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MORPHOMETRIC ANALYSIS OF THE SOUTHERN PENINSULA OF MICHIGAN

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ABSTRACT

MORPHOMETRIC ANALYSIS OF THE

SOUTHERN PENINSULA OF MICHIGAN

By John W. Pawling

The results of this study incorporate a morphometric description of the major topographic compartments of the southern peninsula of Michigan and the eleven glacial landforms which characterize its terrain. The primary configuration of these landforms occurs within a gross delineation of two dissimilar highlands surrounded by a discontinuous peripheral lowland. Of the highlands, the larger northern highland has greater relief, slope, and elevation in comparison to the lower and less rugged southern one. Each highland and the encompassing lowland is defined on the basis of continuous hypsometric characteristics above or below the 750 foot-isohypse.

Because of the absence of previous morphometric research in the study area, the use of traditional terrain dimensions such as local relief, average slope, and average elevation is adopted in support of the geometrical characterizations of morphometric regions and glacial landform types. A grid network of 6798 2 1/2-minute unit areas, conterminal with the peninsular shores, serves as a matrix of data locations for the computer manipulation

of the Elevation-Relief Ratio, and a new terrain parameter, the Comparative Relief Index. The latter index, devised for the purpose of delineating homogeneous relief regions, failed to achieve significant results because of the lack of abrupt regional changes in local relief.

Each of the morphometric highlands is divided into four levels, called morphometric regions, with continuous altitudinal values. Each level is further compartmentalized into morphometric subregions based on concentrations of stated classes of relief within core locations. Transitional belts of relief units not common to either of two proximate relief cores are shared, equally and arbitrarily, with each core area; the combination of relief cores and their anomalous units provides an index of relief heterogeneity and is advocated as a differential index in formalizing morphometric subregions.

Thirty-four isolated and distinctive relief cores, in conjunction with their aggregates of unlike relief values, are identified in an effort to differentiate the changing topographic surface of the peninsula. Because of the good correlation between increasing slope and relief, and the frequent appearance of certain landform types with given relief slope criteria, both slope and prevailing landform characteristics are stated as additional descriptions of the morphometric subregions.

It is not possible to describe the peninsular lowland as a flat lacustrine plain, in its entirety, nor is it always possible to establish correlations between increased elevation and more rugged relief or steeper slope. Relatively flat till and outwash plains characterize portions of the northern and southern highlands and some of the most rugged topography of the study area is found at lowland elevations along the northwestern littoral. The principal physiographic lineaments of the study area include the amphitheater-like rim of morainic heights which outline northern highland and the northeast-southwest trending moraines of the eastern and western faces of the southern highland. The two highlands are set apart by the trough of the Grand-Maple rivers which rival the incisements of the Manistee, Muskegon, and Au Sable rivers in the northern highland.

In contrast, the clay bottomlands of the eastern side of the peninsula commonly have a relief of less than 25 feet and an average slope of less than $1/2^{\circ}$ per six-square-mile unit area. For sake of comparison, the morainic heights of the northern highland and the drumlin fields of the Traverse City lowland frequently have slopes in excess of 4° and relief in excess of 350 feet. In terms of the landform type of the largest areal extent, and within the constraints of generally subdued topographic surface, recessional moraines are the principal relief-makers of the peninsula.

The future of regional morphometric research, implicit in meeting the exigencies of this work, rests in the innovation of flat-land parameters, automated procedures of data acquisition from topographic maps, and increased accessibility to computers. The principal deficencies in applying morphometric theories are concerned with formalizing the ideal unit area concept, delimiting morphometric subregions on the basis of integrated or weighted terrain data, and devising a rigorous method for determining the class intervals of the data.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the applied virtues of integrity, perseverance, and dedication which this research represents. To his major professor, Dieter H. Brunnschweiler, the author expresses his appreciation for the rigorous standards of scholarly writing and cartographic execution which Professor Brunnschweiler imposed at each stage in the development of this thesis topic.

The perseverance to complete this research arose out of seven years' encouragement and continuing financial assistance from the author's parents, Mr. & Mrs. John A. Pawling. To his father, the writer is grateful for the admonishments and persistent criticisms of the unfinished task -- to his mother, for the quiet and certain knowledge that the task would one day be complete. To Dr. Henry N. Michael, the author is grateful for his critiques of the intermediate drafts of this work. Finally, the author is indebted to Betty Famiglietti for typing the final manuscript and its careful proof-reading.

In dedication, the author offers the merits of this work to his son, John Scott Pawling, with the hope that he will discover in

his time the personal satisfactions of scholastic endeavor.

Any errors contained in this work are the responsibility of author alone and should not be attributed to any other person or persons.

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CHAPTER I

MORPHOMETRY AND ITS APPLICATION TO MICHIGAN'S SOUTHERN PENINSULA

Purpose and Methodology

Geographers are committed to the description of landscape in time from both a physical and a cultural point of view. The physical landscape consists in part of topographic surfaces which represent a variety of individual landforms; because of the relationship with other physical or cultural phenomena, these surfaces must be the subject of objective description in any geographic regionalization:

> "Descriptive landform analysis, as an objective statement of facts, should be the first step in any type of landform study . . . once the descriptive analysis is completed, we can utilize the information for either genetic or functional studies." Zakrzewska (1967: 131-132)

The purpose of this dissertation is to provide a morphometric analysis of the landform types and the terrain regions of the southern peninsula of Michigan. The dimensional reality of the prevailing glacial landform types can be defined according to measurements of slope, relief, and elevation. The study area excludes the northern peninsula of Michigan because this region is a physically separate appendage of the state of Michigan; furthermore, the geographical outline of the southern peninsula exhibits a true peninsular shape and comprises the largest peninsula of the conterminous United States.[1] The primary task of this study is the selection of proper terrain parameters needed to produce an objective and systematic analysis of southern Michigan landform types and their regional characteristics.

The literature on quantitative techniques used in landform analyses is extensive. Neuenschwander (1944) offers a bibliography of 640 items, for the period before 1944, and Carr and Van Lopik (1962) provide a review of 326 studies appearing in the interim. An overwhelming number of these references are concerned with parameters which reveal minor details and individual features of a topographic surface, and a review of the more specialized quantitative measures would serve no purpose here.

Several studies, concerned with the more limited literature of morphometric regionalization, apply a single terrain index to relatively large-scale study areas such as a single drainage basin, a mountain massif, or an isolated valley. This study employs a multiple-factor approach: six terrain parameters were found to be satisfactory in identifying the principal morphometric compartments of the largest peninsula of the conterminous United States. These parameters are concerned with the classical morphometric indices of maximum and minimum elevation, average elevation, local relief, and average slope. The morphometric analysis of glacial landforms, first mapped by Leverett and Taylor (1924) and

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(1)Florida is larger (55,000 sq. mi.) than the southern peninsula of Michigan (40,000 sq. mi.); however, the present study area is slightly larger than peninsular Florida alone (excluding the panhandle area).

revised by Martin (1955), forms an important link between a strictly quantitative and a genetic evaluation of the study area.

Although Hoy and Taylor (1963) suggest an even more comprehensive approach to include change in slope direction, other researchers commonly employ only a single factor in developing topographic regionalizations. Examples of the latter include the use of relief in Illinois and Ohio by Calef (1953) and Smith (1935), respectively, and the analysis of slope in New England and Illinois by Raisz & Henry (1937) and Thoman (1955), respectively. Hammond (1955) and Pike (1963), alone, apply integrated terrain factors for Missouri and southern New England in order to develop geometrical concepts of regional terrain surfaces.

The Field of Geomorphometry

Geomorphometry may be defined as the subfield of geomorphology which employs dimensional values in describing landforms. Statistical characterizations of terrain formations, leading to a higher order of regional description, is a major objective of morphometric research.(2) Discrete terrain characteristics have to be isolated, evaluated, and translated into numerical statements in order to express the surface geometry. Wood and Snell (1960:1) state this objective as follows:

> "Because numbers can be manipulated and carry a preciseness of definition that qualitative terminology lacks, quantitative analysis has increased the value of terrain studies for both theoretical and practical purposes."

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(2)The shorter term "morphometric" will be used in place of geomorphometric in the remainder of this work.

Goldberg (1962:537) comments further that:

> "The problem, therefore, is to discover a method of terrain analysis which will provide both a realistic and a quantitative description of world landforms, <u>the one serving as a key to the other</u>."

Although improved quantitative expressions for topographic models are clearly within the realm of advanced theoretical mathematics (topology), the task of characterizing landforms and landform regions can be accomplished by conventional geometrical relationships extracted from topographic maps. It is probable that these improved parameters will utilize basic terrain dimensions, such as slope, elevation, and relief, in either new relationships with each other or as primary data in newly devised mathematical concepts.

Description of the Study Area

The topography of the southern peninsula consists of a peripheral lowland of varying width surrounding two highlands, a northern and a southern, which are separated by the Grand River corridor. The structure, materials, and orientation of landforms occupying these surfaces are mainly the result of widespread deposition during the later substages of the Wisconsin stage of glaciation. Glacial drift is unevenly distributed over the peninsula varying in depth from 100-300 feet in the southern highland to a maximum of 1000 feet in the northern upland. The total area of these drift materials amounts to approximately 40,000 square miles and incorporates a maximum regional relief of 1200 feet from the surface of Lake Erie (565 feet) to the morainic heights (1706 feet) near Mesick, Michigan.

The underlying bedrock surface of a structural basin has had little effect in controlling the surface configuration of landforms although buried cuestas may be related to morainic heights along the outer perimeter in the northwestern sector of the peninsula. Drift is deepest in the interlobate moraines of Otsego County and the West Branch Moraine of Ogemaw and Clare counties. No similar correlation can be made between the thickness of the drift mantle and the primary topographic heights of Hillsdale County; however, secondary heights in the Kalamazoo Moraine and the interlobate moraines of Oakland County have somewhat thicker drift accumulations. In every case, the 100-300 feet of glacial overburden of the southern highland points to a bedrock surface which is uniformly closer to the present topographic surface than is the case in the northern highland.

The "Map of the Surface Formations of the Southern Peninsula of Michigan," Martin (1955),[3] summarizes more than fifty years of field work in identifying and locating the various glacial formations of the study area. Table 1 lists the glacial landforms, differentiated in this work, and indicates the fragmentation and areas of the various surface formations. The formation parcels, in turn, determine the prevailing landform type in the identification of unit areas in the morphometric analysis of glacial landform types (Chapter 3).

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[3] Hereafter referred to as M.S.F. Map.

TABLE 1

Area of Surface Formations of Southern Michigan: *
Summary of Genetic Types after Helen M. Martin (op. cit.)

Regional Type	Number of Parcels**	Area in Sq. Miles	Average Parcel** Size (Sq. Miles)	Percent of Total Area
Recessional Moraines	681	11,860	17.5	30
Outwash and Glacial Channels	70	9,130	130.4	24
Sand Lake Beds and Spillways	38	6,595	173.6	18
Ground Moraines (Till Plains)	270	5,270	19.5	14
Clay Lake Beds	49	4,062	82.9	11
Waterlaid Moraine	24	550	19.5	1
Ponded Water or Interior Lake Formations	10	441	44.1	1
Drumlins	9	275	30.5	1
Sand Dunes	20	119	5.4	---
Boulder Belts	2	45	22.7	---
TOTAL	1,173	38,347	55.0	100

* Determined with use of Bruning Areagraph Set No. 4850, degree of precision stated to be at 97% of area surveyed.

** Parcels are defined as irregular-shaped land units of homogeneous genetic landforms.

The surface formation map clearly depicts the pattern of recessional and interlobate maorines as arcuate residuals of the ice lobes of Lakes Michigan, Huron, Saginaw, and Erie. The best linear expressions of these moraines occur along the outer fringes of the northern and southern highlands; hundreds of small, isolated

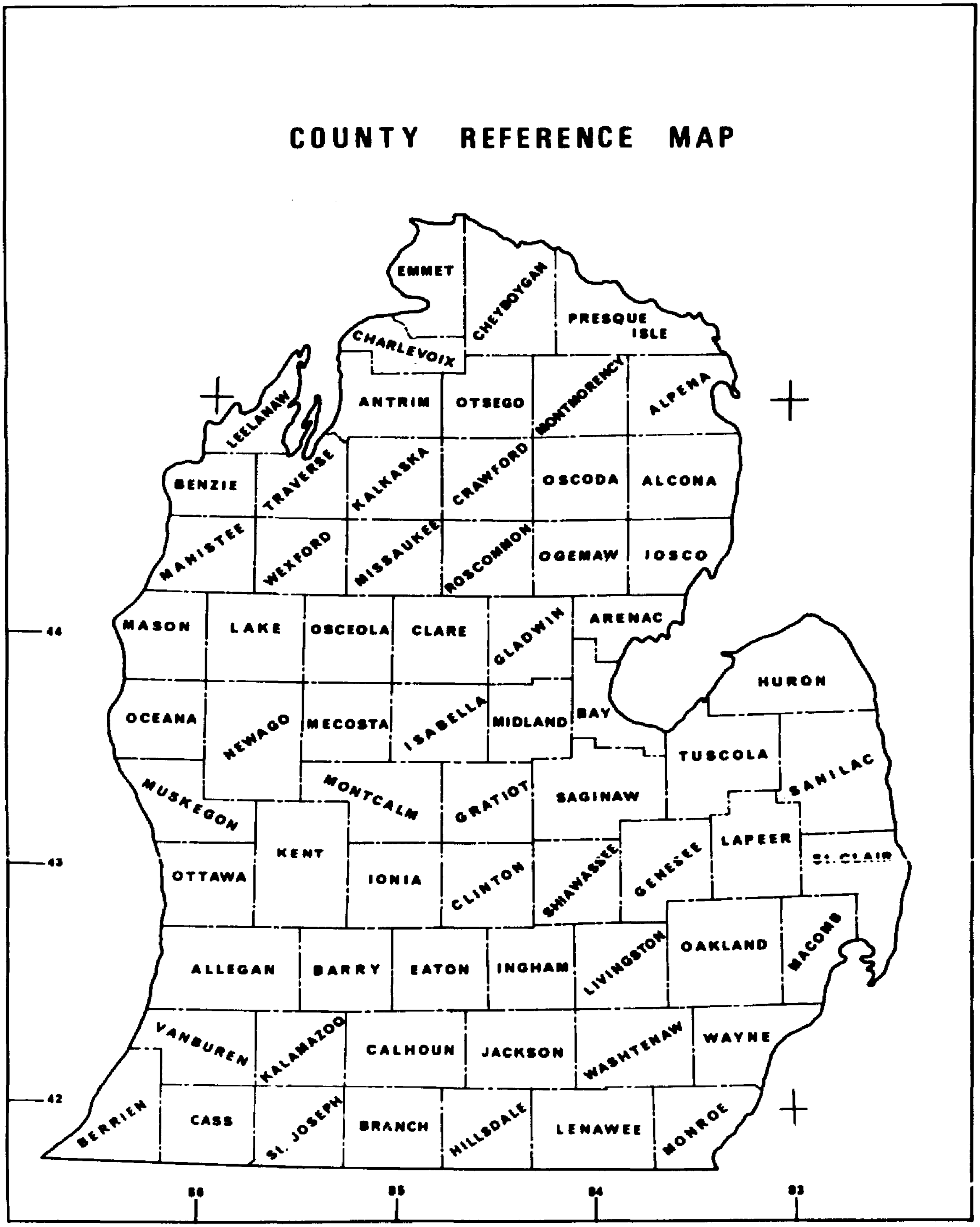

COUNTY REFERENCE MAP
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
LEELANAW
ANTRIM
OTSEGO
MONTMORENCY
ALPENA
BENZIE
TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
ARENAC
HURON
OCEANA
NEWAGO
MECOSTA
ISABELLA
MIDLAND
BAY
TUSCOLA
SANILAC
MUSKEGON
MONTCALM
GRATIOT
SAGINAW
LAPEER
ST. CLAIR
OTTAWA
KENT
IONIA
CLINTON
SHIAWASSEE
GENESEE
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
OAKLAND
MACOMB
VANBUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
WAYNE
BERRIEN
CASS
ST. JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE
44
43
42
86
85
84
83

Fig. 1

morainic parcels dominate the interlobate areas of the southern highland and dozens of irregular tracts occur within the rim moraines of the northern highland (Fig. 2). If the map of the principal drainage systems (Fig. 3) is superimposed on the pattern of moraines, it becomes apparent that moraines control the locally dominant heights and are, in fact, adjusted to their locations in alternating outwash belts.

Till plains (Fig. 5) are typically associated with moraines and occupy major tracts in Gratiot, Montcalm, Clinton, Shiawasee, and Genesee counties. Their segmented linear pattern is not surprising here, but, where tills are found in association with outwash and lacustrine formations, their pattern and outline are highly irregular. Later, the morphometry of till surfaces will be shown to vary from nearly slope-less surfaces to hills of rugged relief; however, the generalization that till formations occur mainly at intermediate elevations in moderate slopes and relief will also be demonstrated.

Lacustrine surfaces (Fig. 6) occupy nearly one-third of the peninsular study area (Table 1). With the exception of interior proglacial lake beds and certain sandy river bottoms of the southern highland, fully 98% of the lacustrine surfaces occur below the 750 foot-contour on the peninsular lowlands.

Not shown in Figure 6, owing to the small scale of the map, is a discontinuous belt of lake-border sand dunes extending from the Leelanau Peninsula to Benton Harbor (Fig. 25). Clearly illustrated in Fig. 6, however, is the glacial Grand River spillway now occupied by the Grand River and its tributary from the Saginaw

