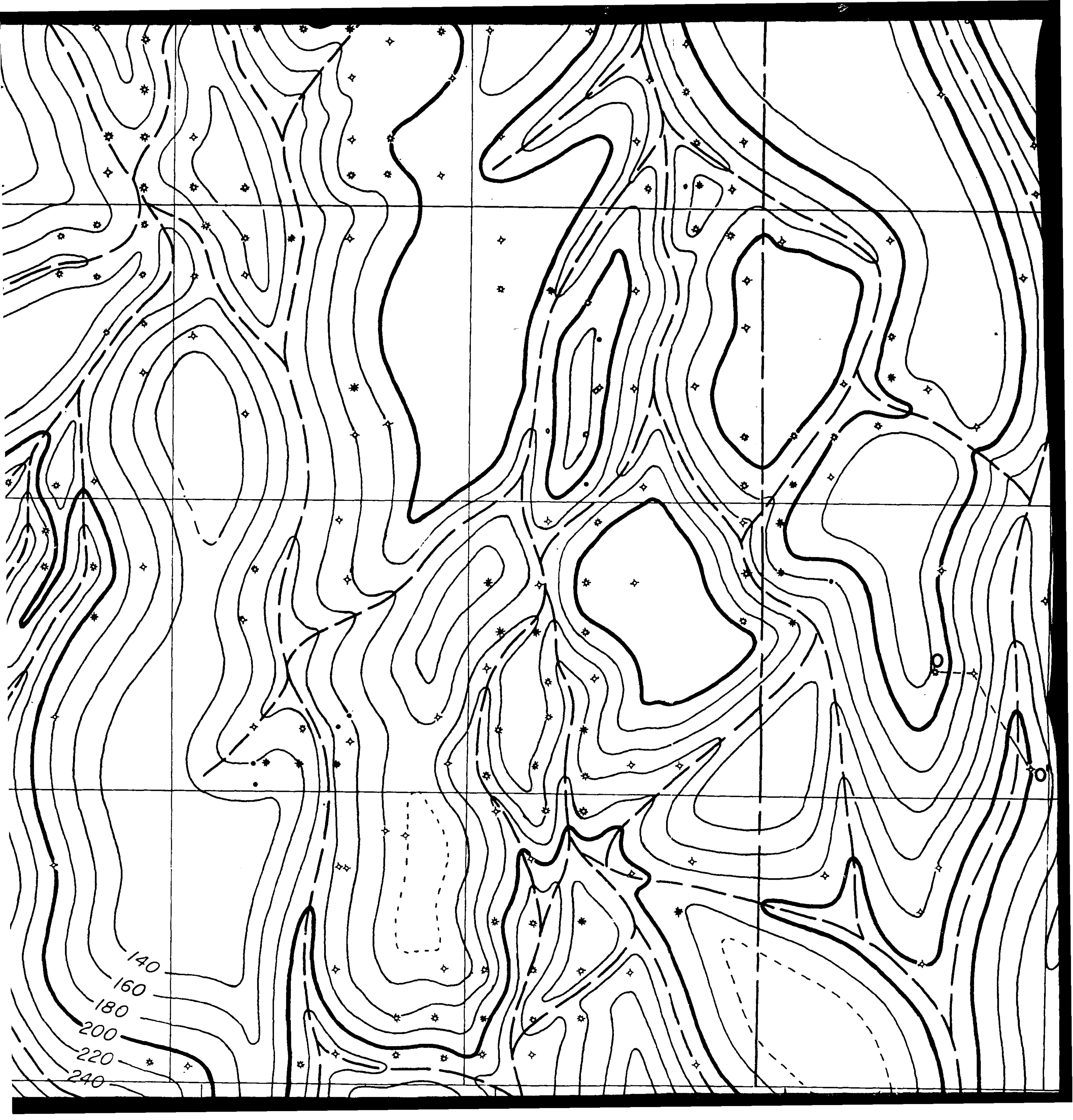

24
23
22
80
100
120
120
100
100
120
120
100
80
ELLIS CO.


