DEPARTMENT OF THE INTERIOR
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A SEARCH FOR STRATIFORM MASSIVE-SULFIDE EXPLORATION TARGETS IN APPALACHIAN DEVONIAN ROCKS---A CASE STUDY USING COMPUTER-ASSISTED ATTRIBUTE-COINCIDENCE MAPPING

By

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ABSTRACT

The empirical model for sediment-associated, stratiform, exhalative, massive-sulfide deposits presented by D. Large in 1979 and 1980 has been redesigned to permit its use in a computer-assisted search for exploration-target areas in Devonian rocks of the Appalachian region using attribute-coincidence mapping (ACM). Some 36 gridded-data maps and selected maps derived therefrom were developed to show the orthogonal patterns, using the 7-1/2 minute quadrangle as an information cell, of geologic data patterns relevant to the empirical model. From these map and data files, six attribute-coincidence maps were prepared to illustrate both variation in the application of ACM techniques and the extent of possible significant exploration-target areas. As a result of this preliminary work in ACM, four major (and some lesser) exploration-target areas needing further study and analysis have been defined as follows: 1) in western and central New York in the outcrop area of lowermost Upper Devonian rocks straddling the Clarendon-Linden fault; 2) in western Virginia and eastern West Virginia in an area largely coincident with the well-known "Oriskany" Mn-Fe ores; 3) an area in West Virginia, Maryland, and Virginia along and nearby the trend of the Alabama-New York lineament of King

and Zietz approximately between 38- and 40-degrees N. latitude; and 4) an area in northeastern Ohio overlying an area coincident with a significant thickness of Silurian salt and high modern seismic activity. Some lesser, smaller areas suggested by relatively high coincidence may also be worthy of further study.

INTRODUCTION

Review of geological data related to large exhalative, sediment-associated sulfide and related mineral deposits, such as those in Devonian rocks at Meggen and Rammelsberg in the Federal Republic of Germany (FRG) and in the Selwyn Basin in northwestern Canada, by geologists of the German Federal Institute for Geosciences and Natural Resources (BGR), Hannover, led to the recognition that the coincidence of a large variety of diverse factors is needed to produce the geologic environment necessary to host such deposits (Klau and others, 1976). Further study by a team of BGR geologists of the previously mentioned deposits in Devonian strata as well as of similar deposits in Precambrian rocks in Australia and Canada (for example, McArthur River, Mount Isa, and Sullivan) has led to the development of an empirical model that can be used in the search for more of these deposits (Large, 1979 and 1980). The empirical model is perhaps preferable to other models, such as the stochastic, random, and genetic types, in that it is based upon facts only rather than theoretical concepts. It can thus more readily adapt to new data as they become available. Recent consideration of stratigraphic data on the Devonian sequence of the Appalachian Basin in eastern United States has shown that a number of the diverse factors needed for the occurrence of the massive-sulfide deposits according to an empirical model are also found in this region (Wedow, in U. S. Geological Survey, 1978, p. 2).

With the development of plans for cooperative investigations between the BGR and the U. S. Geological Survey (USGS) in 1975 and extended in 1978, a program finally matured for joint research on the application of the empirical model (Large, 1979a and 1980) to the search of selected large regions for target areas in which more detailed studies could be conducted. The joint effort centered initially around the adaptation and development of data-reduction methods for the large quantities of regional information related to BGR's empirical model. Geographically, this phase of the project reported herein is confined essentially to the Devonian and selected aspects of pre-Devonian rocks, in the Appalachian region.

The chief parameters or attributes that form the empirical model comprise some tens of items that vary considerably in scale, ranging over several orders of geographic magnitude. In order to facilitate the study, selected data from a literature review have been reduced to a series of specially prepared maps for computer input. This literature search and data reduction was done through at the Department of Energy's Oak Ridge National Laboratory (ORNL) under a Memorandum of understanding (dated April 30, 1979) with the USGS. The first phase of the work was completed in September 1979 and was presented as a progress report by Wedow, Klau, and Large (1979).

The second phase of the study, to adapt and, where necessary, develop computer software for map-data management and attribute-coincidence and pattern-analysis studies, was slow in starting being finally formalized in a direct contract between Wedow and the Office of International Geology (OIG) of the USGS in June 1980. This document is a report on the results of this latter contractual effort.

The attributes or parameters of stratiform massive-sulfide and related deposits (Large, 1979 and 1980) are summarized by Wedow, Klau, and Large in a separate section of this report. Also discussed briefly are the methods for the reduction of regional data for the succeeding coincidence studies and pattern analyses.

The writer wishes to thank the many geologists and computer specialists for the guidance and assistance received in the course of this study. The support of Alfred H. Chidester of OIG/USGS, as Project Officer for the study, has been invaluable and is gratefully acknowledged.

THE EMPIRICAL MODEL

By Helmuth Wedow, Jr., Wolfgang Klau, and D. E. Large

An empirical model for a certain type of ore deposit is based entirely on collecting facts (parameters or attributes) on the controls that localize that type of ore deposit. Search for new ore deposits thus depends on noting the local coincidence of as many of these parameters or attributes as can be determined in areas away from the known ore occurrences. The attributes range over several orders of geographic magnitude. Thus some attributes are of a regional nature and extend over distances of hundreds of kilometers or cover areas of hundreds to thousands of square kilometers. Other attributes are of intermediate size and are more related to district-size mineral occurrences. They are features averaging in the tens of kilometers or square kilometers range. The smallest size of attributes considered in this model will generally be less than one kilometer in size and no probably more than 10 square kilometers areally. This tri-level basin classification and the characteristics of each level have been discussed in recent years by Krebs (1979), Large (1980), and Sangster (1981). The most significant parameters or attributes are mentioned briefly below and are also listed in table 1. The bracketed annotations in table 1 indicate the specific gridded-data maps that present the map patterns or their proxies (see below) of the attribute or attributes the annotations subtend.

The prime large regional or first-order parameter for sediment- associated sulfide ores is large sedimentary basins, such as aulocogens, intracratonic depressions, and continental margin foredeeps. These large basins are generally graben-like or at least fault-bounded on one or more sides. They usually contain or are recognized by the presence of a thick sequence of clastic sediments, features of which include delta-front silts and turbidites, evaporites, red beds, and marine shales and cherts.

Intermediate- or district-size attributes are associated with second-order basins. Although such basins are defined as being only several tens of kilometers in maximum dimension, they can be larger. Tectonic aspects of the intermediate basins include such evidence of vertical movement as rifting, basin and rise (becken und schwellen) features, abrupt changes in sedimentary facies and their thicknesses, and hinge zones. Lineaments and lineament intersections are also important. Volcanic activity is of a "hot-spot" nature. Volcanic-rock types generally associated with the sediments are spilites or keratophyres or both, although alkalic pyroclastics are also common.

The smallest or third-order basin generally covers no more than a few square kilometers in original horizontal extent. Its attributes, in addition to the massive sulfide and barite deposits themselves, comprise such items as syndepositional faulting and slumping, sedimentary dikes, local marine transgression, euxenic (black) shales or other evidence of a relatively high content of organic matter, the presence of more than trace amounts of diagenetic pyrite---either in nodules or as pyritized fossils, and accumulations of pelagic faunas due either to nondeposition of associated sediments or to catastrophic destruction. Other possible third-order features closely associated with mineralization are the vertical zonation of the ore elements from copper below (or in the veins of the feeder zone) upward through zinc and lead to barite and ferruginous and manganiferous cherts in a halo around the concentration of sulfidic materials. The footwall-feeder zone, in addition to containing sulfide minerals, may be brecciated, silicified (kniest), or tourmalinized.

Contemporaneous igneous activity is a major attribute of the empirical exploration model for massive sulfide and barite ores. It can range through all size-orders of the basins. This is not to say that the ores are of magmatic hydrothermal origin but rather that an anomalous heat source may be necessary to establish fluid-convection in the basin sediments. The occurrence of contemporanous igneous materials can thus suggest the former presence of a thermally driven fluid convection cell or cells in the sedimentary pile of the basin. Thin tuffs, tuffites, and bentonites are evidence of widespread ashfalls related to contemporanous volcanism. Widespread zones of glauconite as well as certain cherts are believed by some geologists also to be the result of volcanic activity. Intrusive rocks are generally of alkaline persuasion, as such rock types are most frequently associated with zones of crustal extension or vertical tectonism. Contact metamorphism is minimal. Regional metamorphism can obliterate or significantly modify many of the attributes mentioned.

METHOD OF STUDY

A review of the attributes related to the occurrence of massive sulfide and their size ranges has shown that those of intermediate size have an area or are contained in the area generally equivalent to several 7-1/2 minute quadrangles. The 7-1/2 minute quadrangle is used in the United States as the standard area for relatively detailed topographic and geologic mapping at a scale of 1/24,000 or 1/25,000. Therefore, the cataloguing of the presence, absence, or other single characteristic value of an attribute as a simple quantity for each quadrangle can show the regional orthogonal pattern of the attribute. The quadrangle is thus used as a basic information cell. The 7-1/2 minute quadrangles of the United States are uniquely named and widely used in many walks of life. Consequently, it should be easier for a student of this method of data synthesis to relate more closely to geographic aspects of data location through the standard quadrangle map, rather than through other squares, rectangles, or polygons of similar size that eventually in themselves must be plotted on a geodetic base. A standard-quadrangle cell will hereinafter be referred as a geodetic cell, where the N-S length and E-W width of the cell is defined in units of latitude and longitude, respectively. Thus, the information cell used in this study is 7-1/2 minutes latitude by 7-1/2 minutes longitude or simply a 7-1/2 minute quadrangle.

Regional attributes of an empirical ore-search model show widespread map patterns of either areal or linear habit. Intermediate-size parameters show similar patterns but of lesser extent but generally of greater frequency of occurrence. Such data as are known of the third-order features of our model will generally characterize but one or two of the 7-1/2 minute cells. The regional distribution of third-order attributes will thus be only be a broad scattering of single cells frequently, for the most part, showing no apparent clustering. However, this lack of clustering or obvious pattern might simply be, in many cases, the effect of an incomplete data set.

In summary, this method of data synthesis uses the geographical array of each geological attribute of the model as a number set. Target cells for further investigations are defined by study of the overlap or coincidence relations among the sets of the more highly correlated attributes. The procedure used in this study is being called attribute-coincidence mapping or ACM. The principles underlying computer-assisted ACM are the same as those used intuitively by the exploration geologist. However, with computer assistance, the interrelation of many more variables can be considered, relevant relations stored for later retrieval and analysis, and comparisons with other complex relations can be developed and remapped for further study and field checking.

The ACM method developed for the investigation reported herein uses the statistical concepts of bivariate-frequency or scatter-diagram analysis. However, in the case of map analysis the X and Y variables of the row-column matrix are rectilinear map directions, and cell frequencies (Z-values) are density patterns or their derivatives of the nth variable or group of variables under spatial analysis.

A simple example taken from the Appalachian region map pattern prepared for the current study will serve to introduce and illustrate basic ACM. For example, the distribution pattern of extensive chert development in the Middle Devonian (Onesquathaw stage) shown on Gridded-Data Map D05 when plotted for ACM on the pattern of relatively thick Tioga Bentonite

(Gridded-Data Map D04) shows a zone of coincidence (that is, 1 + 1 = 2) as in Gridded-Data Map C21. By equating all cell values to 1 (that is, 1 = 1 and 2 = 1) the combined pattern can be used to suggest the extent of strong volcanic activity (Gridded-Data Map D21). Thus, map patterns can be combined or recombined with or without enhancement or coincidence to illustrate geologic patterns related to selected model attributes.

One of the problems frequently encountered in selecting map patterns for specific attributes of a model is that in many cases the particular data needed are neither mapped or otherwise yet available. Consequently, certain other kinds of related data that may reflect some particular aspect or derivative of the attribute are used as proxies in lieu of the actual attribute pattern. For example, no geochemical data from the Appalachian Devonian rocks are available to detect the possible anomalous Mn-Fe halos generally believed to be associated with the sulfide-ore bodies. Thus, in lieu of these data the presence or absence of the well-known supergene Oriskany ores that overlie Middle Devonian strata was noted (Gridded-Data Map 11). Such proxy patterns, where needed in this study, are mentioned in the annotations of tables 1 and 2.

The computer-mapping system used for preparing the gridded-data maps of this study is IMGRID, Version 2.75, under devlopment for interactive use by H. A. Price in 1979-1980 while employed by Science Applications, Inc., Oak Ridge, Tennessee. Although this interactive version of IMGRID was not completely finished, it can be used if supplemented by judicious manipulation of data in various editing systems. The geologic map-pattern files for input into IMGRID were digitized visually and entered into the computer directly via terminal keyboard. The computer used in this work was a VAX 11/780, on which time was purchased commercially from Science Applications, Inc., Oak Ridge, Tennessee. Many of the concepts of data management and manipulation needed for the type of synthesis and analysis used in this study are being incorporated in a new gridded-data management and graphics system currently under development.

RESULTS

More than 50 digitized-data files of selected map patterns have been prepared for this study. Twenty of these files have been mapped as the "M" series of maps of the attached "Devonian-target atlas" (see list in table 2). Also included in this atlas are 16 derivative maps ("D", "E", and "F" series), that is, subset maps for use in overlay and coincidence mapping of selected parts of the data files. And, finally, six coincidence maps ("C" series) are presented at the end of the target atlas. Thus, in all, 42 computer-derived gridded-data maps of information related to the search for massive-sulfide exploration targets in Devonian rocks are presented in this report. Many more are not only possible but are needed to enhance the search results.

DISCUSSION

Inasmuch as the attribute-coincidence maps (ACMaps) are the prime end product of this investigation, only these of all the maps presented will be discussed in detail. Comments about the other maps are contained in the annotations of tables 1 and 2 and are deemed sufficiently self-explanatory. Coincidence as used in this study is simple cell-by-cell recording of attribute frequency. The ACMaps of the Appalachian Region are thus bivariate-frequency tables of 108 rows and 132 columns.

ACMap C21 demonstrates the basic concept of attribute-coincidence mapping (ACM). This map (C21) shows the proximity with little overlap of massive chert development (> 50 percent) in the Onesquathaw Stage of the Middle Devonian (Map D05) and the relatively thick zone of influence (> 10 meters) of the Tioga bentonite (Map D04). If it is assumed that this heavy chert development is ultimately of volcanic origin, we can derive a map (D21) suggesting a single area of intense volcanic activity from the coincidence of the two map patterns. This is accomplished simply by reducing all coincidence values of Map C21 to "1", that is, 1 = 1 and 2 = 1, and remapping.

ACMap C22 shows the relation of possible high-angle faults, many of which have likely penetrated deep into the basin sediments if not into basement, including the possible geosuture, the Alabama-New York lineament (King and Zietz, 1978) (Map D08---merged with D09), to the distribution of Silurian salt (Map D03). This distribution is of particular importance in the stratiform exhalative massive-sulfide model as it shows possible avenues for the egress of highly saline fluids from the basin as it subsides and the sediments within it compact---providing, of course, that the faults were active and open at the specific times of interest in the history of the basin. In the case of the current study this time is the zone that spans the Middle to Late Devonian epochs. In addition, ACMap 22 demonstrates how coincidence mapping can be used to retain the individuality of two attribute patterns and also show the cells of coincidence or zones of overlap. This is accomplished simply by entering one of the attribute patterns twice.

ACMap C23 is an attribute-coincidence map of the same six variables or attributes used in a manual-coincidence experiment in 1979 (Wedow and others, 1979). The coincidence results are essentially the same. Of the 6 attributes input, 4 geodetic cells (that is, 7-1/2 minute quadrangles) show 4 attributes each and 53 cells exhibit coincidence frequencies of 3 each. As noted in the previous report (Wedow and others, 1979) two major areas of interest are readily apparent. In western New York, an area of 18 cells straddling the Clarendon-Linden fault (Map M08) shows an interesting target centered on a nucleous of 3 cells with 4 attributes each. The specific stratigraphic zone of interest in this target is the outcrop and immediate downdip subcrop area of the Genesee Group of earliest Late Devonian age (de Witt and Colton, 1978). The four attributes coincident in this area are high epicenter density, high-angle faults, Silurian salt, and the occurrence (Wedow, 1939) of the pteropod, "Styliolina fissurella", in great abundance.

The second area of interest on ACMap C23 is approximately between latitudes 37 degrees and 38 degrees north in western Virginia and eastern West Virginia. Here, some 17 cells with 3 attributes each lie in an open cluster around 1 cell with 4 attributes. The four attributes in this locality are high epicenter density, the thick (> 1 meter) zone of influence of the Tioga bentonite (tuffite), the occurrence of supergene Mn-Fe in the residuum overling Middle to Upper Devonian rocks (that is, the so-called "Oriskany ores"), and occurrences of the pteropod, "Styliolina fissurella". Other areas of one to several cells with 3 attributes each extend along the trend of the folded Appalachians (Valley and Ridge province) from Virginia through Maryland to Pennsylvania. Some of these smaller areas could be of as much interest for further study as the two discussed in more detail previously.

ACMap C24 shows coincidence of the same attributes shown in ACMap 23 but with variation in weighting. Map C24 thus shows the technique of enhancing the values of smaller-order attribute patterns over those of higher order with larger, longer or broader, pattern-extent or -area. For this map (C24) weighting values are as follows: 1, patterns of broad areal extent (high epicenter density (Map D07), extent of Silurian salt (Map D03), and zone of thick Tioga bentonite (Map D04)); 2, patterns of significan linear extent (high-angle faults and lineaments (merged Maps D08 and D09)); and 3, patterns of smaller areal extent, essentially from point-source data, that exist only as single cells or, at most, clusters of several cells (occurrence of "Styliolina fissurella" (Map D12) and of supergene Mn-Fe deposits (Map D11)). This technique is used to give more importance to the value of single cells during target-area selection. Thus, two small-area attribute patterns weighted at 3 each for a total of 6 are deemed of considerably more importance than two large-area patterns weighted at only 1 each for a total of 2. In ACMap C24 the total possible weighted frequency is 11 (that is, 1 + 1 + 1 + 2 + 3 + 3 = 11). Because of the different regional positions of some of the broader attributes, it is not possible, in this map, to reach the maximum of 11, although several cells attain values of 7 and 8. The same two areas of target interest are pointed-up in ACMap C24 as in ACMap C23 but with slightly different pattern configurations. In general both areas are of slighly larger areal extent, being extended further along the outcrop of Middle and Upper Devonian rocks in both New York and Virginia. The smaller clusters in Virginia and Pennsylvania are further enhanced and become significant targets in their own right.

ACMap C25 shows the "simple" coincidence of nine attribute-patterns for stratiform, exhalative massive sulfides in the Devonian of the Appalachian Basin. In ACMap C25 all nine attribute patterns are weighted equally, or unweighted, depending on the reader's point of view, and are tabulated below in descending order of approximate size (derivative map numbers are given parenthetically for reference):

1) high-epicenter density (Map D07);
2) extent of Silurian salt (Map D03);
3) zone of strong Devonian-age volcanic activity (Map D21);
4) high-angle faults (Map D08);

5) possible geosuture---the Alabama-New York lineament (Map D09);
6) possible Silurian-Devonian hingeline (Map F19);
7) possible Middle to Late Devonian hingeline (Map F20);
8) occurrence of anomalously high supergene Mn-Fe (Map D11); and
9) occurrence of pteropod, "Styliolina fissurella", Map D12.

ACMap C25 not only reiterates the importance of the possible exploration-target areas shown by ACMaps C23 and C24 but adds, also, two others not previously indicated. The first of these two new areas is in West Virginia, Maryland, and Pennsylvania approximately between 38- and 40-degrees north latitude and extending along the trend of and lying immediately northwest of the Alabama-NewYork lineament. The second area is centered in northeastern Ohio at about 41-degrees, 15-minutes north latitude and 81-degrees, 45-minutes west longitude. Both targets would be deep in the subsurface, precise depth not yet estimated, as essentially all defining attributes are based on subsurface data patterns.

The final ACMap (ACMap C26) presented in this study illustrates the use of coincidence mapping for the comparison of geologic favorability with certainty of resource occurrence. In this instance, these two broad concepts are equated, respectively, to possible exploration-target areas (those cells with 3 or more of the 9 attributes from ACMap C25) representing geologic favorability and to occurrences of trace to significant amounts of Zn-Pb mineralization in Silurian, Devonian, and Mississippian rocks. The coincidence, or in some localities, the near or proximal coincidence, of areas in this "two-derivative" map clearly suggests that essentially all of the possible major exploration-target areas discussed in previous paragraphs show the presence of at least some type of Zn-Pb mineralization associated with relatively "high" attribute coincidence.

Table 1.--Annotated outline of attributes for an empirical model of sedimented-associated stratabound, massive-sulfide deposits and Appalachian region map patterns and their derivatives possibly related to selected attributes in the outline.

I. GEOTECTONIC AND RELATED FEATURES.

A. First-order basins (aulacogens; epicratonic or intracratonic basins).

(Shown by area of Appalachian Basin, Maps M01 and M02.)

1. Graben-like or fault-bounded basins.
2. Thick sequences of clastic sediments, shallow-water marine carbonates, delta-front silts, turbidites, and marine shales and cherts.

   (Suggested by isopachous map of Silurian and Devonian carbonate sequence, Map M19, particularly where thickness is greater than 1,200 feet, Map E19; also by occurrence of Devonian red beds, Map M05.)
3. Evaporites

   (Shown by pattern of Silurian salt on Ma M03.)

B. Second-order basins

1. Vertical tectonism.

   (Suggested by pattern of high-angle faults, Maps M08 and D08.)

2. Becken (basins) and schwellen (rises).

   (Might be reflected in pattern of variation of Bouguer gravity map, see Maps M10, D10, and E10.)

3. Abrupt changes in sedimentary facies and thicknesses.

   (Suggested in part by isopachous map of Silurian-Devonian carbonate sequence, Maps M19 AND F19; and, in part, the cumulative thickness map of Devonian black shales, Maps M20 and F20. As the lowest cell frequencies in the mid-range values imply the steepest slope of the isopach contours (4, in both Maps M19 and M20), these selected values are used to proxy for possible hinge-zone position patterns (Maps F19 and F20).)

4. Hot-spot activity.

   a. Minor intrusions.

   b. Local metamorphism.

   (May be suggested by variations in patterns of conodont-color-aletration index, see Maps M17 and D17.)

5. Contemporaneous igneous activity.

   a. Spilites and keratophyres (not calc-alkaline).

   b. Tuffs, tuffites, bentonites, and other evidence of ashfalls.

(Suggested by distribution and thickness of Middle Devonian Tioga bentonite, Maps M04 and D04.)

6. Lineaments.

   a. Rift zones in basement and sedimentary cover (extensional fractures).

   (Locations of postulated high-angle faults, Maps M08 and D08; and the Alabama-New York lineament, Map M09.)

   b. Geosutures.

   (Suggested by Alabama-New York lineament, Map M09.)

   c. Hinge zones.

   (As in Item I.B.6.a., above.)

   d. Intersections of lineaments.

   (As in Item I.B.6.a., above.)

C. Third-order basins.

1. Local marine transgression.

2. Euxenic environment in autochthonous sediments.

   a. Black shale.

   (Shown by cumulative thickness map of Devonian black shales, Maps M20, D20, and E20.)

   b. Evidence for low-energy environment (e. g., lack of coarse-grained clastics).

   c. Relatively high content of organic carbon, including graphite in metamorphic rocks

   (As in Item I.C.2.a., above; may also be related to patterns of oil and gas deposits in Silurian and Devonian rocks in Aplachian region, Maps M14 and M15.)

d. Diagentic pyrite and pyritized fossils.

e. Relatively high (anomalous) content of phosphorus, sulfur, and vanadium.

3. Anomalous accumulations of pelagic faunas.

(Location maps of reported occurrences of pteropod, "Styliolina fissurella", Maps M12 and D12.)

4. Syndepositional fault activity.

a. Abrupt local changes in facies and thickness of sediments.

b. Slump breccias.

c. Intraformational conglomerates (allochthonous sediments).

d. Sedimentary dikes.

e. Local zones of intense folding and fracturing.

II. OTHER FEATURES (CHIEFLY THIRD ORDER IN SIZE) REFLECTING PRESENCE OF DEPOSITS.

A. Hydrothermal mineral deposits.

(Reported occurrences of Zn and/or Pb in Silurian to Mississippian rocks, see Maps M13 and D13.)

1. Stratiform deposits.

a. Volcanic chert (silica).

(Distribution of significant chert in Middle Devonian (Onesquathaw) rocks, Maps M05 and D05.)

b. Barite.

c. Iron and base-metal sulfides.

(See comment under Item II.A., above.)

d. Ferruginous and manganiferous deposits including cherts.

(Only data available are occurrences of supergene deposits of Mn and Fe in Devonian and Mississippian rocks (chiefly the so-called "Oriskany ores", see Map M11; Map M16 showing area of Pleistocene glacial activity included to show effect on distribution of supergene deposits.)

2. Epigenetic deposits.

a. Disseminated copper minerals and cross-cutting copper-bearing veins.

B. Element zonation.

1. Vertical zonation of Cu---->Zn---->Pb---->Ba.

2. Lateral zonation of Cu---->Pb---->Zn---->Ba.

3. Halo of Mn and Fe cherts.

(See Item II.A.1.d., above.)

4. Copper-bearing veins and disseminations generally and near center and stratigraphically beneath stratiform-ore minerals.

C. Alteration.

1. Silicification (e. g., kniest, high-silica dolomite).

2. Hydrothermal brecciation.

3. Tourmalization.

III. ISOTOPES.

A. Lead isotopes.

1. Pb-isotope data are conformable between host rock and mineral deposit.

B. Sulfur isotopes.

1. s*34 sulfur in pyrite is from reduced sea-water sulfate.

2. s*34 sulfur in galena and sphalerite is of hydrothermal origin.

3. s*34 sulfur in barite is from sea-water sulfate.

IV. AGE RELATIONS.

A. Deposits are general found in:

1. Middle Proterozoic rocks.

2. Middle Paleozoic rocks.

(Model is being applied to Devonian sequence of Appalachian region; for surface outcrop pattern of Lower and Middle Devonian rocks of region, see Map M18.)

Table 2.--List of maps of Appalachian region geologic patterns annotated to show their relation to selected attributes of sediment-associated stratiform massive-sulfide deposits as outlined in table 1.

MAP M00.--BASE MAP OF PART OF EASTERN UNITED STATES SHOWING STATE BOUNDARIES.

MAP M01.--AREA OF APPALACHIAN REGION. 1, indicates the cell is wholly or at least half within the region.

(Item I.A., table 1. First-order sedimentary basin; shows maximum area of basin.)

MAP M02.--BASEMAP OF EASTERN UNITED STATES SHOWING OUTLINE OF APPALACHIAN REGION. @, indicates cell contains boundary of region.

(Item I.A., table 1. First-order sedimentary basin; shows outline of basin for inclusion with subsequent maps.)

MAP M03.--DISTRIBUTION OF SALT IN SILURIAN ROCKS OF THE APPALACHIAN REGION. Adapted from Colton (1961). Cumulative thickness of salt: 1, $<$ 1 to 500 feet; 2, $>$ 500 feet.

(Item I.A.3., table 1. Distribution of major portion of evaporites in first-order basin. Possible source of saline brines for transport of metal ions.)

MAP M04.--DISTRIBUTION OF TIOGA BENTONITE. Adapted from Dennison (1961) and Dennison and Textoris (1970). Thickness of zone of influence: 1, $<$ 3 feet; 2, 3-10 feet; 3, 10-30 feet; and 4, $>$ 30 feet.

(Item I.B.5.b., table 1. Indication of regional and local volcanic activity. Feature is both 1st and 2nd order, with 2nd order, that is, the thickest zone of bentonite influence, suggesting "hot-spot" activity or proximity to center of volcanic activity.)

MAP D04.--DERIVATIVE OF TIOGA-BENTONITE DISTRIBUTION. (See Map M04.) Thickness of zone of influence: 1, $>$ 3 feet.

(Item I.B.5.b., table 1. See comment under Map M04; Map D04 is thus used to illustrate areas proximal to center of volcanic activity and, hence, also a source of silica for "volcanic-chert" formation.)

MAP M05.--DISTRIBUTION OF CHERT IN THE ONESQUATHAW STAGE (MIDDLE DEVONIAN). Adapted from Oliver and others (1967). Chert content: 1, 10-50 percent and 2, >50 percent.

(Item II.A.1.a., table 1. Abundance of silica may reflect possible association with contemporaneous volcanic activity as shown by distribution of Tioga bentonite (see Maps M04 and D04.)