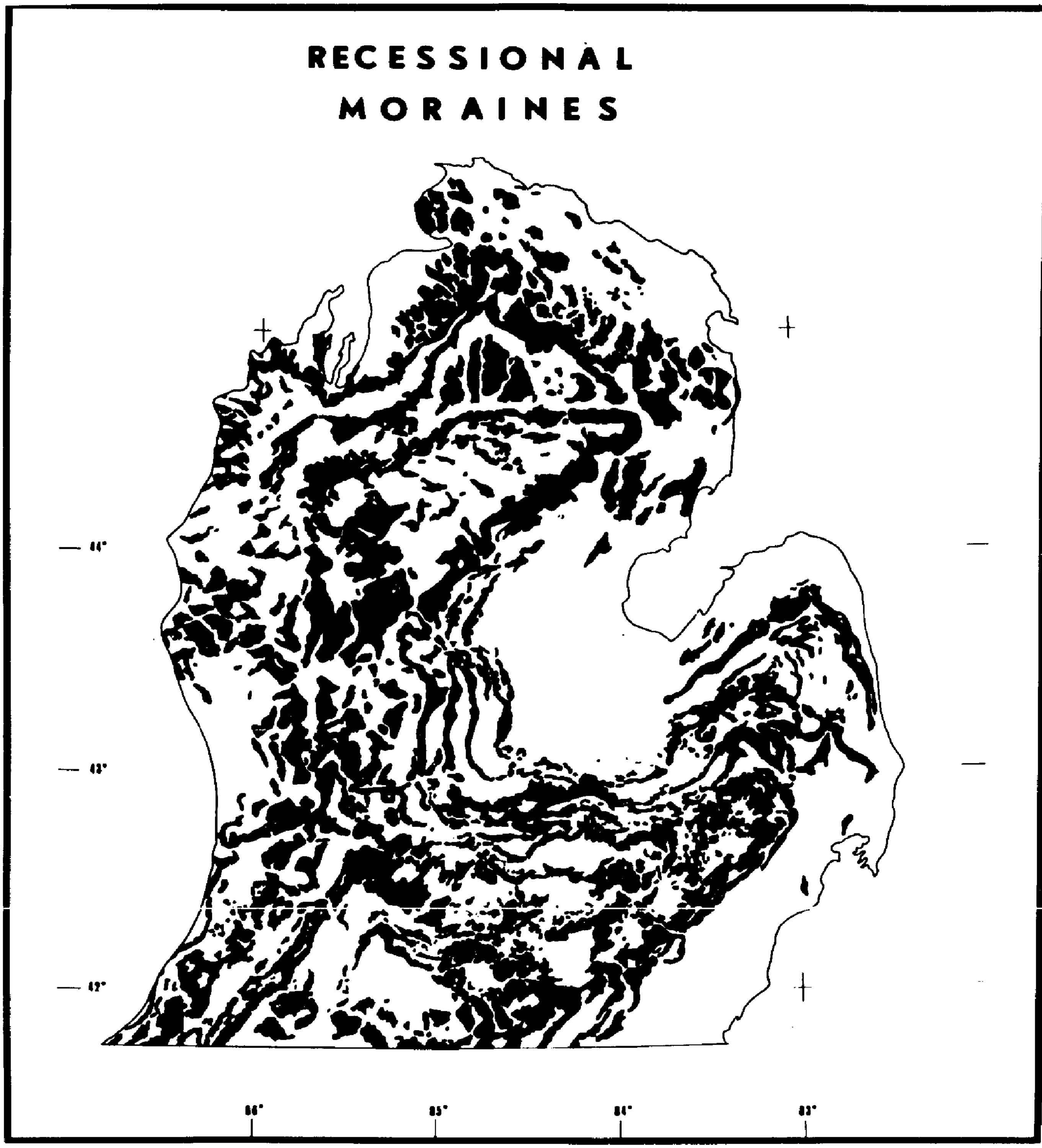


Fig. 2

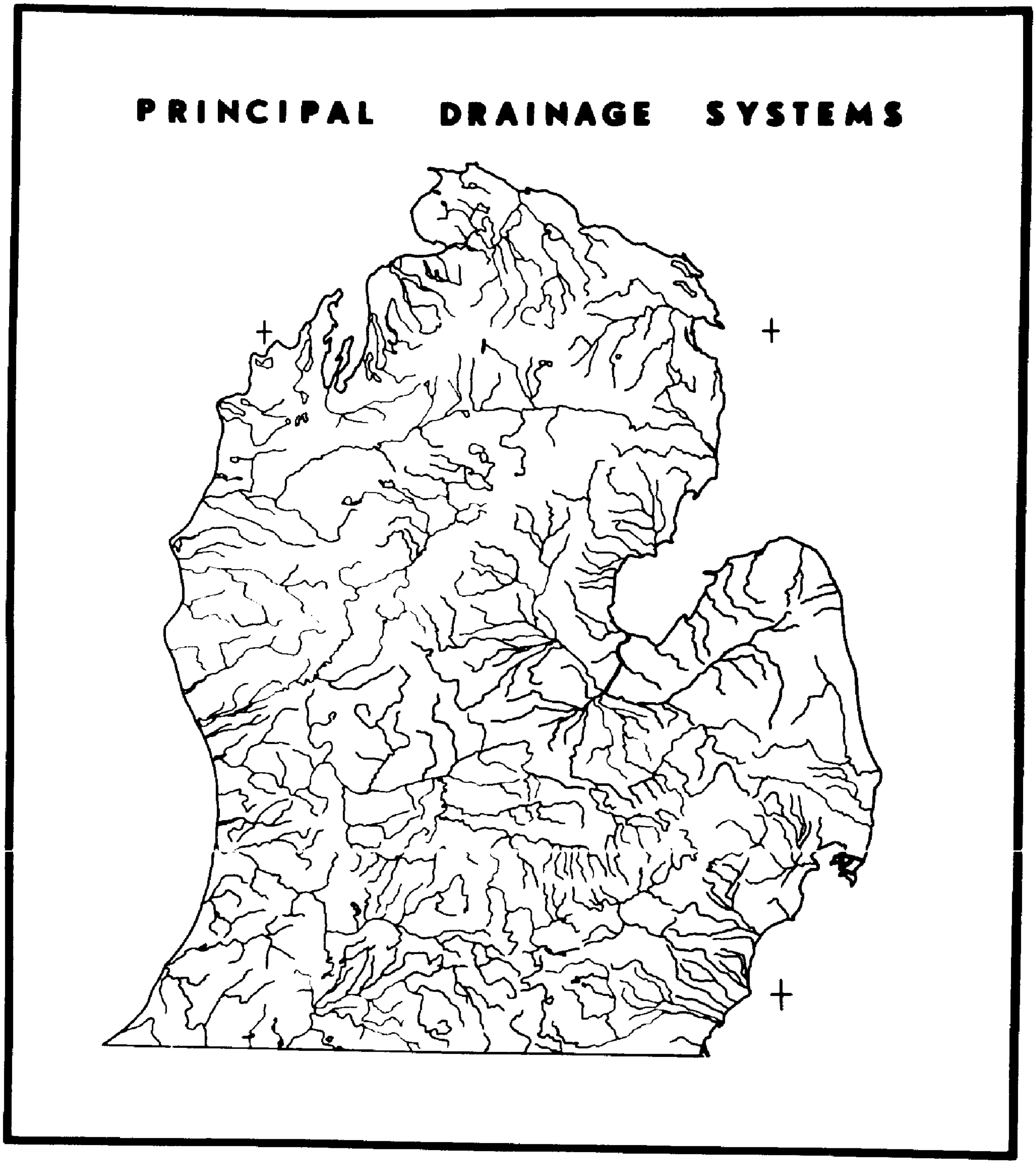


Fig. 3

Fig. 4

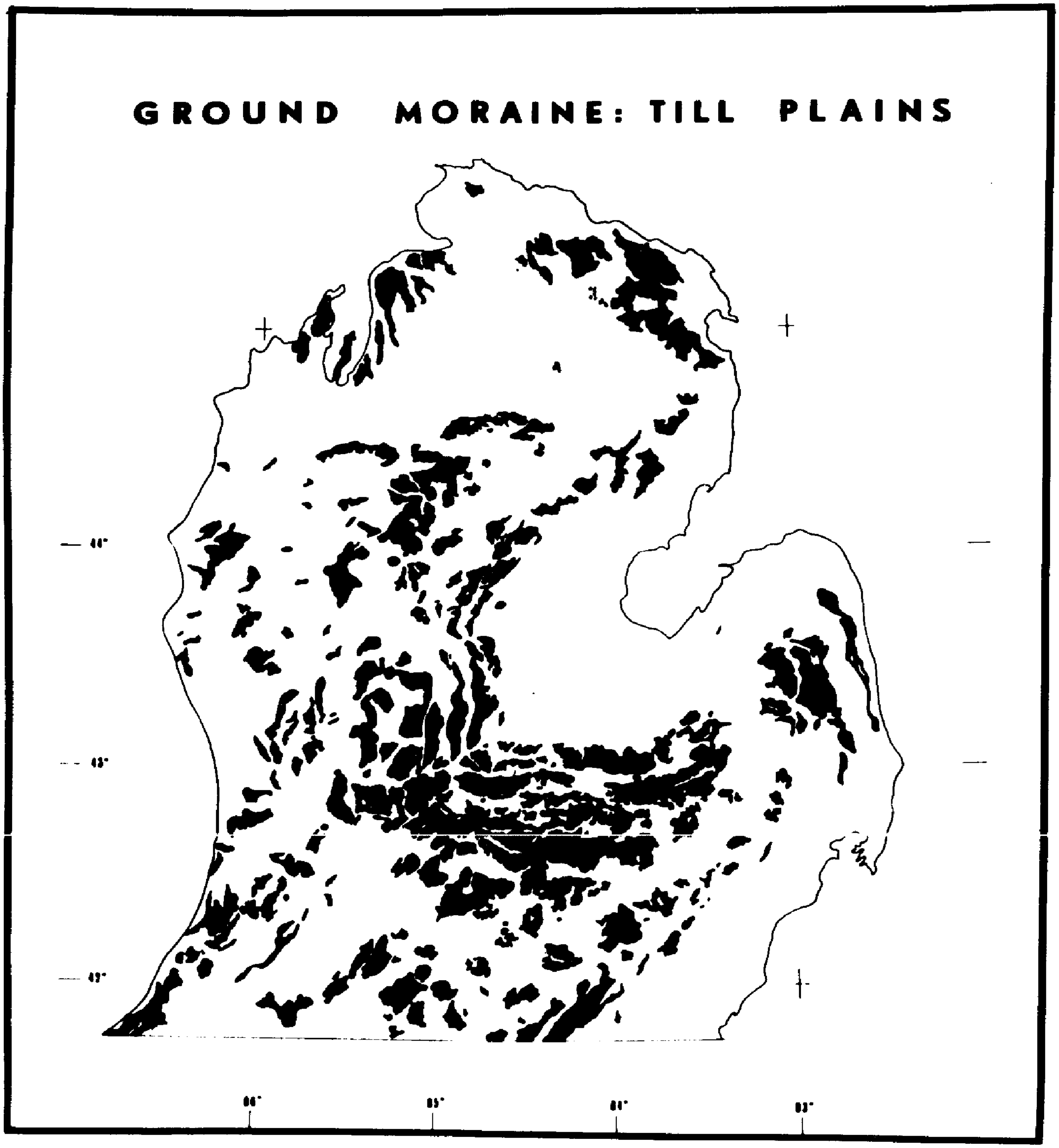


Fig. 5

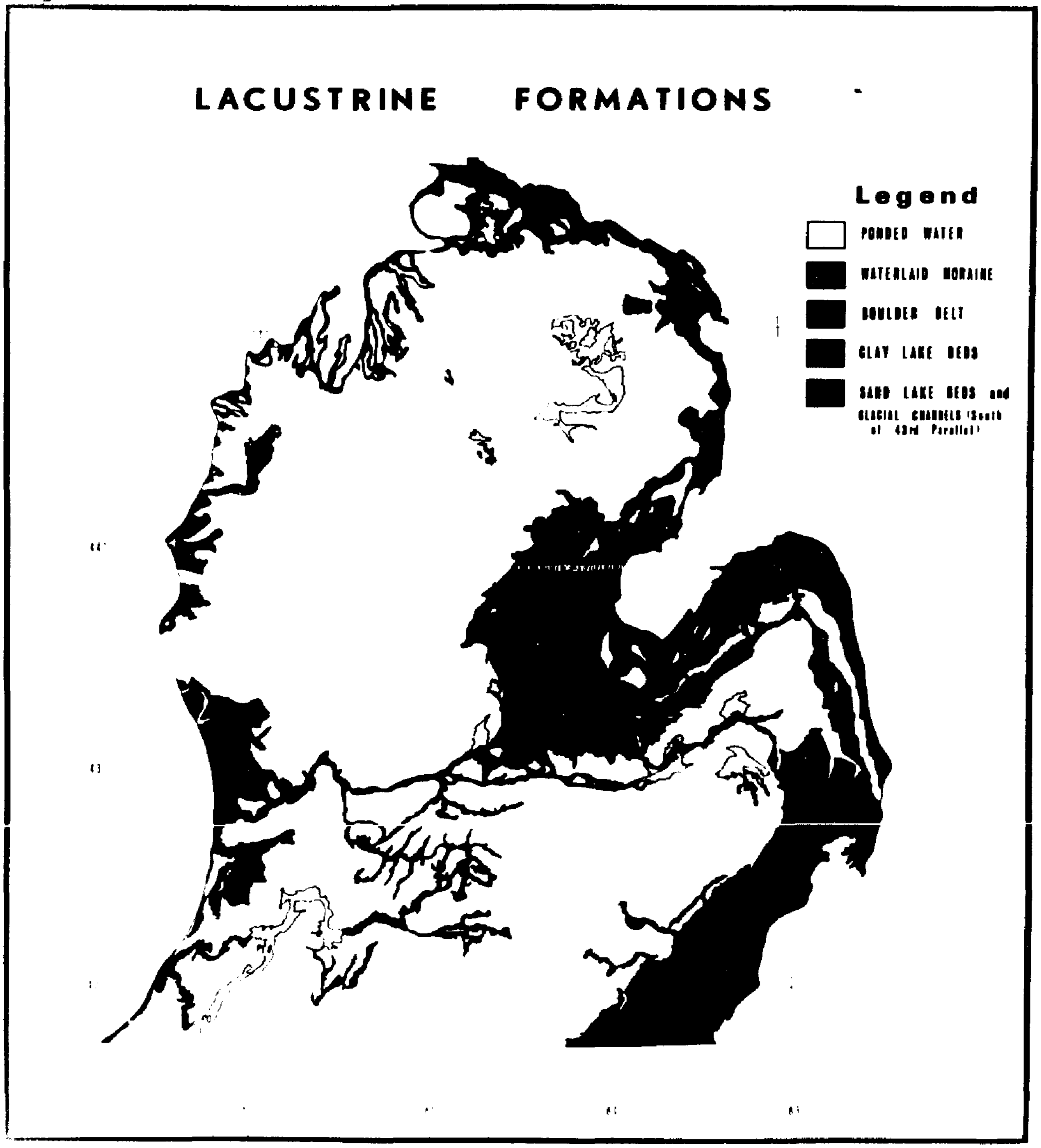

LACUSTRINE FORMATIONS
Legend
PONDED WATER
WATERLAID MORAINE
BOULDER BELT
CLAY LAKE BEDS
SAND LAKE BEDS and GLACIAL CHANNELS (South of 43rd Parallel)

Fig. 6

Basin, the Maple River; this narrow corridor provided a westward outlet for a succession of impounded glacial lakes (Saginaw, Maumee, and Whittlesey) to the east.

Outwash plains (Fig. 4) extend over approximately one-fourth of the study area (Table 1). They are particularly evident at higher elevations in the northern highland where they spill over the Lake Border Moraine and occur as major landforms, at lower elevations, in Newago, Lake, Manistee, and Benzie counties. The outwash trains of the southern portion of the peninsula are found in conjunction with both moraines and tills, however, and their areal pattern is more tenuous than the more extensive, blocky tracts in the northern highland.

The topography of the western half of Charlevoix and Antrim counties, including the Old Mission and Leelanau peninsulas, is dominated by drumlins which are among the locally most prominent landforms of the peninsula. Eskers, locally conspicuous microfeatures of the study area, are found almost exclusively to the south of the Grand-Maple line.

The Unit Area Concept

In the Study of Genetic Landform Types and Morphometric Regions

A grid network of 6832 unit areas was superimposed on the National Topographic Maps of the study area in order to obtain terrain dimensions of the landform types included in each unit. The decision to use the 2 1/2-minute grid was made after the 5-minute and 7 1/2-minute grids, used in previous studies, failed to provide a fine-mesh reticulation suited to the restricted areal extent of most individual landforms of the study area. A standard-size unit area was chosen in place of the variable-size landform parcels of the surface formation map (Table 1 and Figs. 2-6) because of the bias toward increased ranges of terrain data taken from the larger parcels in each landform category. In addition, a cartographic problem arose in transferring the spectrum of parcel sizes and shapes between the larger-scale topographic and the smaller-scale surface formation maps.

All morphometric data are obtained from a standard 2 1/2-minute sample area. These data, in turn, are used as the basis of terrain descriptions given for the various landform types. As mentioned earlier, the reticulation of this uniform grid is compatible with the grain or texture of topography in the study area. However, the accuracy of terrain description for unit areas is based upon the accuracy and completeness by which they are rendered on the surface formation and topographic base maps. It is obvious that such insufficiencies, should they exist, cannot be controlled by the author.

Each unit area of the uniform grid comprises a 2 1/2-minute rectangle aggregating 6.12 square miles between 42° and 43° North Latitude, 6.02 square miles between 43° and 44° North Latitude, and 5.93 square miles between 44° and 45° North Latitude. This slight reduction in area is a result of the polar convergence of meridians with increasing latitude. A 14.4 mile system of linear transects, in the form of a diamond outline superimposed on the unit's diagonals (Fig. 8; Panel 2), is part of the physical design of each unit area. Spaced as northeast-southwest and northwest-southeast lines .88 miles apart, these transects facilitate the acquisition

UNIT AREA REFERENCE MAP

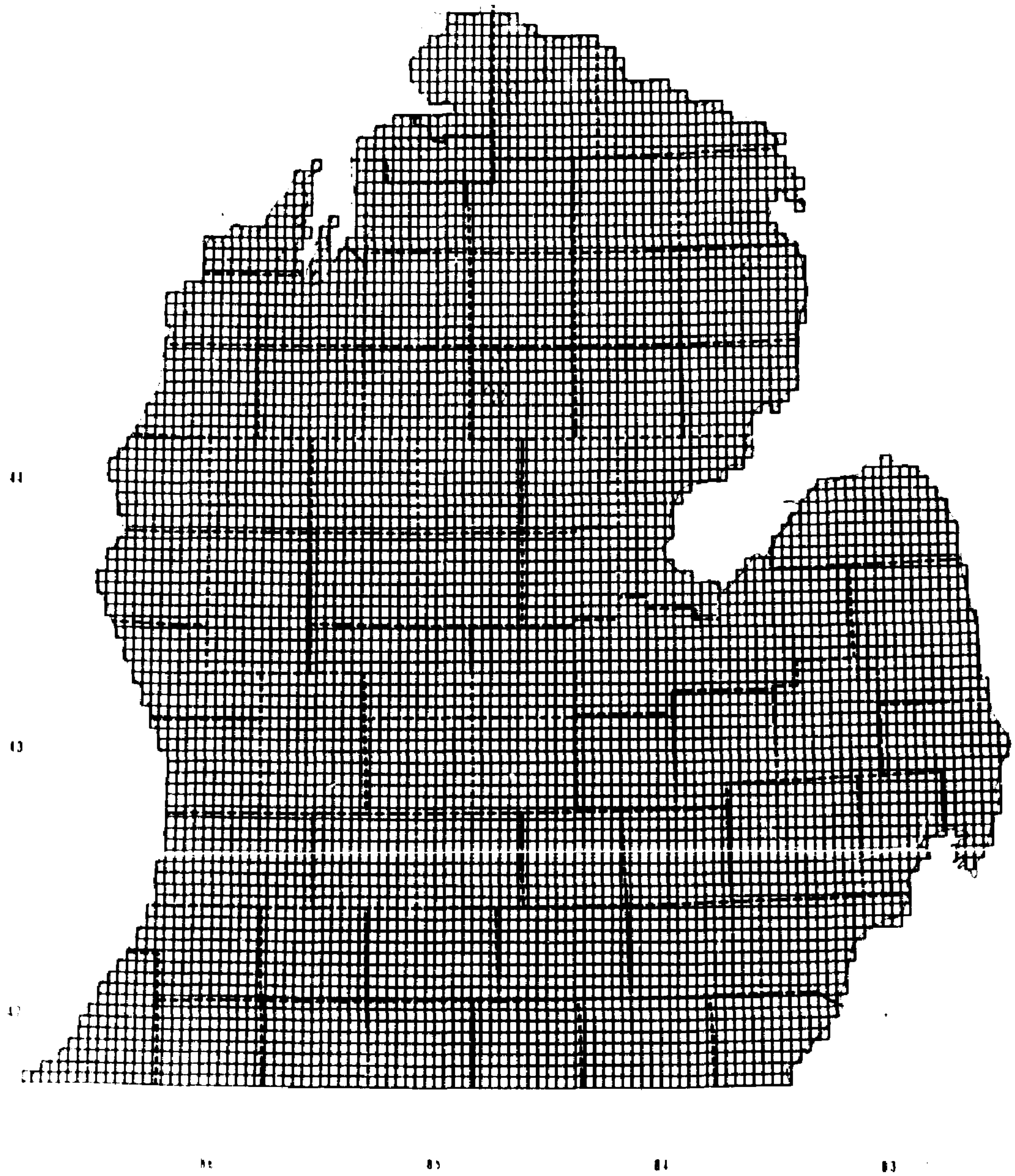


Fig. 7

of contour crossing-counts as a measure of topographic roughness (cf. Chapter 2, Average Slope). The intersections of transects (Fig. 8; A, B, C, and D) provided four systematic locations in each unit for the purpose of taking spot elevations in support of the average elevation parameter (cf. Chapter 2, Average Elevation).

The relatively small size of the 2 1/2-minute unit area permitted the accumulation of a large number of units for a given homogeneous landform type; as a result, only one of eight units failed to produce a prevailing landform type when constrained by the requirement that the landform type must cover 50% or more of the area of the unit. It can be concluded, therefore, that the 2 1/2-minute reticulation avoided the problem of excessive fragmentation of landform types which would have occurred if a larger grid had been used.

Unit areas were arranged in a column-and-row matrix of the study area, and each of the following data were recorded on IBM data cards: (1) matrix location, (2) average elevation, (3) maximum elevation, (4) minimum elevation, (5) local relief, (6) contour interval, (7) length of transect, (8) count of contour crossings, and (9) the matrix location of the eight contiguous unit areas. This procedure allowed the calculation of certain complex parameters, e.g. average slope and comparative relief (see Chapter 2) with the assistance of electronic computers.

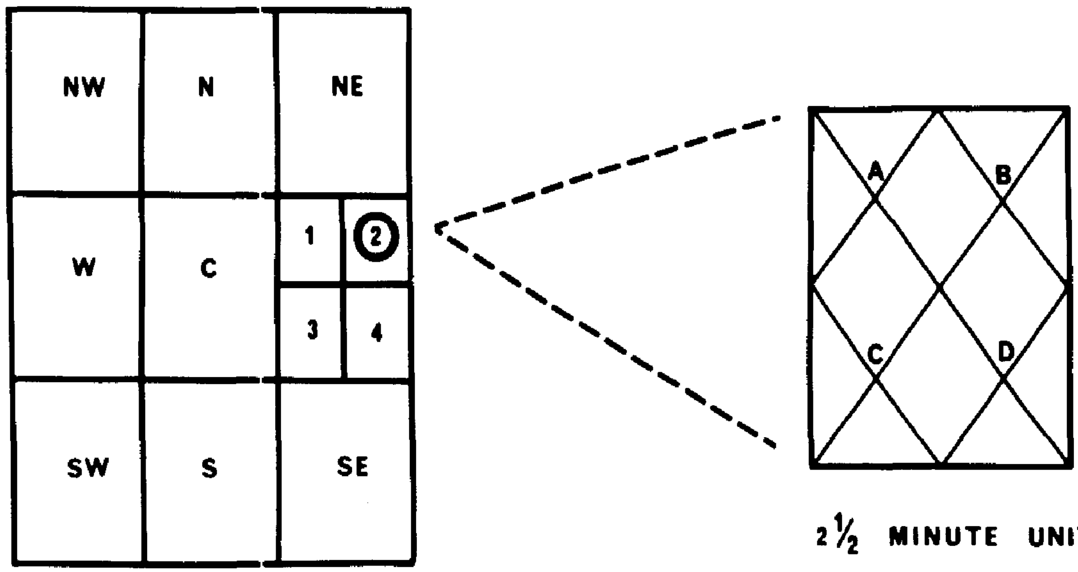
Status of Topographic Coverage

The United States Geological Survey, in conjunction with other agencies of the federal government, is engaged in the compilation of 209 National Topographic Maps with a scale of 1:63,360

Fig. 8

GRID NETWORK OF UNIT AREAS, TRAVERSES, and SPOT ELEVATIONS

Panel 1 **Panel 2**



15 MINUTE QUADRANGLE; CIRCLED: POSITION TWO, EAST SECTION.

2½ MINUTE UNIT AREA, TRAVERSE LINES, AND SPOT ELEVATIONS (A,B,C,D) for the southern peninsula of Michigan. Of these, 144, with a contour interval of 20 feet, were completed at the time of this research (1966) either as published maps or as pre-publication maps of the 15-minute series.

In the present study, the 7 1/2-minute map series (1:24,000 scale) was used in place of the 15-minute series wherever possible (see Fig. 9). This procedure was followed because of the recency of publication (80 of the 207 extant maps appearing between 1963 and 1965 and the smaller contour intervals (5 or 10 feet) of the 7 1/2-minute series. The status of topographic is summarized in Table 2 and Fig. 9; Table 2 states the smallest available contour interval, by a count of affected unit areas, as a percentage of the total study area.