22
21
20
19
WOODS CO.
20
19
WOODWARD CO

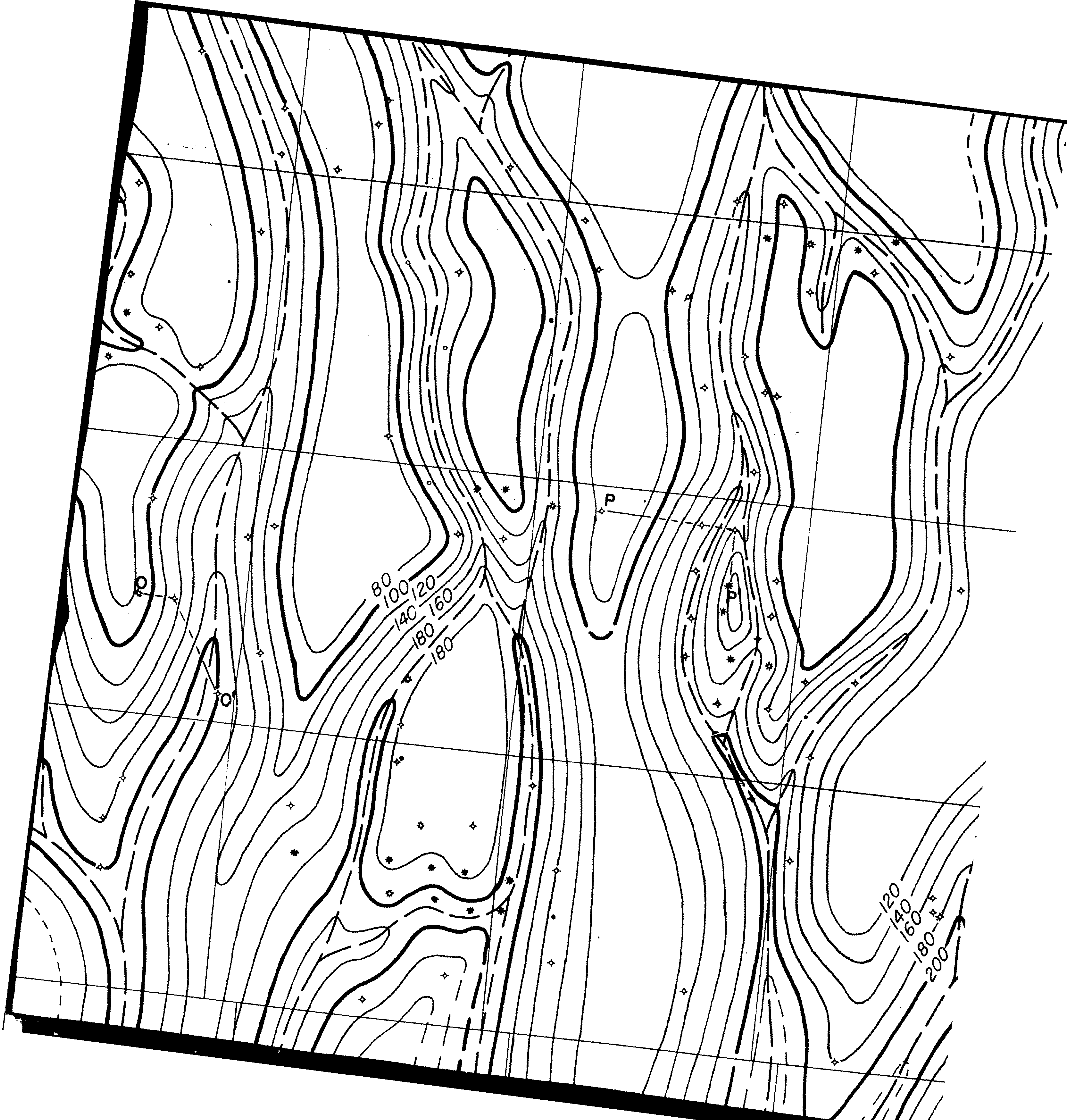


9
S CO.
18
17 W
27
26
25
18
17
24
Q

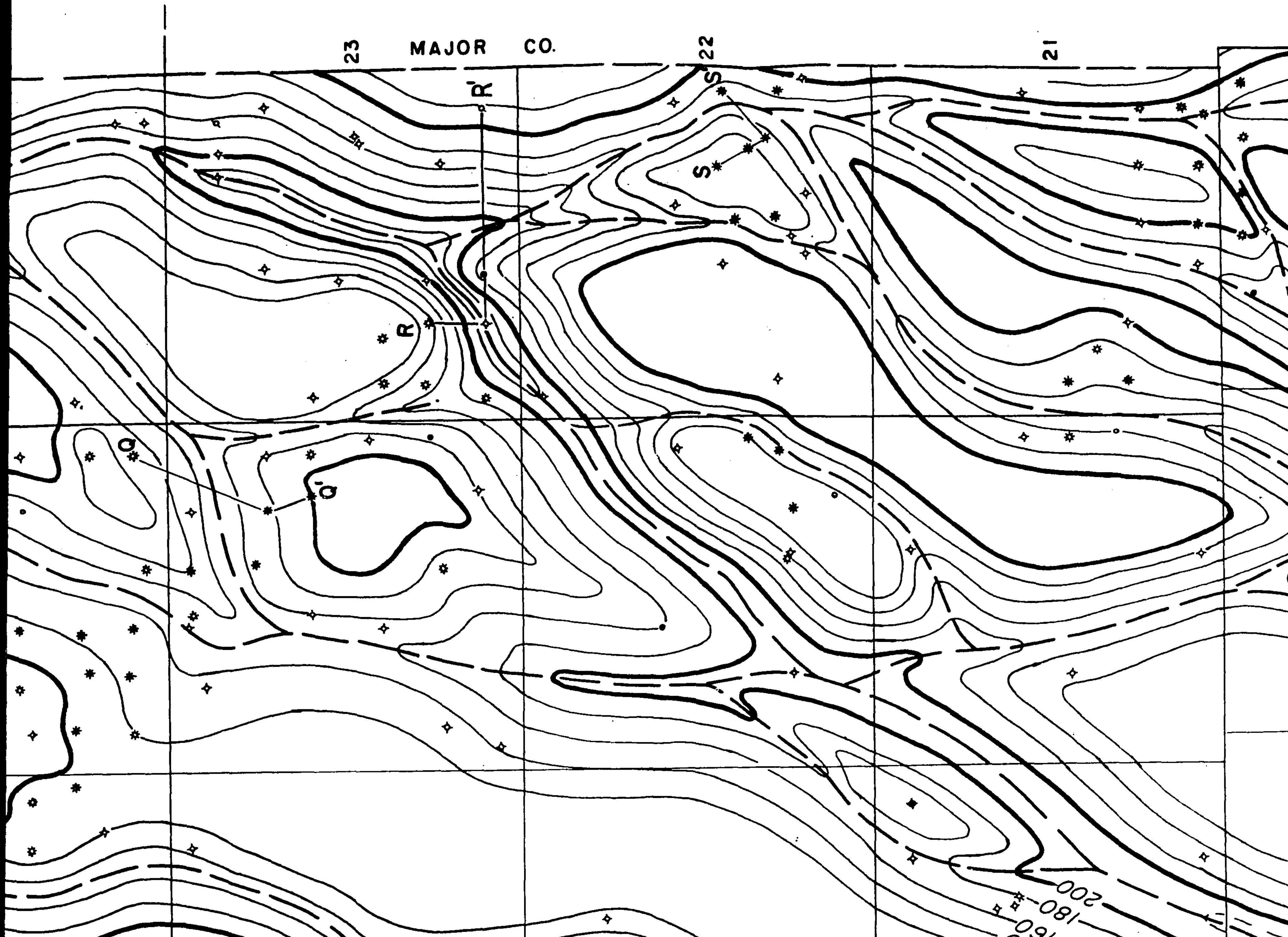

1
N
24
23
22
21
EXAS STATE LINE
140
160
180
200
220
240

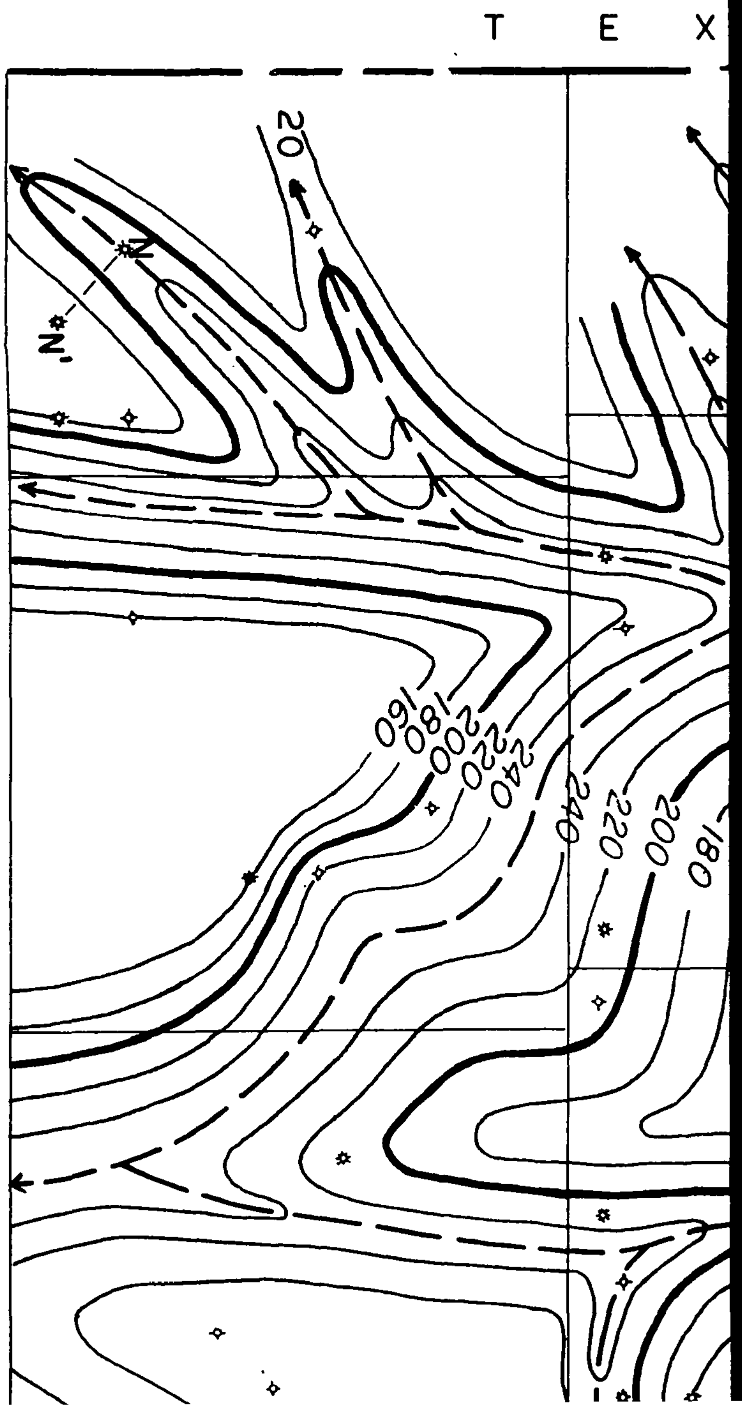


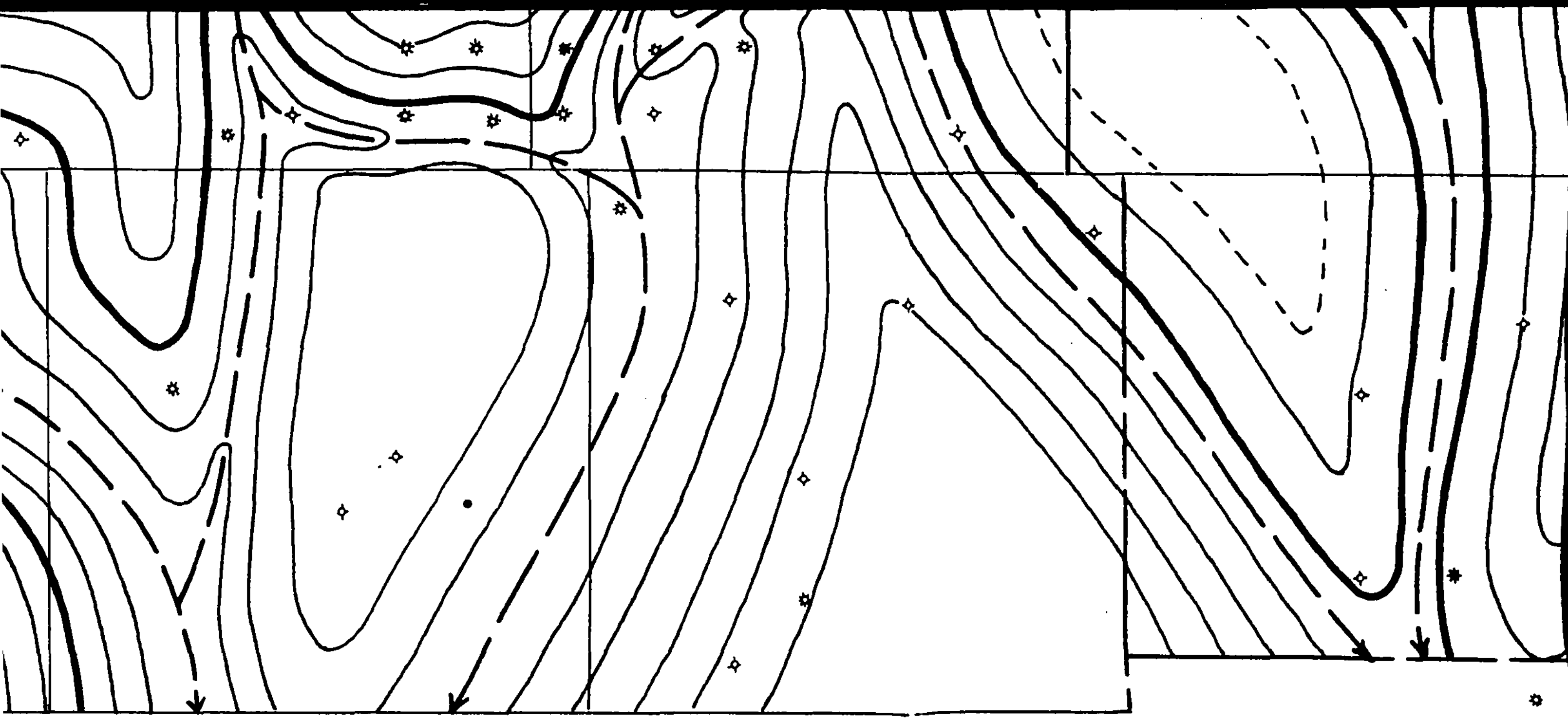
140
160
180
200
220
240



80
100
120
140
160
180
180
P
P
O
O
120
140
160
180
200


23
MAJOR CO.
22
21
R'
R