MAP D05.--DERIVATIVE OF CHERT DISTRIBUTION IN THE ONESQUATHAW STAGE (MIDDLE DEVONIAN). (See Map M05.) Chert content: 1, > 50 percent.

(Item II.A.1.a., table 1. High concentration (> 50 percent) of silica and close affinity with thick (> 3 feet) Tioga bentonite strongly suggests that chert in Onesquathaw is of volcanic origin.)

MAP M06.--DISTRIBUTION OF RED BEDS IN DEVONIAN ROCKS. Adapted from Colton (1961, fig.15). Red bed thickness densities as follows: 1, occur but are less than 40 percent of sequence; and 2, more than 40 percent of sequence.

(Item I.A.2., table 1. Suggests that part of 1st-order basin may have subsided along rift structure.)

MAP M07.--VARIATIONS IN MODERN SEISMIC ACTIVITY AS SHOWN BY PATTERNS OF EPICENTER DENSITY. Adapted from Hadley and Devine (1975). Reported epicenters per 10,000 square kilometers as follows: blank, data not shown; 1, < 4; 2, 4-8; 3, 8-16; and 4, > 16.

(Item I.B.1., table 1. Is used to reinforce fault patterns that suggest vertical tectonics and rifting. Although data shown relate to modern seismic activity and possible present-day rifting, such areas most likely were also active intermittantly or periodically through geologic time, particularly during the part of the Devonian during which the massive-sulfide model is being applied.)

MAP D07.--DERIVATIVE OF MODERN SEISMIC ACTIVITY AS SHOWN BY PATTERNS OF EPICENTER DENSITY. (See Map M07.) Reported epicenters per 10,000 square kilometers: blank, data not shown or < 4; 1, > 4.

(Item I.B.1., table 1. Derivative of data shown in Map M07 so that only areas of higher epicenter density are used in pattern comparison.)

MAP M08.--COMPOSITE OF REPORTED HIGH-ANGLE FAULTS MAPPED AT SURFACE OR INTERPRETED FROM SUBSURFACE WELL DATA. In the case of overlapping occurrences only that mapped last is indicated. Sequence of numbers indicates order of sources mapped as follows: 1, Hadley and Devine (1974); 2, Harris (1975); 3, Chadwick (1920), Fletcher and Sykes (1976), and Hutchinson and others (1977); 4, Heckel (1973); 5, Rodgers (1953); and 6, Harris, Harris, and Epstein (1978).

(Items I.B.1. and I.B.6.a., table 1. Possible evidence for vertical tectonism. Data are from various sources are interpretive and may be repetive. Size of features range from 1st to 3rd order.)

MAP D08.--COMPOSITE (DERIVATIVE) OF REPORTED HIGH-ANGLE FAULTS MAPPED AT SURFACE OR INTERPRETED FROM SUBSURFACE-WELL DATA. (See Map M08.) 1, cell contains part of a fault trace from one or more map sources.

(Items I.B.1. and I.B.6.a., table 1. Derivative adaptation of data shown in Map M08 so that all values of cell densities are reduced to unity for use with simple ACM.)

MAP M09.--ALABAMA-NEW YORK LINEAMENT. Adapted from King and Zietz (1978). 7, indicates trace of postulated crustal break beneath Appalachian basin.

(Item I.B.6.a., table 1. The Alabama-New York lineament of King and Zietz may be that type referred to as a "geosuture"; many of the other geological patterns used in this experimental analysis shows a close spacial correlation with this AL-NY feature.)

MAP M10.--BOUGUER GRAVITY ANOMALY MAP OF THE APPALACHIAN REGION. Adapted from American Geophysical Union and U. S. Geological Survey (1964). Gravity levels as follows: 1, < -100 mgal; 2, -100 to -80 mgal; 3, -80 to -60 mgal; 4, -60 to -40 mgal; 5, -40 to -20 mgal; 6-20 to 0 mgal; 7, 0 to +20 mgal; and 8, > +20 mgal.

(Item I.B.2., table 1. There is a suggestion that some of the sedimentary column overlying basement may have some influence on the ultimate gravity value, as, for example, the low-density thick evaporitesequence in the Silurian rocks of the northern part of the basin. Consequently, the coded Bouguer values have been subset into derivative areas of relatively low gravity (Map D10) and relatively high gravity (Map E10), respectively.)

MAP D10.--DERIVATIVE OF BOUGUER GRAVITY ANOMALY MAP OF THE APPALACHIAN REGION. (See Maps M10 and E10.) Gravity levels: blank, data not shown or > -40 mgal; 1, < -40 mgal.

(Item I.B.2., table 1. See also comment under Map M10, above.)

MAP E10.--DERIVATIVE OF BOUGUER GRAVITY ANOMALY MAP OF THE APPALACHIAN REGION. (See Maps M10 and D10.) Gravity levels: blank, data not shown or < -40 mgal; 1, > -40 mgal.

(Item I.B.2., table 1. See also comment under Map M10, above.)

MAP M11.--DISTRIBUTION OF SUPERGENE IRON AND MANGANESE OXIDE OCCURRENCES UNDERLAIN BY DEVONIAN AND MISSISSIPPIAN ROCKS IN THE APPALACHIAN REGION. Taken from numerous sources, both published and unpublished. Most occurrences are reported mines and prospects of "Oriskany" iron and manganese ores. 1, indicates cell contains at least one significant occurrence of supergene iron or manganese oxides.

(Items II.A.1.d. and II.B.3., table 1. Relates to attribute of anomalous Mn and Fe associated with massive sulfide deposits. As geochemical data on Mn and Fe are not generally available for Devonian bedrock sequences, supergene concentrations (mines, propsects, and reported occurrences) are used as a surrogate for evidence of Mn-Fe exhalates generally found associated with stratiform base-metal ores.

MAP M12.--REPORTED OCCURRENCES OF THE PTEROPOD "STYLIOLINA FISSURELLA" IN MIDDLE AND UPPER DEVONIAN ROCKS. Stated abundance levels: 1, rare or quantity unreported; 2, common; and 3, abundant.

(Item I.C.3., table 1. Possible indictor of catastrophic destruction of pelagic faunas in toxic environment associated with euxenic brine basin. Many of the possible pteropod occurrences are probably missing because of lack of fresh bedrock exposure or because this small fossil is difficult to observe.

MAP D12.--DERIVATIVE OF REPORTED OCCURRENCES OF THE PTEROPOD "STYLIOLINA FISSURELLA" IN MIDDLE AND UPPER DEVONIAN ROCKS. (See Map M12.) 1, reported occurrence regardless of stated abundance.

(Item I.C.3., table 1. Derivative of Map M12 to reduce all levels of abundance to a single level for ACM studies.)

MAP M13.--ZINC AND LEAD OCCURRENCES IN THE APPALACHIAN REGION. Taken chiefly from Wedow and others (1968) and Tooker and Wedow (1980). Ages of host rock are as follows: 1, Cambrian and Ordovician; 2, Early Silurian; 3, Middle Silurian through Middle Devonian; 4, Late Devonian; 5, Mississippian; and 6, Pennsylvanian.

(Item II.A., table 1. Direct evidence of base-metal mineralization in Paleozoic rocks.)

MAP D13.--DERIVATIVE OF REPORTED OCCURRENCES OF ZINC AND LEAD IN THE APPALACHIAN REGION. (See Map M13.) 1, occurrences in Early Silurian through Mississippian rocks.

(Item II.A., table 1. Direct evidence of base-metal mineralization in Middle Paleozoic rocks. Although major target sequence is Middle to Late Devonian in age, occurrences in Silurian and Mississippian rocks are included because of possible interrelationships. Map prepared as a derivative of Map M13.)

MAP M14.--AREAS PRODUCING OIL AND GAS FROM SILURIAN ROCKS IN THE APPALACHIAN BASIN. Adapted from Milici (1980). 2, indicates at least one-half of cell is underlain by area as mapped.

(Item II.C.2.c., table 1. Included because of possible relation to organic-carbon attribute.)

MAP M15.--AREAS PRODUCING OIL AND GAS FROM DEVONIAN ROCKS IN THE APPALACHIAN

BASIN. Adapted from Milici (1980). 3, indicates at least one-half of cell is underlain by area as mapped.

(Item II.C.2.c., table 1. Included because of possible relation to organic-carbon attribute. Used in conjunction with Map M14 as a single derivative map.)

MAP M16.--EXTENT OF PLEISTOCENE GLACIATION IN PART OF EASTERN UNITED STATES. Adapted from King and Beikman (1974). 1, indicates area covered by ice during maximum advances of Pleistocene continental glaciers.

(Item II.A.1.d., table 1. Included to show effect of post-mineralization glaciation on distribution pattern of supergene Mn-Fe deposits. In ACM combination with Map M11 note how few Mn-Fe occurrences of this type occur north of the edge of Pleistocene glacial deposits.)

MAP M17.--VARIATION OF CONODONT COLOR-ALTERATION INDEX IN SILURIAN THROUGH MIDDLE DEVONIAN CARBONATE ROCKS. Adapted from Harris, Harris, and Epstein (1978, sheet 2). CAI ranges: 1, <1.5; 2, 1.5-2; 3, 2-2.5; 4, 2.5-3; 5, 3-3.5; 6, 3.5-4; 7, 4-4.5; 8, 4.5-5; and 9, >5.

(Item I.B.4.b., table 1. Variation in conodont color-alteration index (CAI) may suggest "hot-spot" activity and low-rank metamorphism. Use of this variable needs further study with more attention local anomalous CAI values that could be contemporaneous with local sea-floor hot-brine vents.)

MAP D17.--DERIVATIVE OF CONODONT COLOR-ALTERATION INDEX (CAI) IN SILURIAN THROUGH MIDDLE DEVONIAN CARBONATE ROCKS. (See Map M17.) CAI ranges: blank, data not shown or < 2.5; 1, > 2.5.

(Item I.B.4.b., table 1. Derivative from Map M17 to show only areas of relatively higher thermal activity, that is, those areas where the CAI exceeds 2.5 (generally equated with temperatures above 200 degrees C.).)

MAP M18.--OUTCROP BELT OF LOWER AND MIDDLE DEVONIAN ROCKS IN THE APPALACHIAN BASIN. Adapted from King and Beikman (1974). 1, indicates cell surface is wholly or partly occupied by outcrop of Lower, Middle, or Lower and Middle Devonian rocks.

(Item IV.A.2., table 1. Location (at surface) of rocks of interest to application of model in Devonian of Appalachian region.)

MAP M19.--ISOPACHOUS MAP OF THE SILURIAN-DEVONIAN CARBONATE SEQUENCE IN THE APPALACHIAN BASIN. Adapted from Colton (1961, fig. 12). Thickness intervals coded as follows: 1, < 400 feet; 2, 400-800 feet; 3, 800-1,200 feet; 4, 1,200-1,600 feet; 5, 1,600-2,000 feet; 6, 2,000-2,400 feet; 7, 2,400-2,800 feet; 8, 2,800-3,200 feet; and 9, > 3,200 feet.

(Items I.A.2. and I.B.3., table 1. Used to suggest location of local basin deeps and adjacent highs (becken und schwellen) at end of Middle Devonian time.)

MAP D19.--DERIVATIVE OF ISOPACHOUS MAP OF THE SILURIAN-DEVONIAN CARBONATE SEQUENCE IN THE APPALACHIAN REGION. (See Maps M19 and E19.) Thicknesses: blank, data not shown or > 1,200 feet; 1, < 1,200 feet.

(Items I.A.2. and I.B.3., table 1. Derivative of Map M19 to show areas of relatively thin Silurian to Middle Devonian sedimentation, thus, areas that could be considered as interdeep basin highs (schwellen).)

MAP E19.--DERIVATIVE OF ISOPACHOUS MAP OF THE SILURIAN-DEVONIAN CARBONATE SEQUENCE IN THE APPALACHIAN REGION. (See Maps M19 and D19.) Thicknesses: blank, data not shown or < 1,200 feet; 1, > 1,200 feet.

(Items I.A.2. and I.B.3., table 1. Derivative of Map M19 to show areas of relatively thick Silurian to Middle Devonian sedimentation, thus, areas that could be considered as basin deeps (becken).)

MAP F19.--DERIVATIVE OF ISOPACHOUS MAP OF THE SILURIAN-DEVONIAN CARBONATE SEQUENCE IN THE APPALACHIAN BASIN. (See Maps M19, D19, and E19.) Thickness: blank, data not shown, <1,200 feet, or >1,600 feet; 1, 1,200-1,600 feet.

(Item I.B.6.c., table 1. Derivative of Map M19 to show possible hinge-zone pattern in basin.)

MAP M20.--CUMULATIVE THICKNESS OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. Adapted from de Witt and others (1975). Cumulative thickness intervals as follows: 1, < 200 feet; 2, 200-400 feet; 3, 400-600 feet; 4, 600-800 feet; 5, 800-1,000 feet; 6, 1,000-1,200 feet; 7, 1,200-1,400 feet; and 8, > 1,400 feet.

(Items I.B.3., I.C.1.a., and I.C.1.c., table 1.)

MAP D20.--DERIVATIVE OF CUMULATIVE THICKNESS MAP OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. (See Maps M20 and E20.) Cumulative thicknesses: blank, data not shown or > 600 feet; 1, < 600 feet.

(Items I.B.3., I.C.1.a., and I.C.1.c., table 1.)

MAP E20.--DERIVATIVE OF CUMULATIVE THICKNESS MAP OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. (See Maps M20 and D20.) Cumulative thicknesses: blank, data not shown or < 600 feet; 1, > 600 feet.

(Items I.B.3., I.C.1.a., and I.C.1.c., table 1.)

MAP F20.--DERIVATIVE OF CUMULATIVE THICKNESS MAP OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. (See Maps M20, D20, and E20.) Cumulative thicknesses: blank, data not shown, , 600 feet, or > 800 feet.

(I.B.6.c., table 1. Taken from Map M20 to show possible hinge-zone in basin.)

MAP C21.--COINCIDENCE OF THICK (> 3 FEET) ZONE OF TIOGA BENTONITE (TUFFITE) AND HEAVY DEVELOPMENT OF CHERT (> 50 PERCENT) IN ONESQUATHAW (MIDDLE DEVONIAN) ROCKS. (See Maps D04 and D05.) Cell symbols: 1, either thick tuffite or massive chert; 2, zone of overlap (that is, coincidence of the two patterns).

MAP C22.--COINCIDENCE OF SILURIAN SALT WITH PATTERN OF HIGH-ANGLE FAULTS (INCLUDING ALABAMA-NEW YORK LINEAMENT). Developed from Map D03 (Silurian salt) and Maps D08 and D09 (high-angle faults and Alabama-New York lineament, respectively). Cell symbols: 1, Silurian salt; 2, high-angle faults and Alabama-New York lineament; and 3, coincidence of fault and salt patterns.

MAP C23.--COINCIDENCE OF SIX ATTRIBUTES FOR STRATIFORM MASSIVE-SULFIDE DEPOSITS IN THE APPALACHIAN REGION. Attributes are equally weighted and taken from derivative maps D03 (Silurian salt), D04 (Tioga bentonite), D07 (high epicenter density), D08 and D09 (high-angle faults and Alabama-New York lineament merged), D11 (supergene Mn-Fe occurrences), and D12 (occurrences of the pteropod "Styliolina fissurella"). Number symbols indicate frequency of coincidences per cell; maximum possible frequency per cell = 6.

MAP C24.--WEIGHTED COINCIDENCE OF SIX ATTRIBUTES FOR STRATIFORM MASSIVE-SULFIDE DEPOSITS IN THE APPALACHIAN REGION. Attributes are the same and from the same maps as in Map C23 but are weighted as follows: 3 each---D11 (Mn-Fe occurreences) and D12 (Styliolina fissurella"); 2---D08 and D09 (merged, respectively, high-angle faults and Alabama-New York lineament; and 1 each---D03 (Silurian salt), D04 (Tioga bentonite), and D07 (strong epicenter density). Number symbols indicate weighted frequency of coincidences per cell; maximum possible value = 11.

MAP C25.--COINCIDENCE OF NINE ATTRIBUTES FOR STRATIFORM MASSIVE-SULFIDE DEPOSITS IN THE APPALACHIAN REGION. Attributes are equally weighted and are from derivative maps as follows: Silurian salt (D03), high epicenter density (D07), high-angle faults (D08), Alabama-New York lineament or "geosuture" (D09), supergene Mn-Fe occurrences (D11), occurrences of "Styliolina fissurella" (D12), possible Silurian-Devonian hingeline (F19), possible Middle to Late Devonian hingeline (F20), and area of strong Devonian volcanic activity (D21). Number symbols indicate frequency of coincidences per cell; maximum possible frequency = 9.

MAP C26.--COINCIDENCE OF "HIGH" ATTRIBUTE-COINCIDENCE VALUES FROM MAP C25 WITH KNOWN SILURIAN THROUGH MISSISSIPPIAN ZILEAD OCCURRENCES (MAP D13). Symbols: 1, cells with coincidence frequencies from Map C25 of 3, 4, and 5 (of a possible 9); 2, cells with known Silurian-Mississippian zinc-lead occurrences; and 3, cells with both 1 and 2.

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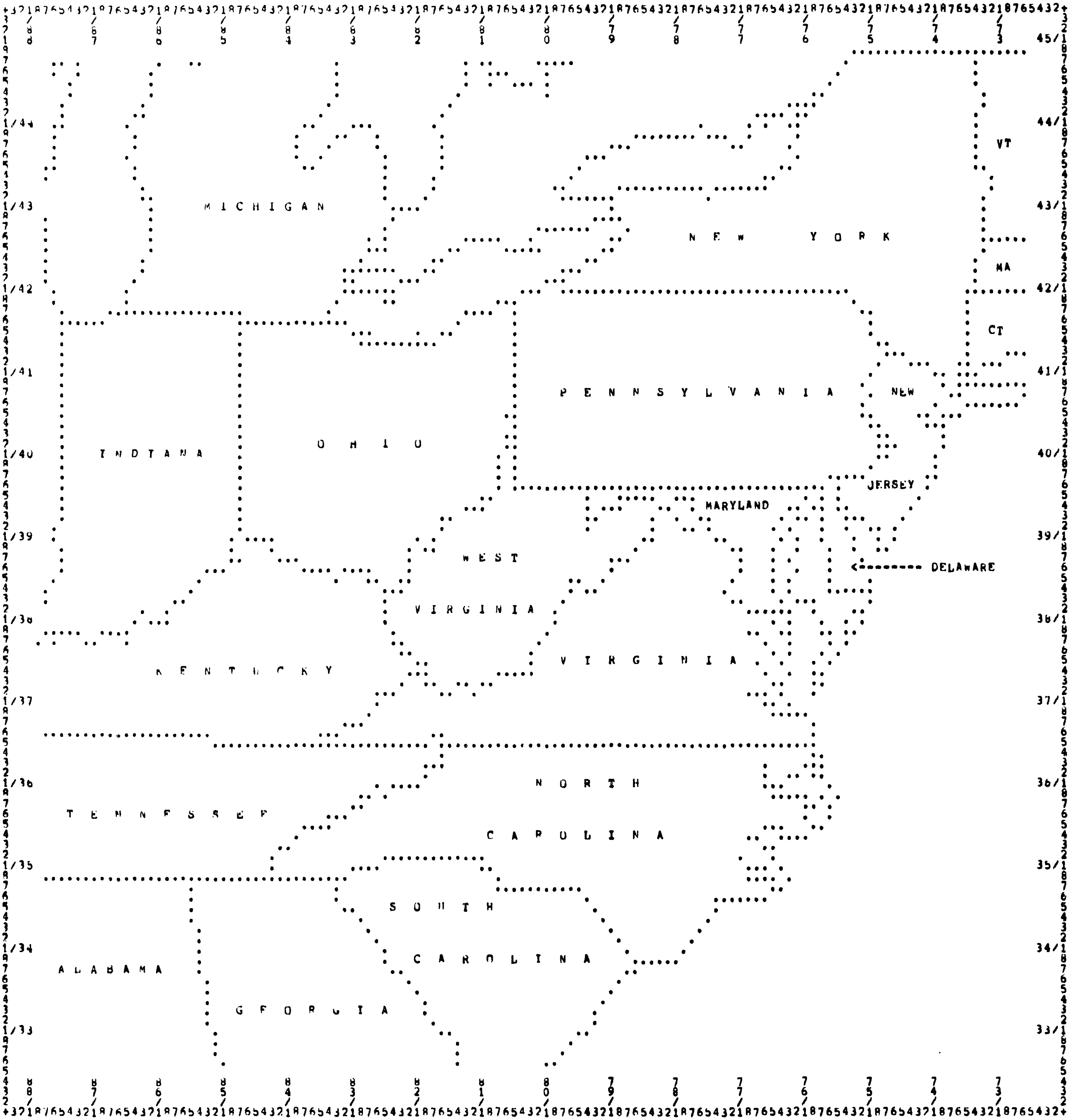
WEDOS, DEVONIAN TARGET ATLAS

GRIDDED-DATA MAP M00

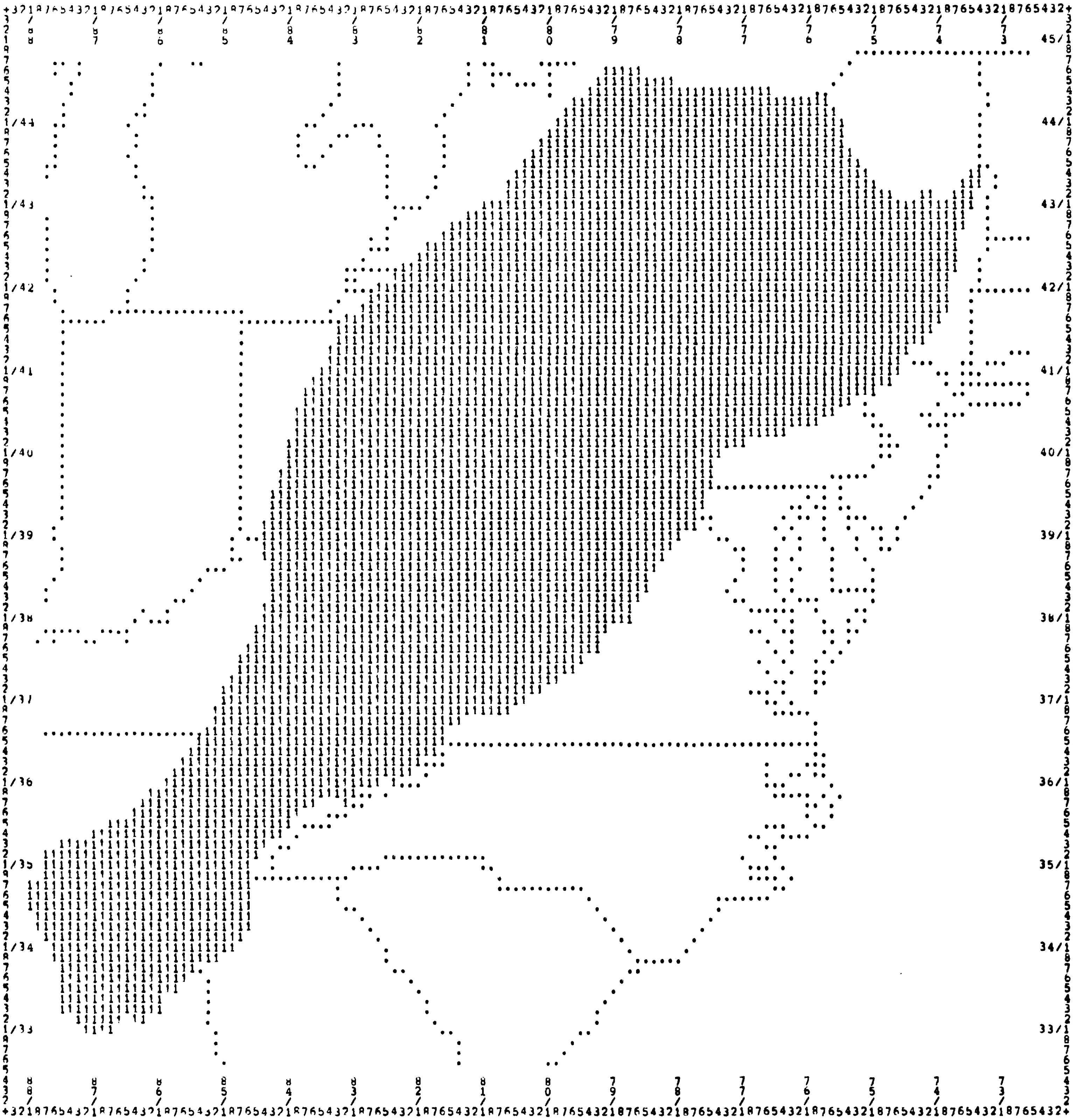


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M00.--BASE MAP OF PART OF EASTERN UNITED STATES SHOWING STATE BOUNDARIES

GRIDDED-DATA MAP M01



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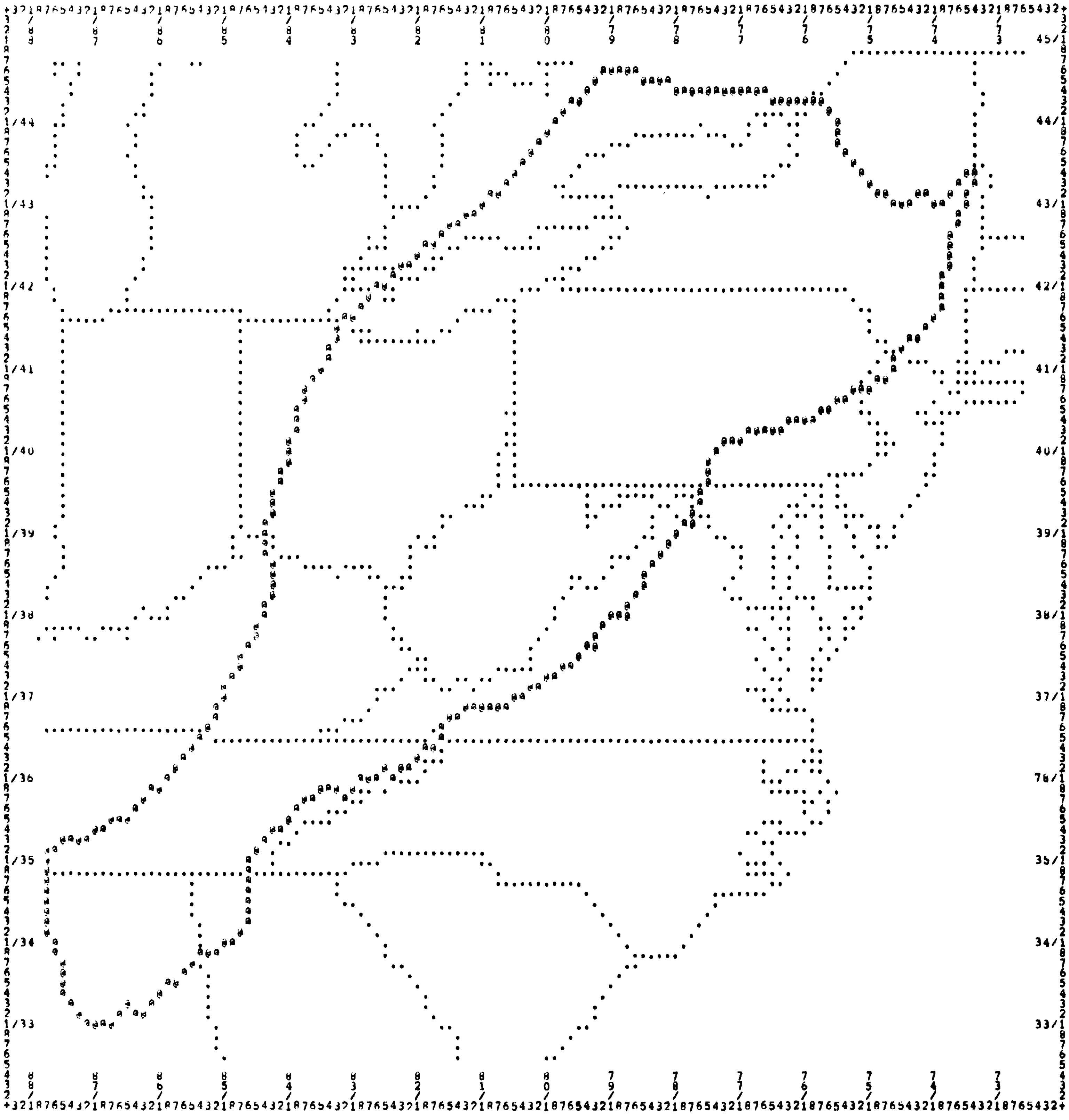
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

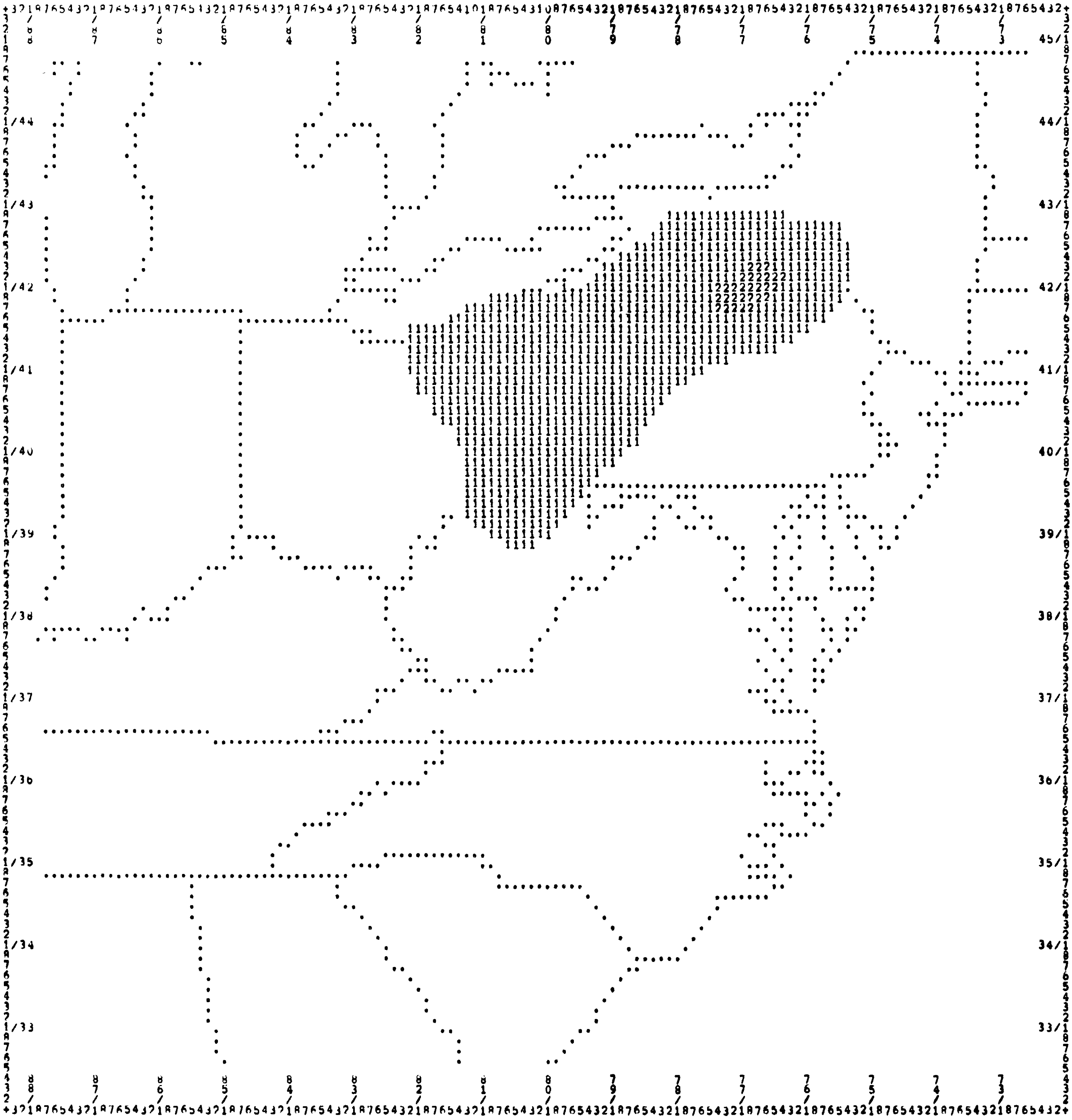
MAP M01.--AREA OF APPALACHIAN REGION. 1, indicates the cell is wholly or at least half within the region.