TABLE 2

Status of Topographic Coverage for the Southern Peninsula of Michigan

Contour Interval	Number of Unit Areas	Percent of Total Unit Areas
5	787	11.52
10	2,251	32.95
20	2,980	43.95
50	814	11.91
Total	6,832*	100.00

* Includes 34 units with 50% or more of water surface

For approximately 12% of the study area, the 1:250,000 series of National Topographic Maps provided the largest-scale maps available. This map series has a 50 foot-contour interval and, unfortunately, constitutes the only coverage available for

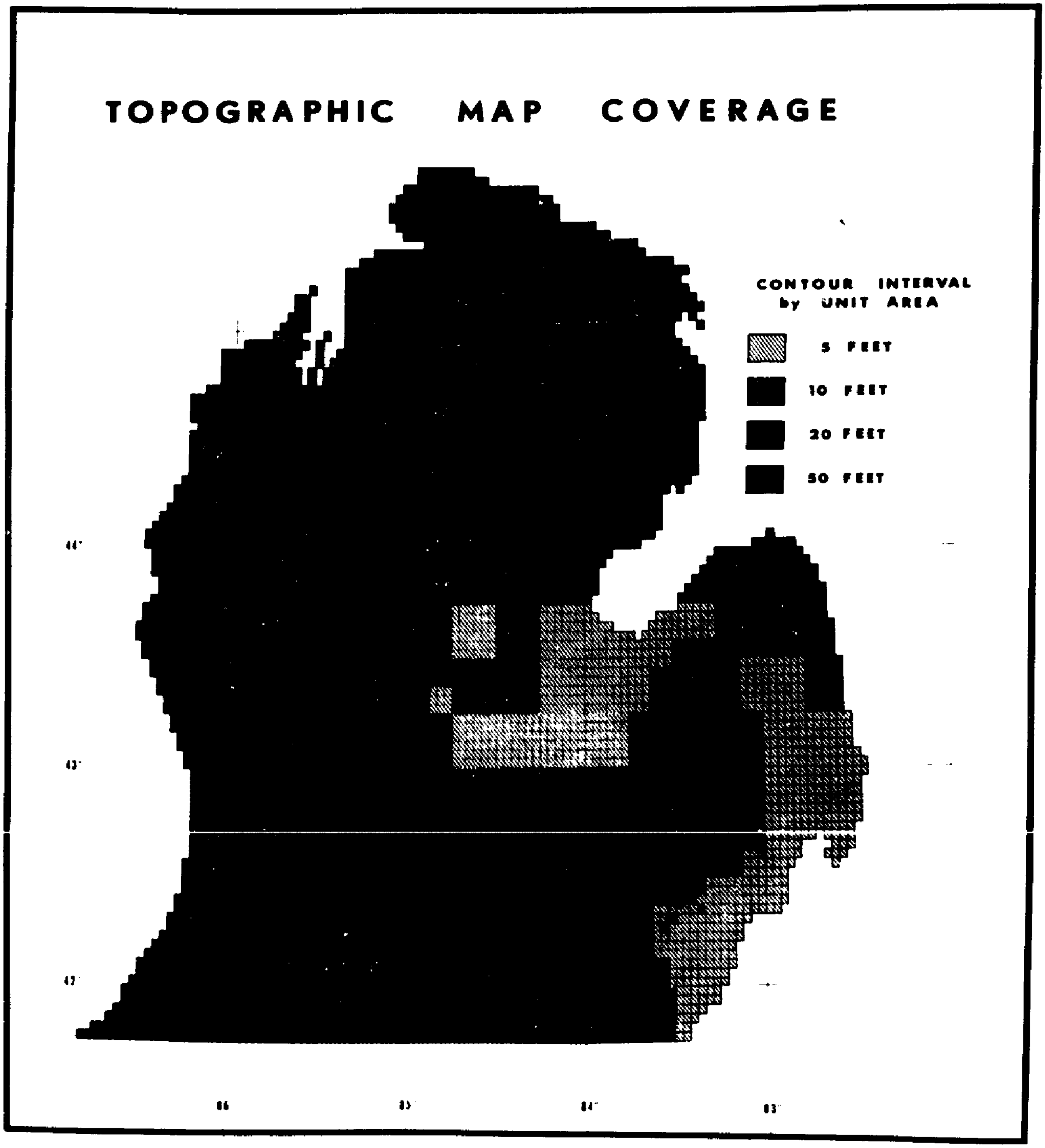

TOPOGRAPHIC MAP COVERAGE
CONTOUR INTERVAL by UNIT AREA
5 FEET
10 FEET
20 FEET
50 FEET

Fig. 9

extensive lacustrine flats in Huron, Clare, Gladwin, Arenac, Presque Isle, and Alpena counties. Because the scale of this series provides a very small 2 1/2-minute unit area (approximately .25 square inches), the 7.2 diamond transect and the four spot elevation were omitted in calculating average slope and average elevation for unit areas in these locations (see Fig. 9).

CHAPTER II

CLASSIFICATION OF TERRAIN PARAMETERS

Rationale for the Selection of Parameters

The selection of specific terrain parameters described in this chapter is based on the three primary attributes of any topographic surface: elevation, relief, and slope. Elevation above sea level quantifies regions of the peninsular landscape at various surface levels within a geographical tract of sizeable proportions (40,000 square miles). At an intermediate scale of study, the local relief dimensions of aggregates of unit areas give morphometric character to the gross hypsometric levels of the peninsula. Slope, an index of such microfeatures as individual hillsides, stream courses, or other surface formations, is localized in large-scale inventory units of the study area.[1]

The problem of selecting morphometric parameters arises out of the availability of a variety of techniques which may be used to quantify the various attributes of elevation, relief, and slope. Elevation of the peninsular landscape, or parts thereof,

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[1]Slope is more localized in area than is relief; when local relief is construed as the elevation change of points separated by some intervening horizontal distance, the "local" character of such elevation change is subject to the control of the intervening horizontal measurement. Slope is an <u>areal</u> characteristic of the topographic surface and is largely confined to restricted, or "local," portions of individual unit areas.

may be evaluated in several ways: (1) as an absolute elevation above the datum plane of sea level, (2) as relative elevation above some local datum plane such as the nearly congruent levels of the surrounding Great Lakes, or, as elevation above the lowest peninsular land-level, and (3) as an average of two or more absolute or relative elevations in arbitrarily designated unit areas.

The relief characteristic of a terrain segment includes, in its broadest sense, all of the geometrical attributes of an undulating topographic surface. This integration of terrain dimensions is implied in the term "relief energy" in which the totality of all sloping surfaces may be assessed in terms of the aggregate pressure generated at a local base point by the overland flow of an imaginary, non-infiltrating fluid cover of constant depth.

The concept of relief energy is somewhat different from the original definition enunciated by Partsch who describes it as "the distance from the level of the (highest) mountain summit and the valley base" within a 32 km^2 section (quoted by Gutersohn, 1932). Krebs (1922) constructed a relief energy map of southern Germany utilizing the elevation change between neighboring landform elements without respect to unit areas. Gutersohn quotes Eckert in rejecting the arbitrary approach of Krebs and Partsch because they fail to quantify the downslope pressure (Energiemasse) -- of a fluid or mobile force -- over a given surface unit (Flächeneinheit).

Local relief, a single aspect of topographic relief, is defined here as the net change between maximum and minimum elevations in unit areas. Regional analyses of local relief, such as Smith (1939) for Ohio, Schaffner (1960) for West Virginia, Chilcote (1953) for McKean County, Pennsylvania, and Straw (1940) for eastern

Tennessee, are all based on the total elevation change within graticules of a precisely defined network of unit areas. Each of these studies represents a pioneer effort in analyzing the relief pattern of a specified region; each study also resulted in the identification of unlike subregions within their respective study areas.

The analysis of topographic slope includes an assessment of the number, area, and inclination of the individual slope facets making up a relief complex. These parameters are principally concerned with the areal concept of slope; slope may also be analyzed as the linear or traverse attributes of terrain and account taken of the slope direction change (up or down) and the length of all such continuous surfaces. Since any finite surface of a terrain model is made up of an infinite number of points, one would have to measure an infinite number of angular values in order to quantify the point-attribute of slope on an irregular terrain model.

In practice, slope representations for limited areas are determined by averaging the inclination of all slopes occurring along the transects of the included tracts. This approach represents a significant generalization of the complex assemblage of discrete or simple slope surfaces of most terrain models. It is not useful to measure the angular inclination of all such slopes, simple or composite,(2) nor is it practical to map the individual slopes in unit areas because of the necessarily small map scales

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(2)A composite slope is made up of two or more (contiguous) simple slope surfaces, each component assuming the same slope direction but exhibiting a significant change in angular inclination at the break-in-slope point.

which must be used in studies like the present one.

The criticism of the average slope method as a technique which "averages out of existence" the difference between steep and gentle slopes is not applicable over most of the study area. The absence of sharp escarpments or steep slopes, combined with the sensitivity of the average slope technique, to subdued slope, justifies its application in place of more sophisticated slope parameters dealing with strike, dip, and angle of slope.(3) These parameters are unsuited to the great variety and abundance of microrelief which characterize the peninsular landscape.(4)

Regional slope studies such as those by Raisz and Henry (1937) for southern New England, Trewartha and Smith (1941) for southeastern Wisconsin, Calef (1950) for northern Illinois, Smith (1939) for Ohio, and Hammond (1957) for Missouri, reflect the traditional concern for analyzing slope as part of the topographic surface. Although Raisz and Henry quantified contour densities on a dasymetric map and Hammond measured the angle of slope at randomly selected points, each of the remaining authors used the average slope parameter in quantifying the relief complex of a regular grid network of unit areas.

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(3)For a summary of these methods see Zakrewska (1967), pp. 138-139.

(4)Carr, Becker, and Van Lopik (1963) describe surface features having less than 10 feet but more than 3 inches of relief as micro-features or microrelief; this definition is justified from a military point of view because such relief provides little impediment to the movement of men or vehicles. In the absence of any other definition in the literature of morphometry, a definition of the term "microrelief" should be proposed which limits the vertical change in elevation of such features to a stated percentage of the total local relief of a given unit area.

The foregoing rationale in support of the selection of parameters is based upon the prerequisite of quantifying, morphometrically, conventional topographic terms used in the description of any terrain surface: elevation, relief, and slope. The selection of average elevation, local relief, and average slope parameters is in keeping with the traditional approach to the morphometric study of topographic surfaces; these choices are also justified by the terrain character of the study area (limited ranges of elevation, relief, and slope values), and the incongruity of geodetic scales on the available topographic and surface formation maps of the study area.

Average Elevation

The average elevation of a topographic surface may be defined as its mean height above sea level or some other datum plane. The representative elevation is obtained by averaging the elevations for a number of randomly or geometrically selected points within a unit area. Average elevation should not be construed as the average of extremes of elevation in an area because such extremes may represent only a small percentage of the total surface area. In this study, the values of maximum and minimum elevations and four geometrically located spot elevations are averaged in each unit area to produce the representative or mean elevation.

Berry (1962:7) asserts that a systematic or aligned network of points does not allow for an equal opportunity to sample all parts of the unit area and is therefore not as reliable as the random selection of points. However, the objective in determining average elevation is to ascertain the modal value which best characterizes the finite number of all elevations within the unit area. The obvious disadvantage in the random sampling technique rests in the possibility that spot elevations may be concentrated in one of the corners of the unit area or, possibly, at the coterminous corners of the four units. Geometrical spacing of spot elevations allows not only the recovery and verification of all elevation readings, but it also provides a more uniform data coverage of the surface of the study area.

The values for the highest and lowest elevations supplement the four values derived from data points at the intersections of transects in each unit area (Fig. 8). The random location of maximum and minimum elevation points serves to recover the principle of equal opportunity cited by Berry. However, minimum elevation points frequently occur in a non-random fashion along one of the four sides of the unit area where a stream reaches its local base level. The use of six elevation points, an approximate ratio of one elevation reading per square mile of terrain, provides a good sample of the range of elevations in a unit and is more accurate in determining a modal elevation than averaging the extremes of maximum and minimum elevations.

The average elevation map (Fig. 10) portrays the major landform divisions of the southern peninsula of Michigan. Two highland formations emerge as the principal topographic features. The northern highland is larger in areal extent, higher in average elevation, and more dissected than the southern highland. While the southern highland displays a prominent northeast-southwest rim along its southeastern boundary, the northern highland contains some of the elements of a topographic amphitheater: a rim of

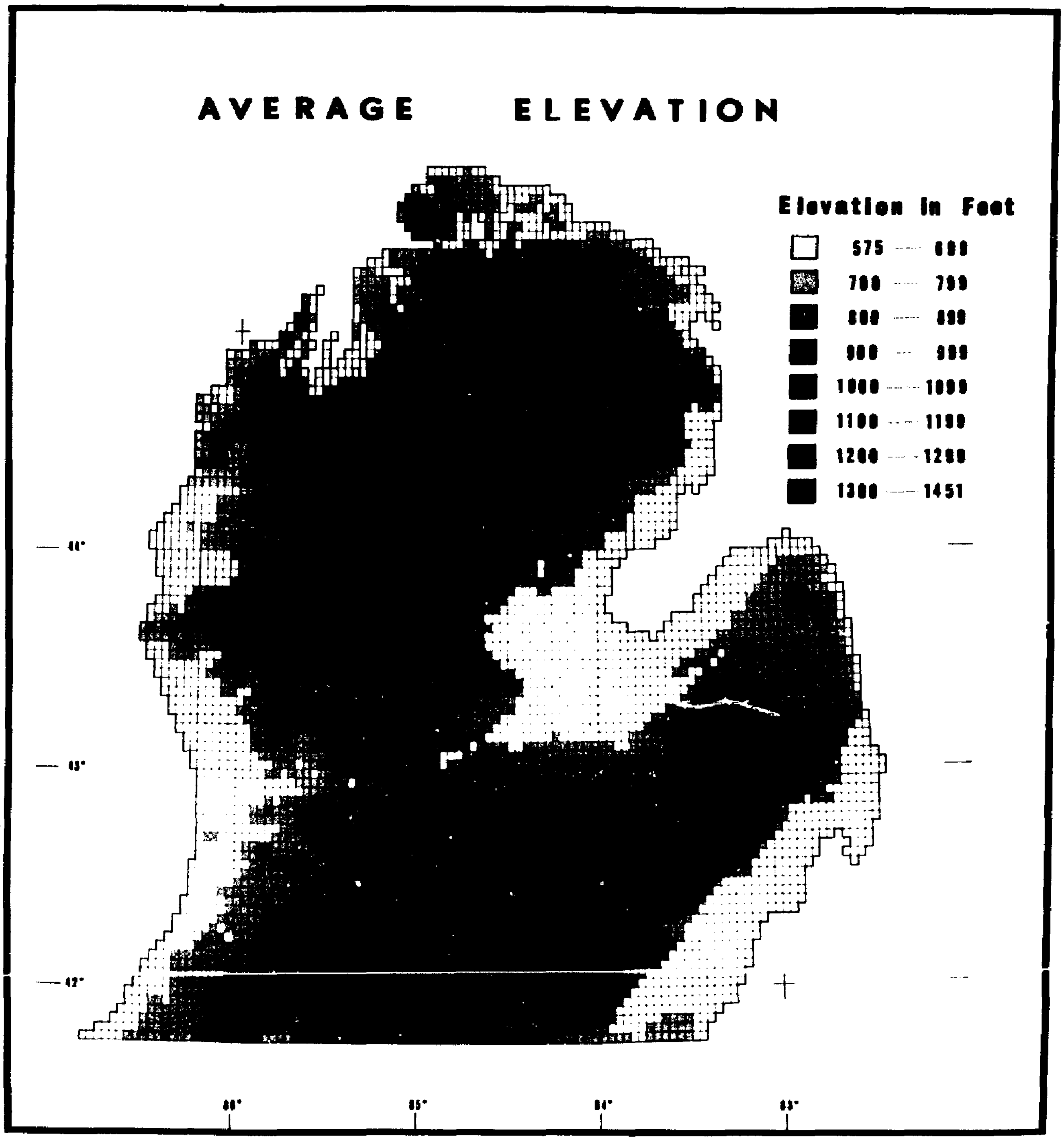


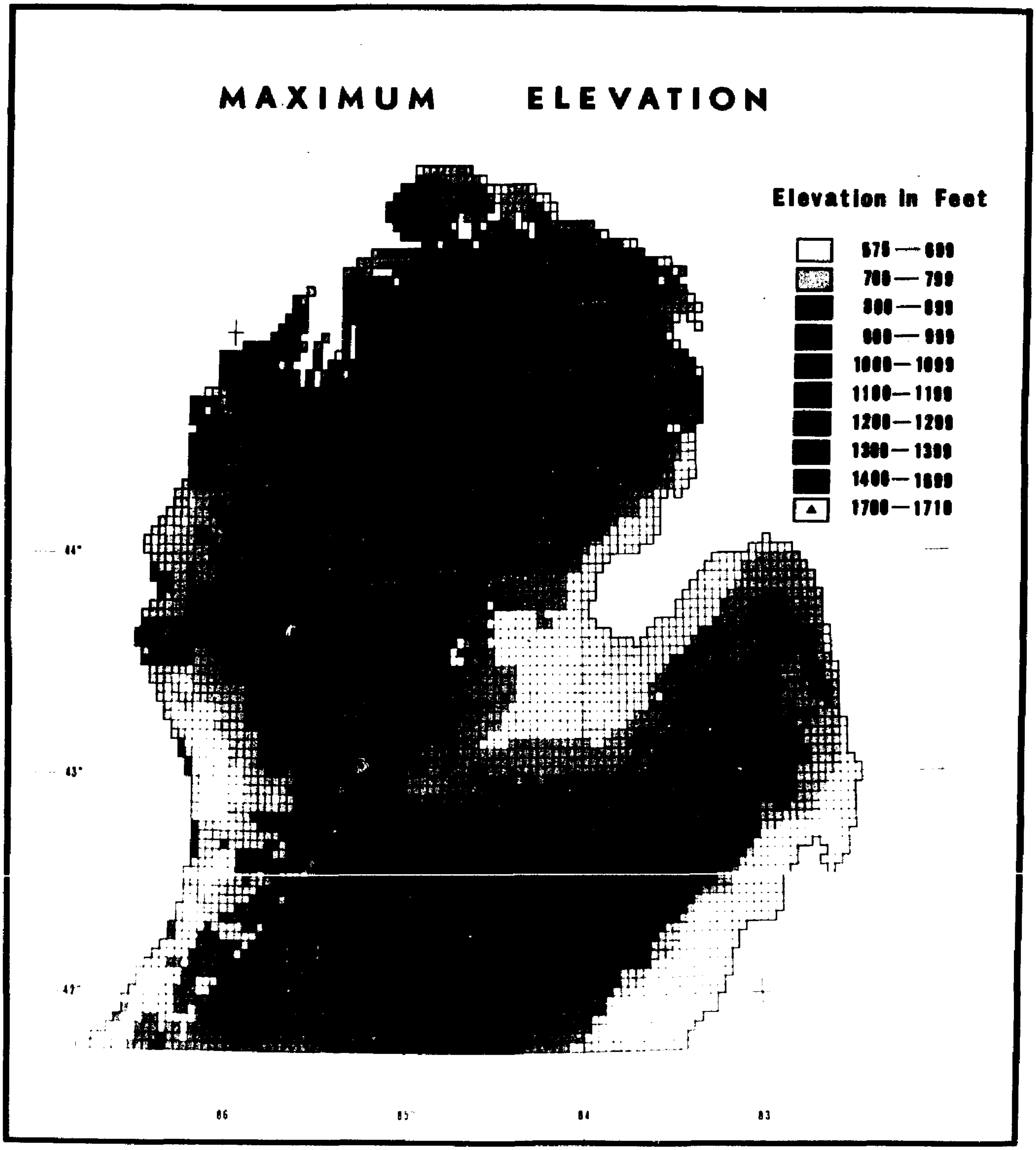
Fig. 10

generally higher elevation surrounds a lower, interior, bowl-like plain containing Lake Higgins and Lake Houghton. The highland rim is discontinuous as the result of breaching by the Muskegon, Au Sable, and Manistee rivers. The primary and secondary cores of the southern highlands, in Hillsdale and Oakland counties, respectively, are also the result of breaching, but less conspicuously so, by the Huron River system.

A discontinuous lowland surrounds the two highland structures; it is broadest in the littoral plains along the east side of the peninsula, and is supplanted by broken terrain with higher general elevation along the northwestern littoral (Traverse Bay). An isolated lowland lies to the west of the northern highland in Mason County. Another western lowland, along the southwestern face of the northern highland and west of the southern highland, is centered on the lower reaches of the Grand River. Fig. 10 lends prominence to the Grand-Maple River depression as the only well-defined and broad-floored valley system of the study area.