S
S'
Q
Q'
200
180
160


T E X
20
N
N'
160
180
200
220
240
240
220
200
180



# ISOPACH, TOP O

# BASE OF END

## SHOWING DELTAIC

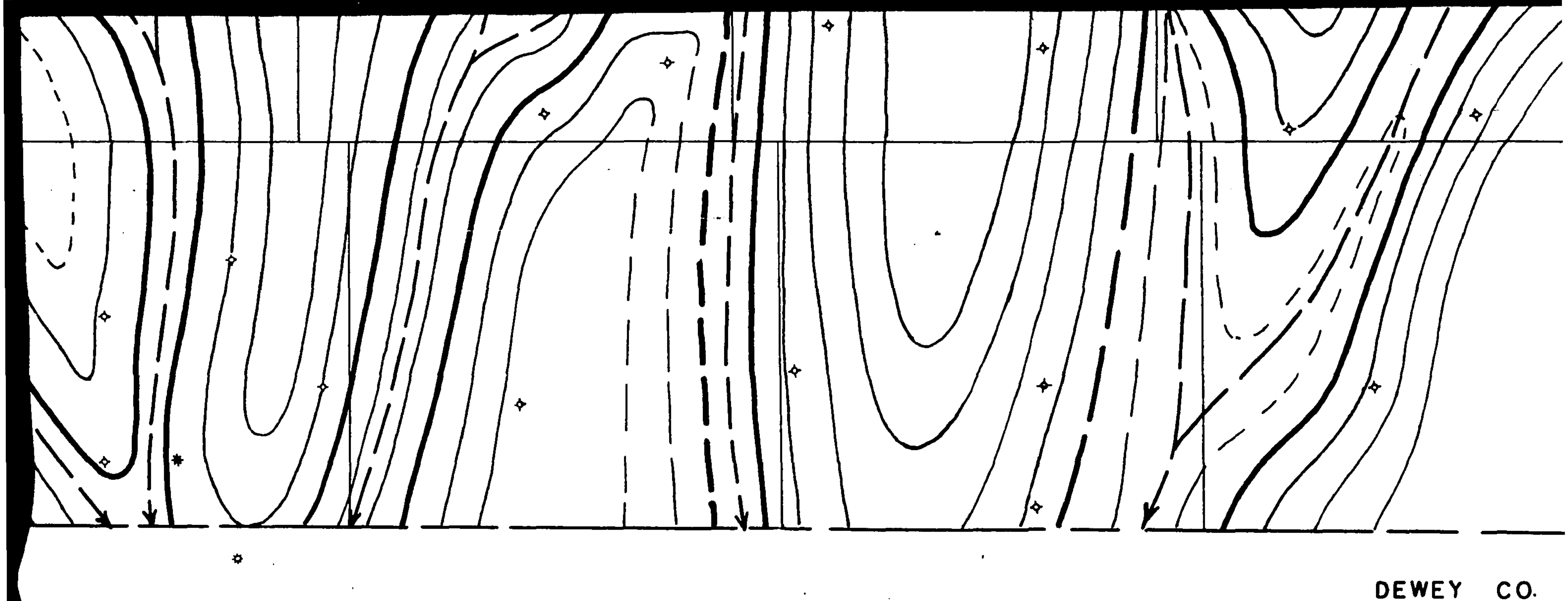
NORTHWE

C. I.

0 2 4

F

MOAYAD H. KHAIWKA – UN




# TOP OF OREAD FORMATION
# TO
# F ENDICOTT SANDSTONE

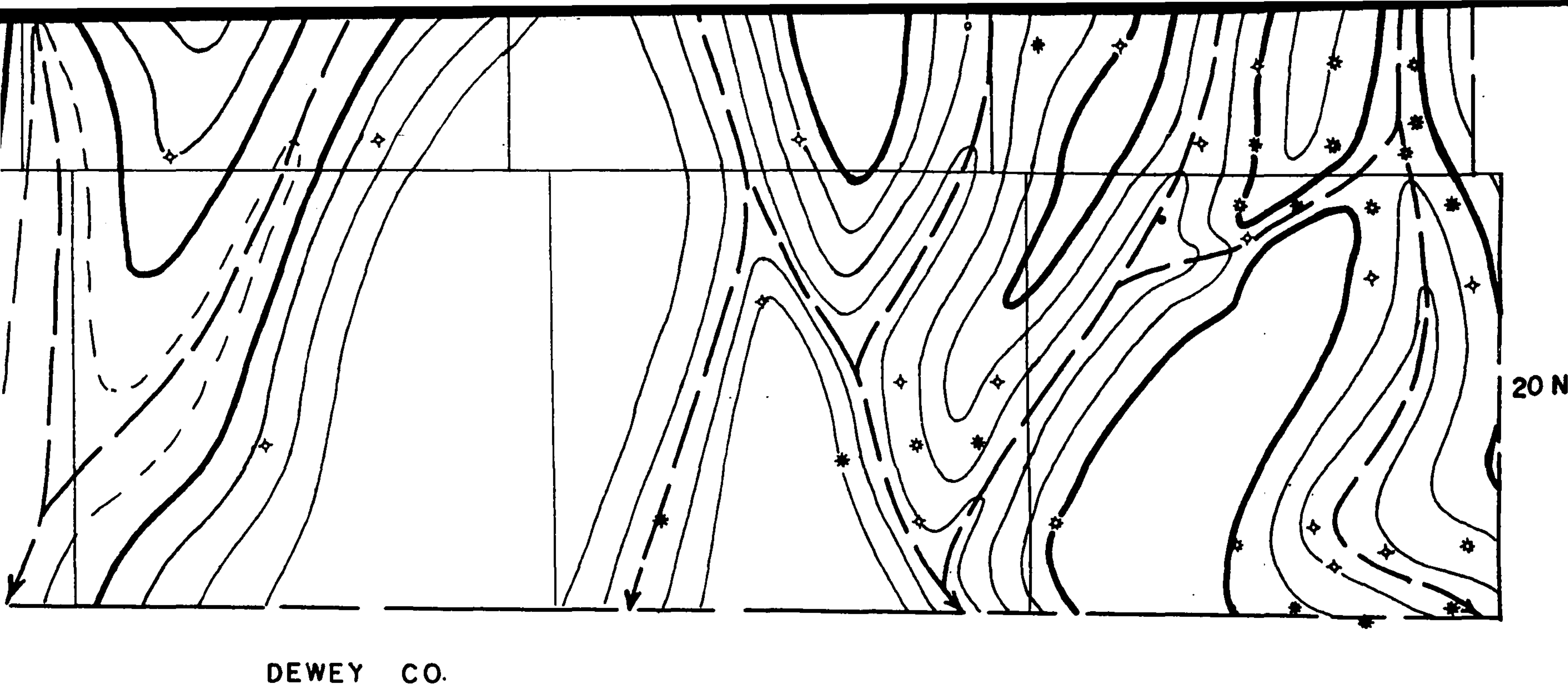
## ELTAIC DISTRIBUTION PATTERN
## NORTHWESTERN OKLAHOMA

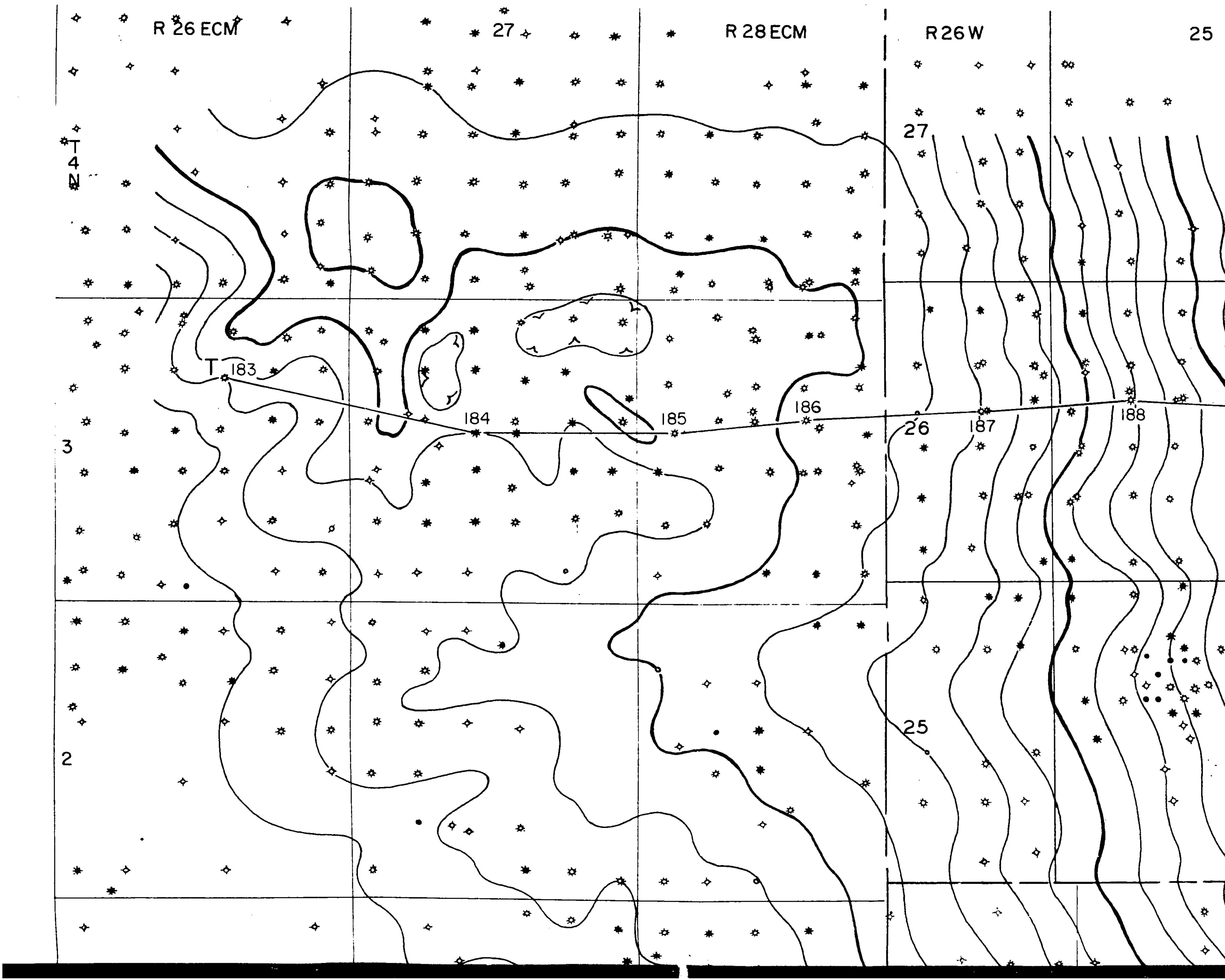