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M02.--BASEMAP OF EASTERN UNITED STATES SHOWING OUTLINE OF APPALACHIAN REGION
@, indicates cell contains boundary of region



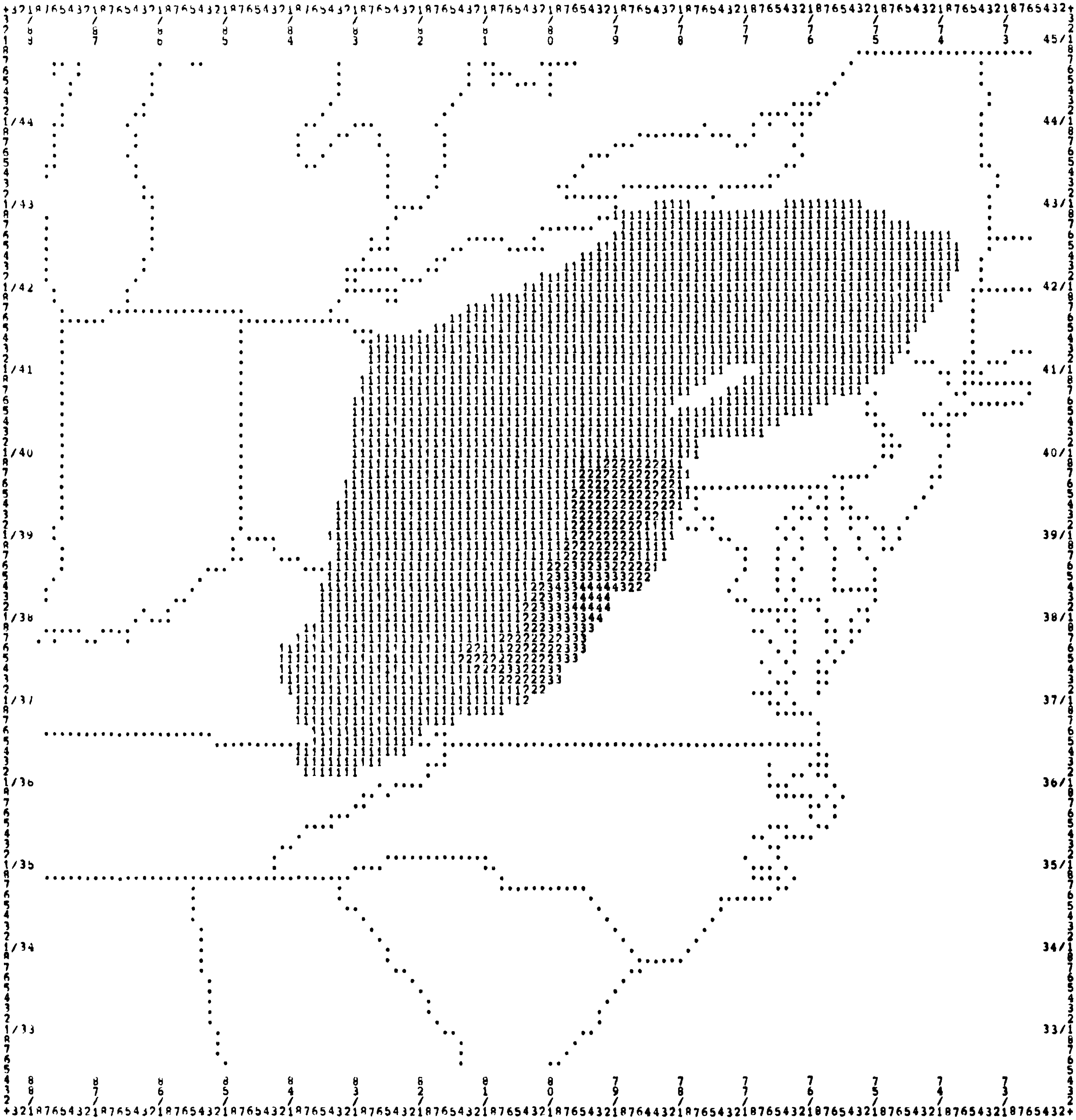
SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles,
width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M03.--DISTRIBUTION OF SALT IN SILURIAN ROCKS OF THE APPALACHIAN REGION.
Adapted from Colton (1961). Cumulative thickness of salt:
1, < 1 to 500 feet; 2, > 500 feet.

NE US, DEVONIAN-TARGET ATLAS

GRIDDED-DATA MAP M04

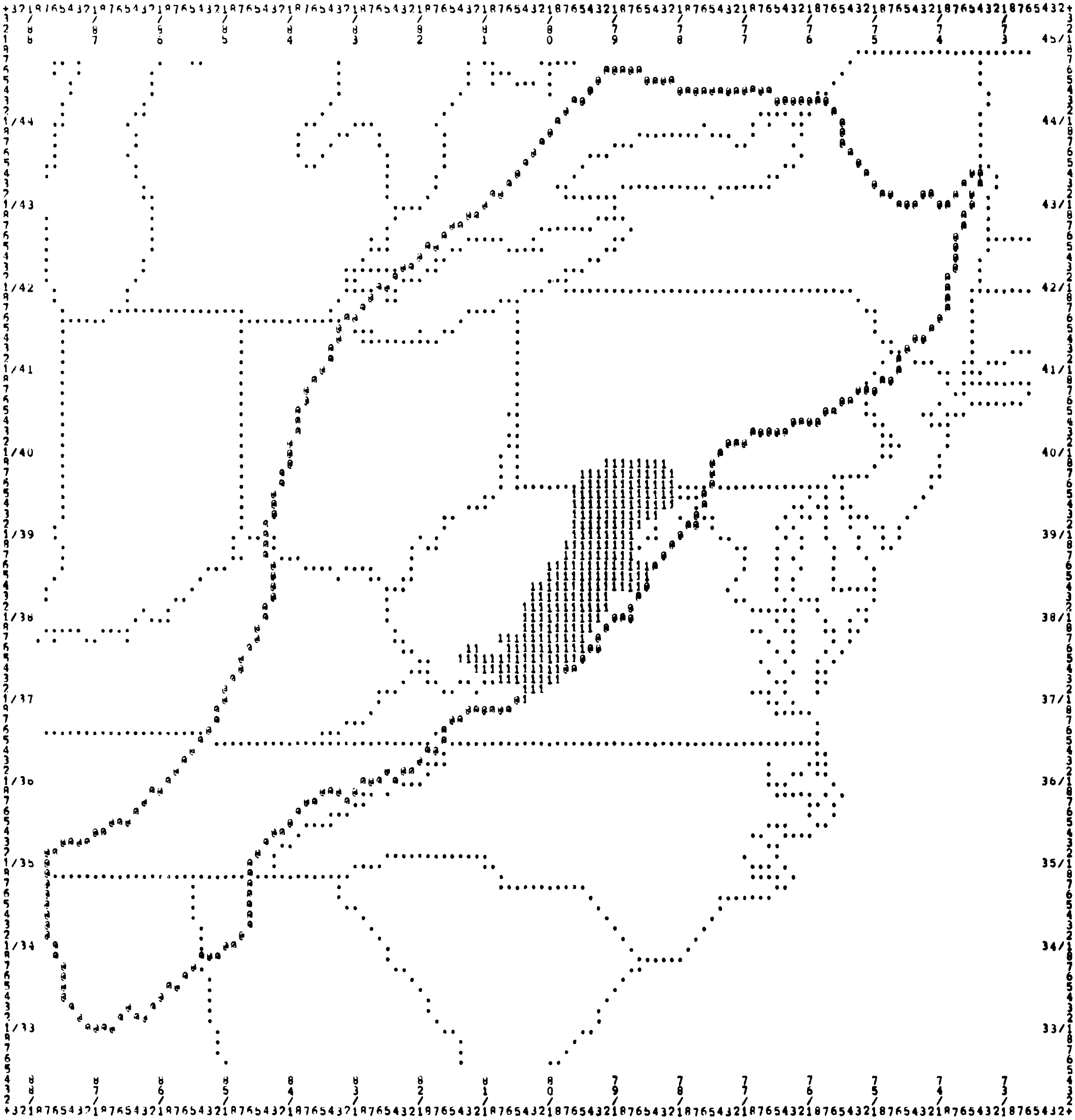


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M04.--DISTRIBUTION OF TIOGA BENTONITE. Adapted from Dennison (1961) and
Dennison and Textoris (1970). Thickness of zone of influence:
1, < 3 feet; 2, 3-10 feet; 3, 10-30 feet; and 4, > 30 feet.

GRIDDED-DATA MAP D04

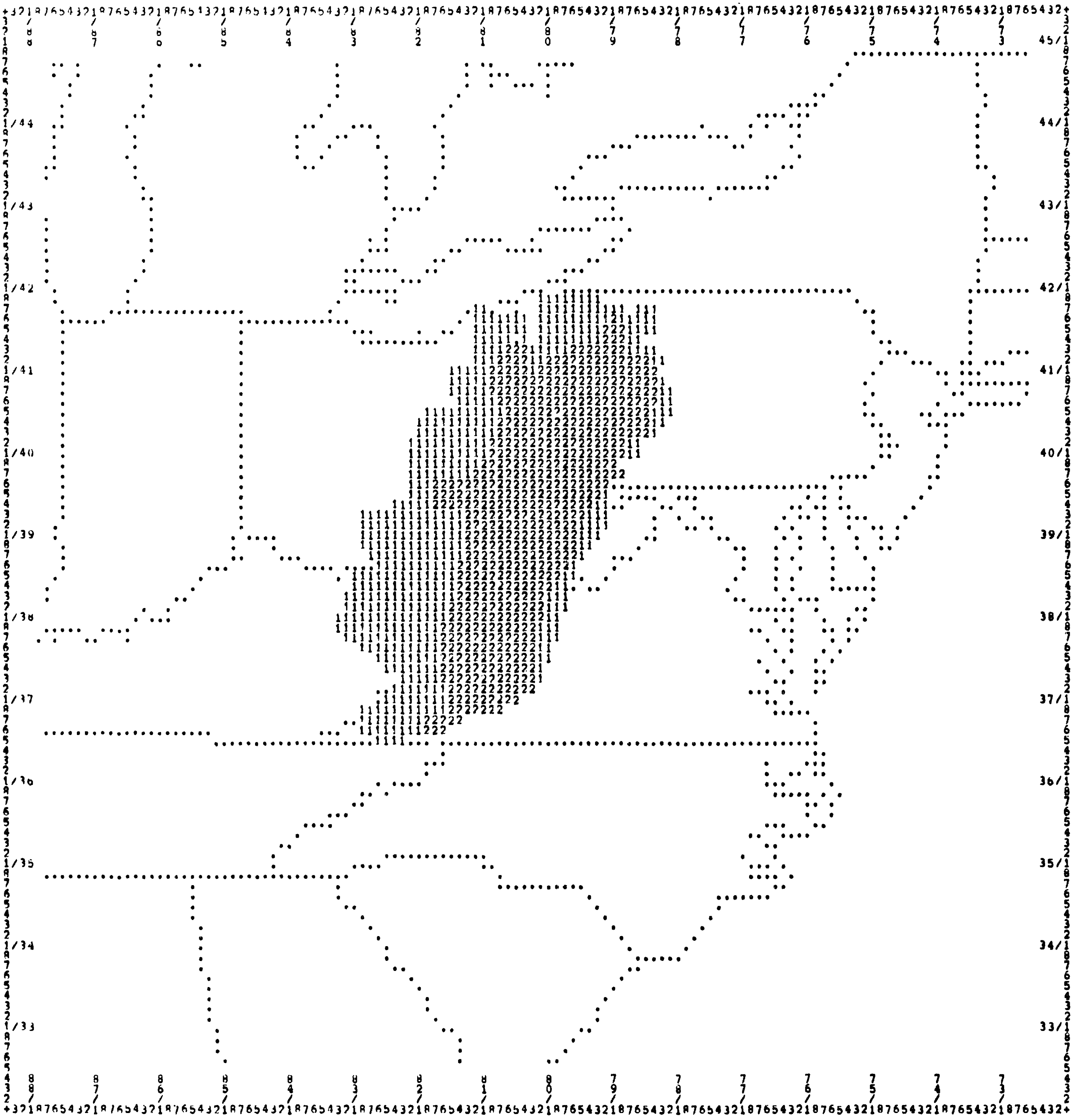


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D04.--DERIVATIVE OF TIOGA-BENTONITE DISTRIBUTION. (See Map M04.)
Thickness of zone of influence: 1, > 3 feet.

WEDOW, DEVONIAN-TARGET ATLAS GRIDDED-DATA MAP M05

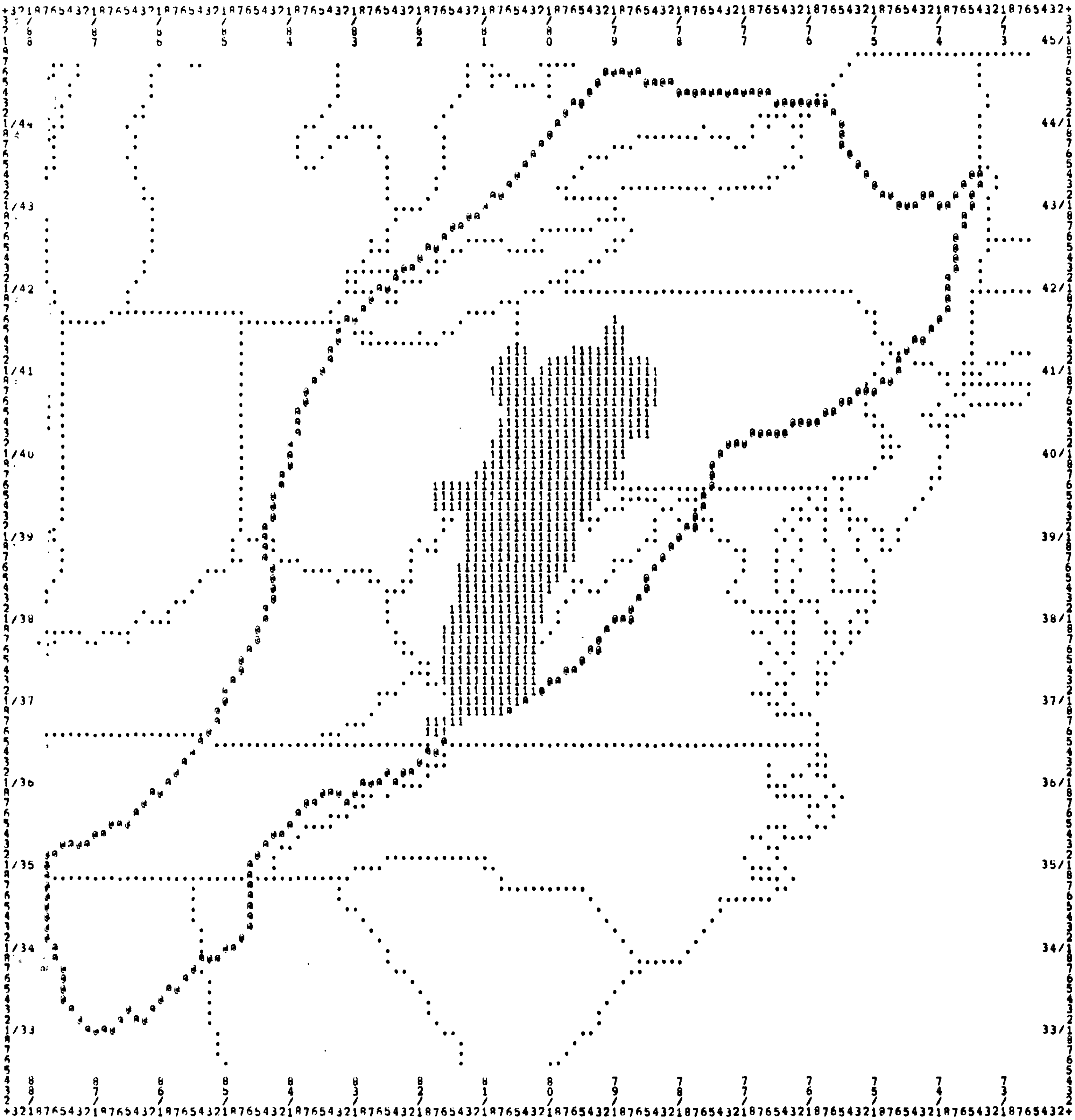


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M05.--DISTRIBUTION OF CHERT IN THE ONESQUETHAW STAGE (MIDDLE DEVONIAN).
Adapted from Oliver and others (1967). Chert content:
1, 10-50 percent and 2, >50 percent.

 GRIDDED-DATA MAP D05

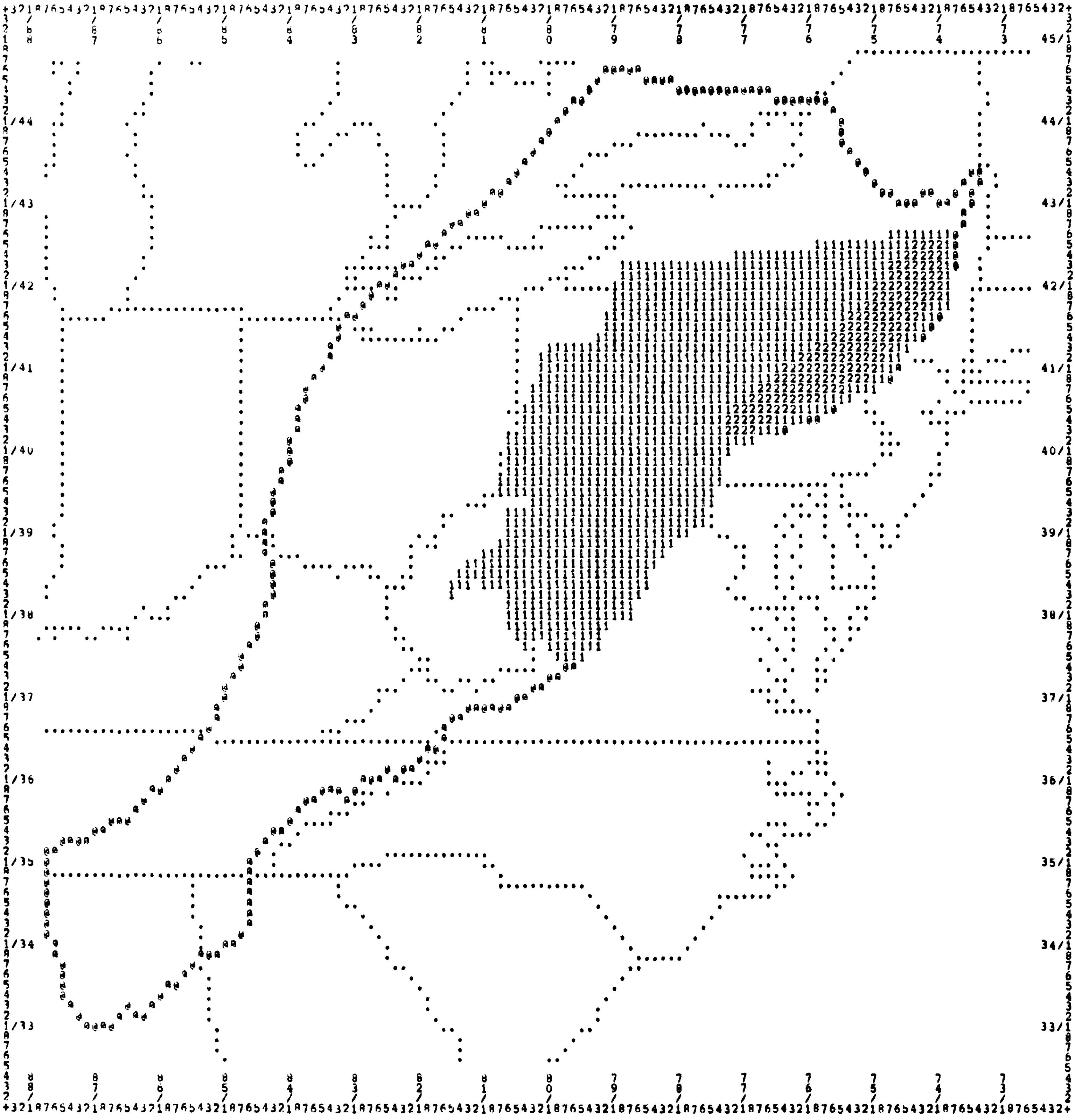


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D05.--DERIVATIVE OF CHERT DISTRIBUTION IN THE ONESQUATHAW STAGE (MIDDLE DEVONIAN). (See Map M05.) Chert content: 1, > 50 percent.

GRIDDED-DATA MAP M06

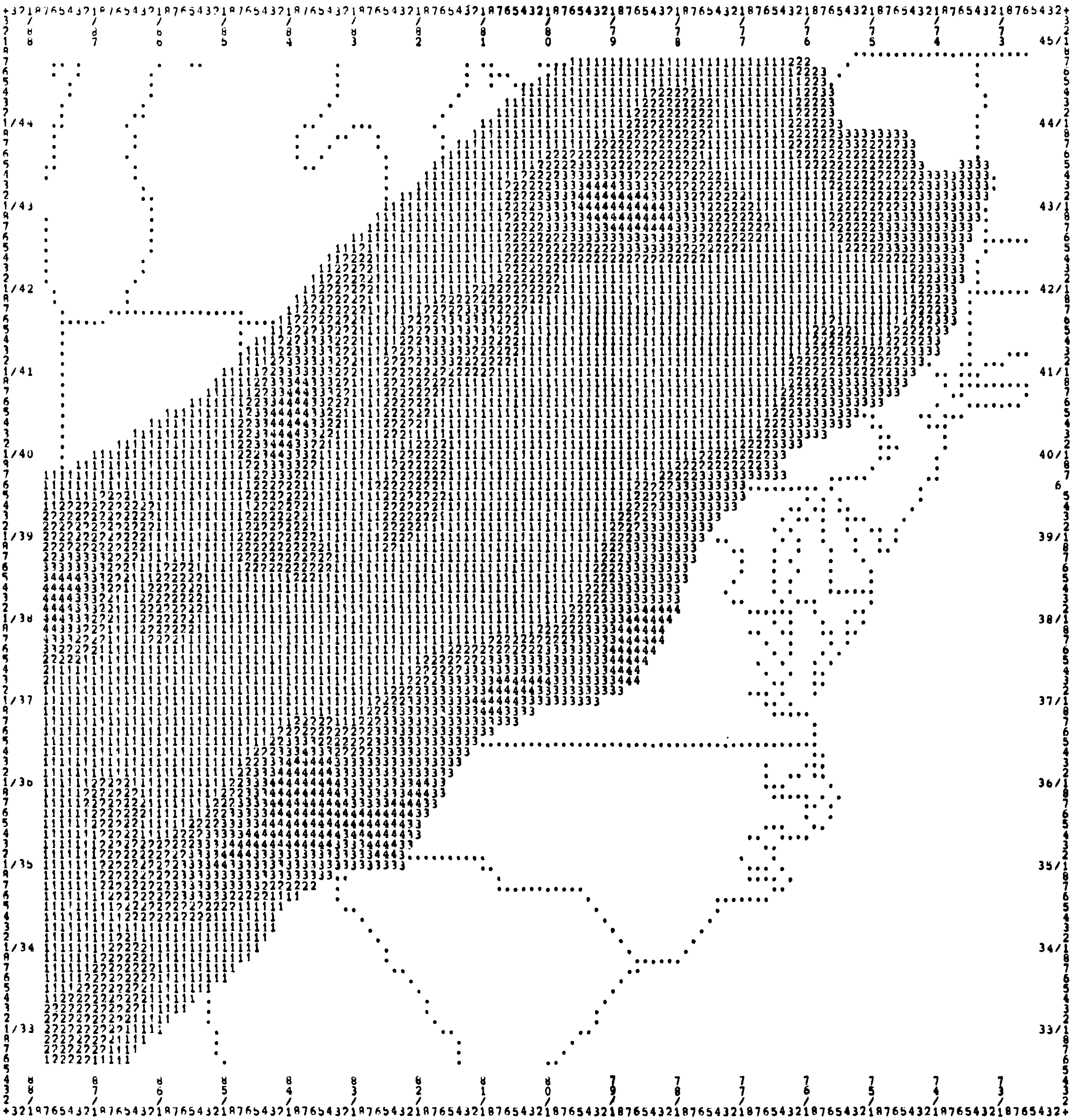


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles,
width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M06.--DISTRIBUTION OF RED BEDS IN DEVONIAN ROCKS. Adapted from Colton (1961, fig.15). Red bed thickness densities as follows: 1, occur but are less than 40 percent of sequence; and 2, more than 40 percent of sequence.