Maximum and Minimum Elevation

The maps portraying maximum and minimum elevation (Figs. 11 and 12) result from the more than 13,500 maximum and minimum elevations of the 6832 unit areas. Most of these values are based on interpolated contour values. Errors of interpolation are not likely to exceed one-half the value of the contour interval. In accepting the limits of this assumption, errors approaching 25 feet are possible for only 12% of the unit areas (Table 2) and the remaining 88% should have maximum errors of not more than 10 feet. While errors may approach the one-half contour interval limit in rough



MAXIMUM ELEVATION
Elevation in Feet
700 — 799
800 — 899
900 — 999
1000 — 1099
1100 — 1199
1200 — 1299
1300 — 1399
1400 — 1699
1700 — 1710
44°
43°
42°
86
85
84
83

Fig. 11

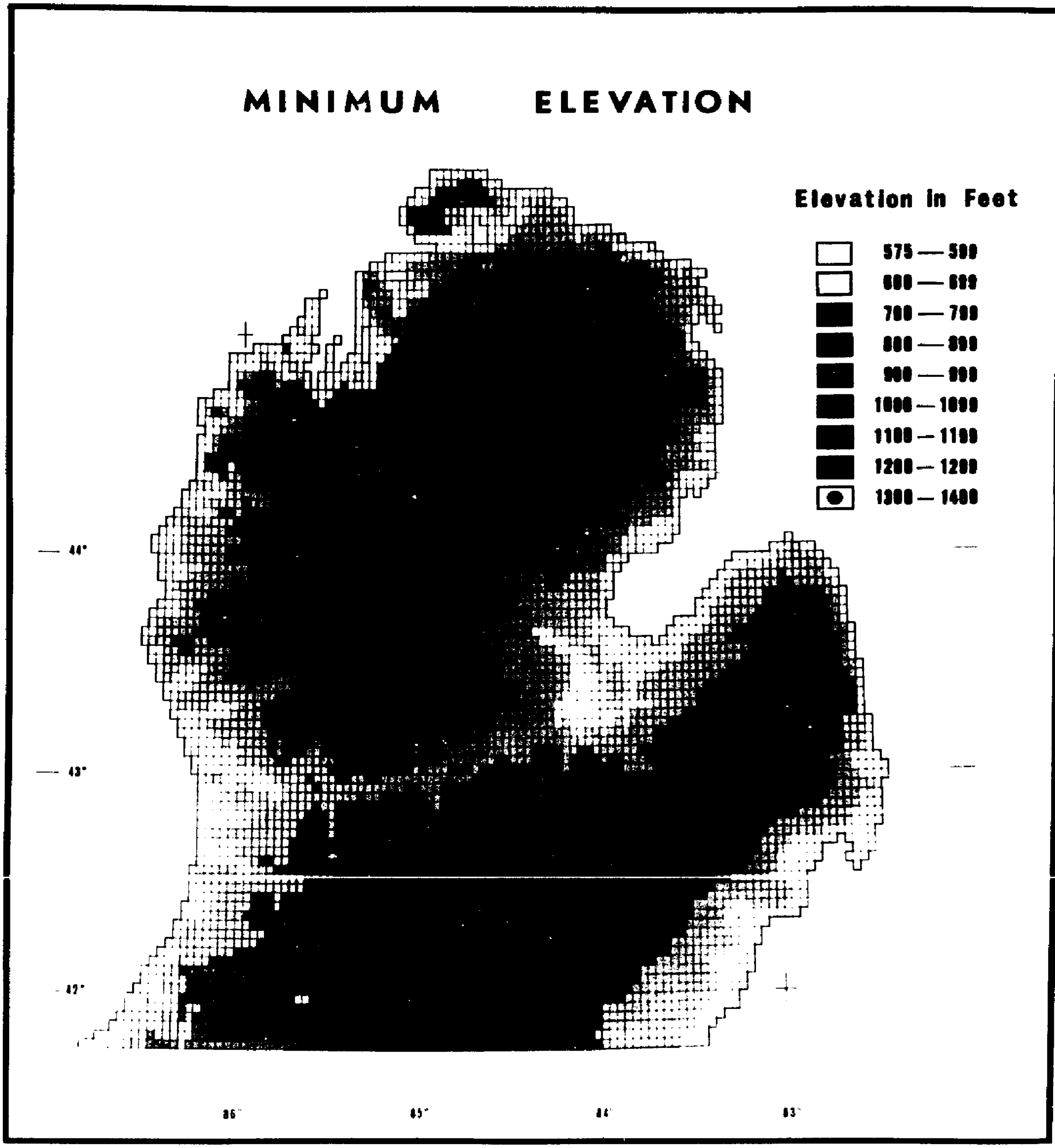

MINIMUM ELEVATION
Elevation in Feet
575 — 599
600 — 699
700 — 799
800 — 899
900 — 999
1000 — 1099
1100 — 1199
1200 — 1299
1300 — 1400
44°
43°
42°
86°
85°
84°
83°

Fig. 12

terrain, a limiting factor of less than one-quarter of the contour interval, i.e. 10-15 feet, is to be expected in flat or only gently undulating topography.

Both of the maps (Figs. 11 and 12) illustrate the extent of the northern and southern highlands. In general, the maximum elevation map conveys a somewhat larger representation of these highland areas; the minimum elevation map, in contrast, provides a clearer rendition of the Grand-Maple depression. Both maps indicate the larger area and substantially higher maximum and minimum elevations of the northern highland as compared with the southern highland. They also reflect the principal and secondary highland cores of the southern highland and confirm the amphitheater configuration, including the river-breached rim, of the northern highland.

The maximum elevation map (Fig. 11) is useful in differentiating the lowlands of the peninsula. It is apparent that the lake border plains on the east side of the peninsula do not exceed 700 feet maximum elevation. By comparison, one-third of the unit areas of the western lowlands, including the sand dune fringe along the Lake Michigan littoral, have maximum elevations above 700 feet. The highest elevations of the peninsula (1700-1710 feet) occur in the northern highland and represent topographic peaks associated with recessional moraines. The maximum elevation map also verifies the existence of an outlier of the northern highland in Emmet County.

The map of minimum elevation (Fig. 12) effectively portrays some features of the post-glacial landscape as modified by fluvial erosion. The northern highland is penetrated by linear depressions of comparatively reduced minimum elevation (700-800 feet) along the courses of the Au Sable, Muskegon, and Manistee rivers. By contrast, the Kalamazoo, Huron, and St. Joseph rivers occupy less well-defined valleys as they traverse the flanks of the southern highland. The Huron River is bisecting a continuous highland ridge connecting the two upland cores in Hillsdale and Oakland counties. The minimum elevation map augments the maps of average and maximum elevation in differentiating a primary core in Hillsdale County and a secondary core in Oakland County.

The combined courses of the Maple and Grand rivers stand out as one of the two linear depressions with minimum elevations of less than 700 feet. In addition, both the maximum and minimum maps mark this trough as the "lowland" route connecting the eastern and western lowlands. Although shorter in linear extent, the Mullet Lake-Burt Lake-Traverse Bay corridor has even lower minimum elevations (less than 600 feet).

Extensive areas of less than 600 feet elevation, associated with Torch Lake and Charlevoix Lake in Charlevoix and Antrim counties, suggest the possibility of a lowland surface; however, this is an area of rough topography with most unit areas assuming maximum elevations in excess of 800 feet. Similar or greater local relief (200 feet or more) in Manistee, Benzie, and Leelanau counties is related to a rapid increase in maximum elevations away from the Lake Michigan shore rather than to an inland penetration of continuing low minimum elevations (less than 600 feet) as is the case in Charlevoix and Antrim counties.

Local Relief

Local relief is defined as the difference between the highest and lowest elevation in a given unit area. The selection of the appropriate size and shape for unit areas is critical in defining both the elevation change of various landform types and the areal extent of regions with different relief character.[5] Oversize unit areas, which may include external relief forms, produce disproportionately high relief values for a given landform, such as a glacial spillway, a morainic hill train, or an outwash plain, may reveal only a portion of the local change in elevation of these landforms.[6]

In dealing with this problem of scale, the use of the 5-minute unit area failed to develop regional patterns of relief and

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(5)Pike (1963) and Wood and Snell (1960), adopting the suggestions of Gutersohn as set forth in Neuenschwander (1944), utilize characteristics of local relief data to determine topographic grain size. After admitting that "The size of an (unit) area on which local relief should be computed has always been questionable," Wood and Snell turn to this same relief attribute of the terrain in order to resolve the initial problem: the determination of a proper size of unit area. This juxtaposition of "solutions" is implicit in their statement that "The sample (unit areas) selected according to grain will give the analyst the <u>optimum</u> size area to take his measurements. This is particularly true when trying to delimit local relief."

Pike states that "With the introduction of the concept of topographic grain (based on local relief), the dilemma (of seeking the proper size of unit areas) has been solved . . ." Because characteristics of local relief are used to determine unit area size (always a geometrical circle), it seems to me that the "dilemma" of seeking a proper unit area size to assess local relief has been compounded rather than resolved.

(6)To derive irregular or topographically-biased unit areas for the Michigan landscape is hardly feasible because it is not a "normal" or mature fluvial surface; it has an intricate or fine-grained mesh which contrasts sharply with the typical ridge-lines and long slopes of a fluvial landscape. With the exception of the drumlin fields east of Traverse Bay, it is difficult to detect any marked grain in the other topographic forms of the study area.

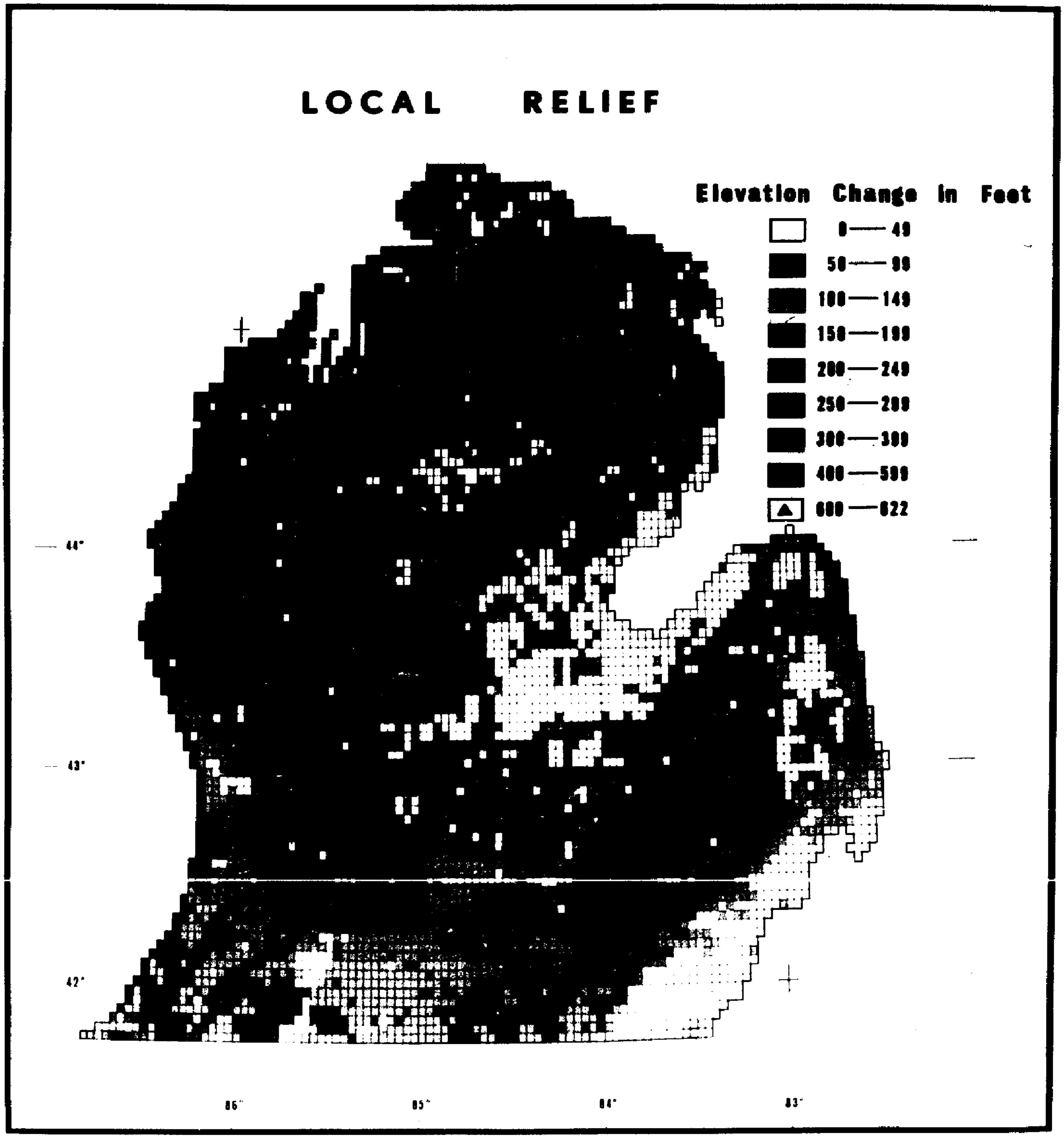
LOCAL RELIEF
Elevation Change in Feet
0 — 49
50 — 99
100 — 149
150 — 199
200 — 249
250 — 299
300 — 399
400 — 599
600 — 822
44°
43°
42°
86°
85°
84°
83°

Fig. 13

it became apparent that the fine-grained topography of the study area required a smaller areal unit to assess the elevation change of individual landforms. The adoption of the 2 1/2-minute unit area resolved these difficulties.[7] The local relief data are displayed in Fig. 13.

Although local relief is utilized in the identification of morphometric subprovinces later on, regions of increased or reduced relief do not entirely correspond with arbitrarily selected elevation levels. A comparison of elevation patterns (Figs. 10-12) with that of local relief (Fig. 13) establishes the general principle that local relief increases with increased elevation. However, analysis of the local relief map points to certain regional anomalies: local relief of less than 100 feet prevails at average elevations above 1100 feet in the Lake Houghton area; conversely, local relief in excess of 300 feet characterizes elevations of less than 800 feet in Antrim and Charlevoix counties.

Another elevation-relief anomaly exists in a broad belt of subdued relief (50-99 feet) extending southwest of the Saginaw lake plains and impinging on higher general elevations (900-1000 feet) along the northwestern flank of the Thumb Upland (Hillsdale to Oakland counties). Although the primary and secondary cores of the southern highland are prominent features on the maps of average, maximum, and minimum elevations, these topographic heights are considerably less apparent on the map of local relief.

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[7]The 2 1/2-minute unit area was also chosen because it provided a large sample of unit areas with 90% or more areal coverage of a specific landform type (Table 5); this size of unit area is also capable of photographic reproduction of grey-tones (at the scale of Fig. 13) in the depiction of regional differences in local relief.

The four maps mentioned above clearly identify the three most prominent topographic breaks of the peninsula: (1) the southeastern rim and slope of the northern highland, (2) the southeastern slope of the southern highland, and (3), less strikingly, the northeastern face or slope of the northern highland. The rapid increase of relief and elevation in these areas produce "belts" of topographic change which parallel rather closely the orientation of the nearest shoreline.

The most extensive area of local relief in excess of 400 feet is found in eastern Charlevoix and in the central portion of Antrim County. As previously noted, these areas of relatively great relief are based on the inland penetration of low minimum elevations (less than 600 feet) while maximum elevations of 800-900 feet begin at the shore and increase rapidly inland.

According to the maps of average and minimum elevation, drumlins seem to occur mainly in the lower areas of the peninsula However, the local relief map distinguishes two contrasting areas of relief: a coastal or outer belt with relief of 150-300 feet and an inner belt of broken topography with relief of 300-600 feet. Water-filled depressions (Torch, Elk, and Charlevoix lakes) occur in the outer portion of the drumlin field, as indicated by the nine unit areas without elevation or relief data (see white spaces, Fig. 13).

Similar areas of broken topography occur in the western half of Emmet County and throughout Leelanau County. These areas are isolated from the drumlin fields of Charlevoix and Antrim counties by Traverse and Little Traverse bays. Significantly greater maximum elevation values, higher by 300 feet or more, are obtained for the morainic hills of Emmet County in comparison to the maximum elevations present in the drumlin formations of the Leelanau peninsula. Local relief in excess of 150 feet clearly marks the Mullet Lake-Burt Lake corridor already evinced on both the maps of average and minimum elevation.

In addition to substantiating the lower general relief values for the extensive peninsular lowland areas, the local relief map clearly differentiates the terrain character of the eastern and western littorals. With the exception of the shore strip extending from Port Huron to the northern tip of Saginaw peninsula, the eastern shore of the peninsula has a local relief of less than 50 feet. Contrarily, the majority of unit areas bounding the western or Lake Michigan littoral exhibits local relief in excess of 150 feet. This shoreline, south of Leelanau County, is characterized by sand dune formations occurring in more than one-half (52%) of the coastal unit areas.

The areas of greatest local relief south of the Maple-Grand demarcation, at elevations of less than 900 feet, rim the eastern margins of the Muskegon lowland in central Kent, western Barry, and southeastern Allegan counties. Local relief in excess of 200 feet characterizes most of the hill county north of Kalamazoo at relatively low average elevations. The only other area with similar relief is found in the highland core of northern Oakland County.

Areas of reduced relief (less than 50 feet) are conspicuous on various upland surfaces in the watersheds of the Kalamazoo and St. Joseph river valleys. Similar flatland occurs at 800 feet of general elevation on the Thumb Upland in Lapeer County. A considerable area of flatlands also appears at higher elevations (1100 feet or more) on lacustrine plains in Roscommon and Missaukee counties. This extensive area of plains is a major feature of the northern highland and makes up much of the lower surface of the already mentioned amphitheater-like configuration of this area.

Average Slope

The mean or average inclination of the individual slope facets of a relief complex, along with that of elevation and local relief, constitutes one of the three fundamental characteristics of any topographic surface.(8) Slope inclination may be measured in either degrees or percent-of-slope which, itself, is based on some angular statement as a "percent" of a 45° slope. Grouping of the slope data may be carried out for the purpose of establishing empirical limits for a qualitative vocabulary which may include such traditional slope terms as "rolling," "steep," or "undulating."(9) Because there is no need to quantify such terms for the purpose of this study, a standard $1/2^{\circ}$ interval is used in the legend of Fig. 14 except in slope classes above 2° where intervals of 1° are used to compensate for a reduced frequency of unit areas

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(8)Pike (1963) ranks average slope first in a weighted ranking of eight terrain parameters used to establish landform regions.

(9)The U.S. Soil Conservation Service formerly characterized slopes in five categories as (1) nearly level, (2) gently sloping, (3) moderately sloping, (4) strongly sloping, and (5) steep, according to precisely stated percent-of-slope limits. Since these qualitative or verbal descriptions failed to equate real slopes with actual drainage, erosion, or crop practices from one soil type to another, the field identification of soil phases is now based on precise numerical percent-of-slope statements (Smith and Aandahl, 1957).

with steeper slopes (See Table 12, 'Total,' for frequency distribution by 1° class intervals).

The method developed by Wentworth (1930:190) is used here in the determination of average slope because it appears to be reliable, reasonably accurate, and useful in quantifying any combination of simple and complex slopes (Carr and Van Lopik, 1962:37). The slope data reproduced in Fig. 14 were obtained according to the requirements of the average slope formula from 14.4 miles of traverse for each unit area (Fig. 8).[10]

Criticism has been directed at the usefulness of the average slope parameter because it takes no account of (1) slope azimuth, (2) changes in slope direction (uphill or downhill), or (3) the length or continuity of such slopes. Each of these criteria are attributes of slope as a linear parameter whereas the average slope technique permits the accumulation of slope <u>in area</u>, a preferable geographic index to most linear profiles.

It can also be shown that a given average slope value may refer either to a long, continuous slope or to a series of shorter

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[10] Following Wentworth, average slope is expressed as follows:

$$S_n = \frac{I\ (N)}{3361}$$

where (S_n) is the slope tangent expressed in degrees of an arc,
(I) the contour interval,
(N) the number of contour crossings per mile, and
(3361) a constant.

For purposes of computer programming, the formula was modified as follows:

$$S_n = \frac{I\ (N)}{3361(14.4)}$$

so that the 14.4 mile traverse, a constant, need not be punched on successive IBM cards; the aggregate contour count along the traverse was entered at (N).

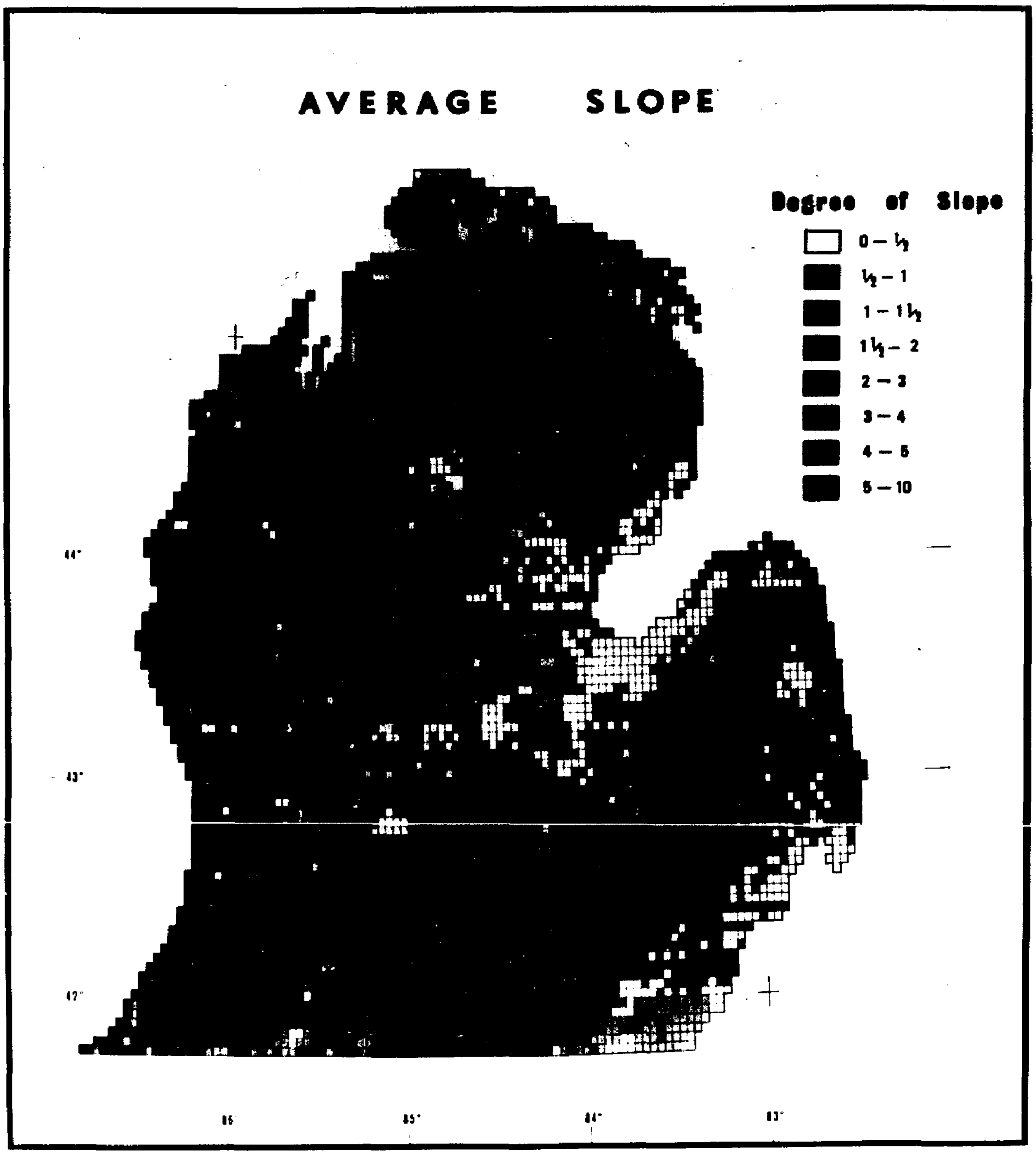
AVERAGE SLOPE
Degree of Slope
0 – ½
½ – 1
1 – 1½
1½ – 2
2 – 3
3 – 4
4 – 5
5 – 10
44°
43°
42°
86°
85°
84°
83°

Fig. 14

slopes of the same inclination but with lower crests and more frequent divides. Because of the lack of strongly oriented, continuous slopes, the average slope map of the study area (Fig. 14) summarizes the mean inclination of the great abundance of short slopes which characterize the study area. As expected, the hilly Michigan topography also exhibits a plethora of individual summits or hilltop levels which are matched by a rich and variegated downslope topography of individual hollows, flats, cul-de-sacs, or valleys.