C. I. = 20 FEET

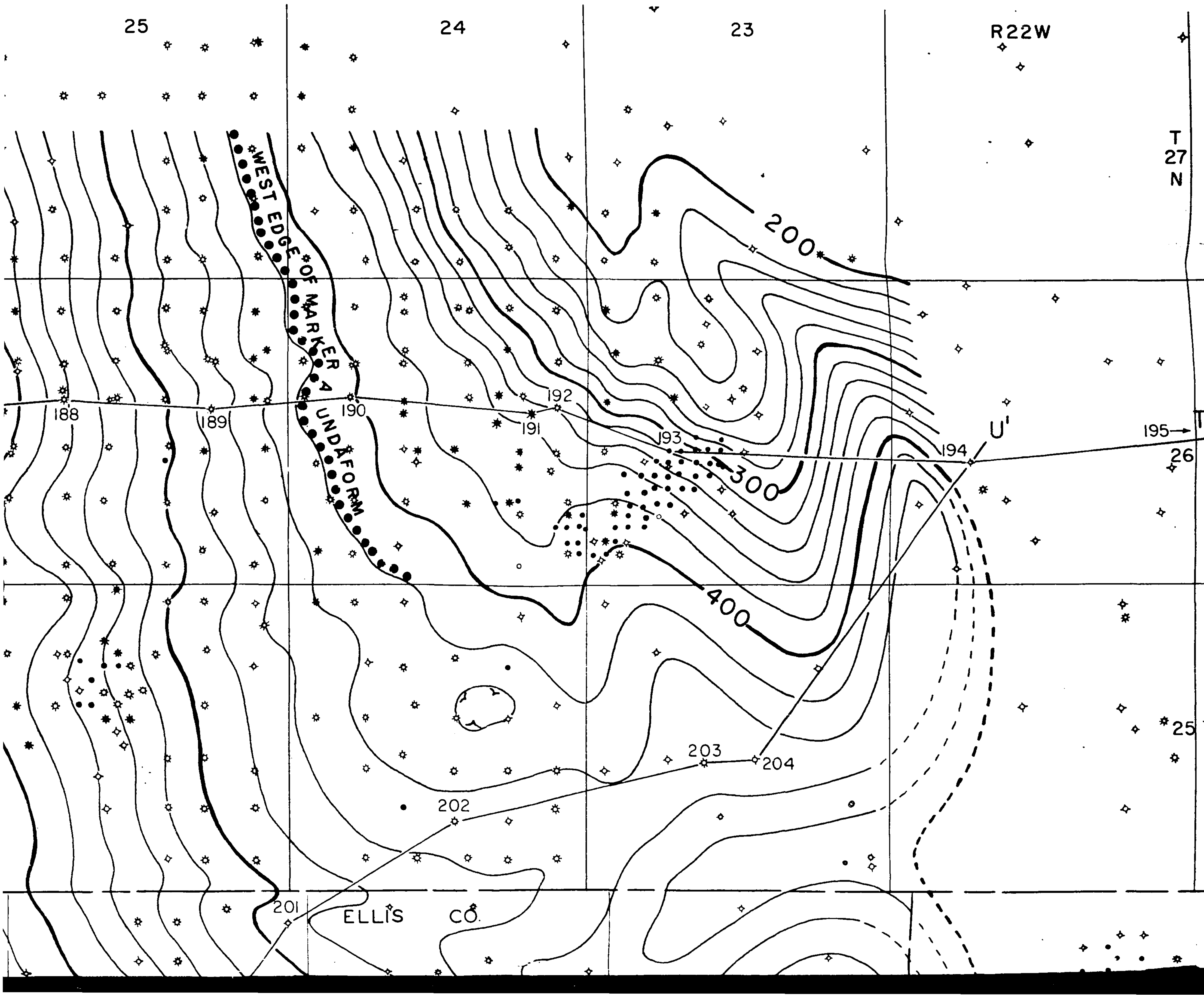
2 4 6 12
MILES

PLATE IX

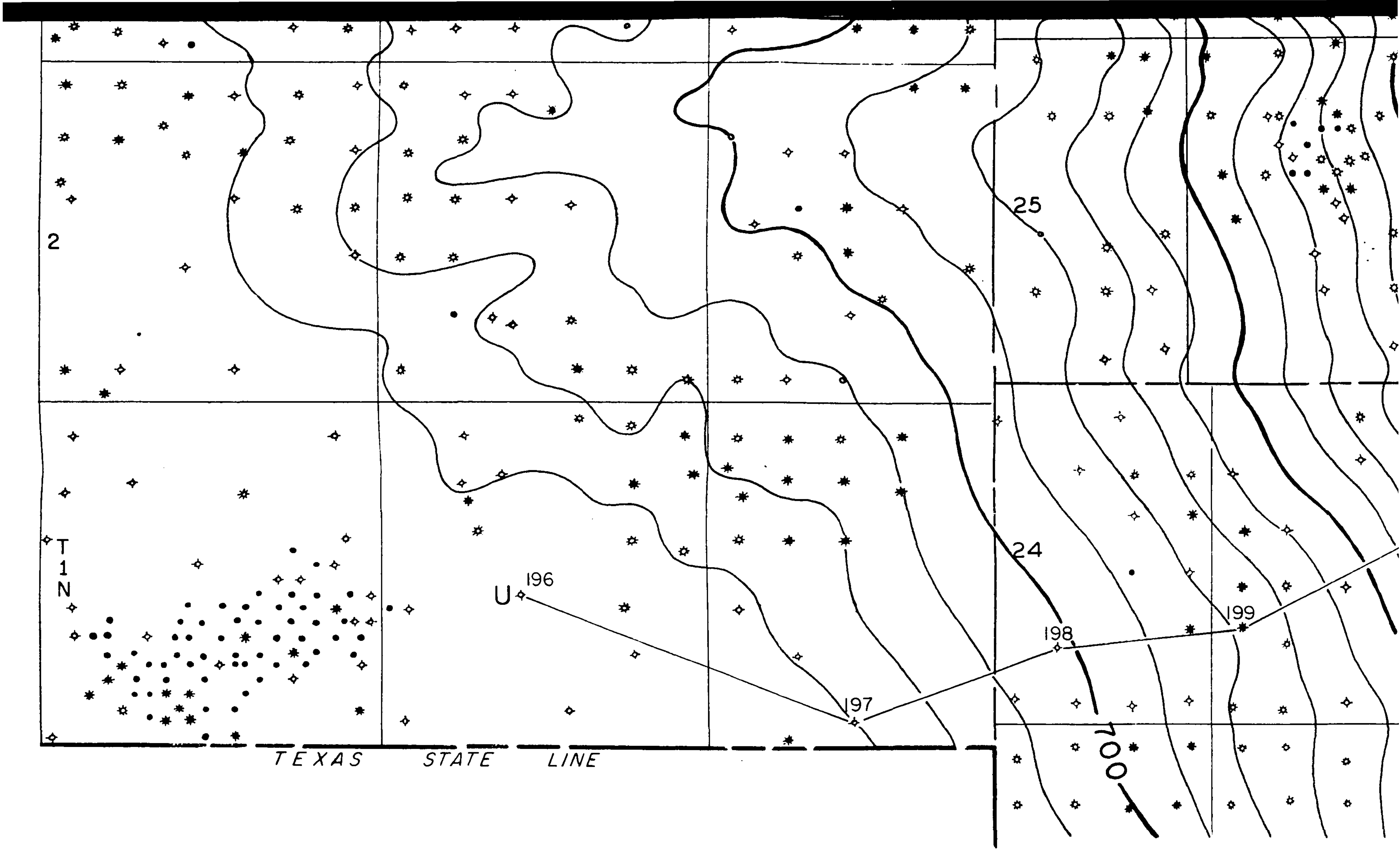
H. KHAIWKA - UNIVERSITY OF OKLAHOMA - Ph. D. 1968


20 N
DEWEY CO.


R 26 ECM
27
R 28 ECM
R 26 W
25
T
4
N
27
T
183
184
185
186
26
187
188
3
25
2



25
24
23
R22W
T
27
N
200
300
400
WEST EDGE OF MARKER 4 UNDAFORM
188
189
190
191
192
193
194
195
T'
U'
26
25
201
202
203
204
ELLIS CO.