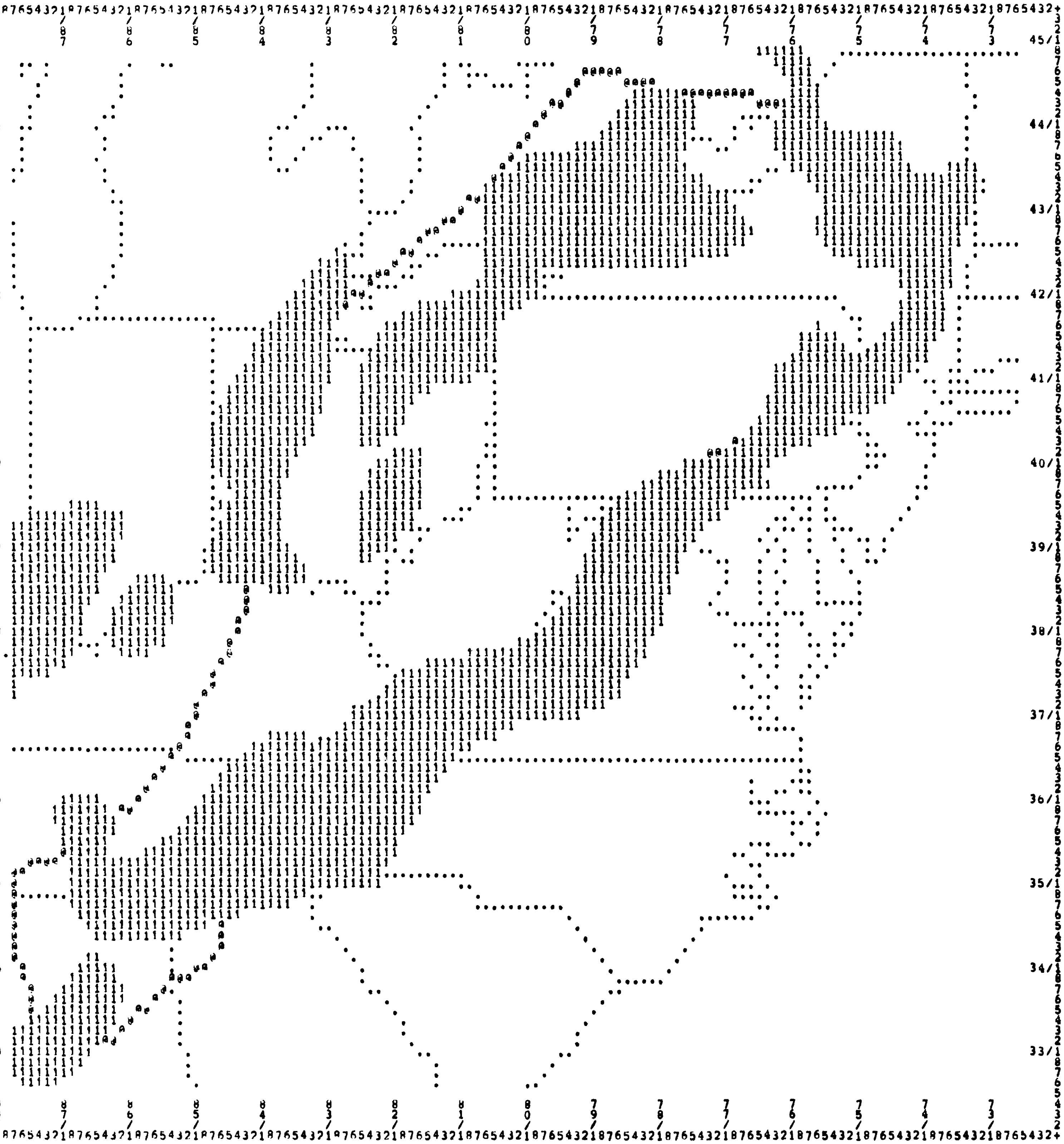
GRIDDED-DATA MAP M07



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles,
width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M07.--VARIATIONS IN MODERN SEISMIC ACTIVITY AS SHOWN BY PATTERNS OF EPICENTER DENSITY. Adapted from Hadley and Devine (1975). Reported epicenters per 10,000 square kilometers as follows: blank, data not shown; 1, < 4; 2, 4-8; 3, 8-16; and 4, > 16.

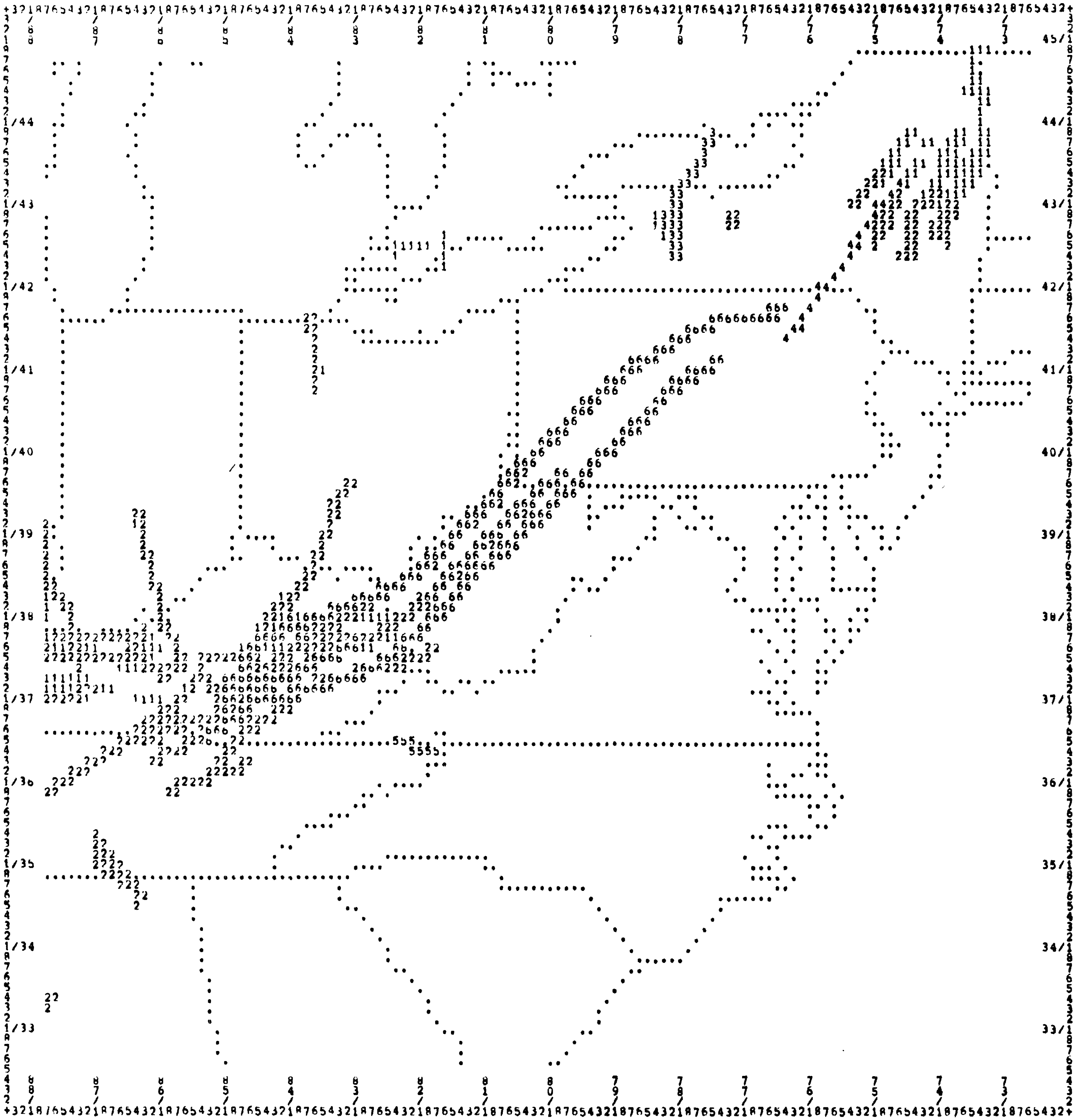


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles. Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D07.--DERIVATIVE OF MODERN SEISMIC ACTIVITY AS SHOWN BY PATTERNS OF EPICENTER DENSITY. (See Map M07.) Reported epicenters per 10,000 square kilometers: blank, data not shown or < 4; 1, > 4.

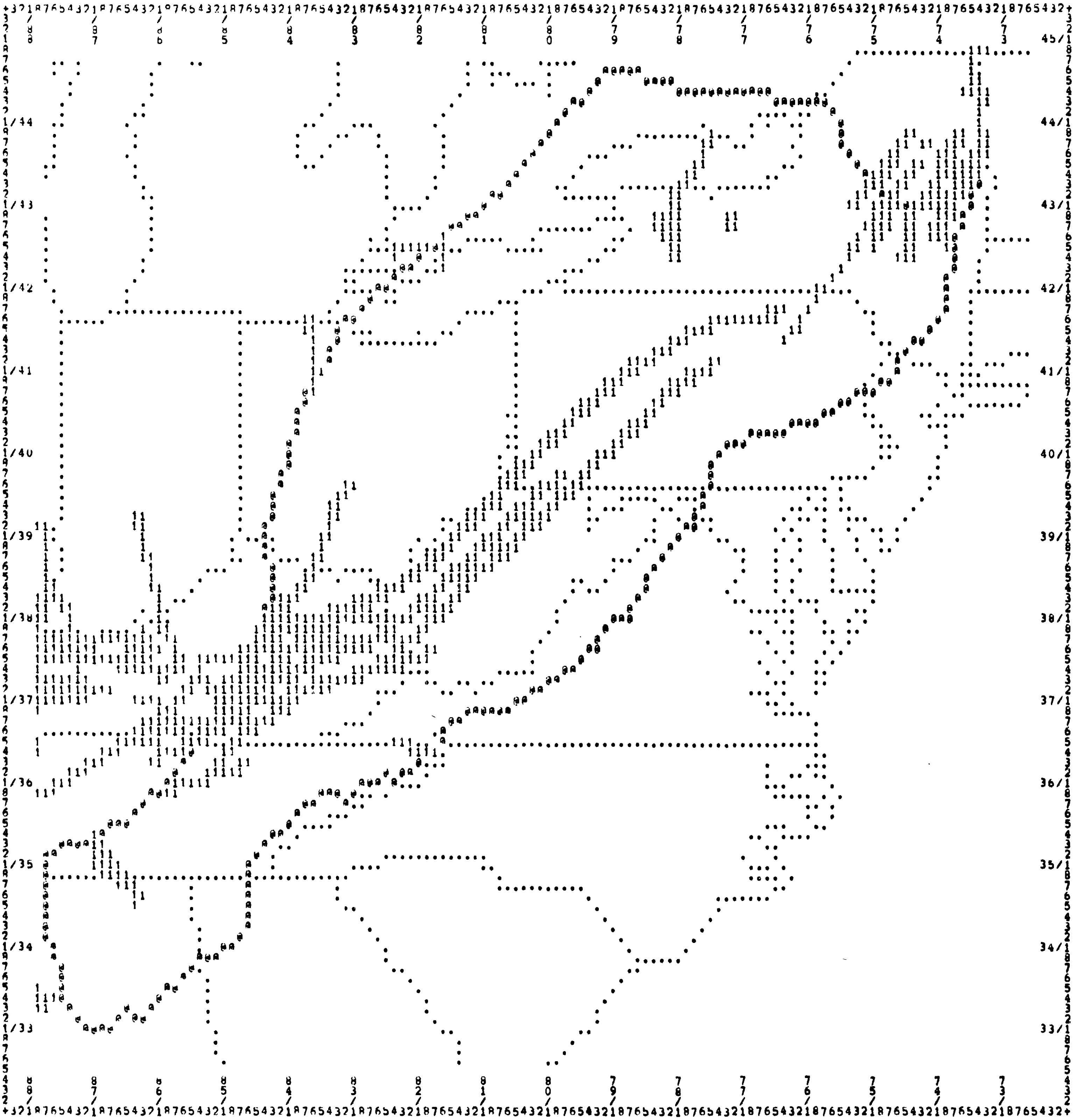
GRIDDED-DATA MAP M08



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

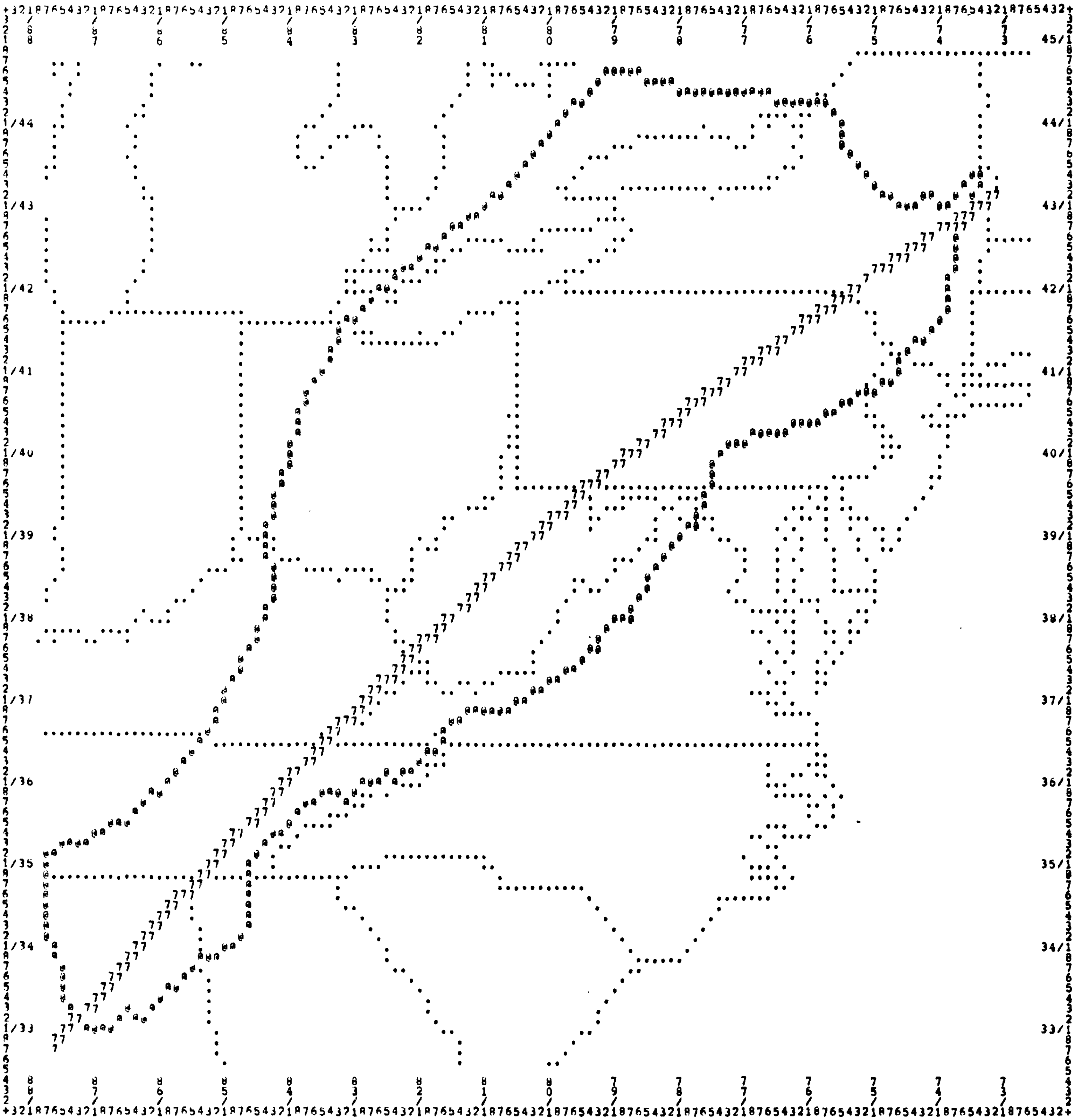
MAP M08.--COMPOSITE OF REPORTED HIGH-ANGLE FAULTS MAPPED AT SURFACE OR INTERPRETED FROM SUBSURFACE WELL DATA. In the case of overlapping occurrences only that mapped last is indicated. Sequence of numbers indicates order of sources mapped as follows: 1, Hadley and Devine (1974); 2, Harris (1975); 3, Chadwick (1920), Fletcher and Sykes (1976), and Hutchinson and others (1977); 4, Heckel (1973); 5, Rodgers (1953); and 6, Harris, Harris, and Epstein (1978).



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D08.--COMPOSITE (DERIVATIVE) OF REPORTED HIGH-ANGLE FAULTS MAPPED AT SURFACE OR INTERPRETED FROM SUBSURFACE-WELL DATA. (See Map M08.) 1, cell contains part of a fault trace from one or more map sources.

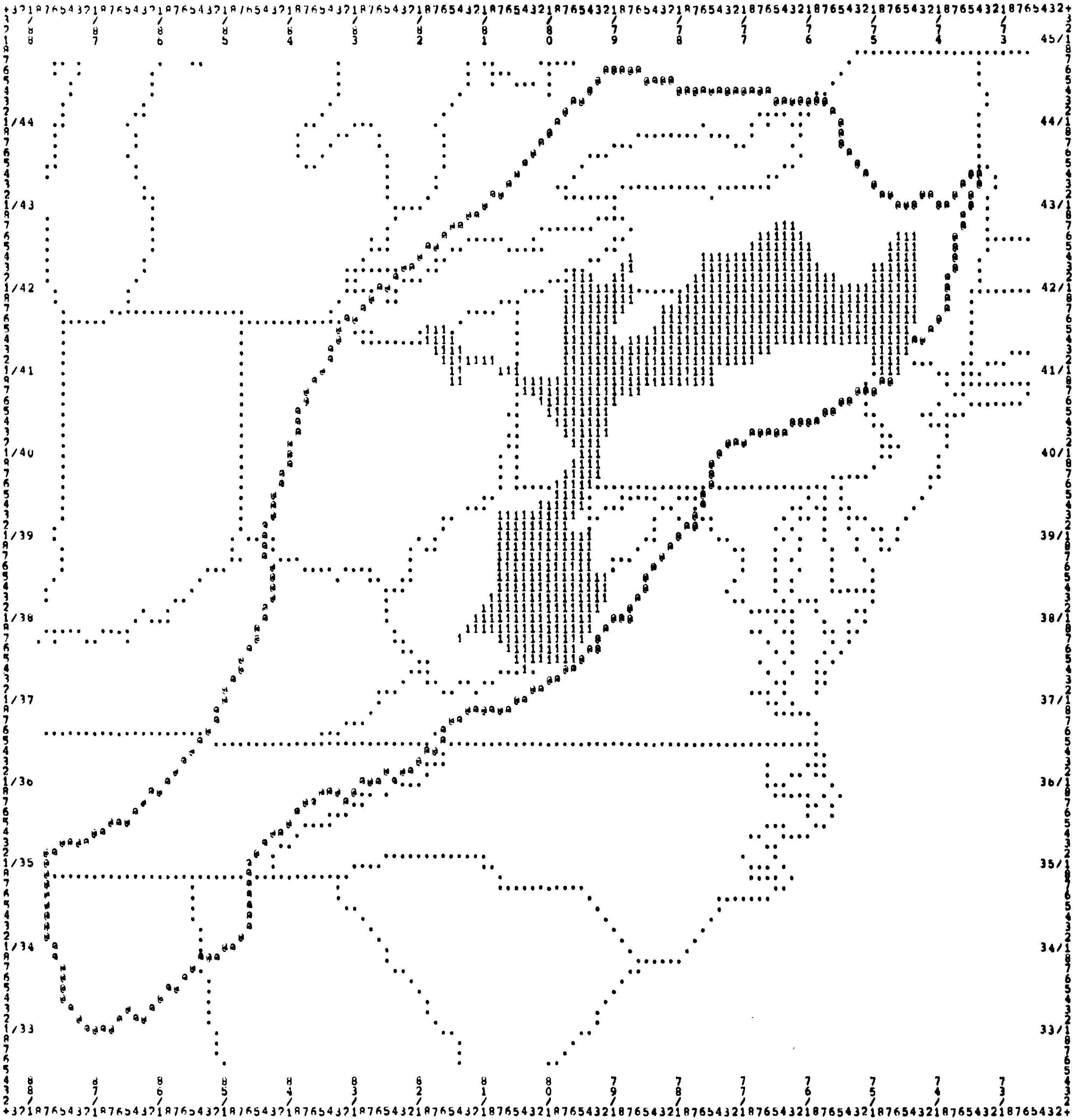


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M09.--ALABAMA-NEW YORK LINEAMENT. Adapted from King and Zietz (1978).
7, indicates trace of postulated crustal break beneath
Appalachian basin.

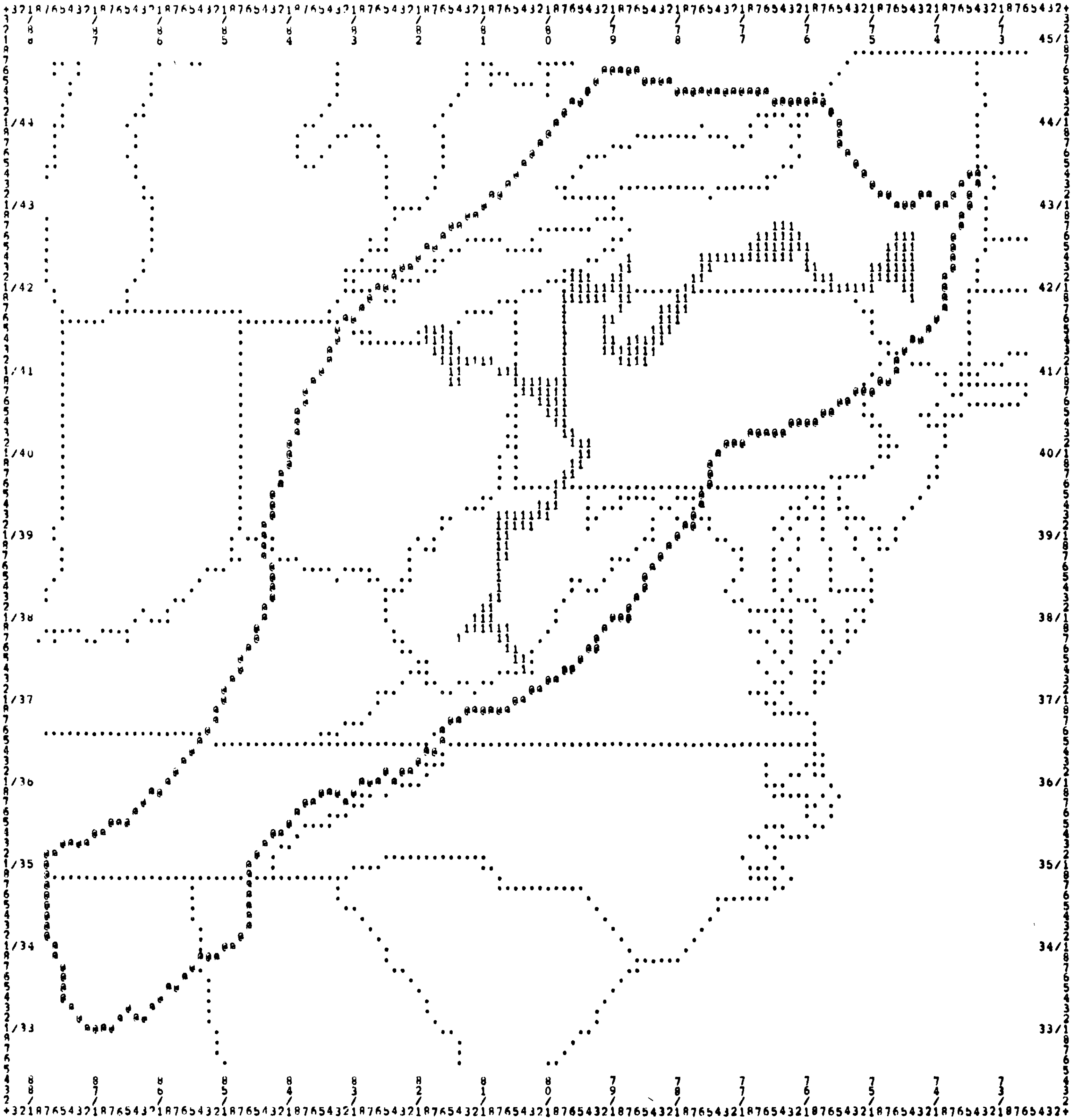
GRIDDED-DATA MAP E20



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

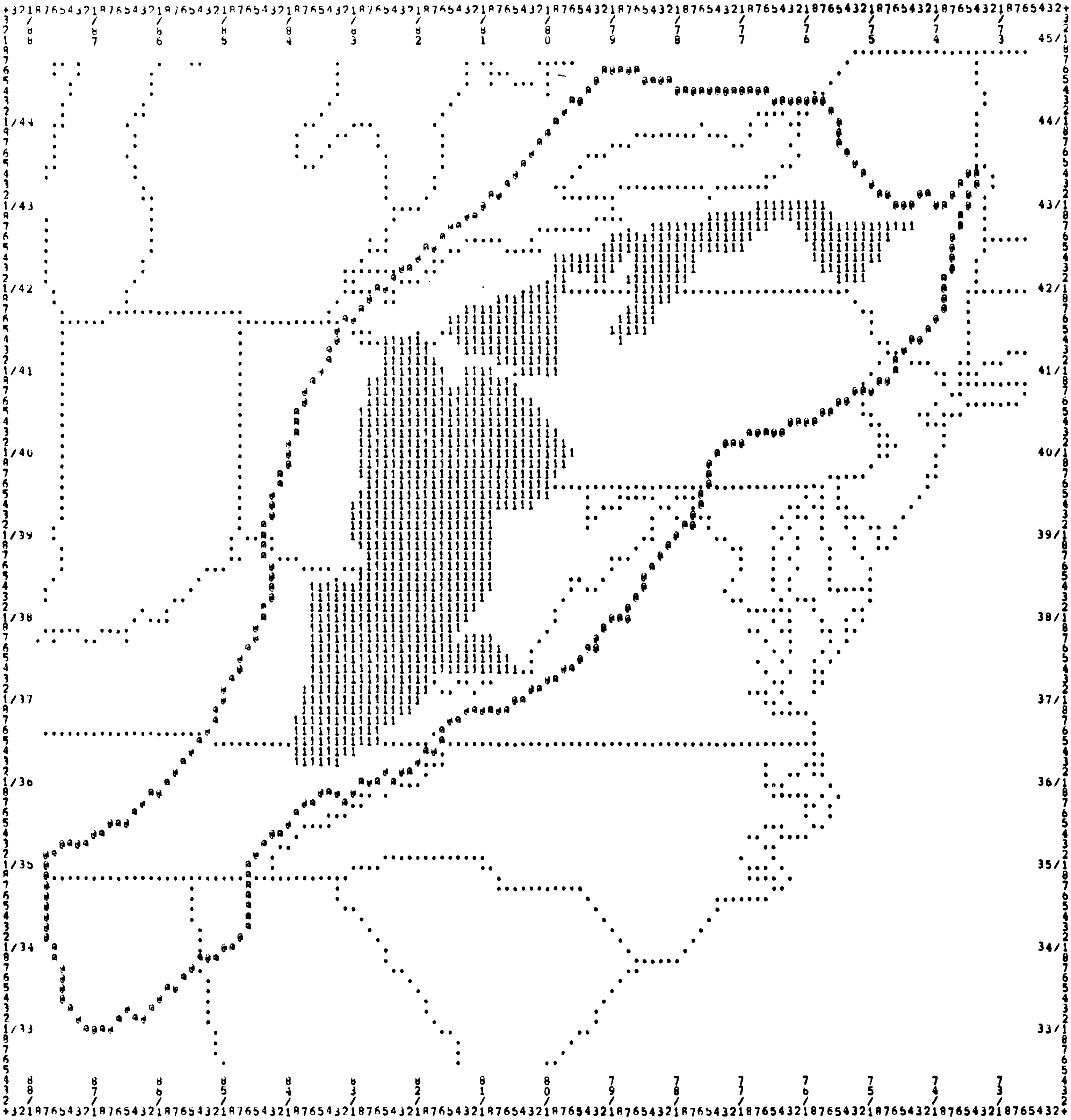
MAP E20.--DERIVATIVE OF CUMULATIVE THICKNESS MAP OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. (See Maps M20 and D20.) Cumulative thicknesses: blank, data not shown or < 600 feet; 1, > 600 feet.