The problem of contour compatibility, i.e., converting contour counts of one contour interval to an equivalent count at another interval, resulted from the use of several different map series with different contour intervals: three different map scales and four different contour intervals were encountered in aggregating the contour-count along the unit area traverse lengths.

TABLE 3

Comparisons of Area and Traverse Lengths at Varying Map Scales

Map Scale	Contour Interval (feet)	Traverse Length: (Map Distance) in inches	Map Area/ Unit Area: Sq. inches
1:125,000	50	3.6	.54
1: 63,360	20	14.4	6.36
1: 24,000	5 or 10	37.5	41.43

Table 3 itemizes the variation of traverse lengths at the three map scales used in obtaining contour counts. Since each of the different traverse distances represents the same ground distance of 14.4 miles,[11] the larger map scales tend to produce inordinately

[11] A 7.2 mile traverse was used with the 2 1/2-minute unit area of the 1:125,000 map series because of the small size of unit areas at this map scale. Contour crossings were doubled to effect compatible figures with contour counts obtained on the 14.4 mile traverse of the larger scale maps.

high contour-counts due to increased topographic expression, a smaller contour interval, and a more precise depiction of topographic detail.

A sample of 318 unit areas (Table 4) was selected to compare 50-foot and 20-foot contour counts in terrain where duplicate map coverage was available with scales of 1:250,000 and 1:63,360. The unit areas of the sample were selected to represent a range of 50-foot contour-crossings from 0-95 crossings per unit area (Table 4, Classes 1-11).

A conversion factor of 4:1 succeeds in correlating the 50-foot contour-counts, by individual classes, to equivalent 20-foot contour classes. For instance, Class 1 of the 50-foot contour-count is made up of unit areas having 0-6 contour-crossings while Class 1 of the 20-foot contour-count consists of unit areas having 0-24 crossings. An examination of the boxed entries in Table 4, representing the 4:1 correlation of 20-foot and 50-foot contour counts, certifies the satisfactory results of this procedure.(12)

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(12)Contour-counts obtained from the 1:250,000 series were complicated at times by the following difficulties:

(1) Generally poor printing quality of contour lines on the map; it proved difficult to determine whether contour lines crossed or merely touched the traverses.

(2) Poor registration of the lithographic color-separation process; in some cases, the v-shaped registration of contours crossing a stream was not in agreement with the map position of the stream.

(3) Sizeable portions of many unit areas were obliterated by the overprinting of traverse and contour lines by various cultural features and index-contour numbers.

(4) The practice of deleting intermediate contour lines in areas of steep slopes occurred with greater frequency on the 1:250,000 maps than it did on the 1:63,360 series.

Three additional difficulties in making contour-counts were encountered regardless of the map scale:

TABLE 4

Derivation of the 4:1 Conversion of 50-foot Contour Counts

(A comparison of 318 unit areas with known 50-foot and known 20-foot contour counts)*

50-foot Contours		Class	20-foot Contour Counts by Class										
Count	Frequency		1	2	3	4	5	6	7	8	9	10	11
0-6	46	1	40	6									
7-12	35	2	9	15	10	1							
13-19	34	3	1	13	8	5	4	2	1				
20-25	27	4		5	5	12	2	2	1				
26-31	44	5		1	4	11	17	6	2	1	2		
32-37	19	6				2	4	4	3	3	3		
38-44	32	7					1	8	8	9	5	1	
45-50	19	8						3	5	2	7	2	
51-62	34	9							2	5	15	11	1
63-75	11	10									3	6	2
76-95	17	11								1	1	5	10
Total	318		59	40	27	32	38	25	22	21	36	25	13

* U.S.G.S. 15-minute Quadrangles: Boyne Falls, Brown City, Evart, Gaylord, Glennie, Harrison, Marion, Mesick, northern half of Bay City, and southern half of Saginaw.

NOTE: Class conversions shown underlined.

The average slope map (Fig. 14) illustrates the essential agreement in the correlation of greater local relief with steeper slopes in individual unit area (see Relief-Slope Factor, Chapter 4). The district consisting of Leelanau, Charlevoix, and Emmet counties stands out with the greatest concentration of marked relief and steep slope in the entire study area. A secondary concentration of high relief and slope values occurs along the northeast-southwest trending hilly belts of the Roscommon moraine.

The dissection of the northern highlands by three major rivers, the Manistee, Au Sable, and Muskegon, is confirmed by the maps of average, maximum, and minimum elevation; however, only the Manistee River valley has both increased slope and relief values which serve to reveal its unique and more deeply-incised cross-sectional profile. The Muskegon and Au Sable troughs do not appear as valleys of marked slope although their cross-valley profiles also produce patterns of distinctly highly relief values (Fig. 13). This example of increased relief, without concomitant increases in slope values, is the result of the existence of broadly-spaced or

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(1) Multiple traverse-crossings of the same contour line tended to elevate contour counts; this was countered as suggested by Wentworth, by enumerating no more than three successive crossings of the same contour.

(2) Repeated contour-counts, in rough topography, of the same traverse produce a variance of 4%-7%; this was due to the subjective decisions made in judging whether or not contact occurred between the contour and the traverse line. The percentage variation accounts for the difference between the higher and lower counts of a sample of twenty unit areas.

(3) Imperfectly-cut plastic overlays, containing the etched traverse lines, varied slightly in absolute size in comparison to the unit areas being analyzed; this problem is a result of meridional convergence. Any error arising from off-size overlays is minimal in comparison to the other problems of misregistration.

isolated knobs on the generally flat river-floodplains.

The high slope values of the Manistee are due, in the main, to the presence of very steep valley walls -- a profile characteristic not as apparent in the Muskegon or Au Sable systems. A comparison of the slope and relief maps indicates a similar cross-valley profile for the Grand River where it marks the boundary between the northern and the southern highlands. It is interesting to note that the slope and relief values of the Grand Valley, in this area, approach the morphometric character (slope and relief) of the Kalamazoo moraine.

The average slope map fails, as does the local relief map, to identify the primary and secondary cores of topographic heights in the eastern sector of the southern highland. This northeast-southwest trending Thumb Upland is characterized by steeper slopes at lower general elevations (particularly along the southeastern front facing the Detroit lowland) and subdued slopes along the upland axis (at the highest elevations of the southern highland). In contrast to the steepest of these slopes, a broad expanse of moderate slopes (less than 2°) characterizes the area west of the upland ridge. Average slope values of 2°-5° identify the Kalamazoo moraine as the western border of this belt of moderate slope values.

The average slope map depicts the eastern lowlands as areas of extreme flatness (less than 1° average slope); the western lowlands have distinctly higher slope values, the result of a somewhat greater degree of river incisement, the presence of a sand dune littoral, and the preponderance of sandy lake bed topography. The clay lake bed materials of the eastern lowland produce smaller average slope angles. Nearly flat surfaces, similar to those of lacustrine plains, are found on the outwash plains in the Houghton Lake area.

The Elevation-Relief Ratio

The Elevation-Relief Ratio, hereafter referred to as the E-R ratio, provides an index of the ratio of upland to lowland surfaces within unit areas. This ratio is expressed as a proportionate percentage of the total area of the unit area. A high E-R ratio indicates a higher percentage of land above the average elevation of the unit area. A low E-R ratio represents a greater percentage of essentially level land below the average elevation, with some rounded summits rising above the modal elevation value. Fig. 17 illustrates the problem of portraying either upland or lowland surfaces as "essentially level." For most of the peninsular land surface, lowland surfaces are essentially level but upland surfaces tend to have more rounded profiles.

Minimum elevation, a terrain parameter not subject to excessive removal from the average elevation value of most lowland surfaces, and average elevation itself (based on six elevation readings per unit area), provide reliable imputs for calculating elevation-relief.[13] The local relief value, however, may strongly

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[13] The Elevation-Relief ratio is calculated as follows (Wood and Snell, 1960:6-7):

$$ER = \frac{AE - ME}{LR}$$

where (ER) is the Elevation-Relief ratio,
(AE) the average elevation of the unit area,
(ME) the minimum elevation of the unit area, and
(LR) the local relief of the unit area.

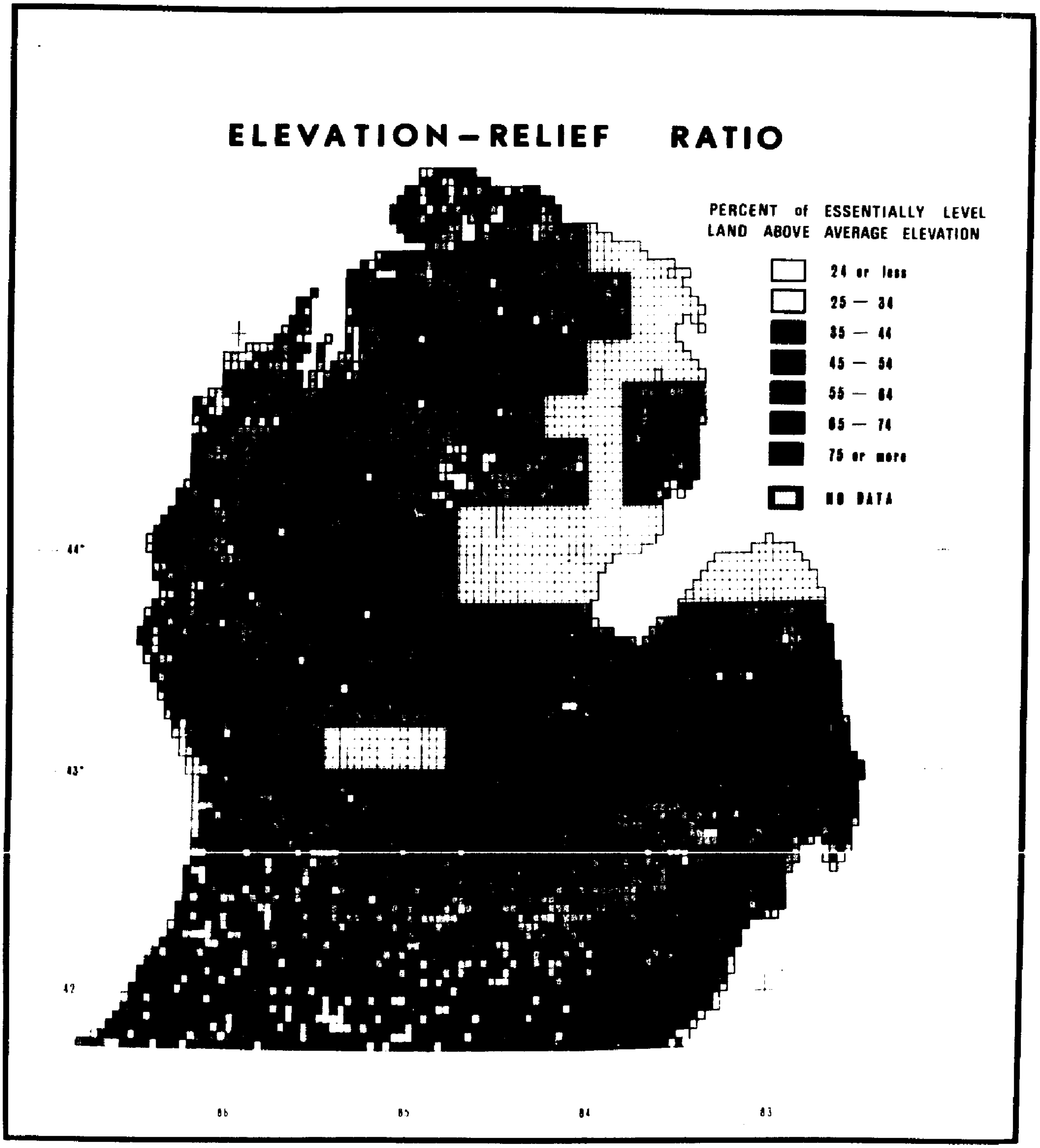
ELEVATION – RELIEF RATIO
PERCENT of ESSENTIALLY LEVEL LAND ABOVE AVERAGE ELEVATION
24 or less
25 — 34
35 — 44
45 — 54
55 — 64
65 — 74
75 or more
NO DATA
44°
43°
42
84
83

Fig. 15

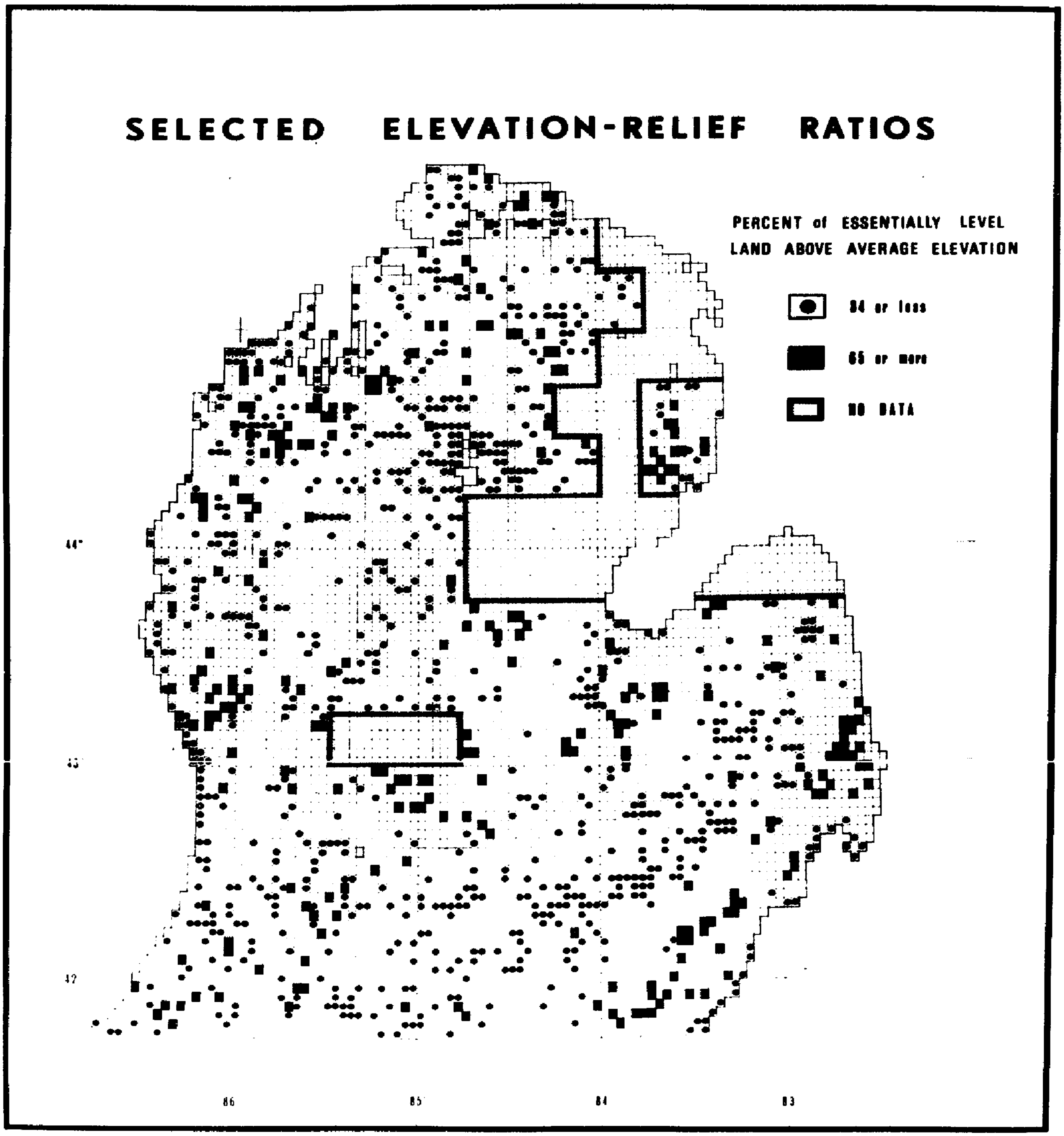
SELECTED ELEVATION-RELIEF RATIOS
PERCENT of ESSENTIALLY LEVEL LAND ABOVE AVERAGE ELEVATION
34 or less
65 or more
NO DATA
44°
43°
42°
86
85°
84
83

Fig. 16

bias the E-R index in a unit area with a single peak and produce an abnormally low E-R ratio. However, this negative aspect of the ratio did not come into play because of the absence of isolated peaks significantly higher than other nearby summits. The infrequent appearance of such discrepancies is explained by the fact that 82% of the unit areas have a local relief of less than 200 feet.

The E-R ratio is particularly sensitive to the difference between average and minimum elevation values in the absence of marked local relief. The utilization of minimum elevation, rather than maximum elevation, takes into consideration the probable existence of a local base level within the unit and the likelihood of essentially level surface at lower elevations.

The range of E-R ratios, represented in Fig. 16, is broken down into three categories: (1) 0%-34%, with lowland surfaces below the average elevation prevailing, (2) 35%-64%, with intermediate surfaces predominating at or about the average elevation, and (3) 65%-100%, with upland surfaces above the average elevation predominating.[14] Approximately 26% of the unit areas occur in the first category. This fact indicates that one-fourth of the peninsular sample units contains some topographic heights which are isolated features of the terrain surface. Unit areas of the first category appear to be widely scattered throughout the study area, although minor concentrations occur in the dune belts of the western littoral and on the highland plains near Houghton Lake.

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[14]The sections labeled "No Data" on Fig. 16 occur in areas for which large scale topographic coverage was unavailable. It was not possible, at map scales smaller than 1:63,360, to obtain the four spot elevations needed to establish a valid average elevation statement.

Only 4% of the study units occur in the third category (65%-100%), and they feature a preponderance of highland surfaces, above the average elevation, in comparison of their respective cells. It is not surprising that the v-shaped profiles suggested by this category are concentrated along the inner portion of the Detroit-Huron lowlands where several rivers are entrenched on the southeastern slopes of the southern highland (see Fig. 16).

The unusually high proportion of unit areas in the intermediate category (left blank on Fig. 16), amounting to 70% of peninsular area, leads to the conclusion that upland and lowland distributions within unit areas tends to concentrate about the 50% modal value. This is a clear indication that anomalous terrain features, i.e., single or isolated summits jutting up from a lowland surface, or, conversely, marked depressions on highland surfaces, are relatively insignificant.

The lack of evidence for such terrain anomalies may be related to the preponderance of unit areas with subdued relief. Additionally, even slight errors in estimating spot elevations may lead to changes of 15% to 25% on the E-R ratios when relief values are less than 25 feet. Only 165 unit areas, however, exhibit such local relief values. Because of the concentration of E-R values in the middle register, this parameter supports the conclusion that marked relief contrasts of surface formations are the exception rather than the rule in depicting the peninsular landscape.

Comparative Relief

The Comparative Relief index, hereafter called the C-R index, was developed in an attempt to test a method for identifying contiguous regions of contrasting relief. The index expresses the degree of relative change by comparing the local relief of a central unit area with the combined differences of local relief values in the eight unit areas surrounding it (Fig. 18, Panel A). This relationship may be expressed as follows:

$$CR = \frac{\hat{\Sigma}_{8} LR}{LR}$$

where (CR) is the Comparative Relief index, (LR) the local relief of the central unit, and ($\hat{\Sigma}_{8}LR$) the sum of the positive and negative change of local relief in eight surrounding units.

The C-R index should be able to delineate regions of little internal change of relief as well as lines or zones of higher index values within the reticulated grid network of unit areas. Such zones (Fig. 18, Panel D) would distinguish adjacent regions with dissimilar but internally consistent relief values. The two regions of dissimilar internal relief, one with consistently reduced and the other with consistently higher relief values, will produce higher C-R values along their borders than within either of the two regions.

The C-R index is a sensitive parameter in detecting subtle changes in local relief such as occur on the subdued terrain of lacustrine formations. Panel A of Fig. 18 demonstrates this sensitivity. The central unit (dashed lines) has a local relief of 10 feet and is surrounded by eight unit areas each of which have a local relief of 20 feet. The sum of the difference in relief between the central unit and the surrounding units amounts to 80 feet which, when divided by the local relief of the central unit, produces a relatively high index value of 8.0.