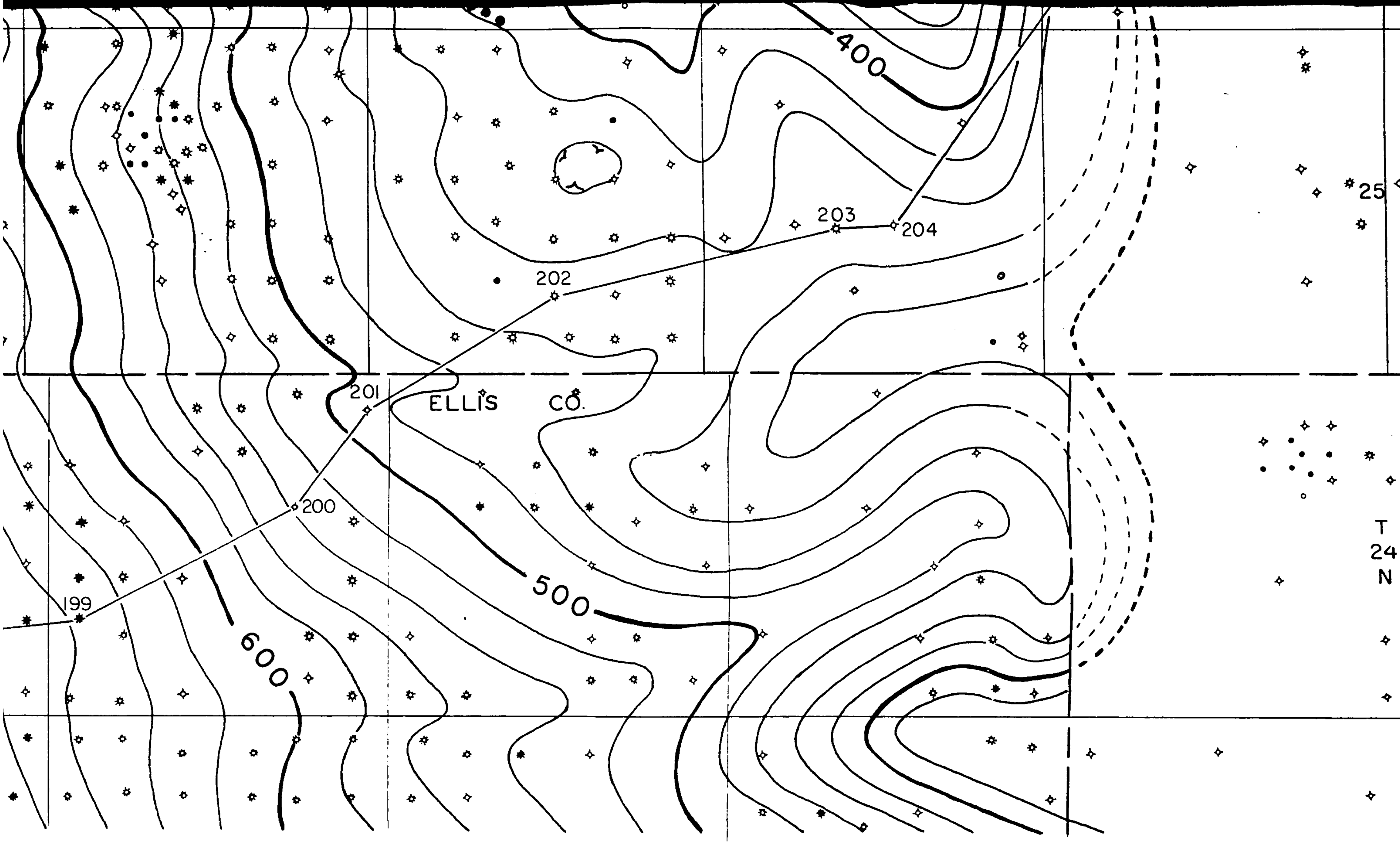

MARKER A PALEODEPOSITI(
SHOWING UNDAFOR
LAVERNE DISTRICT, NORTHWE

C. I. = 20 feet

0 1 2 3 4
MILES

PLATE X

MOAYAD H. KHAIWKA UNIVERSITY OF OKL



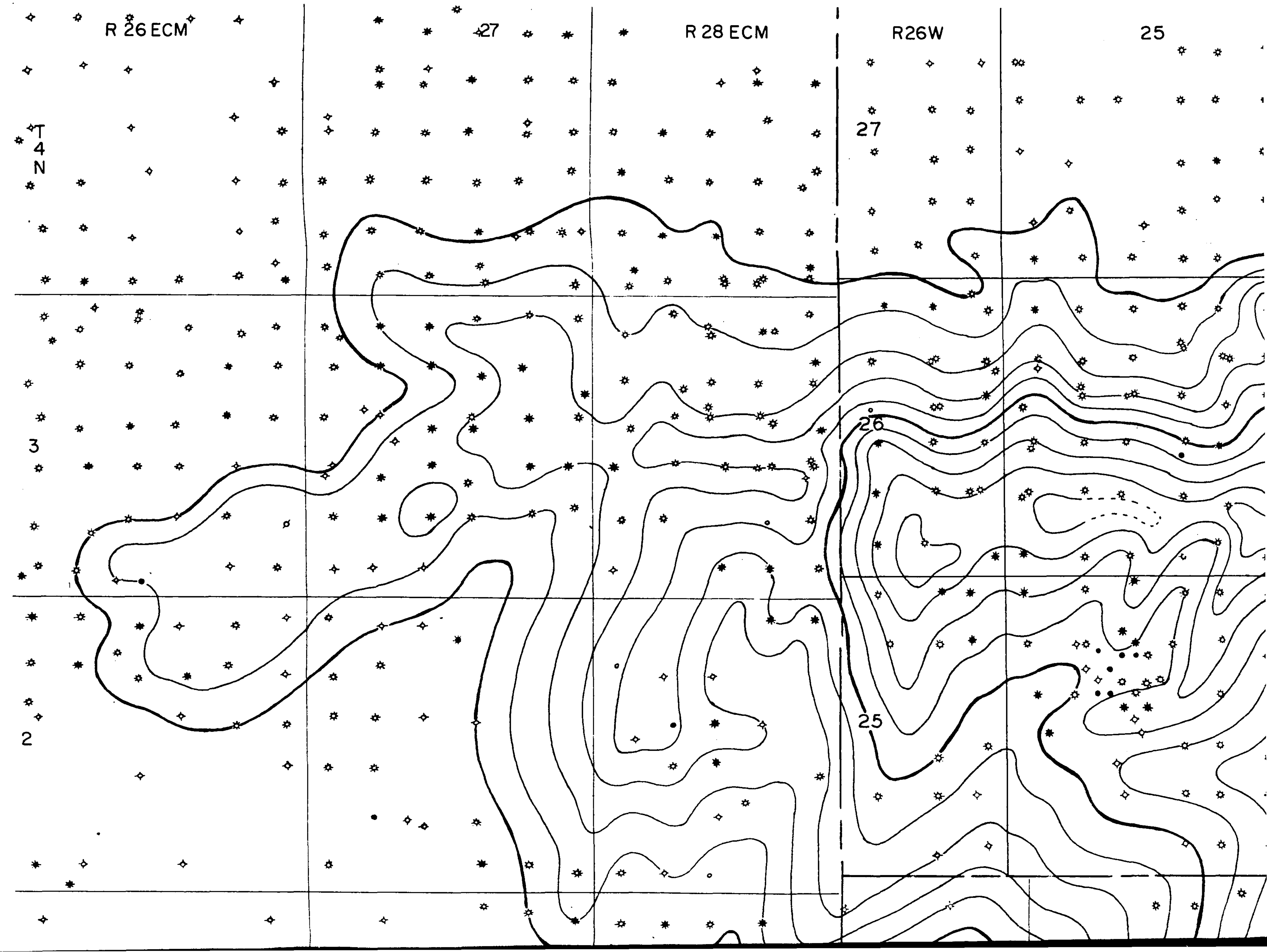

DEPOSITIONAL TOPOGRAPHY
NG UNDAFORM EDGE