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles,
width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP F20.--DERIVATIVE OF CUMULATIVE THICKNESS MAP OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. (See Maps M20, D20, and E20.)
Cumulative thicknesses: blank, data not shown, < 600 feet, or > 800 feet; and 1, 600 - 800 feet.

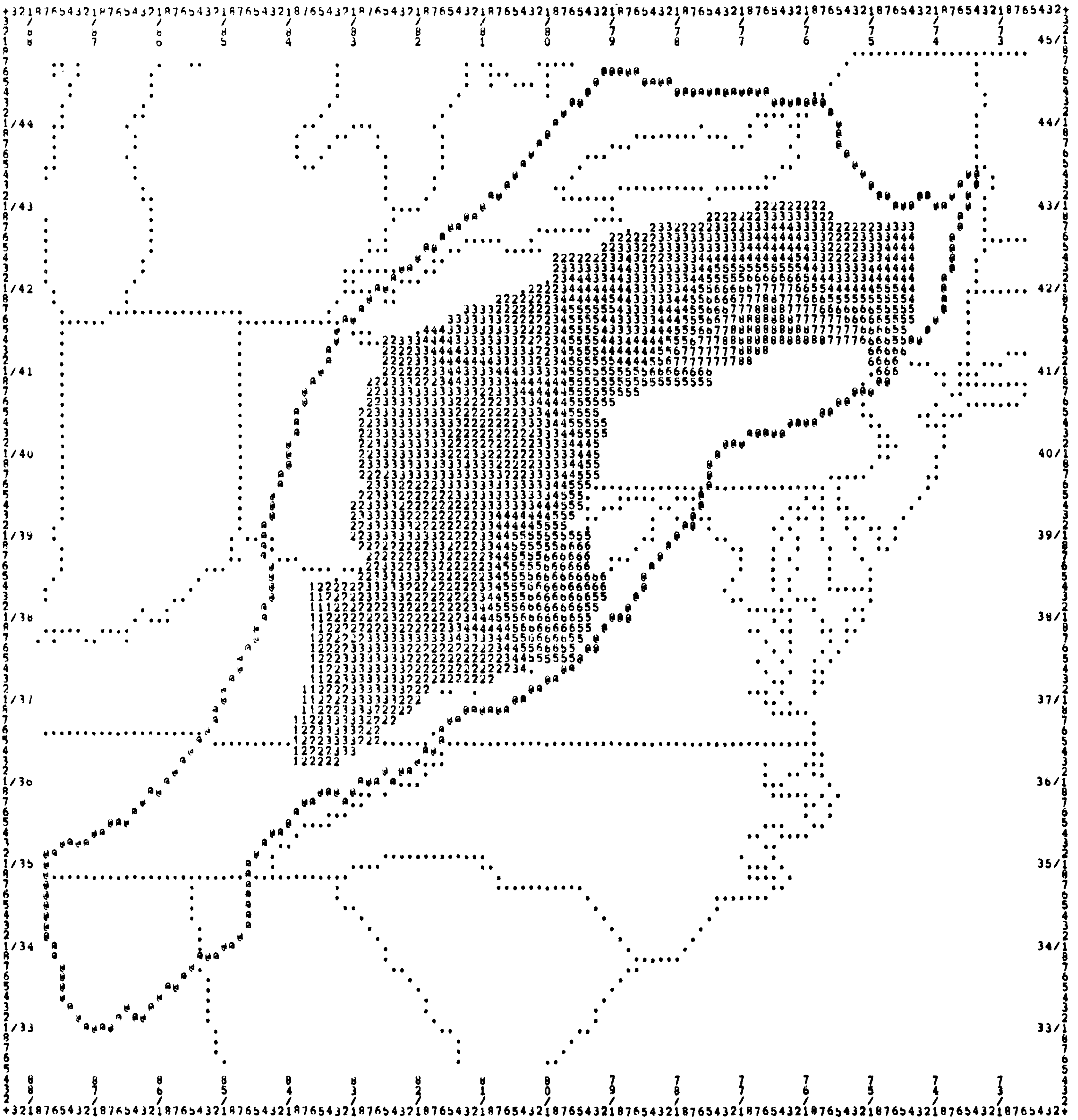


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D20.--DERIVATIVE OF CUMULATIVE THICKNESS MAP OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. (See Maps M20 and E20.) Cumulative thicknesses: blank, data not shown or > 600 feet; 1, < 600 feet.

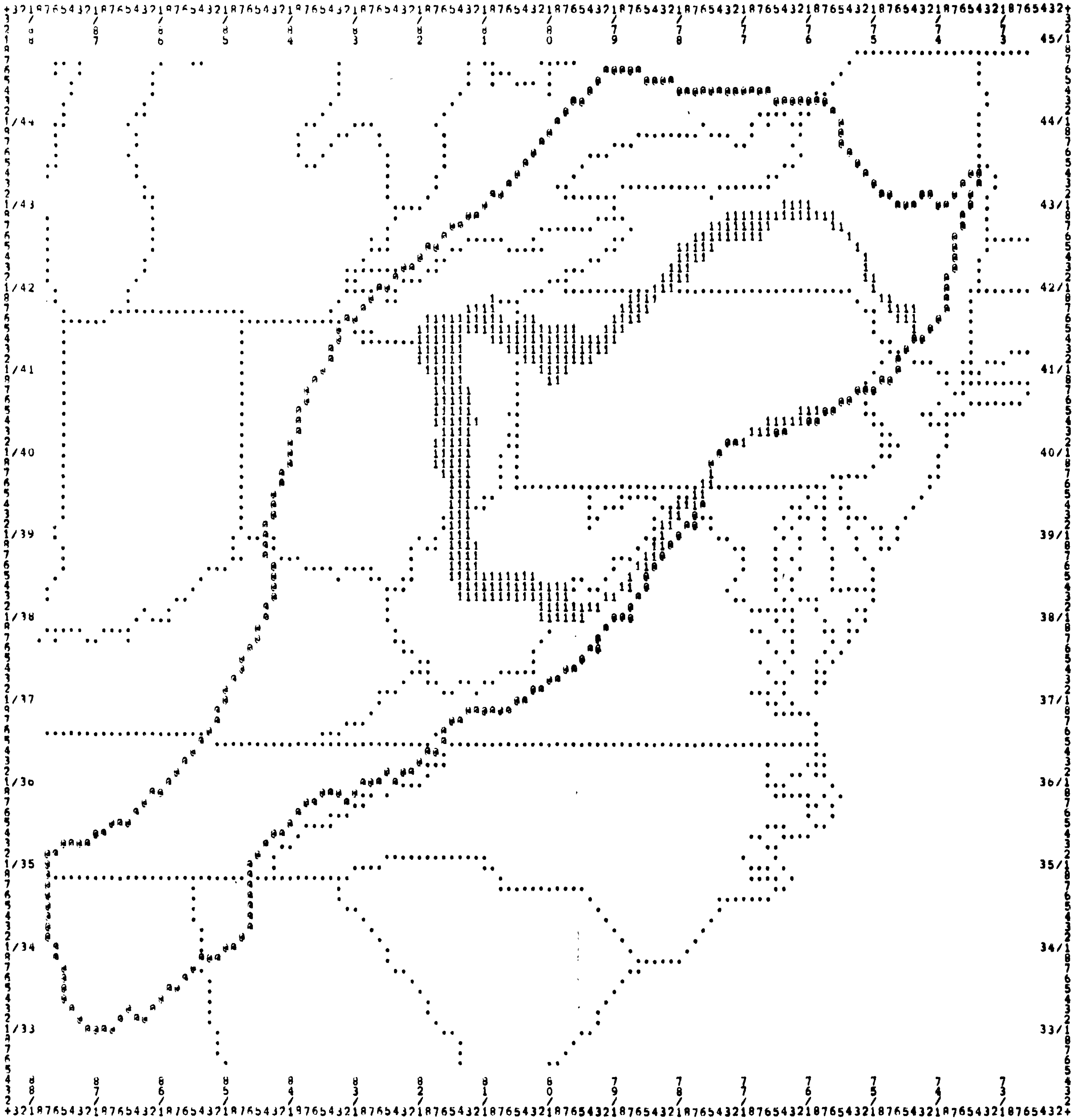
GRIDDED-DATA MAP M20



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

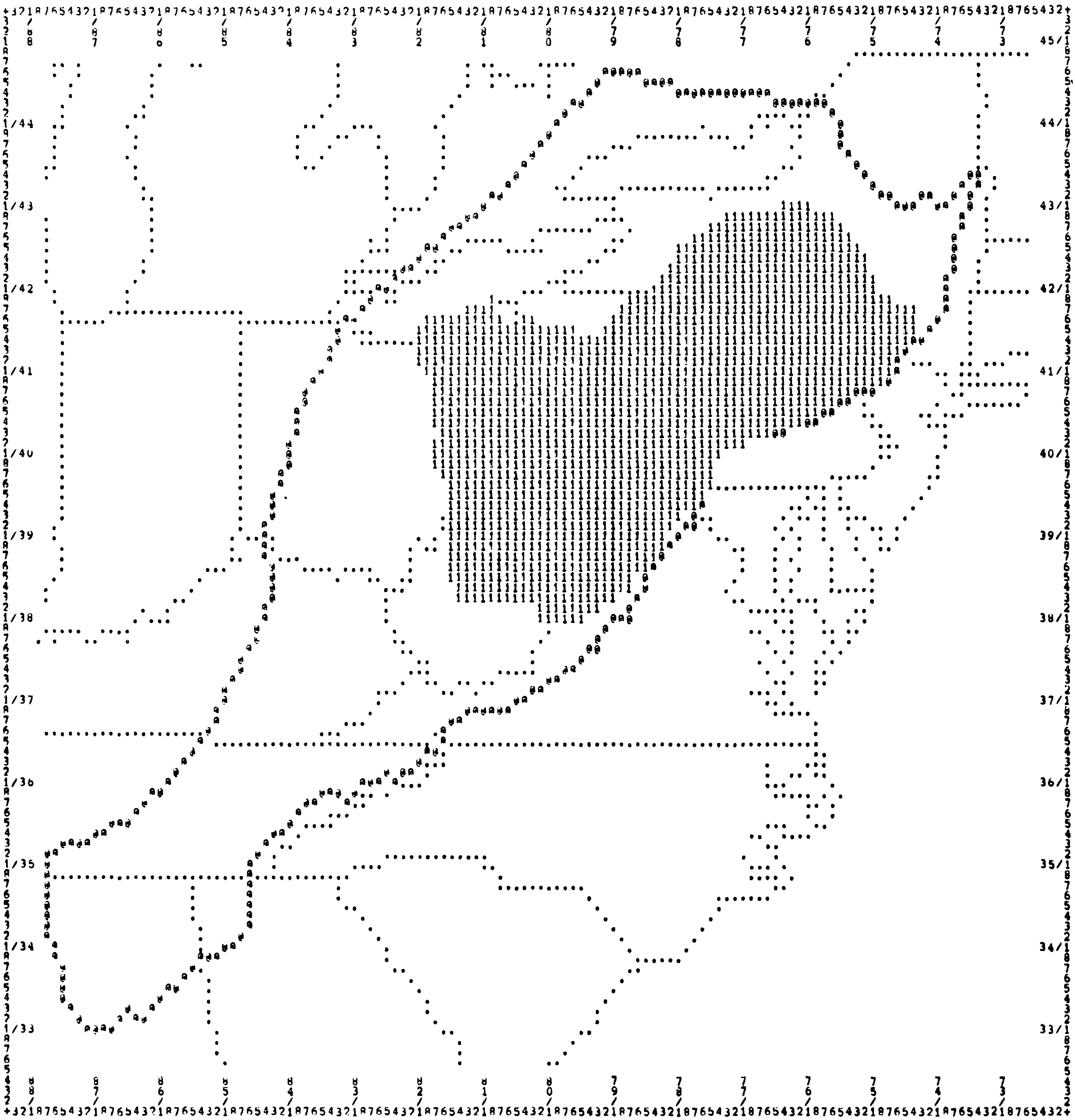
MAP M20.--CUMULATIVE THICKNESS OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. Adapted from de Witt and others (1975). Cumulative thickness intervals as follows: 1, < 200 feet; 2, 200-400 feet; 3, 400-600 feet; 4, 600-800 feet; 5, 800-1,000 feet; 6, 1,000-1,200 feet; 7, 1,200-1,400 feet; and 8, > 1,400 feet.



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP F19.--DERIVATIVE OF ISOPACHOUS MAP OF THE SILURIAN-DEVONIAN CARBONATE SEQUENCE IN THE APPALACHIAN BASIN. (See Maps M19, D19, and E19.)
Thickness: blank, data not shown, <1,200 feet, or >1,600 feet;
1, 1,200-1,600 feet.

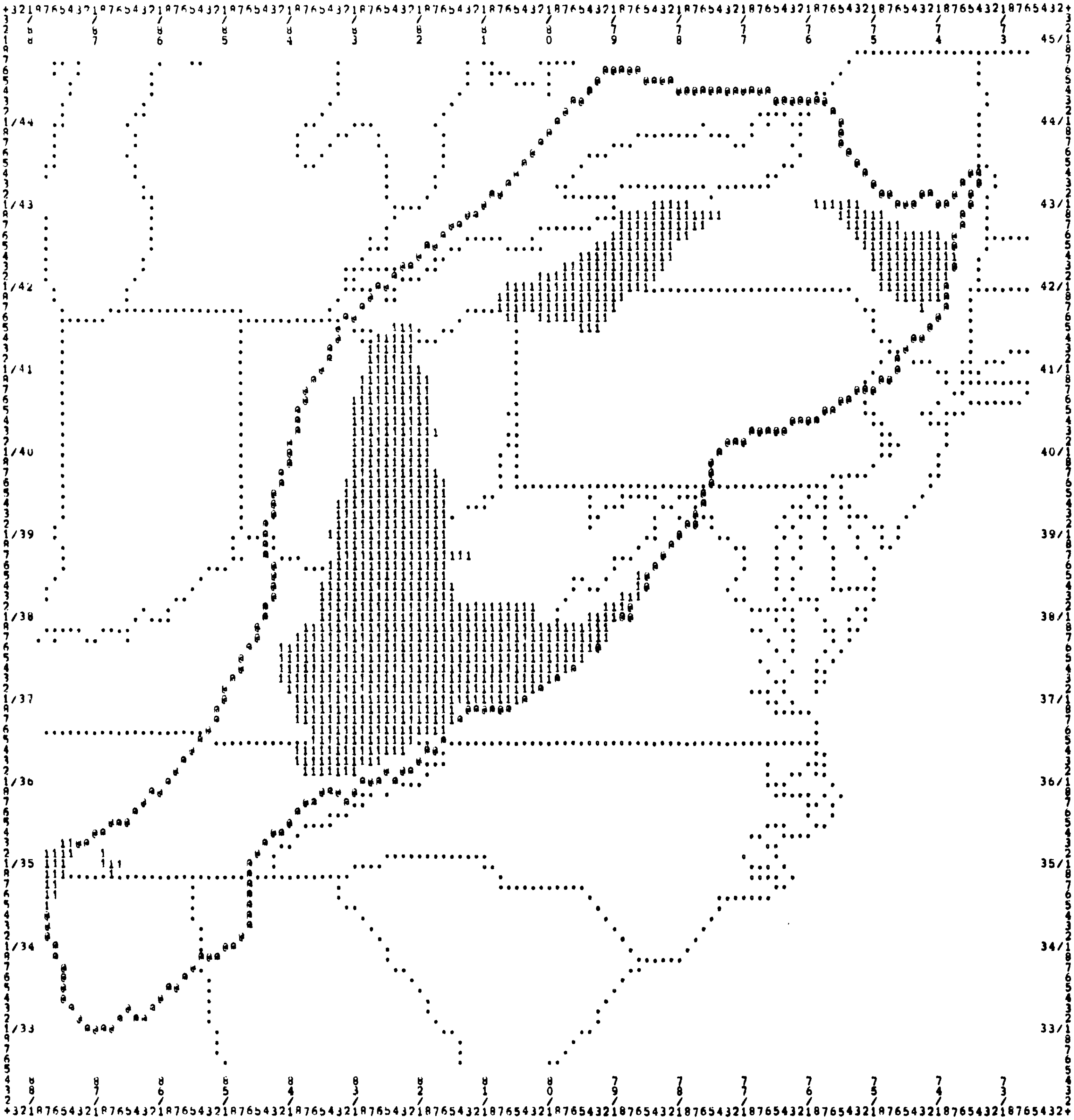


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles, width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP E19.--DERIVATIVE OF ISOPACHOUS MAP OF THE SILURIAN-DEVONIAN CARBONATE SEQUENCE IN THE APPALACHIAN REGION. (See Maps N19 and D19.)
Thicknesses: blank, data not shown or < 1,200 feet;
1, > 1,200 feet.

WEDOW, DEVONIAN-TARGET ATLAS GRIDDED-DATA MAP D19

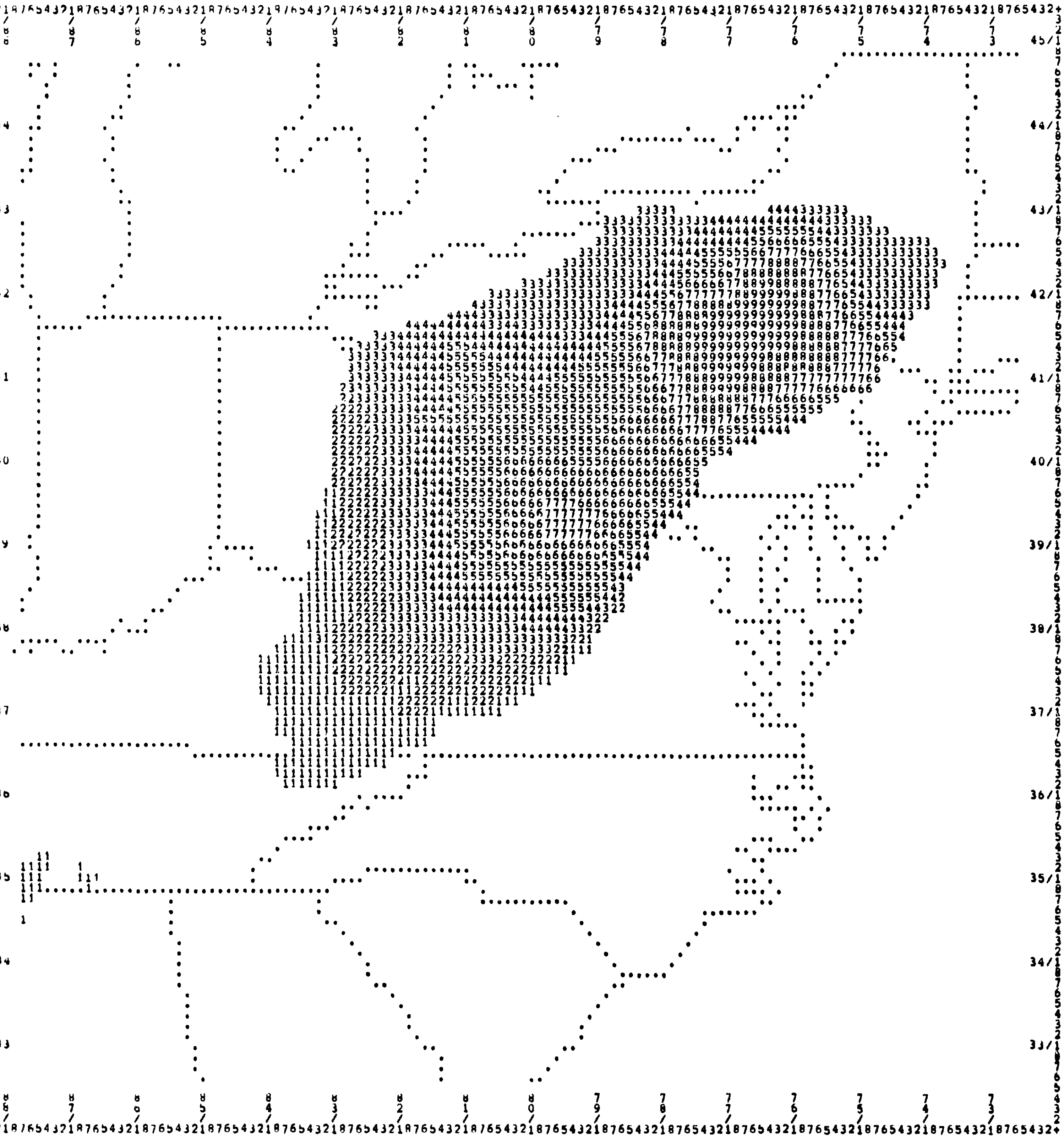


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D19.--DERIVATIVE OF ISOPACHOUS MAP OF THE SILURIAN-DEVONIAN CARBONATE SEQUENCE IN THE APPALACHIAN REGION. (See Maps M19 and E19.)
Thicknesses: blank, data not shown or > 1,200 feet;
1, < 1,200 feet.

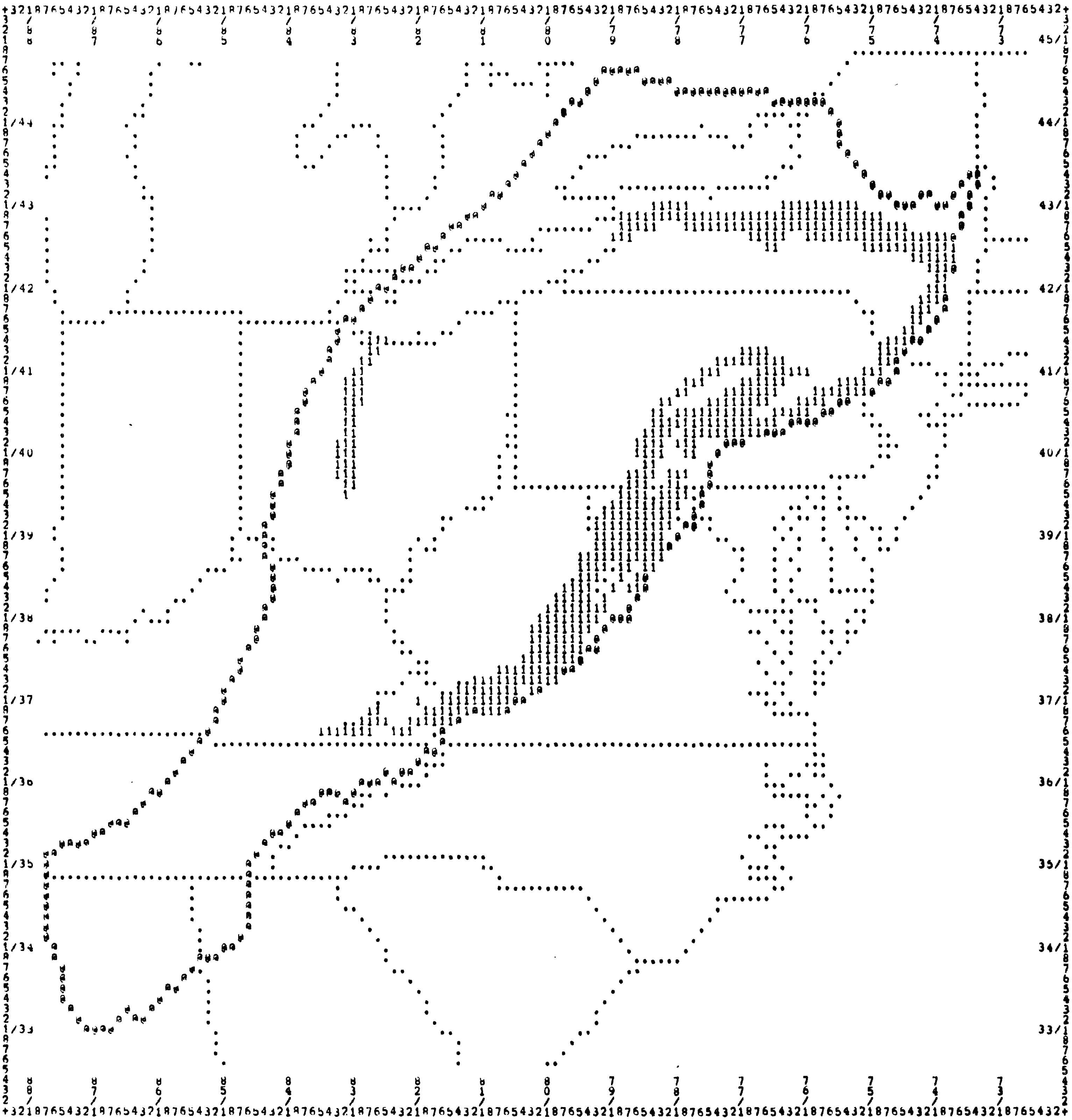
GRIDDED-DATA MAP M19



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M19.--ISOPACHOUS MAP OF THE SILURIAN-DEVONIAN CARBONATE SEQUENCE IN THE APPALACHIAN BASIN. Adapted from Colton (1961, fig. 12). Thickness intervals coded as follows: 1, < 400 feet; 2, 400-800 feet; 3, 800-1,200 feet; 4, 1,200-1,600 feet; 5, 1,600-2,000 feet; 6, 2,000-2,400 feet; 7, 2,400-2,800 feet; 8, 2,800-3,200 feet; and 9, > 3,200 feet.

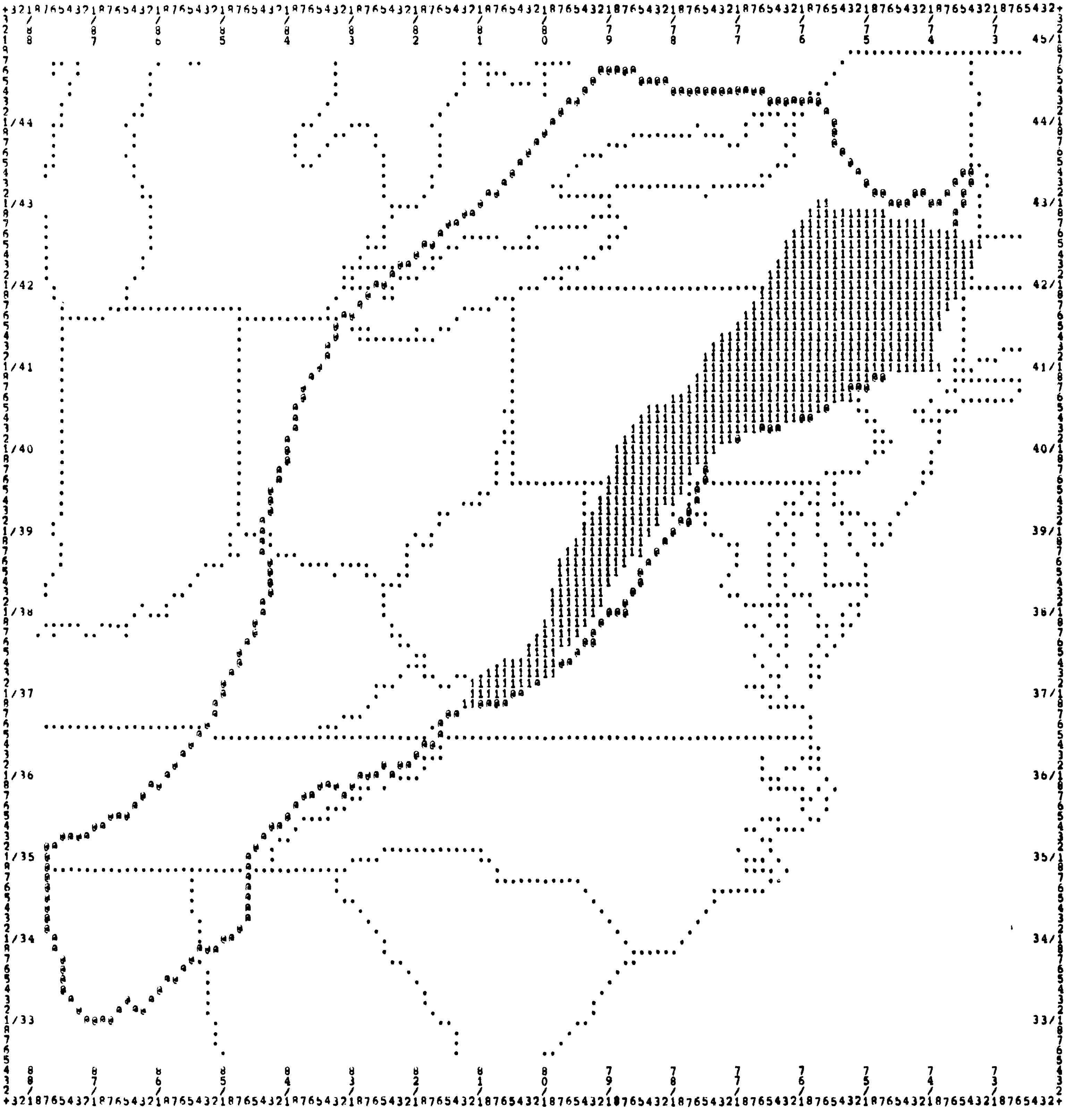


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles. Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M18.--OUTCROP BELT OF LOWER AND MIDDLE DEVONIAN ROCKS IN THE APPALACHIAN BASIN. Adapted from King and Beikmen (1974). 1, indicates cell surface is wholly or partly occupied by outcrop of Lower, Middle, or Lower and Middle Devonian rocks.