A secondary use of this index is found in its ability to

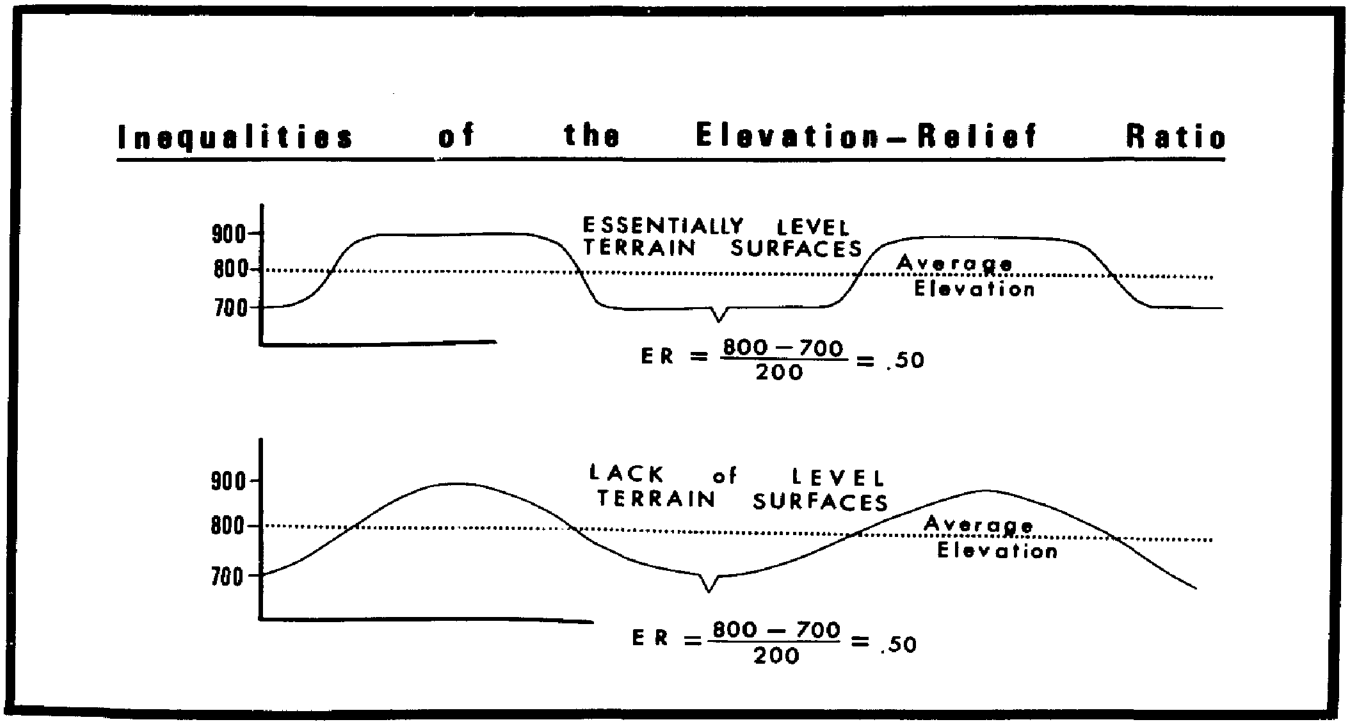
Inequalities of the Elevation-Relief Ratio
900
800
700
ESSENTIALLY LEVEL TERRAIN SURFACES
Average Elevation
ER = (800 − 700)/200 = .50
900
800
700
LACK of LEVEL TERRAIN SURFACES
Average Elevation
ER = (800 − 700)/200 = .50

Fig. 17

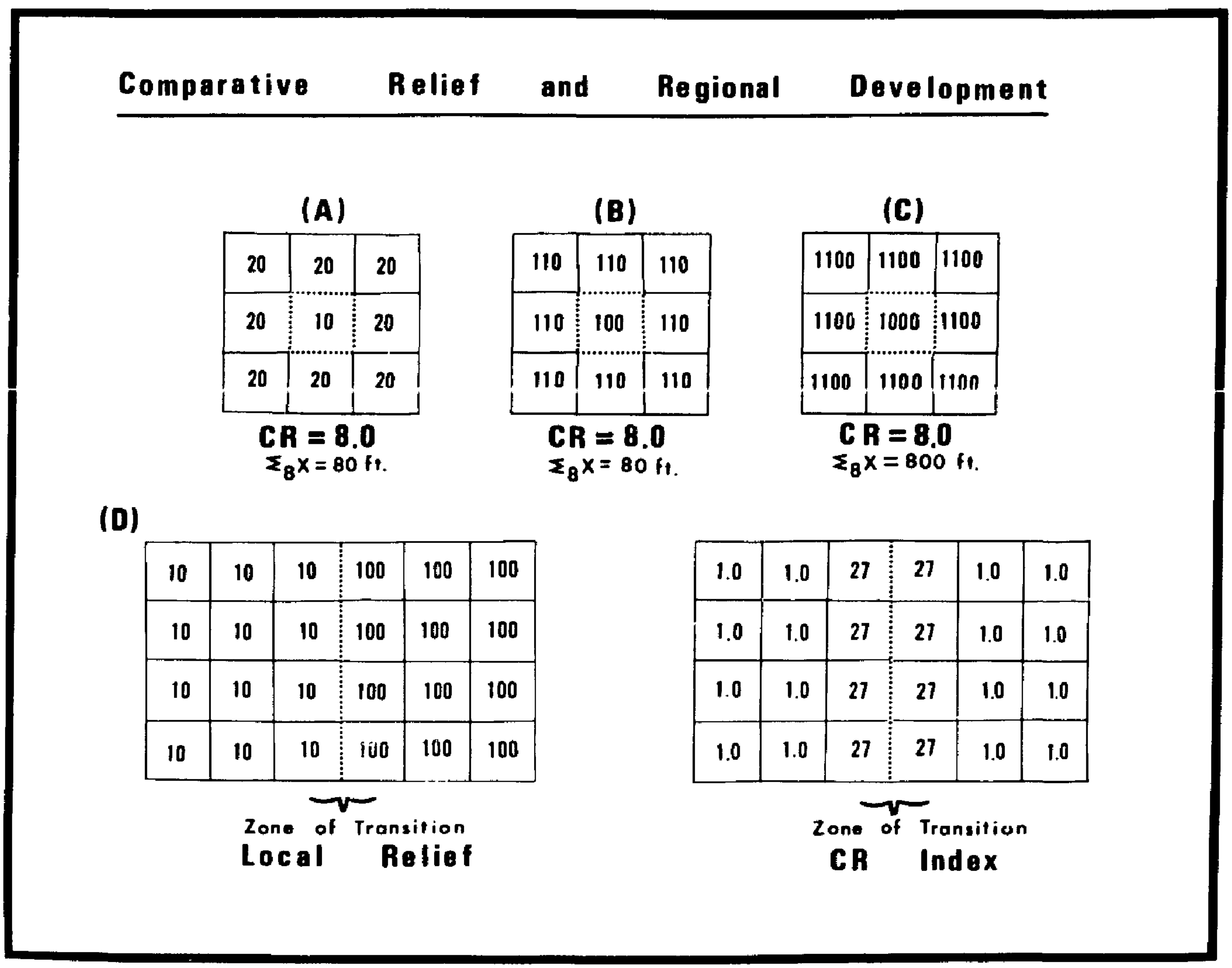
Comparative Relief and Regional Development
(A)
20 20 20
20 10 20
20 20 20
CR = 8.0
Σ8X = 80 ft.
(B)
110 110 110
110 100 110
110 110 110
CR = 8.0
Σ8X = 80 ft.
(C)
1100 1100 1100
1100 1000 1100
1100 1100 1100
CR = 8.0
Σ8X = 800 ft.
(D)
10 10 10 100 100 100
10 10 10 100 100 100
10 10 10 100 100 100
10 10 10 100 100 100
Zone of Transition
Local Relief
1.0 1.0 27 27 1.0 1.0
1.0 1.0 27 27 1.0 1.0
1.0 1.0 27 27 1.0 1.0
1.0 1.0 27 27 1.0 1.0
Zone of Transition
CR Index

Fig. 18

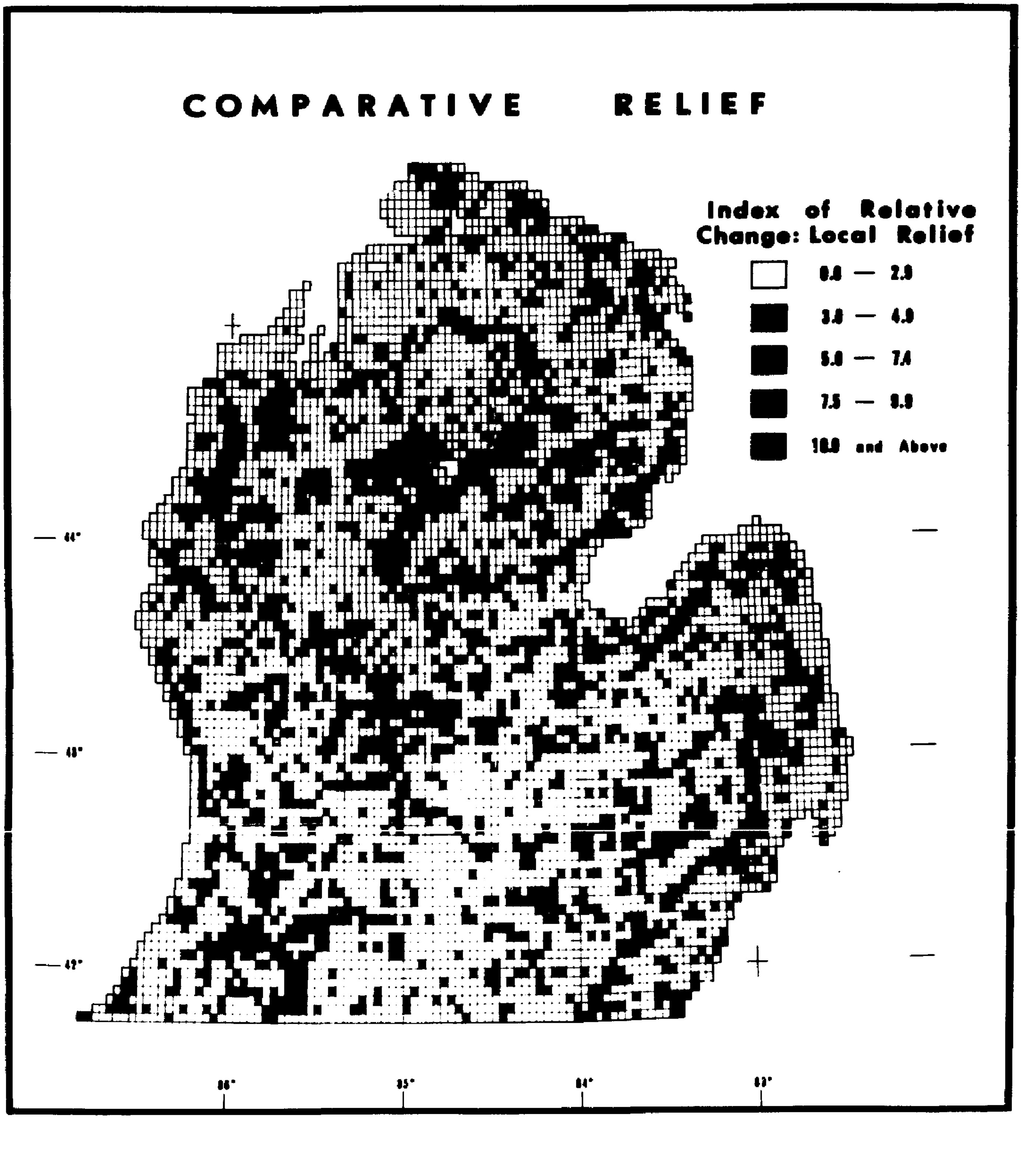
COMPARATIVE RELIEF
Index of Relative Change: Local Relief
7.5
and Above

Fig. 19

delineate rugged terrain of homogeneous internal relief. The higher expected relief summations ($\hat{\Sigma}_8$LR) are offset by the larger absolute relief values common to the units of such regions. For example, Panel B of Fig. 18 demonstrates that regions of high, but similar internal relief (100 feet) produce a lower C-R value (0.8) and confirms the coherent relief character of the region. Other relief summations, on the same order of magnitude (Panel A), will result in substantially higher index values in regions of subdued relief.

The fact that the same C-R value may characterize two different local relief summations constitutes an inherent weakness of this parameter: the C-R value of 8.0 could represent either a central unit with 10 feet of relief surrounded by units with 20 feet relief (Panel A) or a central unit with relief of 1000 feet surrounded by units with relief of 1100 feet (Panel C). Obtaining a relative percentage of change in local relief obscures the magnitude of absolute change between the central unit and the eight units surrounding it. The index is not suited to the delineation of relief boundaries where (1) the horizontal distance required for a change of relief is great, and (2) where there is a lack of homogeneous internal relief within an area.

The results of applying the C-R index to the study area are shown in Fig. 19. Because 84% of all unit areas have an index value of less than 5, the C-R parameter failed to produce an indication of a transition zone (see Panel D, Fig. 18) between two homogeneous regions of unlike relief. The high frequency of low values (61% of all units have a value of less than 3) is due to the overriding character of the reduced composite change ($\hat{\Sigma}_8$LR) for terrain of generally subdued relief. Littoral unit areas, as central units, do not exhibit high C-R values because the summation of relief change does not include surrounding units if they had more than 50% water surface.

In summary, it is not unexpected that the map of Comparative Relief characterizes the peninsular study area as a geometrical surface with few regions of sharply contrasting relief; however, it is possible that transitions between unlike homogeneous relief regions are so gradual that the Comparative Relief parameter is unable to localize these changes.

Review of Diagnostic Indices

Five of the seven parameters discussed in this chapter (excluding the E-R ratio and the C-R index) represent the extraction of specific geometrical identities from the topographic surface of the study area. Each of these parameters succeeds in isolating a discrete terrain dimension but fails, individually, to portray the topographic diversity of the peninsular landscape. The usefulness of any one of the diagnostic maps is based on its association or correlation with one or more of the remaining parameters and, together, the five diagnostic indices verify the existence of certain topographic features which are not evident on a topographic map of a comparable scale.

Certain physiographic features such as land corridors, topographic fronts, highland cores, etc., identified as a map-continuum on one or more of the morphometric maps, are more clearly represented by an areal-symbol in the grey-tone mosaic than by a line-symbol at the scale of the included maps (1:2,000,000, approximately). The contour lines of a topographic map of similar scale, with a contour interval of 100 feet, would serve only to designate the major hypsometric levels of the peninsula: most of the prominent topographic features identified in the preceding chapter are not readily identified on such a map.

The map of average elevation is essentially a simplification of the small-scale topographic map, but a judicious selection of class intervals of the data has produced a representation of the amphitheater-like highlands, the secondary relief cores, and topographic fronts of the two major highlands. As a diagnostic index of drainageway locations, the minimum elevation map provides an excellent basis for comparing the longitudinal profiles of the major rivers of the study area; also, the map of maximum elevation effectively isolates the peninsular summit areas which are even less obvious on the topographic map described above.

A prior knowledge of maximum and minimum elevations, in unit areas, is essential to an interpretation of regional differences in local relief. Increased relief values may not always be due to higher maximum elevations (which normally increase toward the interior), but rather to the influence of minimum elevations which fail to increase toward the interior. Similar values of maximum elevation in both a peripheral and an interior position could produce disparate relief increments based on the change, or lack of change, of minimum elevation. Therefore, all three indices must be integrated in order to assess the significance of any one of the parameters.

Local relief and average slope, highly correlated but nevertheless ordered abstractions of topographic roughness, reflect the attribute of contour-density in topographic source maps. They fail, however, to capture the hypsometric configuration, topographic heights, and major drainageways of the peninsula. The continuity of the terrain subregions -- based on topographic texture -- is best served by the combined application of these two parameters, and evidence is presented in Chapter 4 in support of these being the primary diagnostic criteria in the geomorphic regionalization.

CHAPTER III

MORPHOMETRIC ANALYSIS OF LANDFORM TYPES

Introduction

The morphometric analysis of the major glacial landform types constitutes one of the two major goals of this study. The classification of these landforms was first given and their distribution mapped by Leverett and Taylor (1915) and revised, on the basis of additional field work and air photo analyses, by Martin (1955). In the present study, each landform type is evaluated on the basis of data derived from average elevation, average slope, and local relief (Figs. 27-29).

The range and prevalence of terrain data is discussed under separate sub-headings for each genetic landform type. Regional anomalies and the relationship of glacial processes to specific landform types are sought from an anlaysis of the appropriate morphometric parameters. The histograms of elevation, slope and relief (Fig. 27-29) summarize a primary, lacustrine, and linear classification of the existing landforms to facilitate this analysis.

The description of glacial landforms is based on a survey of only those units in which more than 90% of the area is represented by a single landform type.[1] The locations of these units

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(1)This requirement limits the analysis to 37.4% of the

TABLE 5

Frequency of Landform Types in Unit Areas[1]

Regional Type	Unit Areas: 90% or more Coverage	Percent of All Unit Areas	Unit Areas: 50% - 90% Coverage	Percent of All Unit Areas	Total Number Unit Areas	Percent of All Unit Areas
Recessional Moraines	507	7.45	1084	15.83	1591	23.40
Outwash and Glacial Channels	539	7.93	798	11.74	1337	19.67
Sandy Lake Beds and Spillways	486	7.15	486	7.15	972	14.30
Ground Moraines	300	4.41	623	9.16	923	13.58
Clay Lake Beds	346	5.01	272	4.00	618	9.09
Waterlaid Moraine	20	.29	55	.81	75	1.10
Ponded Water[2]	38	.56	79	1.16	117	1.72
*Drumlins	127	1.87			127	1.87
*Eskers	98	1.44			98	1.44
*Sand Dunes	67	.99			67	.99
*Boulder Belts	21	.31			21	.31
No Prevailing Landform Type	852	24.60			852	12.53
TOTALS	3401		3397		6798**	100.00%

(1) Based on "Map of Surface Formations of the Southern Peninsula of Michigan," Martin (1955).

(2) Lacustrine formations of ponded lakes in the interior of the study area.

* Included on the basis of a trace appearance to a 100% coverage in unit areas.

** Does not include 34 unit areas with 50% or more of water surface.

are presented in Figs. 20-26; these maps should be compared with maps illustrating the areal extent of the same landforms shown in Figs. 2-6.

Counts of unit areas with dominant glacial landforms are summarized in Table 5. Groups of unit areas with noted percentages (50%-90%, 90% or more) of a given formation are expressed as a percentage of all units of the study area.

Primary Genetic Types

The eleven glacial landform types,(2) derived entirely from the M.S.F. map, have been grouped into a three-fold classification of primary, lacustrine, and linear surface formations. Glacial formations occupying units to the extent of 90% or more account for 2549 of the 6798 units of the study area. They are analyzed, according to type, in Table 5 and Figs. 27-29. Each genetic classification contains four specific formations, including those "unclassified" under the primary category.

The primary classification includes four of the areally most extensive landforms of the study area; 63% of the sample units are assignable to the primary group which includes ground moraines, recessional moraines, outwash, and complex or mixed topographic forms. The latter category represents composites of at least three landforms so distributed that none constitutes as much as 50% of a

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6798 units of the study area. Drumlins, sand dunes, and eskers have no coverage requirement for the purpose of this survey.

(2)A twelfth or "unclassified" category of mixed landform types is discussed on p. 68.

unit area. Because unclassified forms occur in nearly one-fourth of the sample units, they are included in the primary group.

GROUND MORAINE (Till Plains)

A sample of 300 units containing till plains gives morphometric validity to this second most common landform of the peninsular study area (see Table 1). Fig. 27 indicates a 73.6% concentration of the sample at elevations of 700-950 feet. Nearly three-fourths of the till plains have a local relief range of 25-125 feet and fully 92% of the units have a relief of less than 200 feet. Ninety percent have average slopes of less than 3° with an approximately equal distribution in Classes 2-5 (Fig. 29).

Approximately 70% of the units representing ground moraine are located south of the Saginaw-Grand River demarcation, at elevations of less than 950 feet; the second maximum (1100-1250 feet) of the bimodal curve (Fig. 27) represents morainic drift fields of the northern highland. They account for 10% of the sample and are found principally in Osceola and Missaukee counties.(3) Another 10% of the sample occurs at 800-950 feet level along the southern fringe of the northern highland (Montcalm and Ionia counties). An isolated area of till plains, at 750-850 feet, lies to the west of Alpena and comprises approximately 8% of the sample.

With the exception of low relief and gentle slope on the till flats to the northwest of Lake Houghton, slopes in excess of

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(3)Statements pertaining to average elevations of a region or county are based on work maps (not included) with a fifty-foot interval; the 100 foot-interval of Fig. 10 utilizes six grey-tones, the maximum number capable of reproduction in this work, to represent the included range of elevation.