CT, NORTHWESTERN, OKLAHOMA

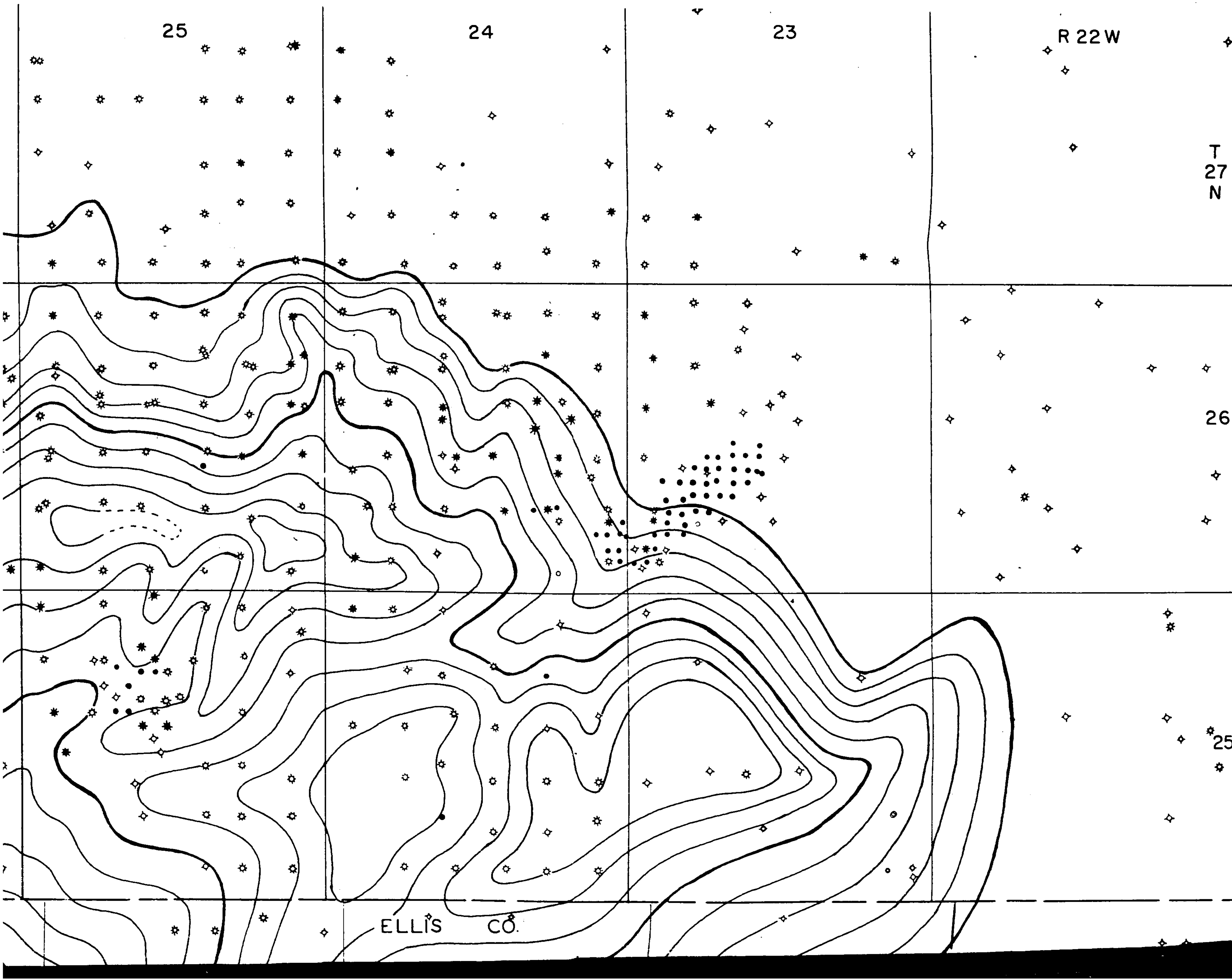
C. I. = 20 feet

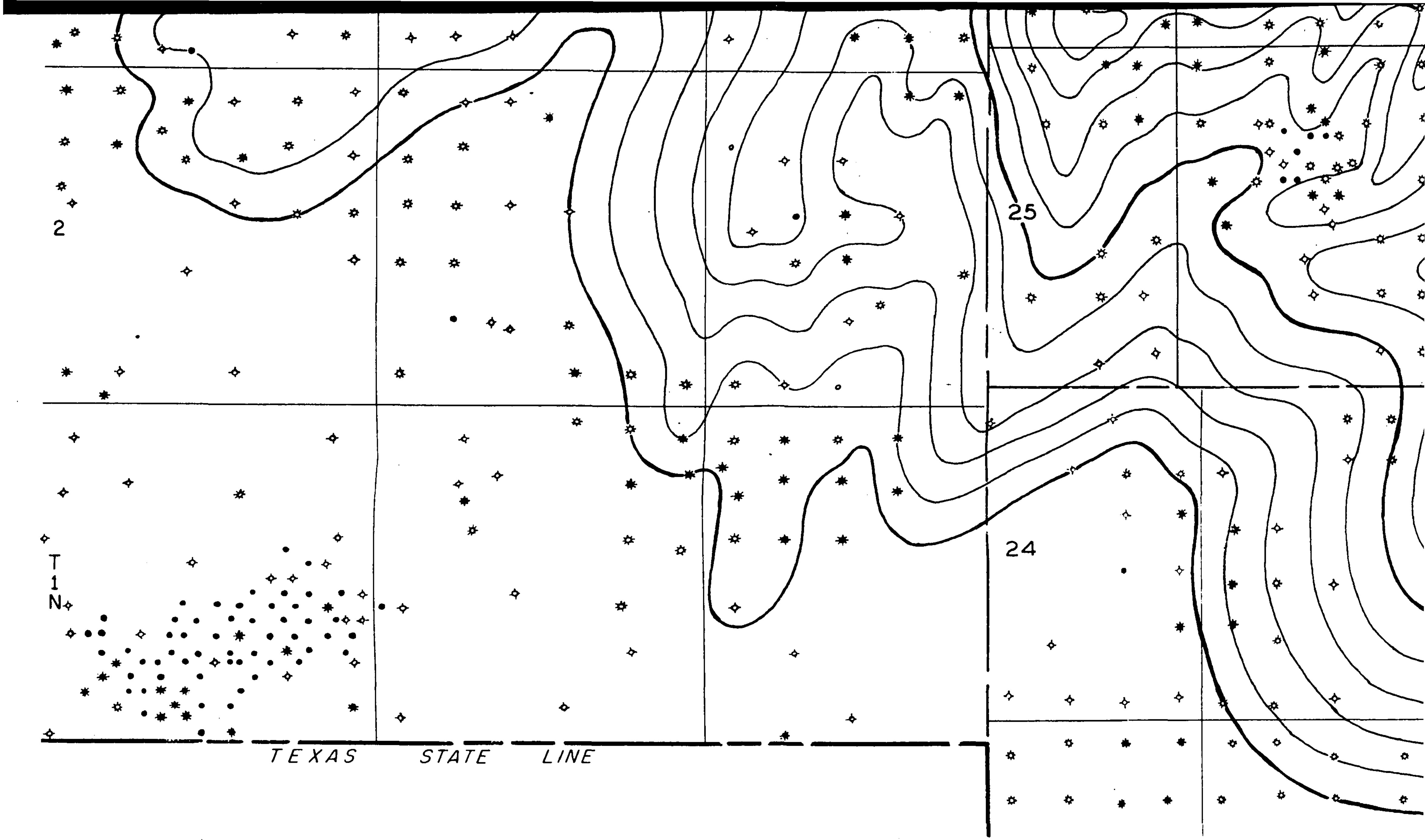
1 2 3 4 5 6
MILES

PLATE X

A UNIVERSITY OF OKLAHOMA Ph. D. 1968


R 26 ECM
27
R 28 ECM
R26W
25
T
4
N
27
3
26
2
25


25
24
23
R 22 W
T
27
N
26
25
ELLIS CO.