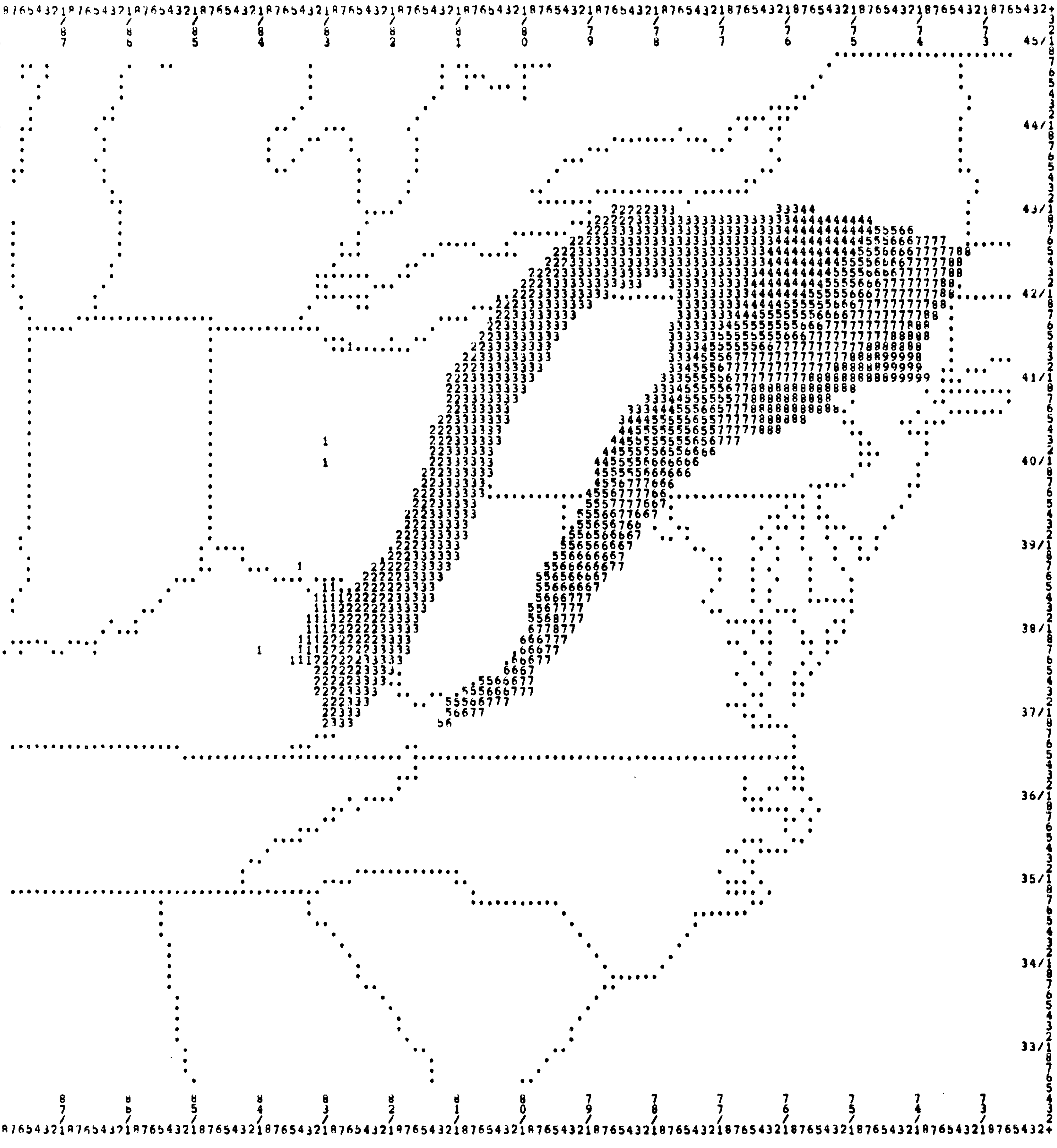
GRIDDED-DATA MAP D17



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D17.--DERIVATIVE OF CONODONT COLOR-ALTERATION INDEX (CAI) IN SILURIAN
THROUGH MIDDLE DEVONIAN CARBONATE ROCKS. (See Map M17.)
CAI ranges: blank, data not shown or < 2.5; 1, > 2.5.

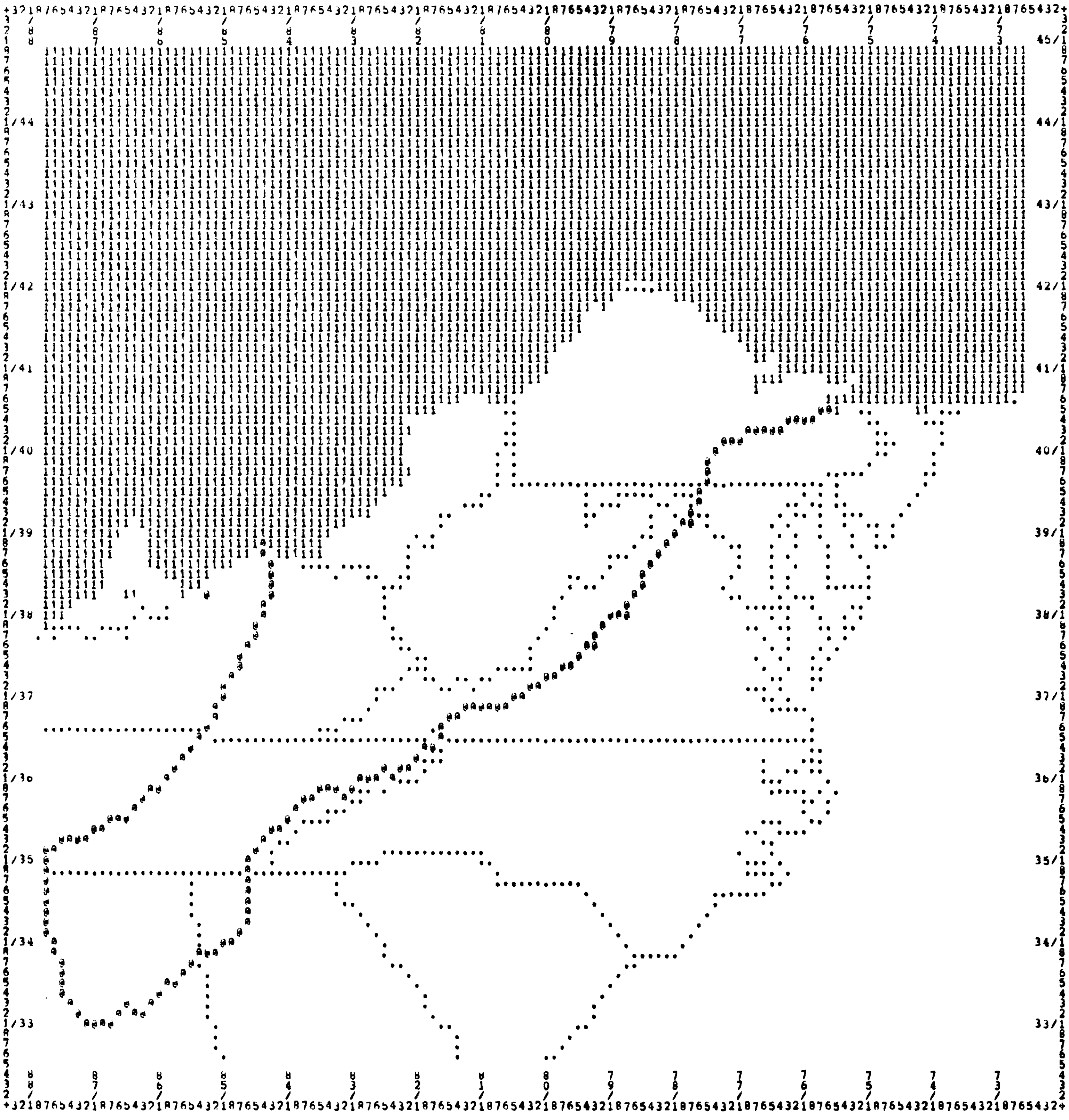


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles,
width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M17.--VARIATION OF CONODONT COLOR-ALTERATION INDEX IN SILURIAN THROUGH MIDDLE DEVONIAN CARBONATE ROCKS. Adapted from Harris, Harris, and Epstein (1978, sheet 2). CAI ranges: 1, <1.5; 2, 1.5-2; 3, 2-2.5; 4, 2.5-3; 5, 3-3.5; 6, 3.5-4; 7, 4-4.5; 8, 4.5-5; and 9, >5.

WEDOW, DEVONIAN-TARGET ATLAS GRIDDED-DATA MAP M16

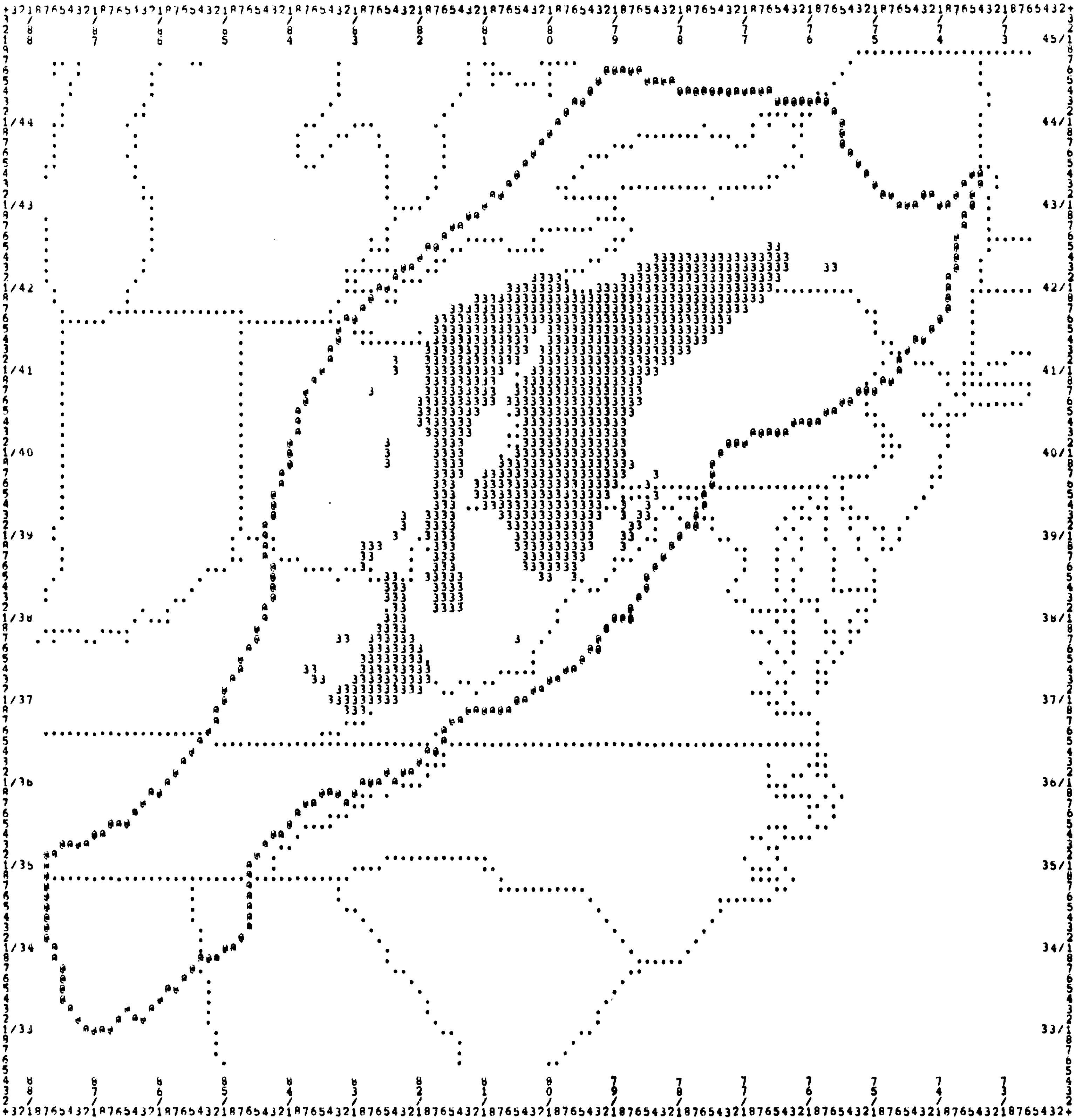


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M16.--EXTENT OF PLEISTOCENE GLACIATION IN PART OF EASTERN UNITED STATES.
Adapted from King and Beikman (1974). 1, indicates area covered
by ice during maximum advances of Pleistocene continental
glaciers.

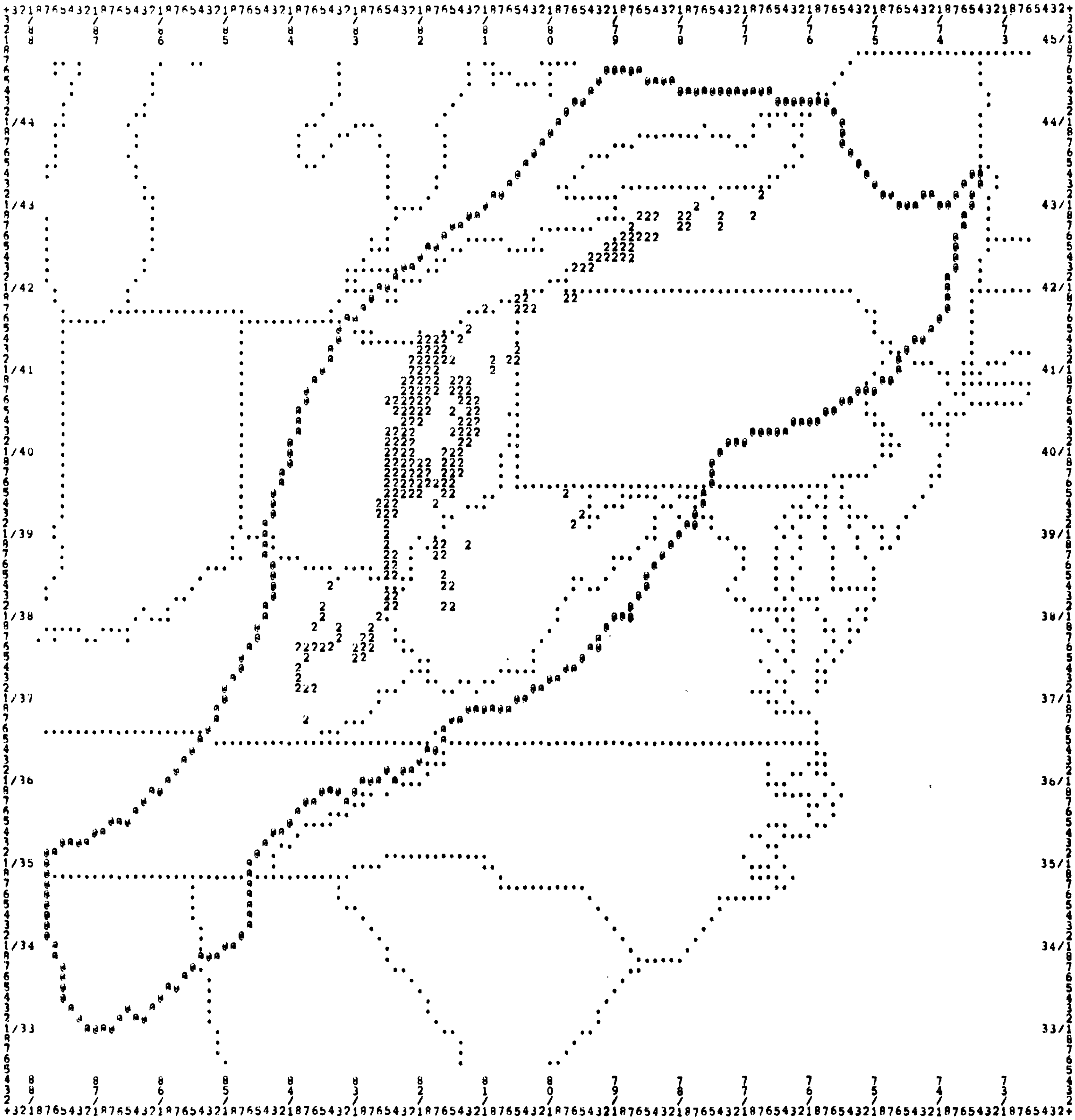
GRIDDED-DATA MAP M15



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M15.--AREAS PRODUCING OIL AND GAS FROM DEVONIAN ROCKS IN THE APPALACHIAN BASIN. Adapted from Milici (1980). 3, indicates at least one-half of cell is underlain by area as mapped.

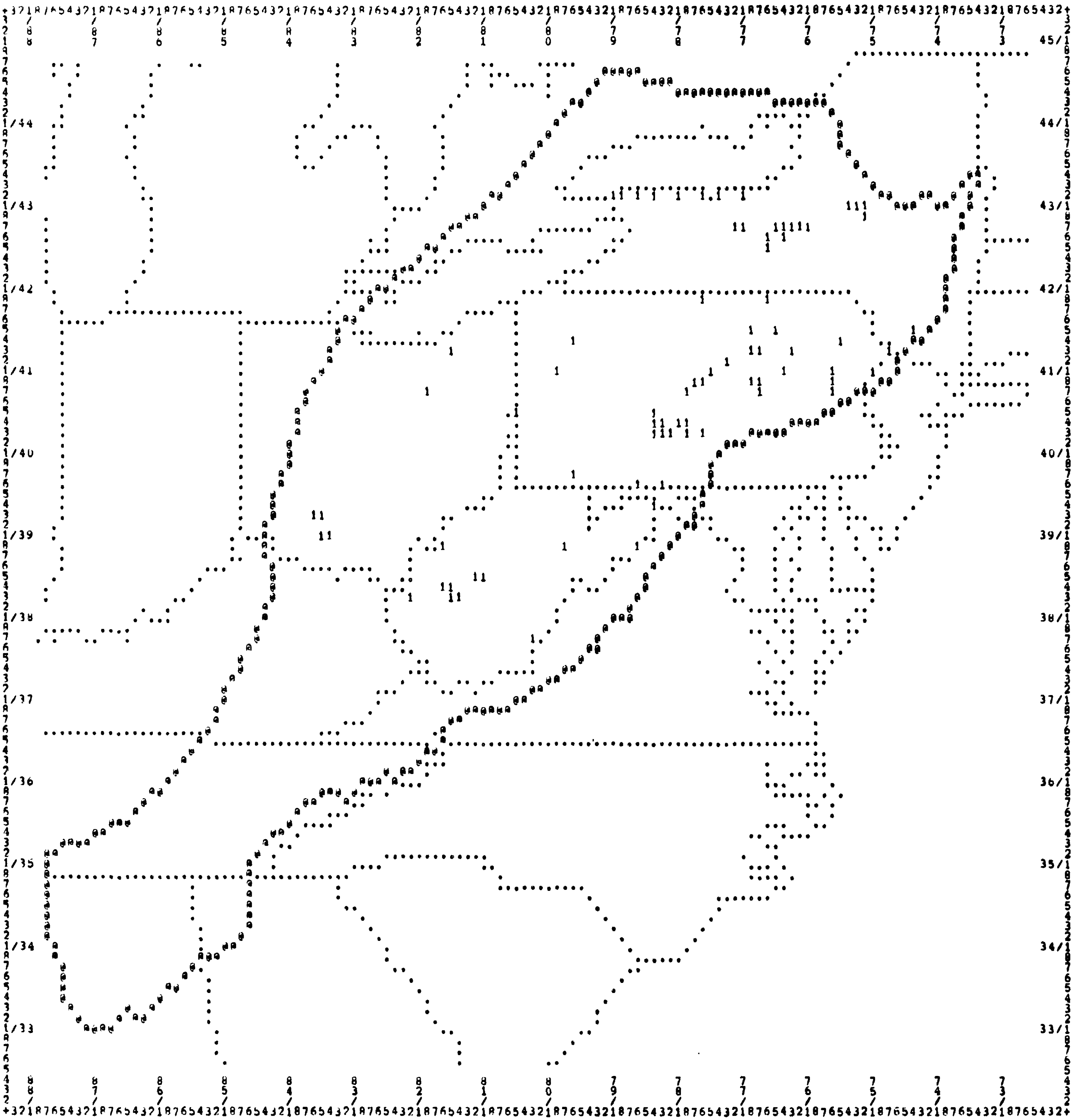


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M14.--AREAS PRODUCING OIL AND GAS FROM SILURIAN ROCKS IN THE APPALACHIAN BASIN. Adapted from Milici (1980). 2, indicates at least one-half of cell is underlain by area as mapped.

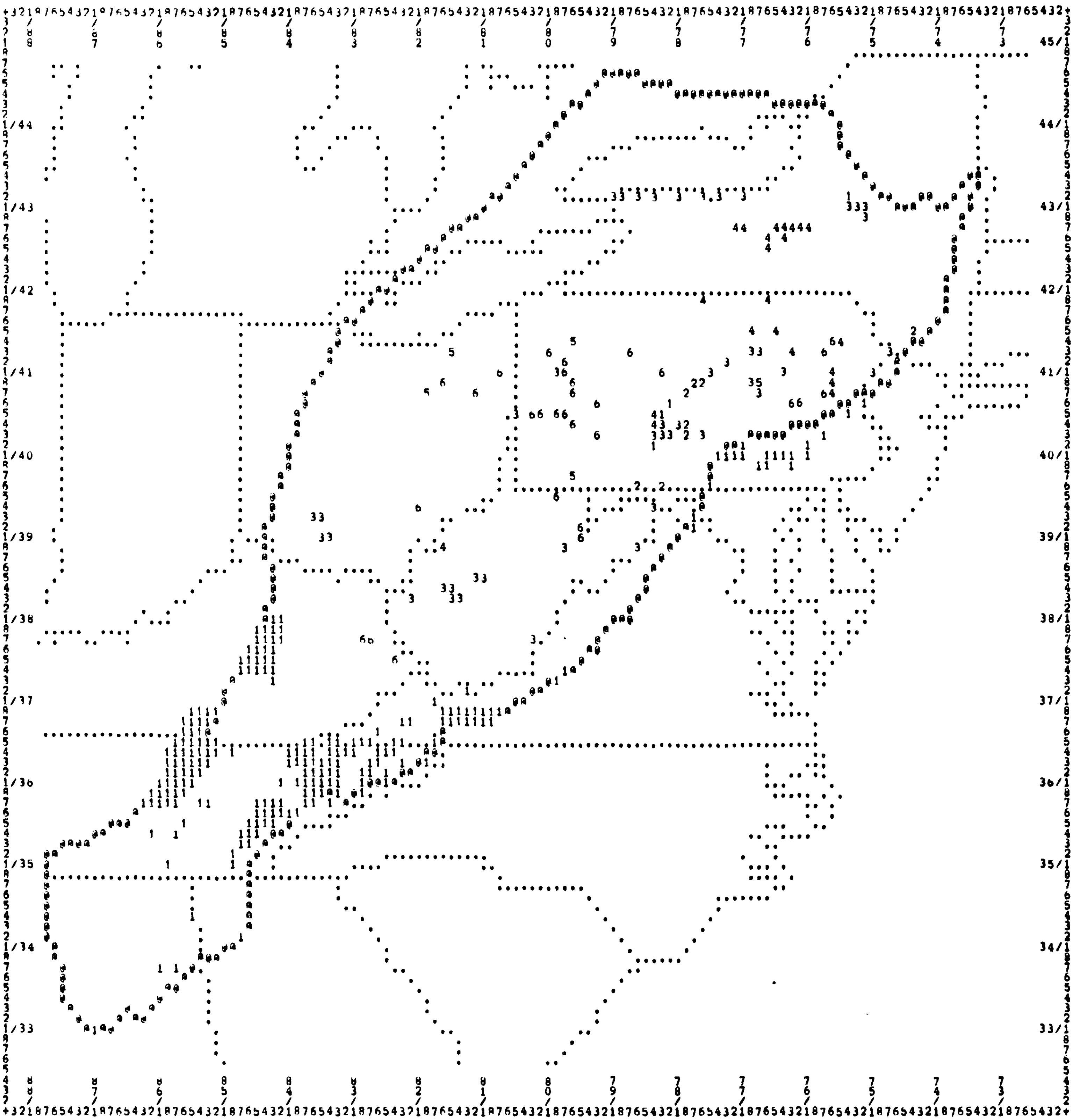
GRIDDED-DATA MAP D13



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles, width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D13.--DERIVATIVE OF REPORTED OCCURRENCES OF ZINC AND LEAD IN THE APPALACHIAN REGION. (See Map M13.) 1, occurrences in Early Silurian through Mississippian rocks.

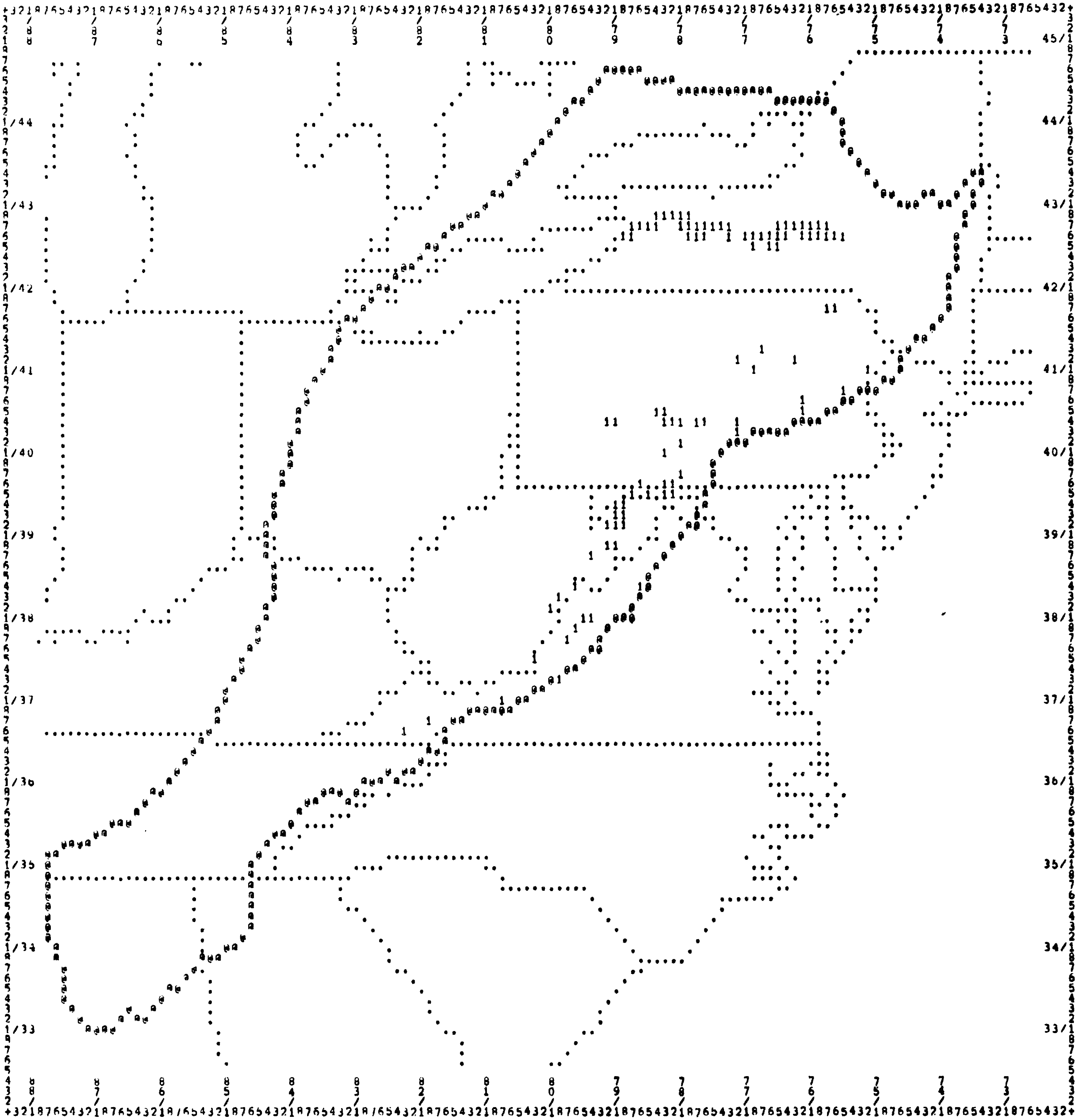


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M13.--ZINC AND LEAD OCCURRENCES IN THE APPALACHIAN REGION. Taken chiefly from Wedow and others (1968) and Tooker and Wedow (1980). Ages of host rock are as follows: 1, Cambrian and Ordovician; 2, Early Silurian; 3, Middle Silurian through Middle Devonian; 4, Late Devonian; 5, Mississippian; and 6, Pennsylvanian.