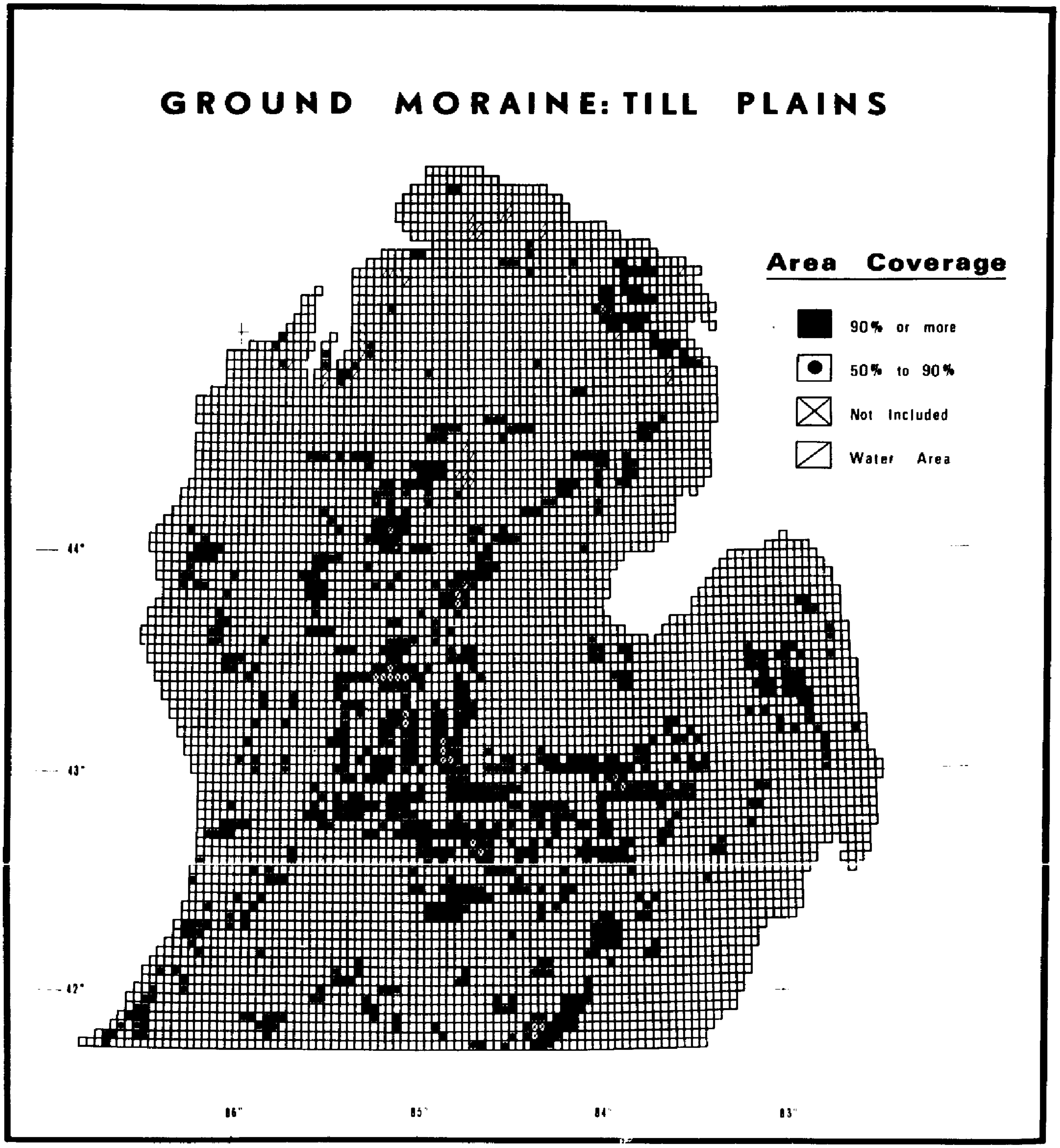
GROUND MORAINE: TILL PLAINS
Area Coverage
90% or more
50% to 90%
Not Included
Water Area
44°
43°
42°
86°
85°
84°
83°

Fig. 20

2^{o} and relief of 100-300 feet express the surface characteristic of till on the high plains of the northern highland. In contrast, more than half of the ground moraine west of Alpena have a relief of less than 100 feet and average slope of less than 2^{o}.

An east-west trending belt of till plains, at general elevations of 800-900 feet, extends from the southern fringe of the northern highland (Ionia County) across the valley of the Grand River and eastward to Lapeer County. It accounts for another 20% of the sample and contains 70% of the till areas with a relief of 50-100 feet. Yet another 20% of the 300 unit sample is located north of this belt, bordering the Saginaw lowland at general elevations of 700-800 feet. The remaining 30% of the sample is found along the flanks of the Thumb Upland (Hillsdale to Oakland counties) at elevations of 850-950 feet; the majority of these units have reduced slopes of 1^{o}-2^{o}. More than 90% of this group has intermediate relief of 75-125 feet.

RECESSIONAL MORAINE

Recessional moraines encompass the largest area (507 units) of steep slope and high local relief (see Tables 1 and 5). Approximately 20% of the moraines sampled have average slopes in excess of 5^{o}; in contrast only 3% have slope of less than 1^{o}. Relief of 100-250 feet characterizes 60% of these hilly formations. Only drumlins have as much as 5% of their units in the upper third of the relief register (400 feet or more) while moraines are ranked second with 4.2%. However, recessional moraines account for nearly one-half (43%) of all units in this register, whereas the smaller drumlin sample makes up only 14%.

Although moraine formations occur at all elevations above 600 feet, more than one-half (58%) are in the range of 750-1050 feet. All moraine units above these elevations, comprising 35% of the sample, are concentrated in Osceola and Otsego counties; these moraines are associated with the highest elevations of the entire peninsula.

The belted morainic hills of the southern highland lie at much lower elevations (Figs. 2 and 10). The Kalamazoo Moraine, for example, has average elevations of only 650-750 feet; the lower portions of this morainic system are thus positioned on the Muskegon lowland. The interlobate moraines of Oakland County have the greatest local (250-300 feet) south of the Saginaw-Grand River line. It occurs at 900-1100 feet, compared with lesser relief (100-200 feet) of the morainic Irish Hills (Hillsdale County) at elevations of 1050-1200 feet.

While 2°-4° slopes characterize the moraines on the Thumb Upland, the interlobate moraines of Barry and Kent counties exhibit less relief (100-150 feet) at lower general elevations (700-950 feet) and surprisingly steep slopes in excess of 4°. This regional characteristic is due to the finer terrain texture of the morainic belts in Barry and Kent counties; the higher average elevation is thus the result of larger areas in slope, per unit, rather than significantly steeper slopes for individual landforms.

Although the Thumb Upland receives 2"-4" greater average annual rainfall, the interlobate complex of Barry and Kent counties have a more complete development of higher-order tributaries to the Grand River and produce greater annual runoff totals (Ash, 1954). The shorter rivers and smaller drainage basins of the Thumb Upland

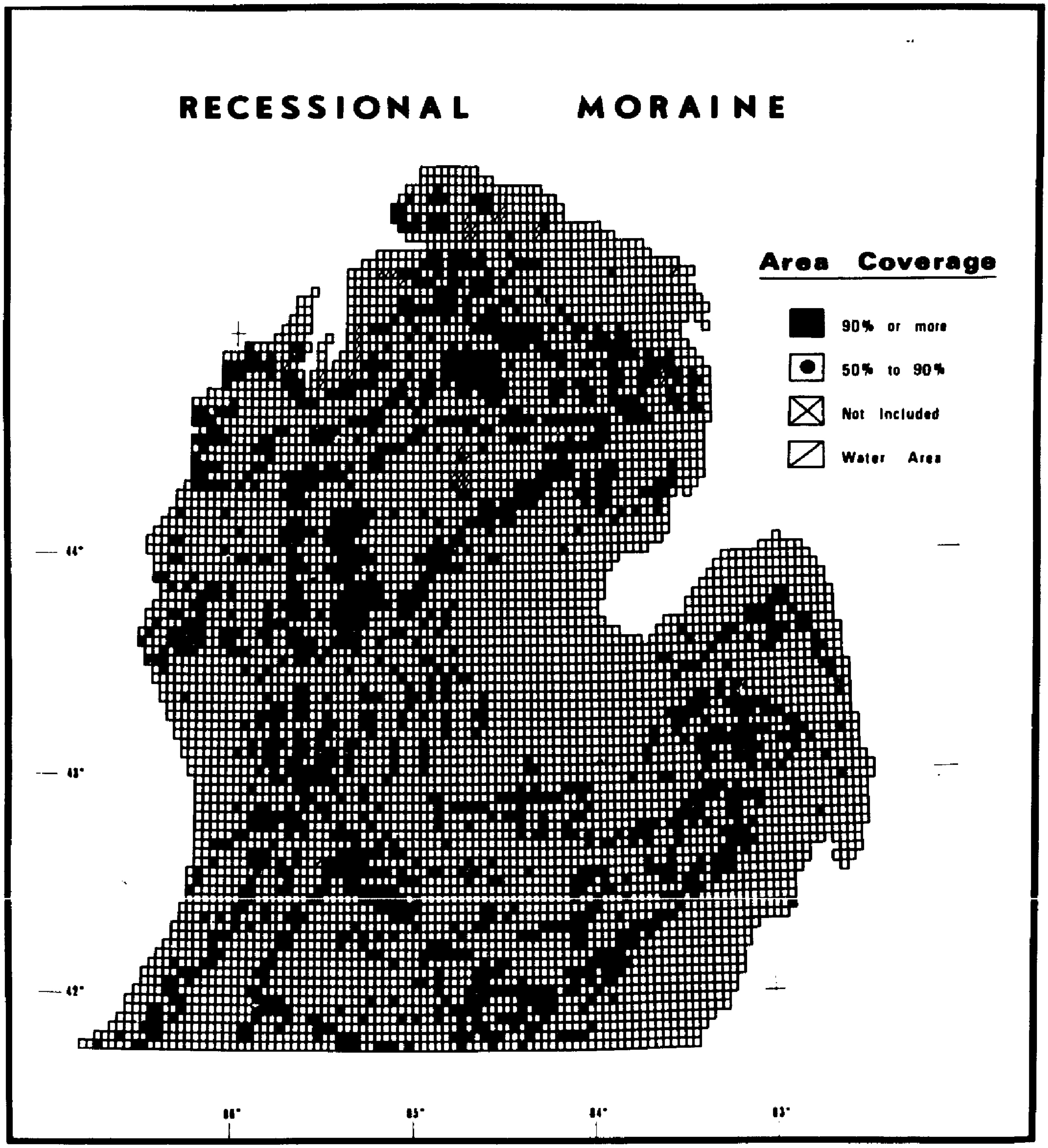
RECESSIONAL MORAINE
Area Coverage
90% or more
50% to 90%
Not Included
Water Area
44°
43°
42°
86°
85°
84°
83°

Fig. 21

are in marked contrast to the intricate channel network of the Grand River system.

Morainic areas of less than 700 feet elevation, constituting 2% of the same, are restricted to the western lowlands of the peninsula -- half of them occur in the Outer Kalamazoo Moraines and the other half in the lowlands east of Ludington and Manistee. The footings of all these recessional moraines were well within the reach of the fluctuating levels of glacial lakes in the Lake Michigan basin.

OUTWASH FORMATIONS

Outwash plains and recessional moraines constitute the prevailing landforms of the northern highland and its associated lowlands; 79% of the outwash and 69% of the moraines, from a composite sample of 1046 units, occur north of the Maple-Grand River line. Outwash trains parallel the major northeast-southwest belts of hilly moraines over most of the highland. Parallel outwash belts bound the Roscommon Moraine, at lower elevations, along its inner or northwest facing margin. In contrast, the topographic heights of the northwestern rim are characterized by outwash formations, rather than morainic hills, with 82% of the units bearing a relief of 100-200 feet. However, the northwestern rim is flanked by outer and, of course, lower morainic belts of even greater relief.

The long western highland rim, capped with morainic hills, is without a similar inner belt of outwash trains. The largest continuous area of these fluvioglacial materials, 30% of the total sample, lies to the west of the highland rim. In turn, only 30%

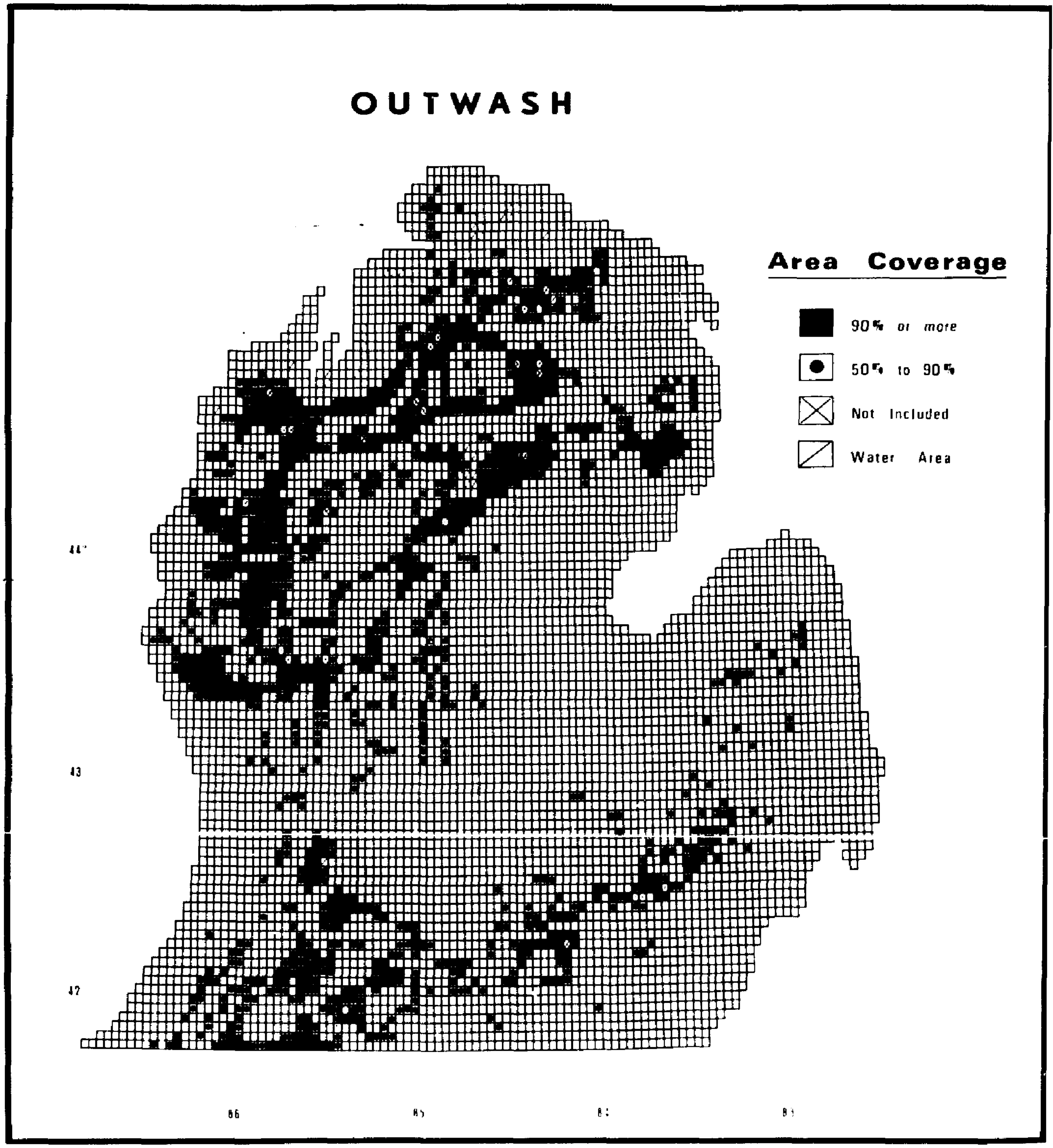
OUTWASH
Area Coverage
90% or more
50% to 90%
Not Included
Water Area
44°
43
42
86
85
84
83

Fig. 22

of this regional aggregate has relief in excess of 150 feet and only 13% less than 75 feet. By contrast, nearly half (47%) of the outwash plains of the southern highland and more than half (52%) of the Roscommon outwash trains have a relief of less than 75 feet.

The comparative analysis of outwash and till plains produces an unexpected result: outwash, i.e., a fluvioglacial landform, manifests steeper slopes and greater relief than till plains (a constructional landform resulting from the uneven deposition of glacial debris by an ablating ice mass). More than one-third (36%) of the outwash terrain has a relief of 125-250 feet in comparison to 22% for the till fields. Slightly more than half (57%) of the outwash areas, but fully three-fourths of the till plains have a local relief of less than 125 feet. Similarly, one fourth of the fluvioglacial units have an average slope in excess of 3^{o} while only 11% of the till do. Also, the former occur over a greater range of hypsometric levels than till plains; they appear nearly twice as frequently as till (34% to 20% respectively) at elevations above 1000 feet.

COMPLEX TERRAIN (Unclassified Formations)

Unit areas with a mixture of genetic landform types constitute a major topographic category in this study. Such formations are characterized by at least three different landform types so that no one formation constitutes as much as 50% of the unit's area. The term 'complex terrain' is used for the lack of a better term. Approximately one-fourth (852 units) of the total sample (3401) consists of mixed topographic forms, a distinctive, though arbitrary, landform "type" of the peninsular study area.

Approximately 80% of the unclassified unit areas have an average elevation of 650-1050 feet and local relief of 50-250 feet and result in negatively skewed distributions in their respective histograms (Figs. 27 and 28). A more balanced distribution occurs in the range of average slope classes (Fig. 29). It is not poswible to account for these variations on the basis of morphometric differences because of the diversity of landforms present. Fig. 26 indicates no significant areal concentration of these mixed formations although unclassified units are notably absent in areas of extensive lacustrine deposition.

Lacustrine Plains

The lacustrine category includes sandy lake beds, clay lake beds, ponded water formations, and waterlaid moraines. Ponded water formations, unlike the other three types, occur as inland, proglacial lake deposits; they are the residual products of fluvially eroded lake deposits. Unlike sand and clay lake bed deposition, these impounded finger lakes produced sedimentation basins down-slope from and perpendicular to the ice front. However, similar processes of quiet-water deposition occurred in both instances; yet, the mantling effects of sedimentation in the finger lakes is incomplete in comparison to flatter lake bed topography at lower elevations. Water-worked moraines, non-lacustrine in origin, are included in this grouping because of their genetic relationship to surrounding lacustrine areas and because of their similar morphometric character (Fig. 6).

There are 894 lacustrine units representing all four terrain types; this amounts to 14.3% of the sample. Morphometric characteristics of low elevation, the lack of apparent slope, and reduced relief are typical of each lacustrine type described below.

LAKE BED FORMATIONS

Bxtensive regions of lake bed topography prevail in the eastern and western lowlands of the peninsula. Because 50% of all lake bed formations of the sample occur in the category of "90% or more coverage," the concentration of units in those lowlands produces the largest continuous "type-terrain" surface of the study area. No other genetic formation appears in a higher percentage or has a greater number of units in the "90% or more" category, nor is any other formation type more concentrated in a restricted sector of the study area. Because of these two factors, lake bed topography is the most extensive and most continuous terrain surface of the peninsula (Figs. 23 and 24).

Nearly twice as many of the clay bottomlands have a local relief of less than 50 feet as compared to the sandy beds. Part of this difference is due to the inclusion of glacial spillways in the sandy lake bed category; these spillways, often occupied by underfit streams, occur at higher elevations in the southern highland (Figs. 6 and 24). The fact that 16% of the sandy beds have slopes exceeding 2^{o}, three times the percentage of clay beds, is partly due to the increased erosional capacity of streams with steeper gradients at elevations above 750 feet. Lake beds usually occur at elevations of less than 750 feet; 85% of the sandy beaches and 95% of the clay bottoms do so.

Because three-fourths of the clay floors and 56.5% of the sandy bottoms have average slopes of less than 1°, lake bed topography is essentially a geometrical plain except where stream banks occur. This combination of a genetic landform type and a distinctive terrain surface will be used for the delineation of specific lowland subregions in Chapter 4.

Figure 23 illustrates the absence of clay lake bed topography on the western lowland while Figure 24 confirms the presence of sandy lake bed surfaces on both sides of the study area. This east-west contrast of lowland surfaces is probably due to the virtual absence of limestone and shale in the source regions of the Lake Michigan lobe whereas the Saginaw and Lake Erie lobes originated in regions rich in argillaceous shale and calcerous materials.