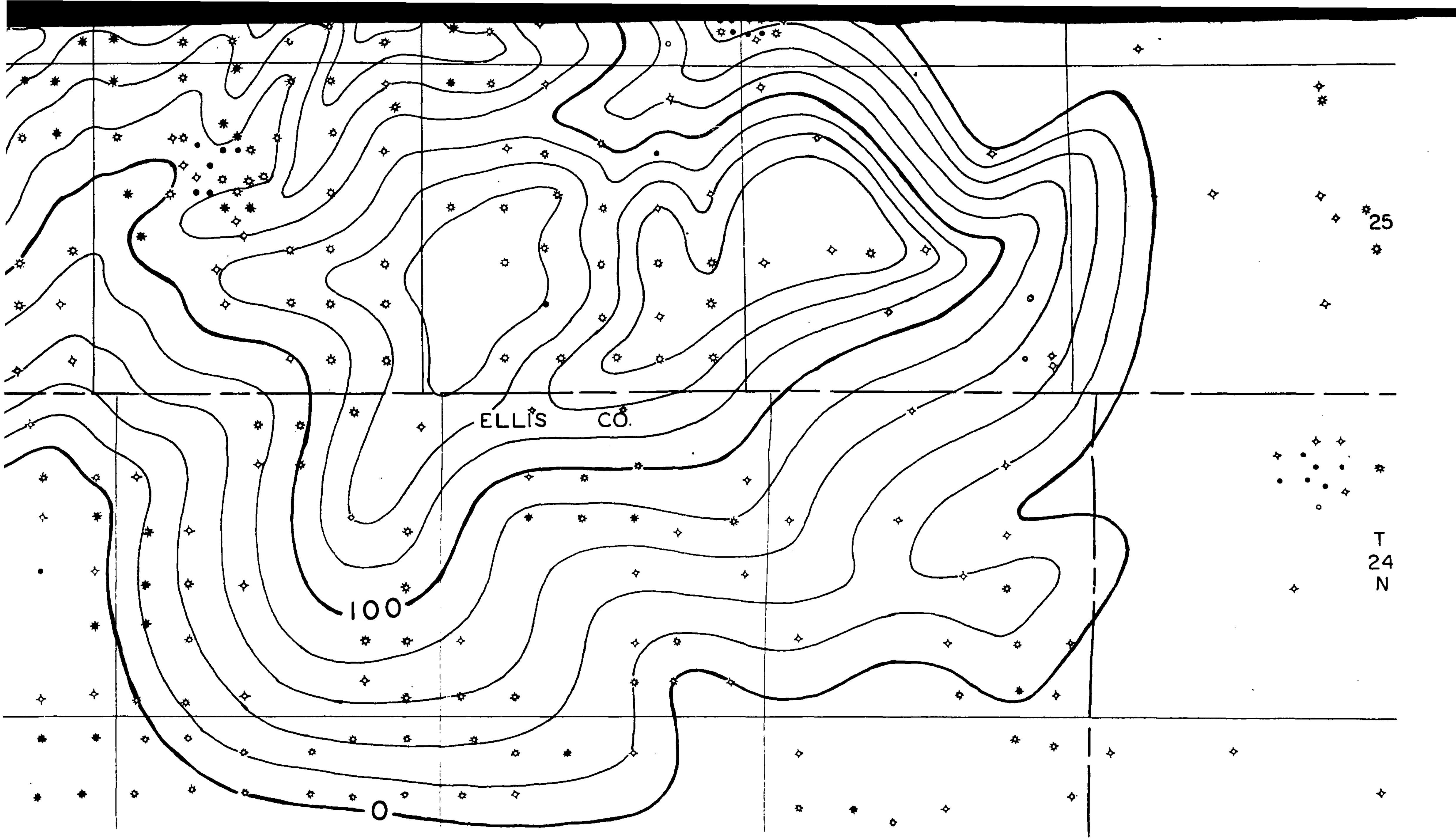

ISOPACH OF PRODUCING HOO
LAVERNE DISTRICT, NORTHWEST

C. I. = 20 feet

0 1 2 3 4 5
MILES

PLATE XI

MOAYAD H. KHAIWKA UNIVERSITY OF OKLAHO



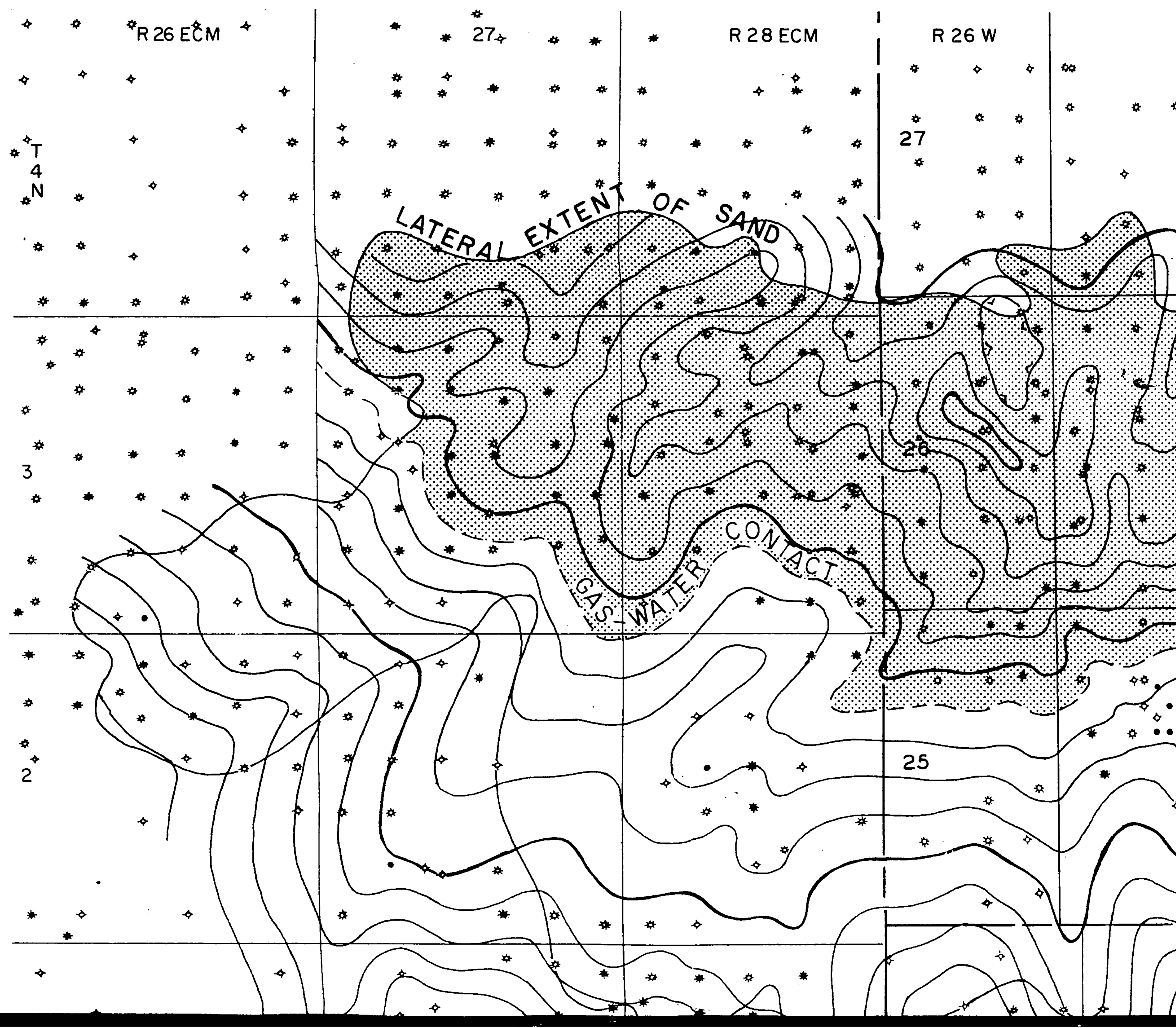

PRODUCING HOOVER SANDSTONE
STRICT, NORTHWESTERN, OKLAHOMA

C. I. = 20 feet

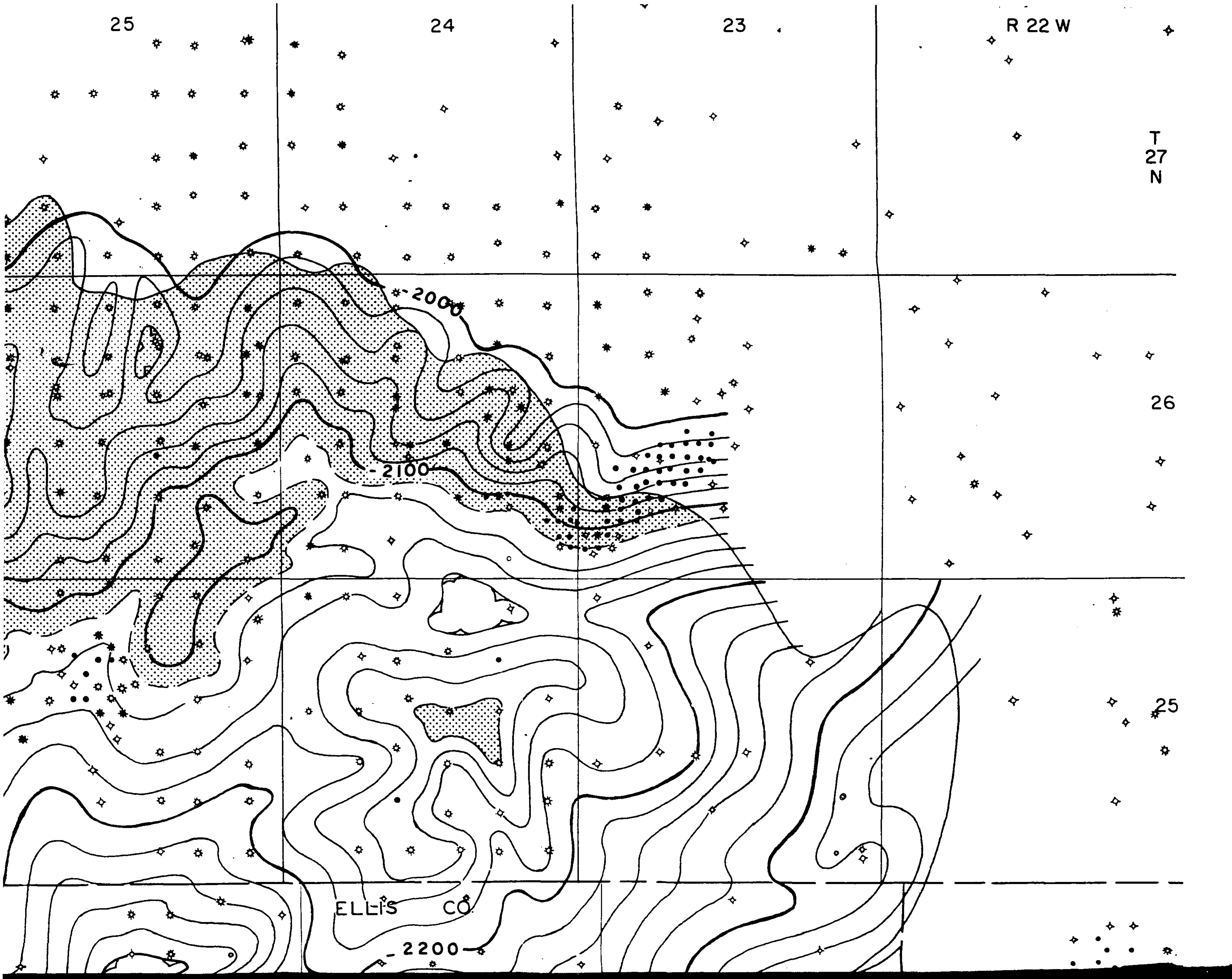
0 1 2 3 4 5 6
MILES

PLATE XI

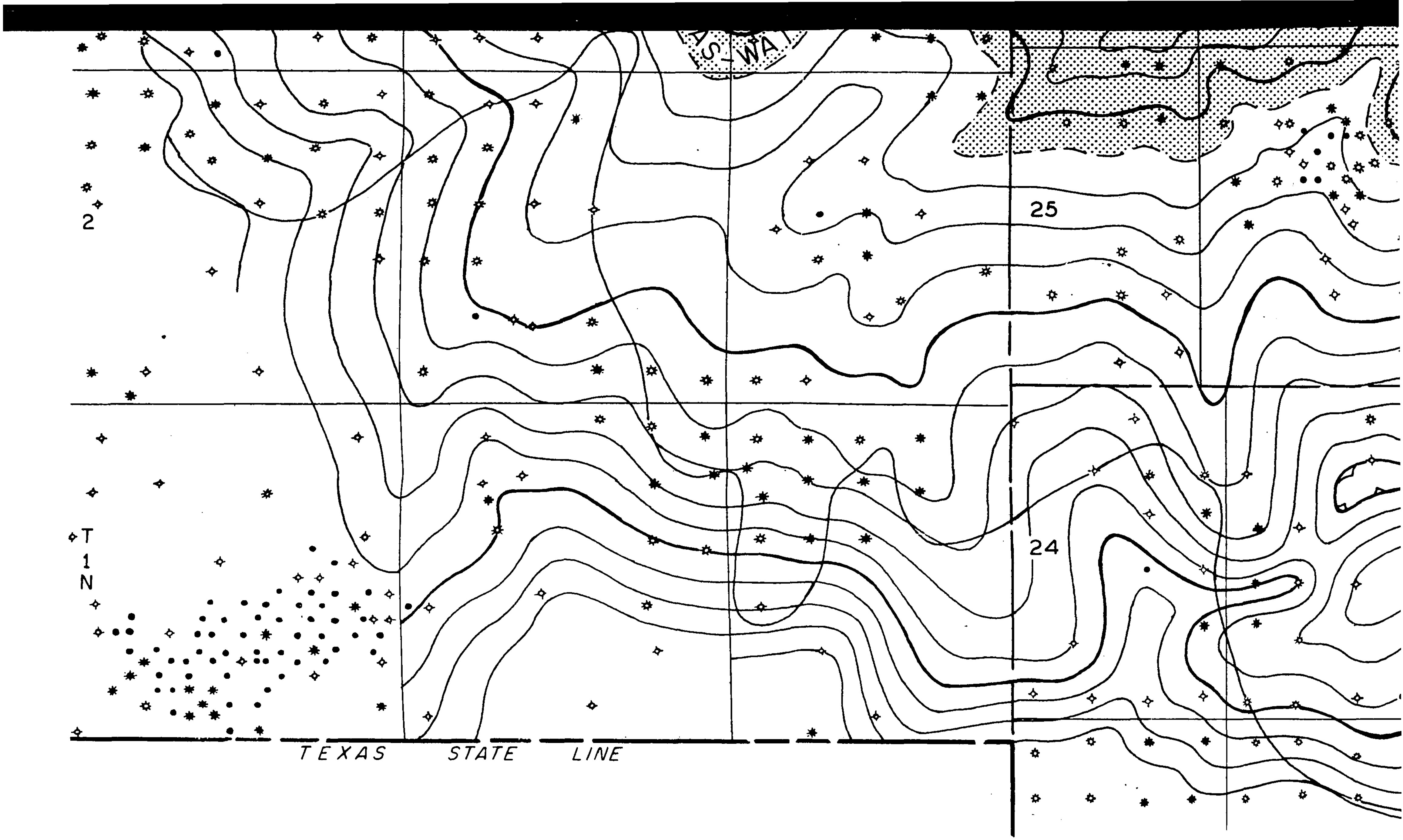
KHAIWKA UNIVERSITY OF OKLAHOMA Ph. D. 1968