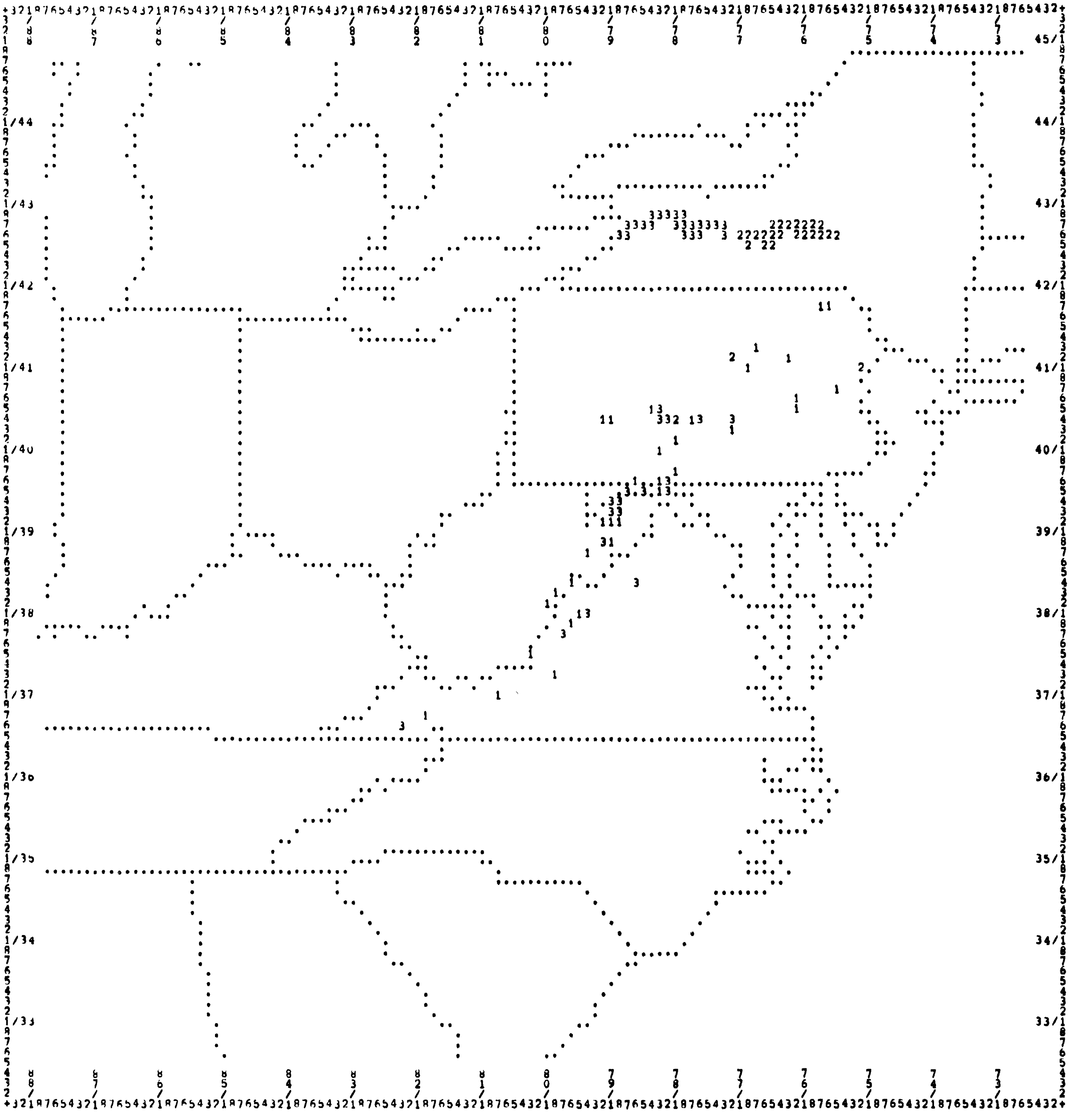
DEVONIAN-TARGET ATLAS GRIDDED-DATA MAP D12



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles,
width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D12.--DERIVATIVE OF REPORTED OCCURRENCES OF THE PTEROPOD "STYLIOLINA FISSURELLA" IN MIDDLE AND UPPER DEVONIAN ROCKS. (See Map M12.)
1, reported occurrence regardless of stated abundance.

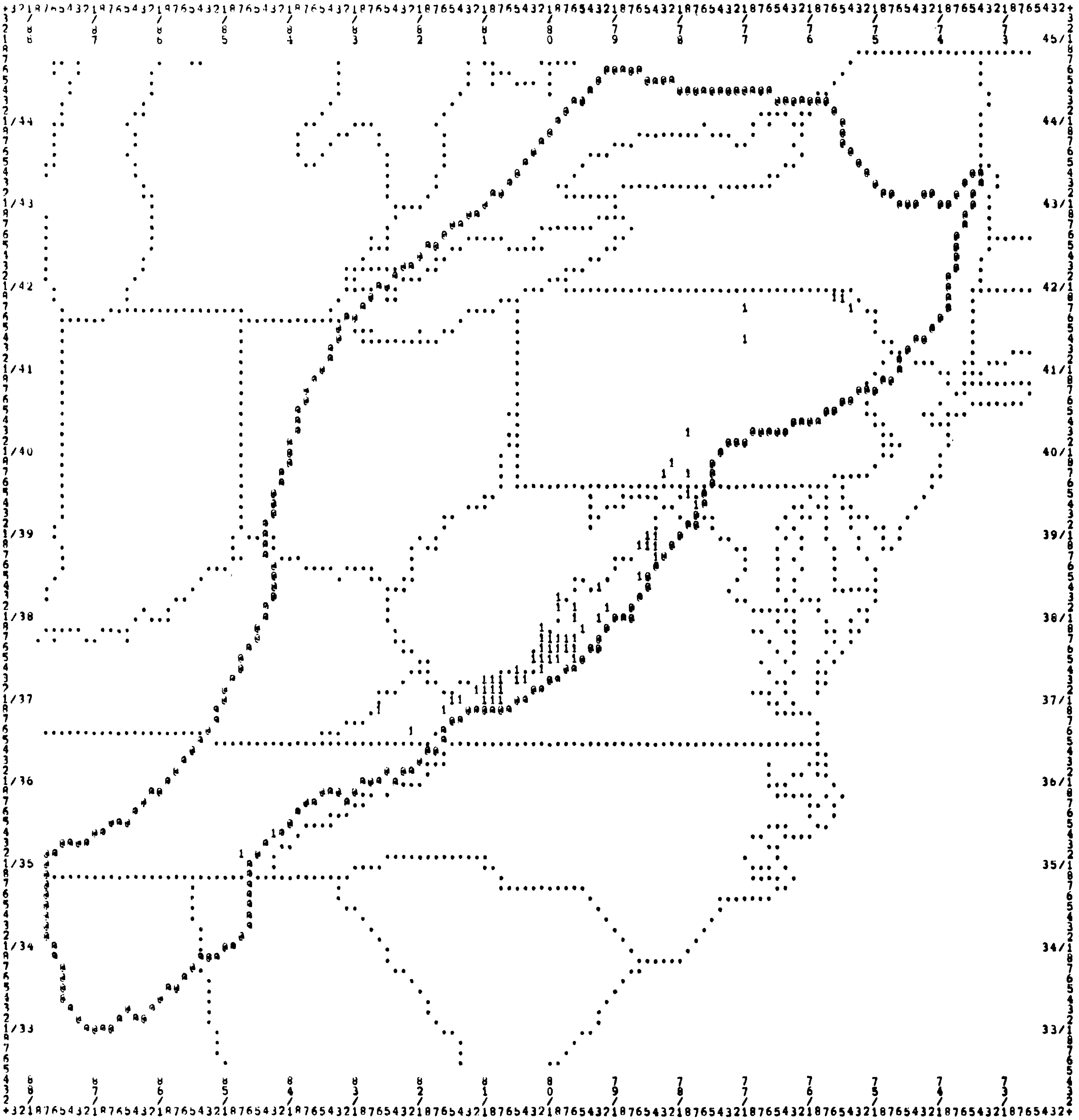


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles,
width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M12.--REPORTED OCCURRENCES OF THE PTEROPOD "STYLIOLINA FISSURELLA" IN MIDDLE AND UPPER DEVONIAN ROCKS. Stated abundance levels: 1, rare or quantity unreported; 2, common; and 3, abundant.

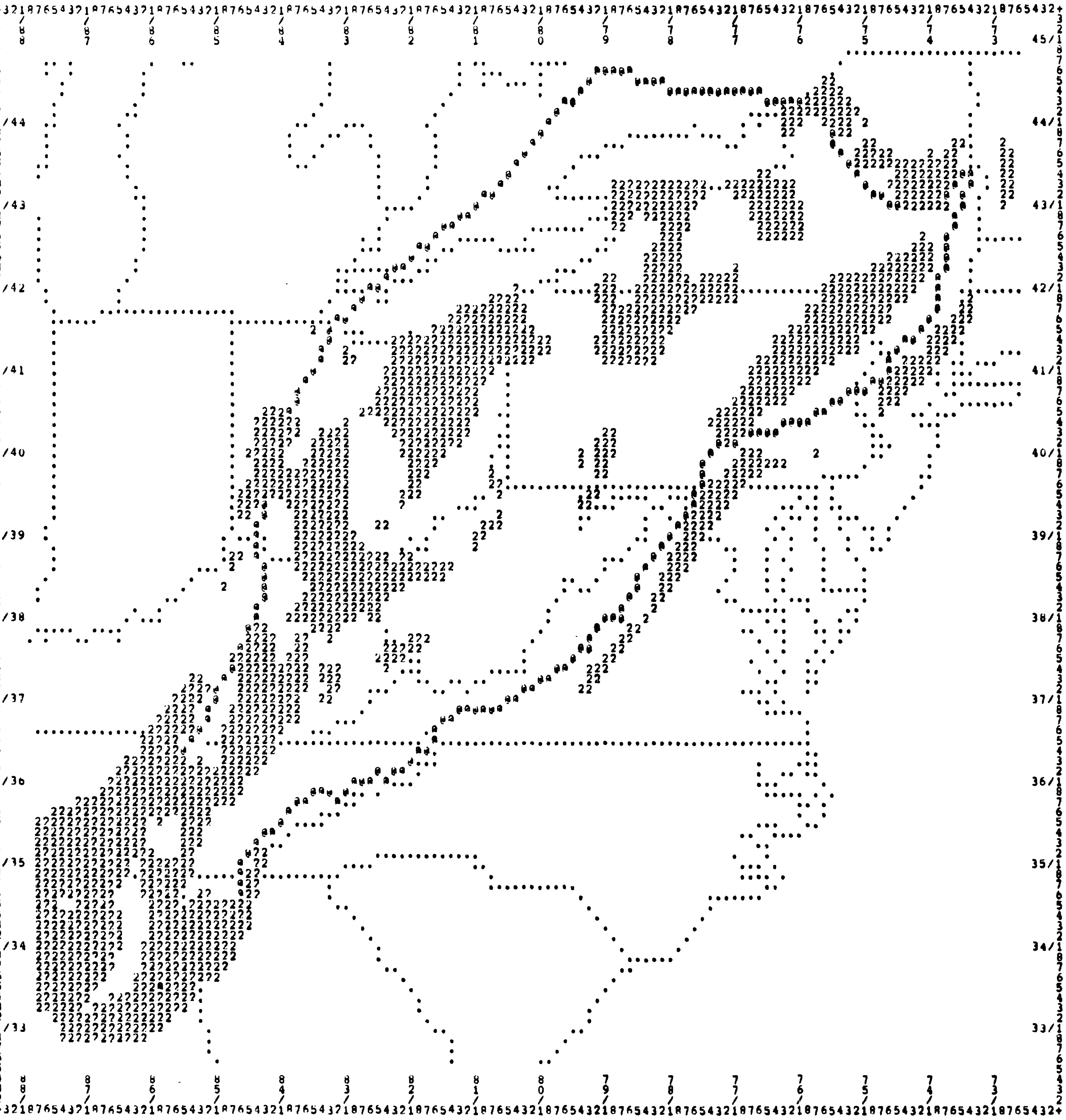
GRIDDED-DATA MAP M11



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M11.--DISTRIBUTION OF SUPERGENE IRON AND MANGANESE OXIDE OCCURRENCES UNDERLAIN BY DEVONIAN AND MISSISSIPPIAN ROCKS IN THE APPALACHIAN REGION. Taken from numerous sources, both published and unpublished. Most occurrences are reported mines and prospects of "Oriskany" iron and manganese ores. 1, indicates cell contains at least one significant occurrence of supergene iron or manganese oxides.



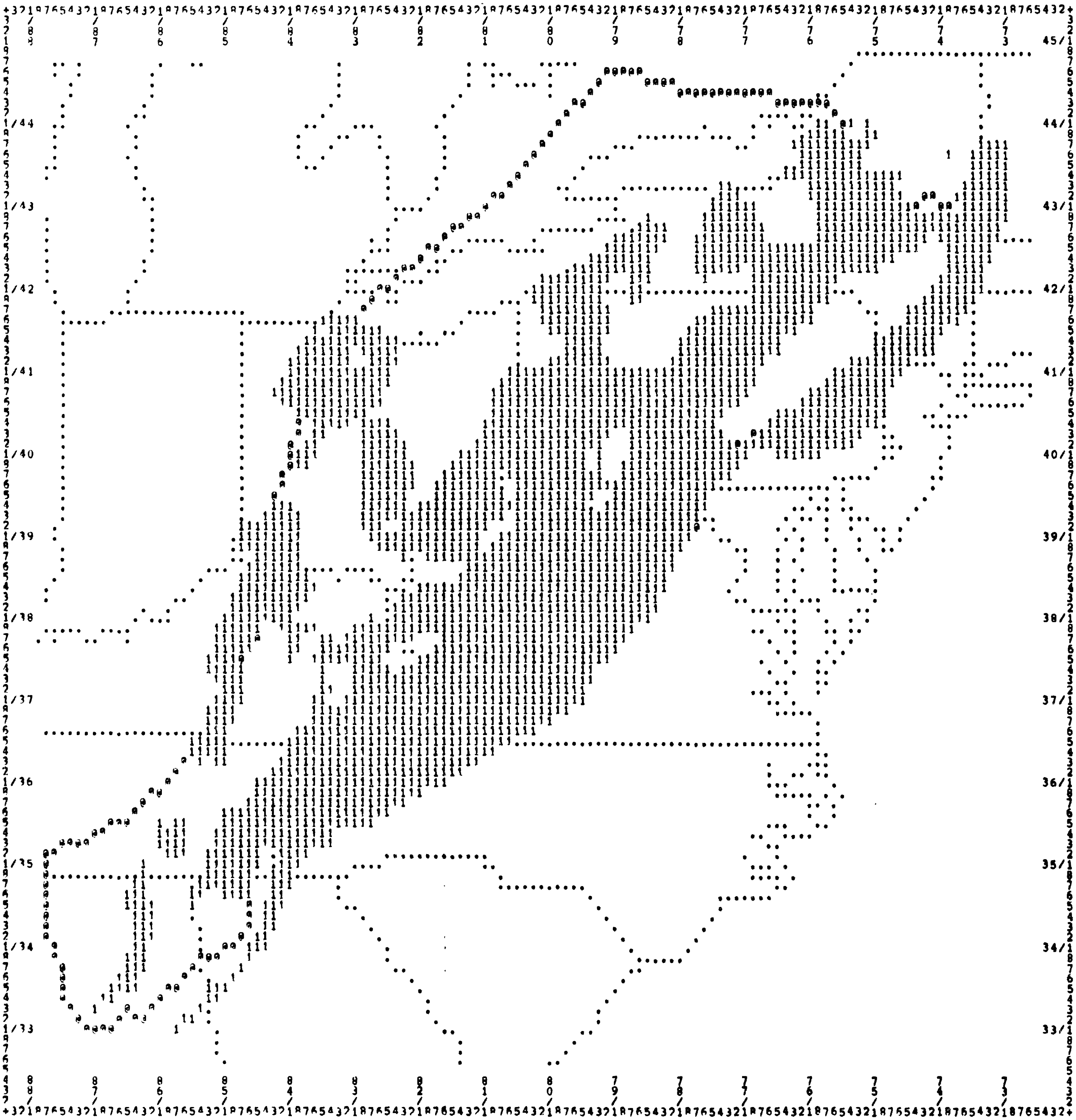
SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles,
width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP E10.--DERIVATIVE OF BOUGUER GRAVITY ANOMALY MAP OF THE APPALACHIAN REGION.
(See Maps M10 and D10.) Gravity levels: blank, data not shown or
< -40 mgal; 1, > -40 mgal.

D10

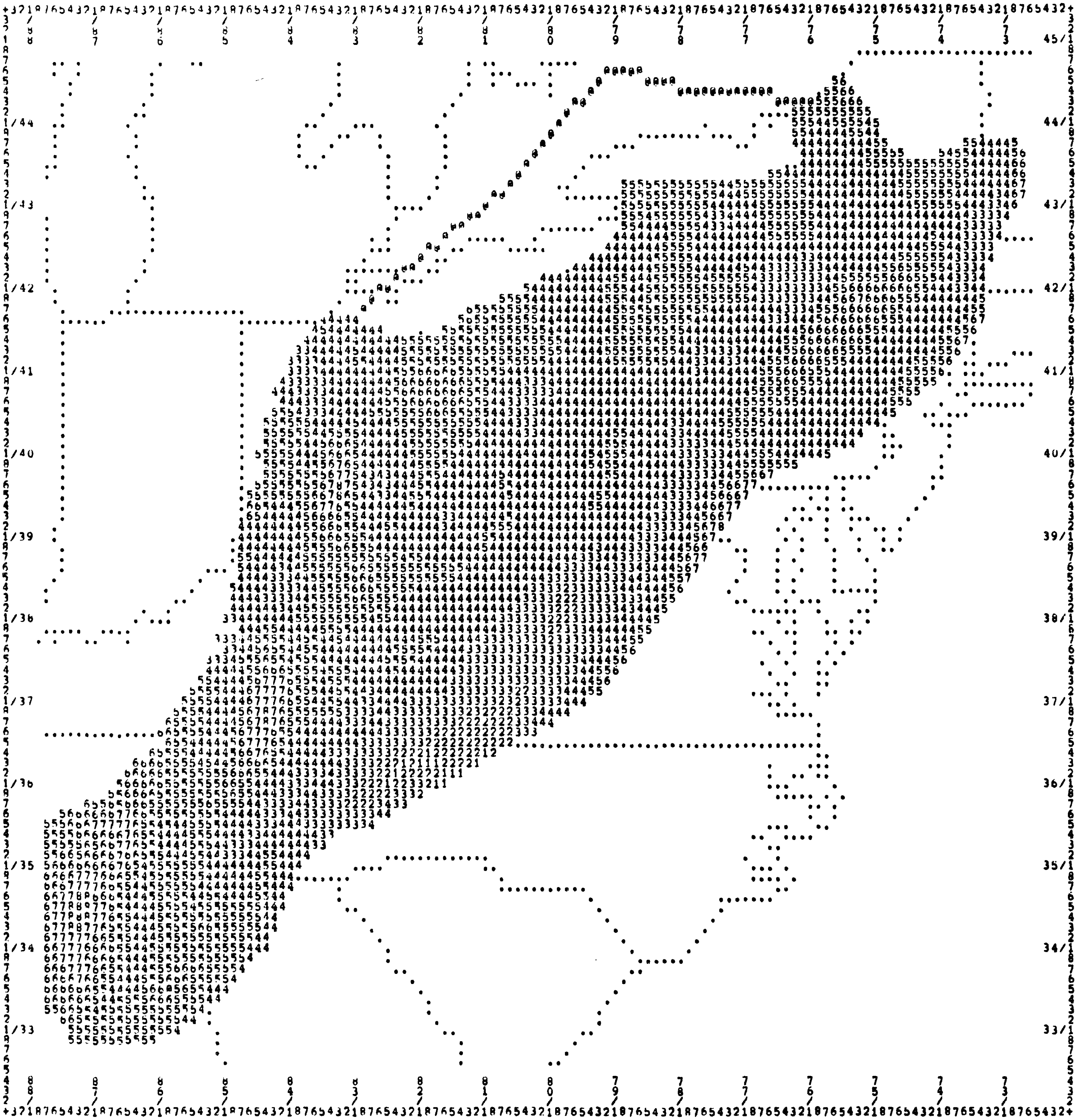
WEDOW, DEVONIAN-TARGET ATLAS GRIDDED-DATA MAP D10



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

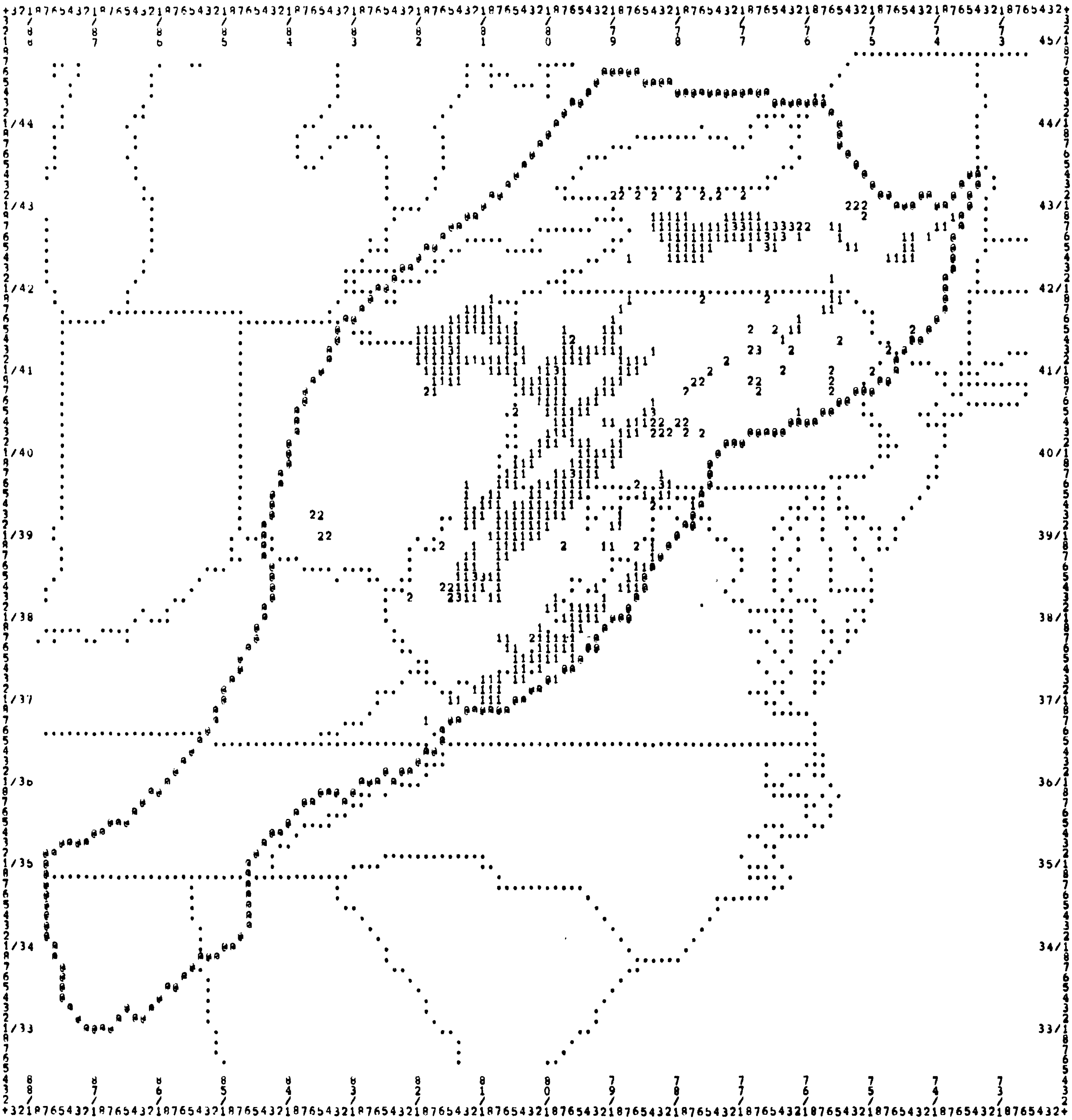
MAP D10.--DERIVATIVE OF BOUGUER GRAVITY ANOMALY MAP OF THE APPALACHIAN REGION.
(See Maps M10 and E10.) Gravity levels: blank, data not shown or
> -40 mgal; 1, < -40 mgal.



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP M10.--BOUGUER GRAVITY ANOMALY MAP OF THE APPALACHIAN REGION. Adapted from American Geophysical Union and U. S. Geological Survey (1964). Gravity levels as follows: 1, < -100 mgal; 2, -100 to -80 mgal; 3, -80 to -60 mgal; 4, -60 to -40 mgal; 5, -40 to -20 mgal; 6-20 to 0 mgal; 7, 0 to +20 mgal; and 8, > +20 mgal.

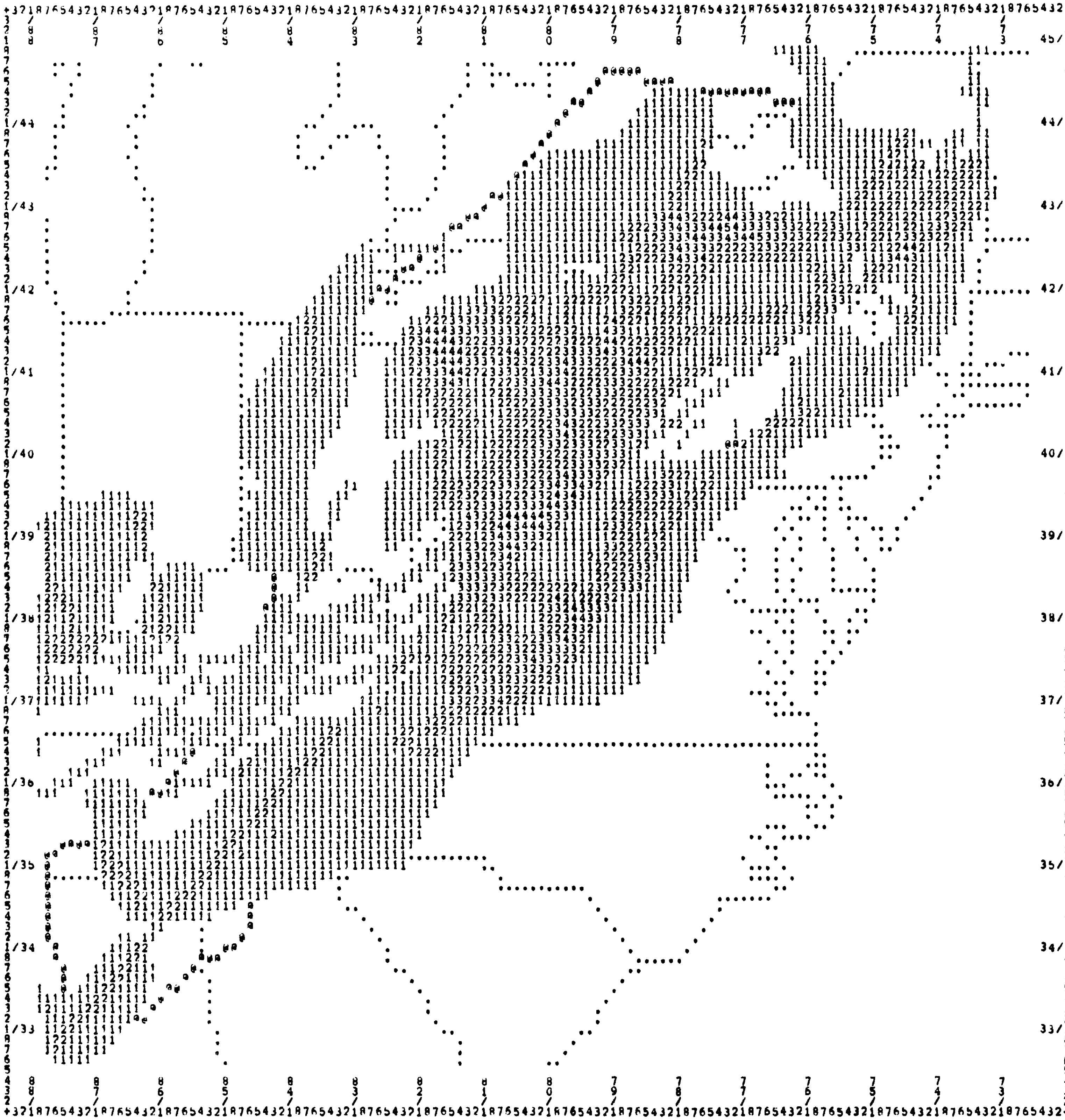


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles, width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP C26.--COINCIDENCE OF "HIGH" ATTRIBUTE-COINCIDENCE VALUES FROM MAP C25 WITH KNOWN SILURIAN THROUGH MISSISSIPPIAN ZINC-LEAD OCCURRENCES (MAP D13). Symbols: 1, cells with coincidence frequencies from Map C25 of 3, 4, and 5 (of a possible 9); 2, cells with known Silurian-Mississippian zinc-lead occurrences; and 3, cells with both 1 and 2.