R 26 ECM
27
R 28 ECM
R 26 W
T
4
N
27
LATERAL EXTENT OF SAND
3
26
GAS-WATER CONTACT
2
25



25
24
23
R 22 W
T
27
N
26
25
-2000
-2100
-2200
ELLIS CO.




WABAUNSEE ("HOOVER") SAND

LAVERNE DISTRICT, NORTHW

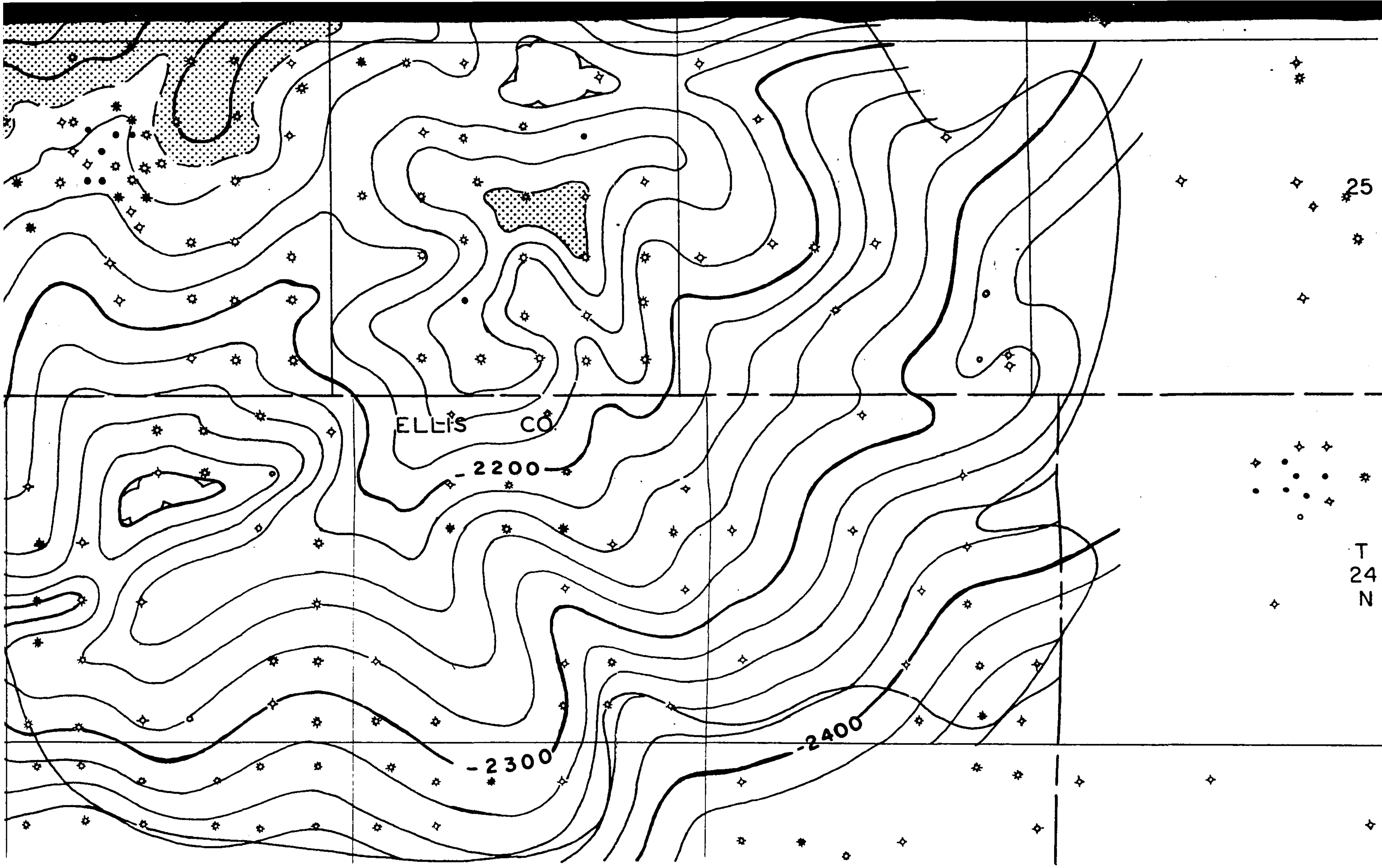
C. I. = 20 feet

0 1 2 3 4

MILES

PLATE XII

MOAYAD H. KHAIWKA UNIVERSITY OF OK




R") SANDSTONE STRUCTURE

, NORTHWESTERN, OKLAHOMA

C. I. = 20 feet

2 3 4 5 6

MILES

PLATE XII

UNIVERSITY OF OKLAHOMA Ph. D. 1968