GRIDDED-DATA MAP C25



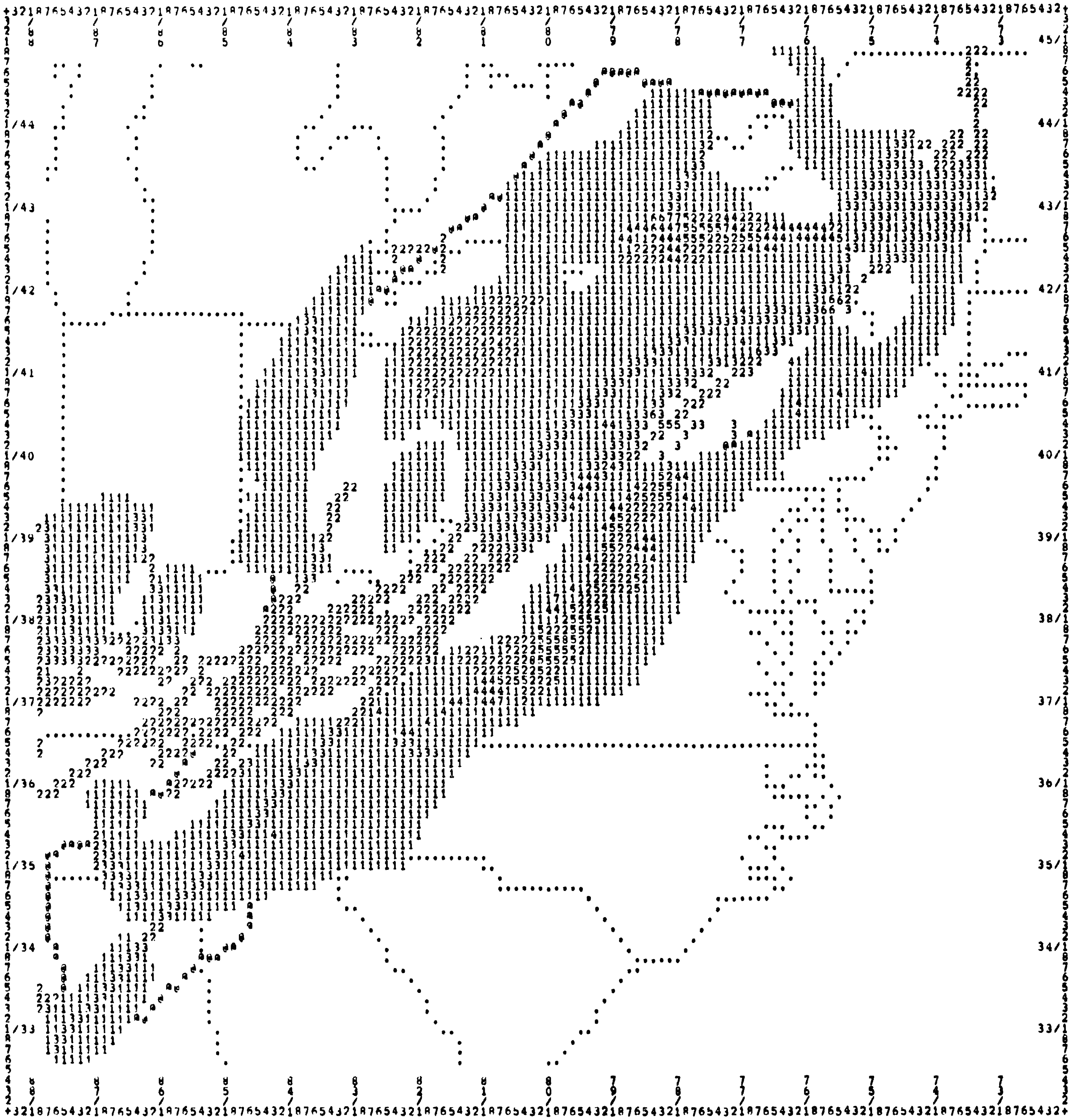
SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP C25.--COINCIDENCE OF NINE ATTRIBUTES FOR STRATIFORM MASSIVE-SULFIDE DEPOSITS IN THE APPALACHIAN REGION. Attributes are equally weighted and are from derivative maps as follows: Silurian salt (D03), high epicenter density (D07), high-angle faults (D08), Alabama-New York lineament or "geosuture" (D09), supergene Mn-Fe occurrences (D11), occurrences of "Styliolina fissurella" (D12), possible Silurian-Devonian hingeline (F19), possible Middle to Late Devonian hingeline (F20), and area of strong Devonian volcanic activity (D21). Number symbols indicate frequency of coincidences per cell; maximum possible frequency = 9.

WEDOW, DEVONIAN-TARGET ATLAS

GRIDDED-DATA MAP C24

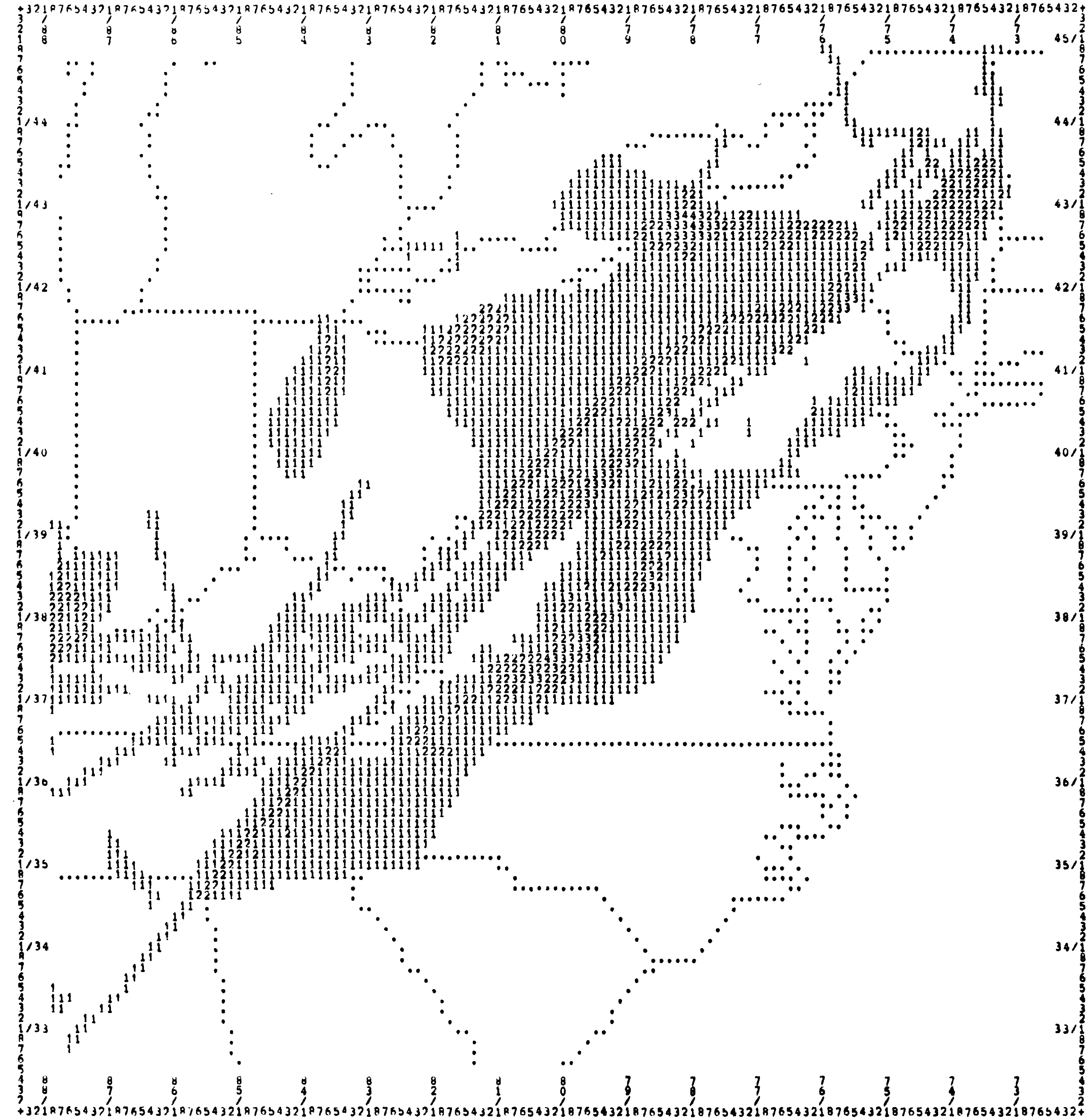


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles, width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP C24.--WEIGHTED COINCIDENCE OF SIX ATTRIBUTES FOR STRATIFORM MASSIVE-SULFIDE DEPOSITS IN THE APPALACHIAN REGION. Attributes are the same and from the same maps as in Map C23 but are weighted as follows: 3 each--D11 (Mn-Fe occurrences) and D12 (Styliolina fissurella"); 2--D08 and D09 (merged, respectively, high-angle faults and Alabama-New York lineament; and 1 each--D03 (Silurian salt), D04 (Tioga bentonite), and D07 (strong epicenter density). Number symbols indicate weighted frequency of coincidences per cell; maximum possible value = 11.

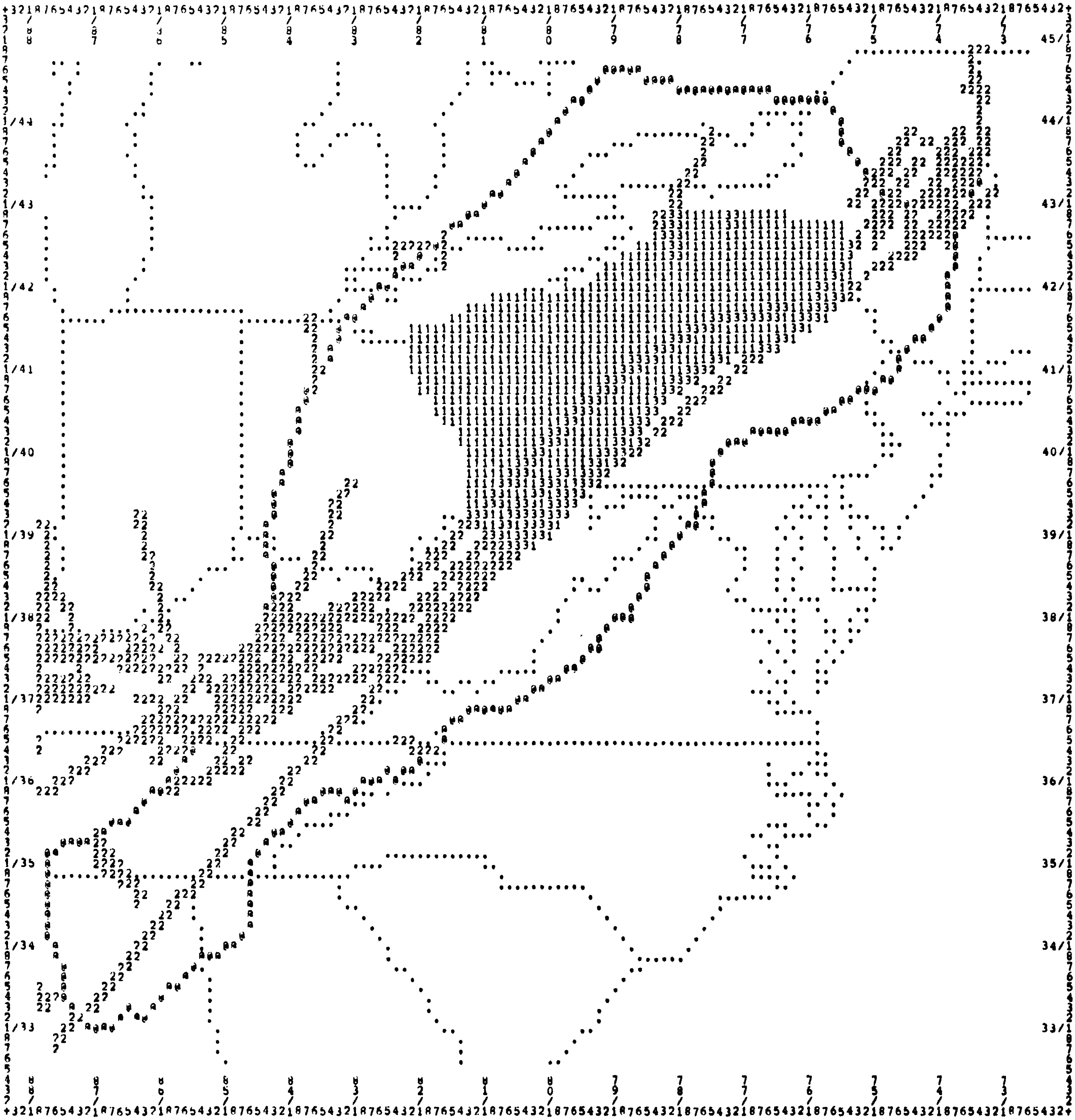
GRIDDED-DATA MAP C23



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

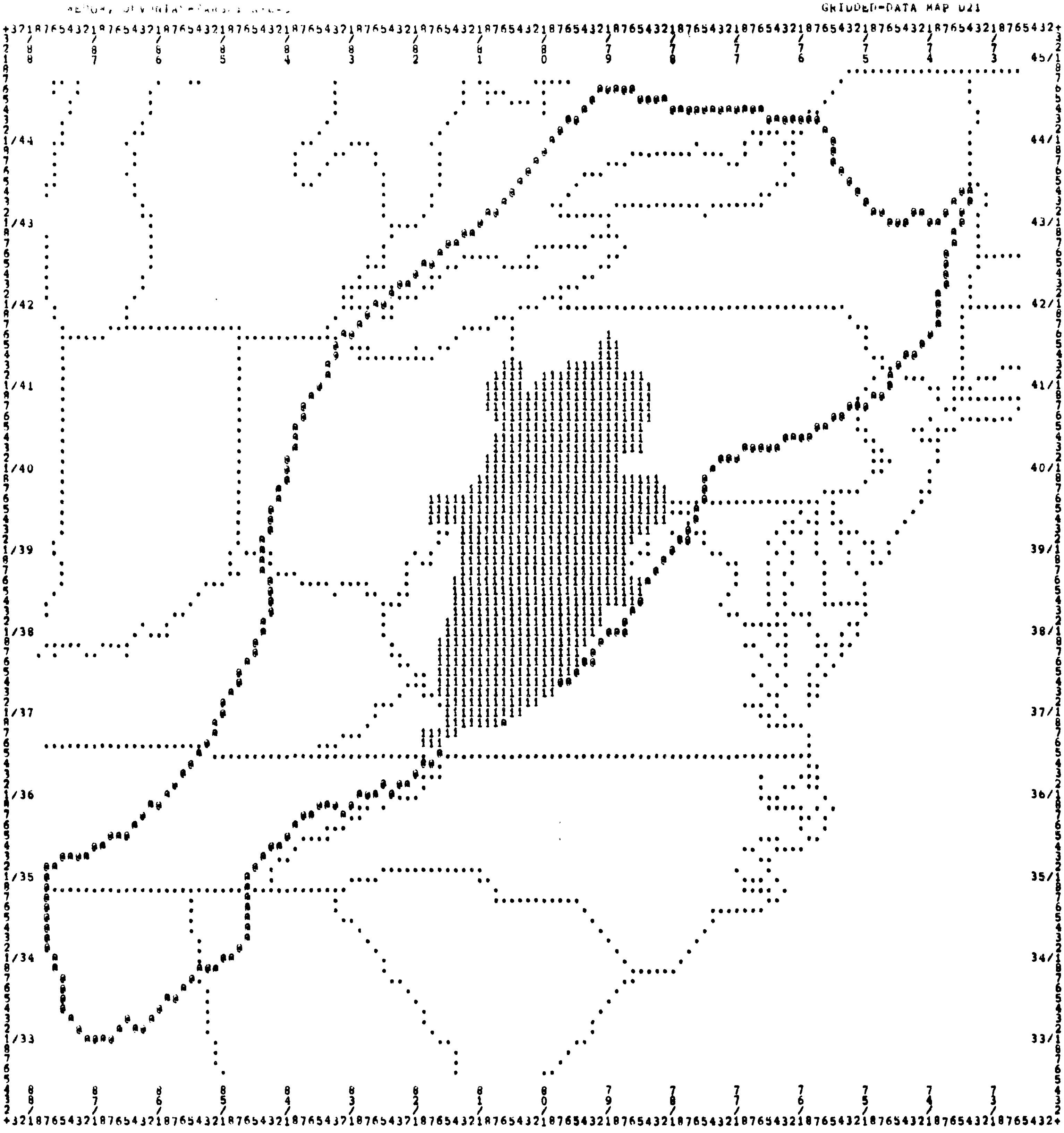
MAP C23.--COINCIDENCE OF SIX ATTRIBUTES FOR STRATIFORM MASSIVE-SULFIDE DEPOSITS IN THE APPALACHIAN REGION. Attributes are equally weighted and taken from derivative maps D03 (Silurian salt), D04 (Tioga bentonite), D07 (high epicenter density), D08 and D09 (high-angle faults and Alabama-New York lineament merged), D11 (supergene Mn-Fe occurrences), and D12 (occurrences of the pteropod "Styliolina fissurella"). Number symbols indicate frequency of coincidences per cell; maximum possible frequency per cell = 6.



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP C22.--COINCIDENCE OF SILURIAN SALT WITH PATTERN OF HIGH-ANGLE FAULTS (INCLUDING ALABAMA-NEW YORK LINEAMENT). Developed from Map D03 (Silurian salt) and Maps D08 and D09 (high-angle faults and Alabama-New York lineament, respectively). Cell symbols: 1, Silurian salt; 2, high-angle faults and Alabama-New York lineament; and 3, coincidence of fault and salt patterns.



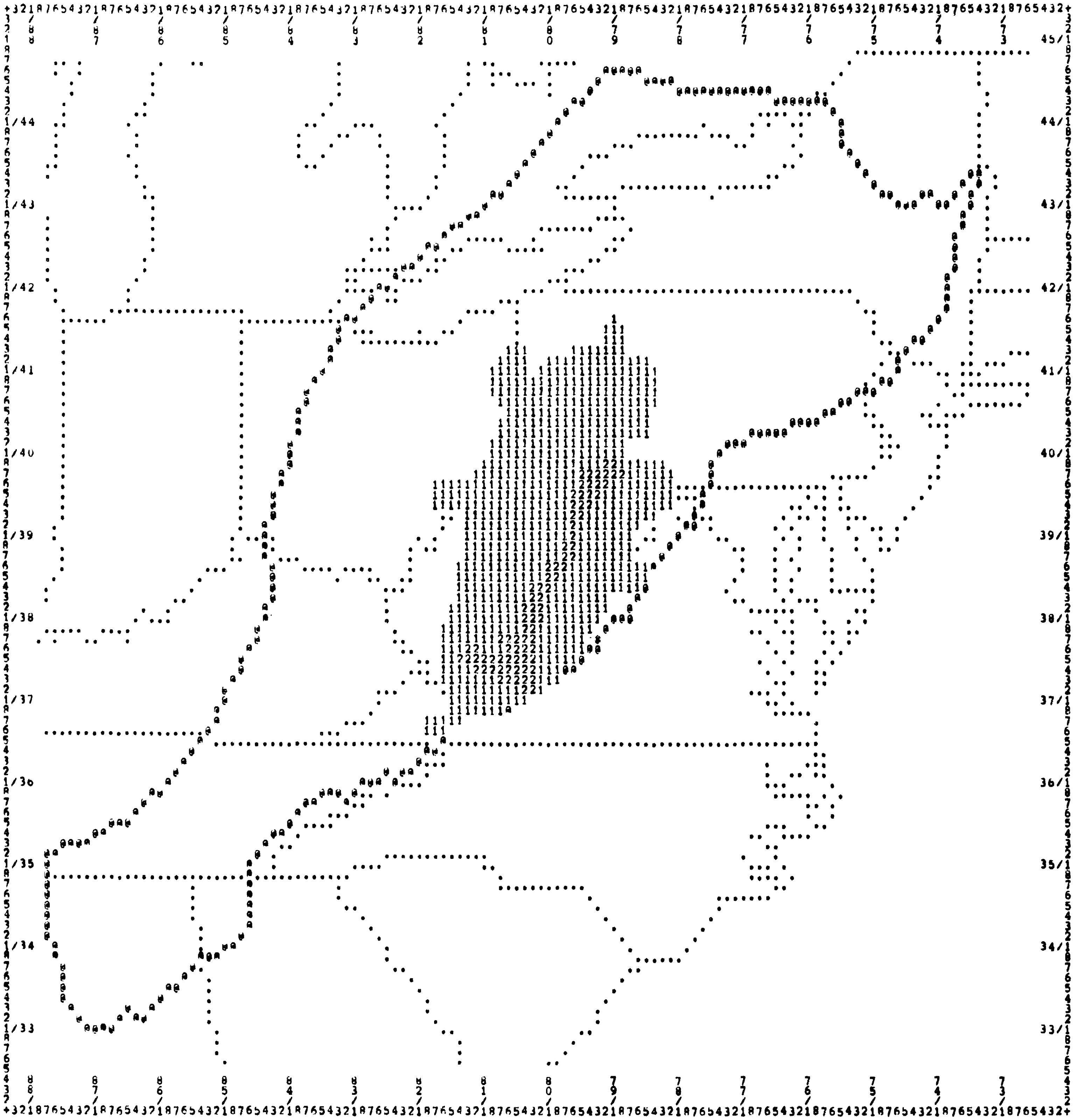
SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles, width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees, 6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP D21.--POSSIBLE EXTENT OF STRONG VOLCANIC ACTIVITY IN THE ONESQUATHAW STAGE (MIDDLE DEVONIAN). Dervived by merging Maps D04 and D05 (see also Map C21). 1, indicates cell contains > 3 feet of Tioga-bentonite influence zone or Onesquathaw Stage contains > 50 percent chert or both.

WEDUP, DEVONIAN-TARGET ATLAS

GRIDDED-DATA MAP C21

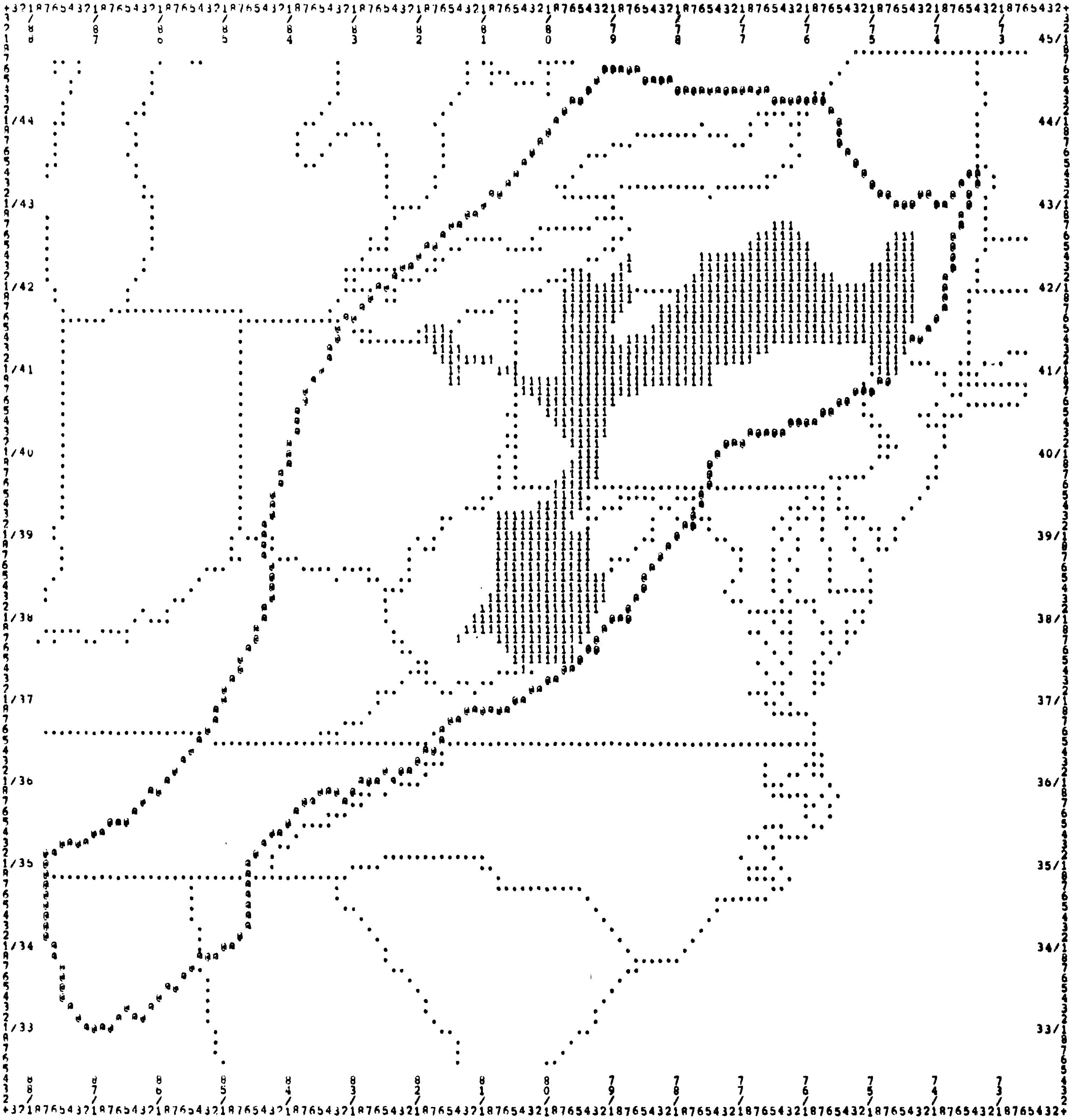


SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP C21.--COINCIDENCE OF THICK (> 3 FEET) ZONE OF TIOGA BENTONITE (TUFFITE)
AND HEAVY DEVELOPMENT OF CHERT (> 50 PERCENT) IN ONESQUATHAW
(MIDDLE DEVONIAN) ROCKS. (See Maps D04 and D05.) Cell symbols:
1, either thick tuffite or massive chert; 2, zone of overlap
(that is, coincidence of the two patterns).

GRIDDED-DATA MAP E20



SCALE

Length of each data cell is 7-1/2 minutes of latitude, or 8.63 miles.
Width of each data cell is 7-1/2 minutes of longitude, or 7.26 miles, at 33 degrees,
6.73 miles at 39 degrees, and 6.12 miles at 45 degrees.

MAP E20.--DERIVATIVE OF CUMULATIVE THICKNESS MAP OF DEVONIAN BLACK SHALES IN THE APPALACHIAN BASIN. (See Maps M20 and D20.) Cumulative thicknesses: blank, data not shown or < 600 feet; 1, > 600 feet.