MINOR LACUSTRINE FEATURES

Waterlaid moraines and interior proglacial or ponded water formations comprise less than 1% of all unit areas and stand in marked morphometric contrast to one another. This contrast is implied by the very different processes from which they originate. Waterlaid moraines are landforms produced at the margin of a rapidly melting ice lobe. Unlike the sub-aerial recessional moraine, the waterlaid moraine (subaquatic in origin) has been largely destroyed by the sorting action of currents and waves in shallow water at the margin of the ablating ice lobe. Ponded water formations, in contrast, represent brief lacustrine phases of ice- or moraine-impounded spillways. As previously noted, these spillways have greater relief and slope characteristics than any of the other three lacustrine

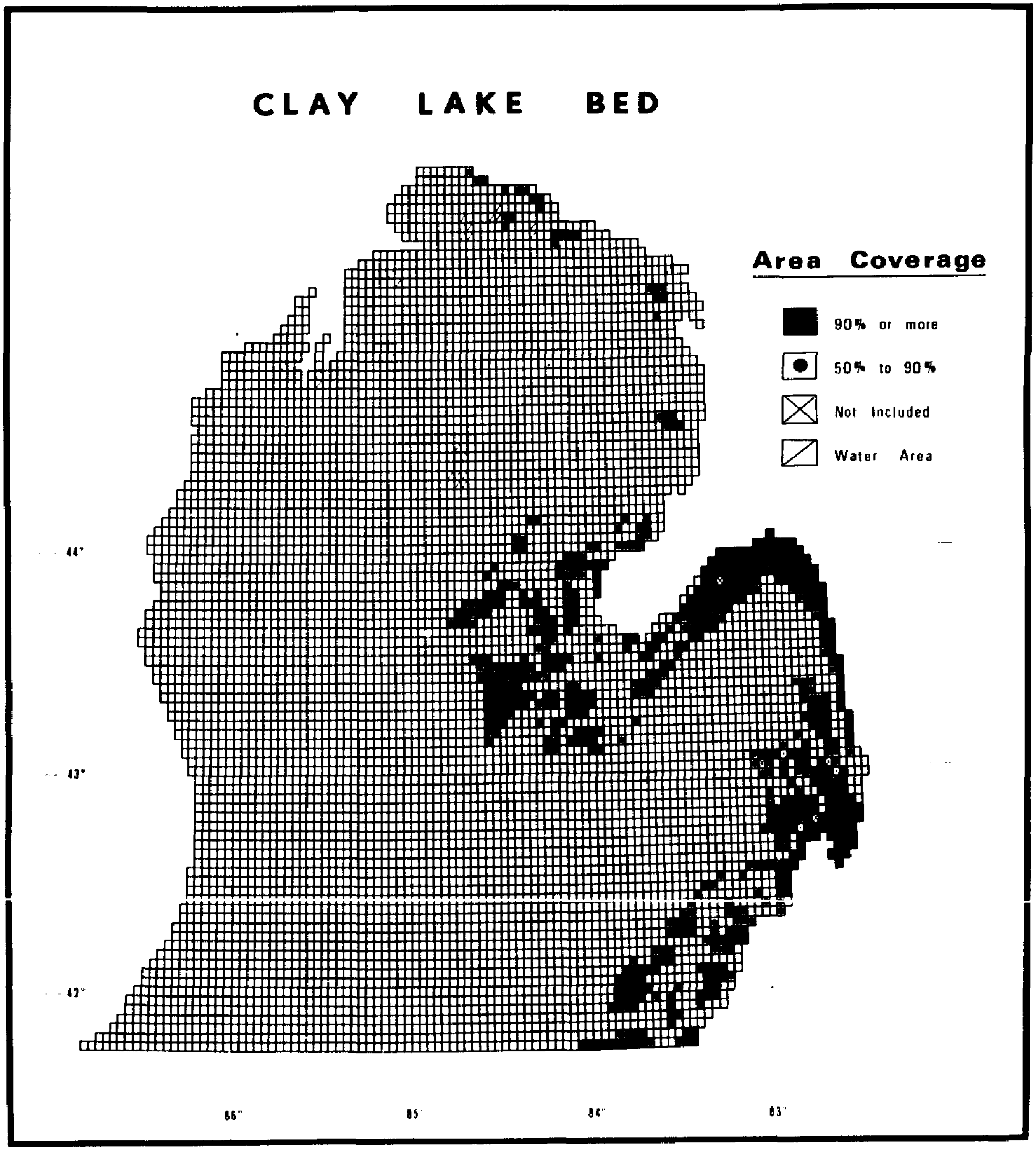
CLAY LAKE BED
Area Coverage
90% or more
50% to 90%
Not Included
Water Area
44°
43°
42°
86°
85°
84°
83°

Fig. 23

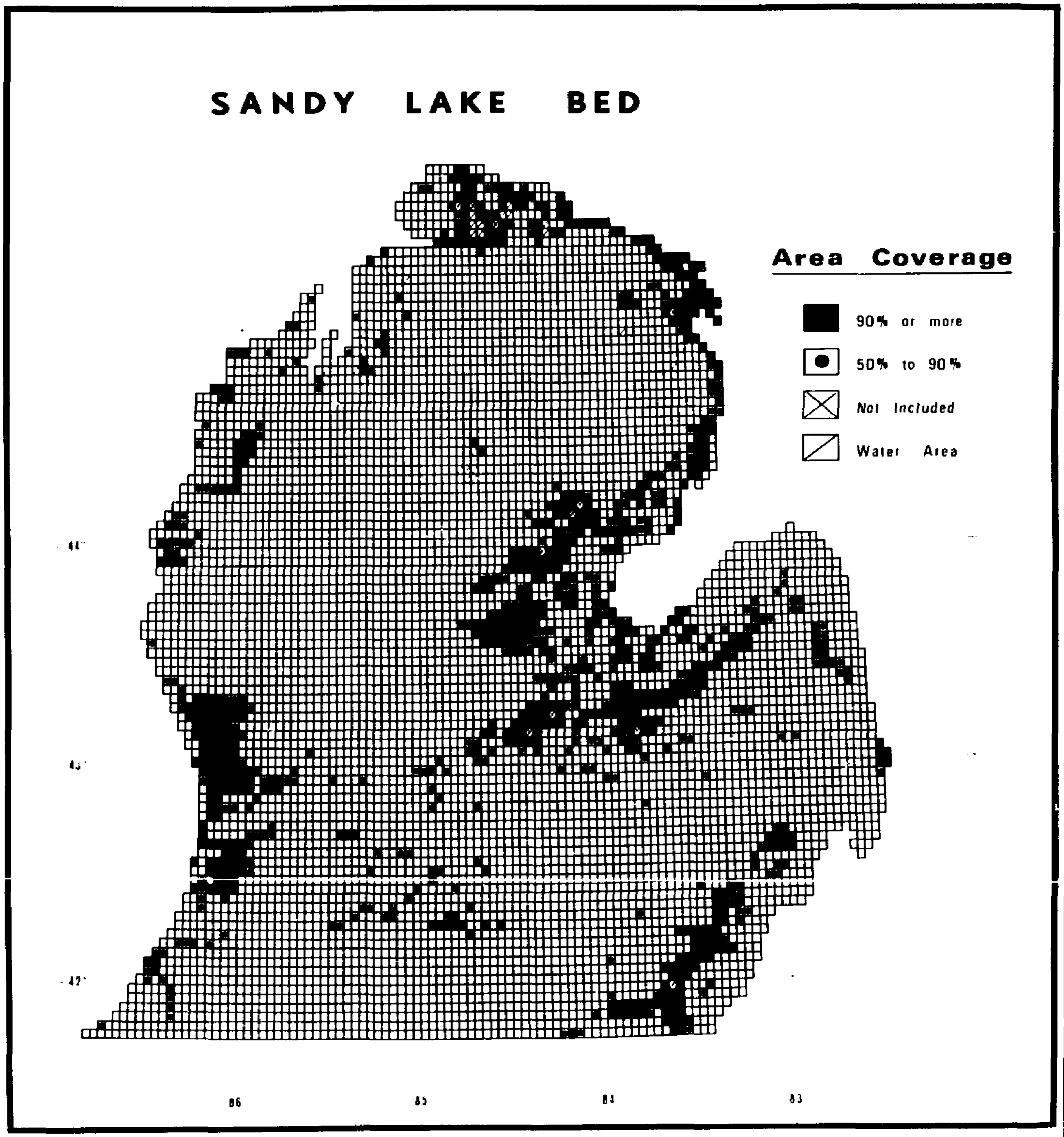
SANDY LAKE BED
Area Coverage
90% or more
50% to 90%
Not Included
Water Area
86
85
84
83

Fig. 24

formations.

The proglacial mantle of lacustrine sediments, confined to the spillway courses of former glacial streams, have been affected by greater rates of stream erosion. Four-fifths of the ponded water sample are located above 750 feet where the effectiveness of stream erosion is enhanced by greater stream gradients. Secondary relief and slope characteristics become evident when the interior lake formations are compared with waterlaid moraines. Less than 30% of the former have average slope of $0^{\circ}-1^{\circ}$; more than 80% of the latter do. Similarly, more than half of the ponded water formations display a local relief in excess of 100 feet, whereas only 10% of the water-worked moraines may be consigned to this register.

Waterlaid moraines and lake beds share similar morphometric characteristics: subdued relief at lower general elevations and a marked lack of steep slope and slope direction change (Figs. 27-29). These similarities, in addition to the enclave position of such moraines on the lake bed plains of the Detroit lowland (Fig. 6), account for their inclusion as a minor lacustrine feature.

The distinction of well-stratified and relatively poorly sorted drift deposits, in lake beds and waterlaid moraines respectively, provides a poor basis for differentiating them into two separate types since their morphometric dimensions provide little indication of their topographic differences. However, the identification of different depositional materials is significant with respect to the processes of differential erosion which have, to a degree, and will continue to produce contrasting terrain surfaces.

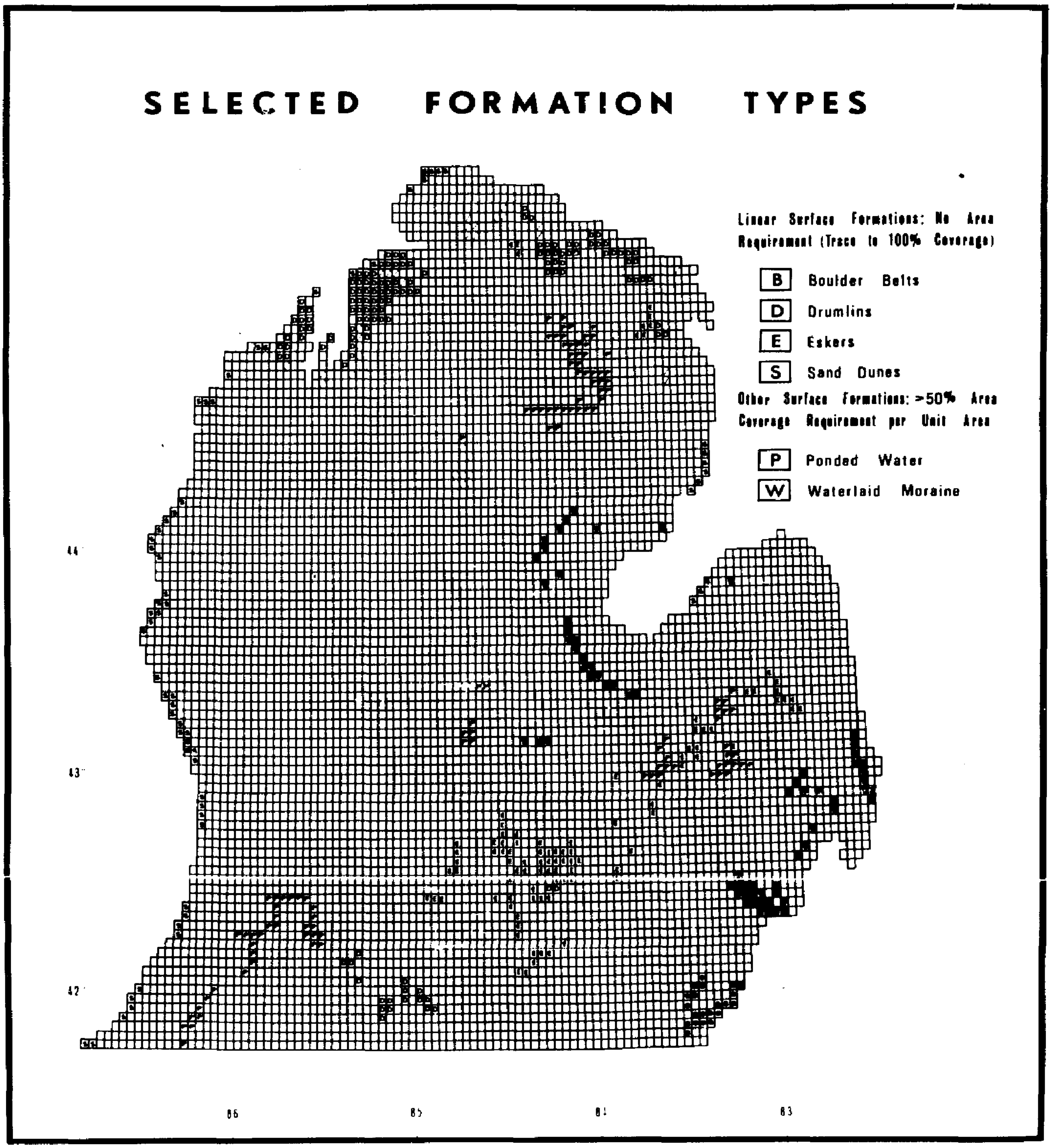
SELECTED FORMATION TYPES
Linear Surface Formations: No Area Requirement (Trace to 100% Coverage)
B Boulder Belts
D Drumlins
E Eskers
S Sand Dunes
Other Surface Formations: >50% Area Coverage Requirement per Unit Area
P Ponded Water
W Waterlaid Moraine

Fig. 25

Linear Landform Types

The linear category of Michigan landforms includes drumlins, eskers, sand dunes, and boulder trains. Each of these landforms, with the exception of boulder belts, is identified in unit areas on the basis of the "trace to 100% coverage requirement; this creiterion is introduced here for the first time. Since a planimetrically undefined symbol is used on the Martin (op. cit.) source map, it is not possible to determine with exactitude the areal extent of drumlins, sand dunes, or boulder belts in a specified unit. The presence of a single symbol met the standard of the "trace" appearance. In no case were sufficient symbols present to indicate a 90% or more coverage in any of the six-square-mile unit areas.

Linear landforms, with the exception of the boulder trains of Monroe County, are conspicuous topographic features. The "linear" designation properly identifies the trend-line characteristic of the four types; the term "sand dune" may imply a conical form, but, at the map scales used in this study, the coalescing dunes of the western littoral constitute a definite ridge-line.

The pertinent group of units comprises only 4.6% of the study area. Because of the "trace to 100%" assignation, drumlins, eskers, and sand dunes may be easily recognized on topographic maps as single grains or individual terrain compartments. A morphometric analysis may be made of individual landform representatives and these randomly selected samples may be used to give statistical validity to the entire collection of a given landform type (Salis-Bury, 1960); however, the morphometry of a collection of given genetic landforms (as individual grains) may produce the same

COMPLEX TERRAIN
(UNCLASSIFIED UNIT AREAS)

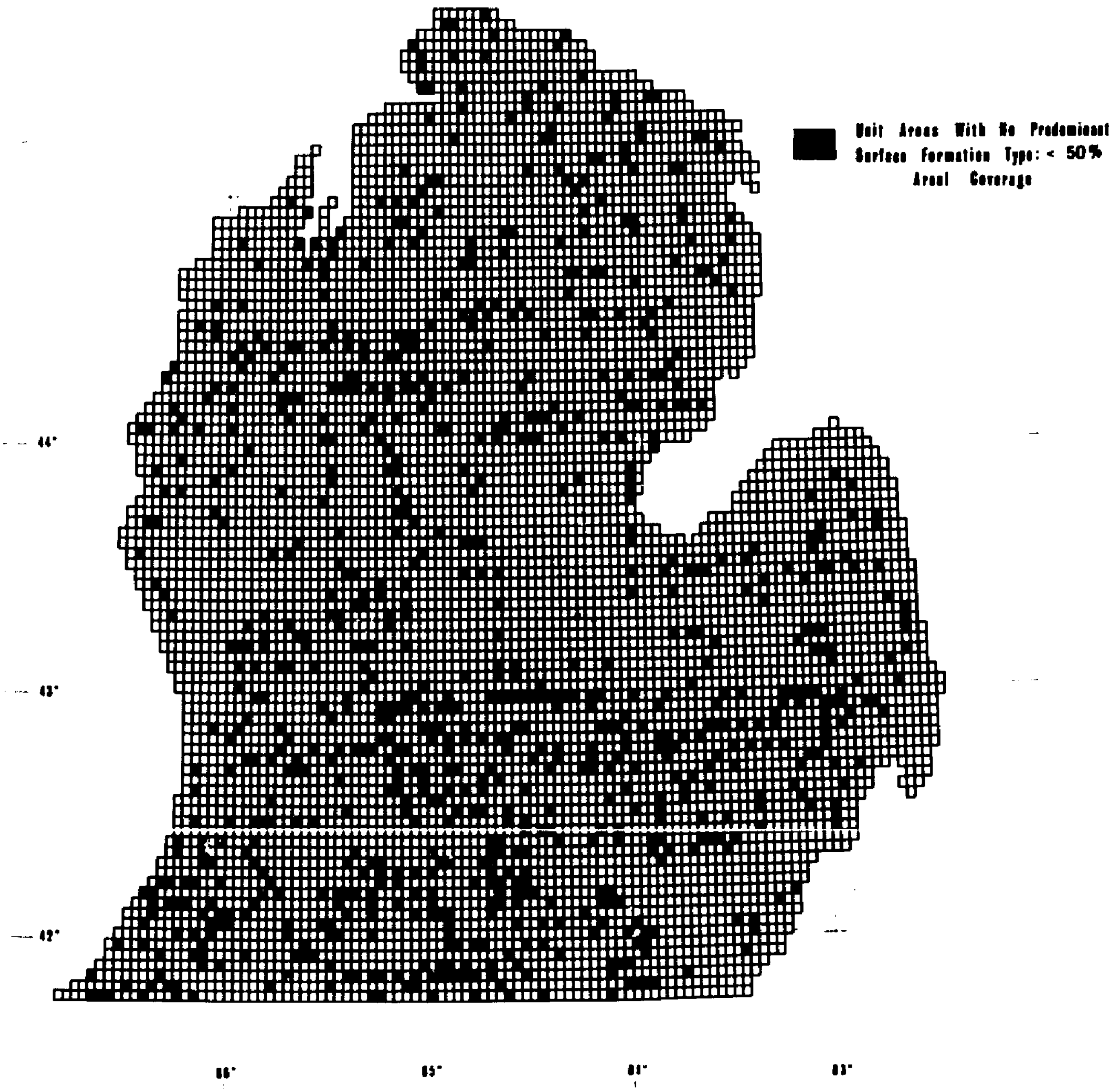

Fig. 26

result as the morphometry of unit areas which contain the same landform.

DRUMLINS

Drumlin fields occur in three widely separated sectors of the study area: (1) Leelanau, Antrim, and Charlevoix counties, (2) Presque Isle County, and (3) Branch County. Individual drumlins are reduced in size, area, and topographic expression in the order enumerated; these regional concentrations are represented in Figs. 1 and 25. The drumlin fields of the largest area constitute more than half (55%) of the sample and are morphometrically distinct from separate formations in Presque Isle and Branch counties. The graphic analyses of average elevation, local relief, and average slope (Figs. 27-29) provide some measure of the overall morphometric character of all drumlin groups, but the data of Table 6 underline their marked regional differences.

Figures 11 and 12 support the statement that maximum elevations of 900-1000 feet are characteristic of all three drumlin groups; decreasing slope and relief factors for the groups in Presque Isle and Branch counties are related to higher minimum elevations -- 700-800 for the former and 900-1000 feet for the latter. Sixty-two percent of the drumlins of the Leelanau-Antrim-Charlevoix complex have minimum elevations of less than 600 feet and all of the units in this region exhibit local relief of more than 250 feet.

In sum, the interpretation of the data indicates increased relief and slope values at lower elevations for the Leelanau-

TABLE 6

Characteristics of Drumlin Fields

LOCAL RELIEF

Under	Leela-nau	Presque Isle	Branch
25 ft.	--	--	--
50	--	--	1
75	--	4	8
100	--	9	8
150	1	9	2
200	7	10	--
250	14	6	--
300	14	1	--
400	26	--	--
500	7	--	--
Unit Area Count	69	39	19

AVERAGE ELEVATION

Under	Leela-nau	Presque Isle	Branch
600 ft.	2	1	--
650	15	1	--
700	22	6	--
750	19	18	--
800	9	3	--
850	1	10	1
900	1	--	10
950	--	--	5
1000	--	--	3
Unit Area Count	69	39	19

AVERAGE SLOPE

Under	Leela-nau	Presque Isle	Branch
$1/2^{\circ}$	2	--	--
1°	--	2	2
$1\ 1/2^{\circ}$	1	2	2
2°	1	3	12
3°	1	12	5
4°	15	1	--
5°	13	--	--
10°	36	--	--
Unit Area Count	69	39	19

Antrim-Charlevoix sample; on the other hand, the Presque Isle and Branch units are at higher elevations and manifest less relief and slope than the north-western drumlin fields.

SAND DUNES

Sand dune formations occur in more than half (51.6%) of the littoral units of the Lake Michigan shore (Leelanau Peninsula to Berrien County). As previously noted (p. 76), these coalescing dunes constitute a ridge-line of higher elevation, slope, and relief than dunes extending inland to the base of the northern and southern highland.

TABLE 7

Characteristics of the Sand Dune Littorals

LOCAL RELIEF			AVERAGE SLOPE		
Under	Michigan Littoral	Huron Littoral	Under	Michigan Littoral	Huron Littoral
25 ft.	--	2	1/2°	--	3
50	--	4	1°	--	4
75	1	5	1 1/2°	4	6
100	1	--	2°	6	1
150	9	3	3°	11	1
200	19	1	4°	8	2
250	10	1	5°	5	--
300	2	--	10°	13	1
400	4	2			
500	2	--			
Unit Area Count	48	18		48	18

The morphometric dimensions of the windworked dunes along the Lake Michigan littoral contrast sharply, in slope and relief, with substantially lower values of the dunes along the Lake Huron littoral (Table 7). Bach of the sand dune units has the adjacent lake level as its minimum elevation; the higher average elevation (Fig. 10) and the greater relief and slope values of the Lake Michigan group are the result of higher maximum elevations (Fig. 11). More than one-third (37.5%) of the Lake Michigan sample has relief in excess of 200 feet while this is the case for only one-sixth (16.6%) of the Lake Huron aggregate. In addition, a similar ratio prevails, 37.6% to 16.6% respectively, when slopes in excess of 4° are considered.

MINOR LINEAR FEATURES

Eskers and boulder belts account for only 119 unit areas or less than 1% of the total sample. Boulder belts are difficult to recognize at even the largest available map scales; they are essentially microfeatures without topographic expression, and their surface expression is probably not related to the genesis of their deposition.

Although eskers are probably the best defined landforms of the study area, on a local basis, they are the least susceptible to quantification at the scale of the unit area grid used in this study. In no case did eskers constitute as much as 50% of a unit and, due to their restricted areal extent, it is clear that values of slope, elevation, and relief assigned to eskers are mitigated by the presence of other landform types.

General Comments on the Histograms of Landform Types

Figures 27, 28, and 29 constitute a graphical representation, by classes of slope, relief, and elevation, of the three genetic classifications of glacial landform types occurring in the sutdy area. With the exception of sand dunes, eskers, drumlins, and recessional moraine, each of the landform types prevails in the form of extensive geometrical surfaces with little evidence of topographic grain in unit areas; the morphometric values obtained for the remaining landform types, which have essentially homogeneous surfaces, provide valid summations of the range and concentration of terrain data for such "extensive" landform types.

"Intensive" landform types, i.e., eskers, drumlins, sand dunes, and recessional moraines, are locally dominant formations which determine morphometric summations of slope and relief in unit areas.(4) A limited check of morphometric values assigned to these unit areas provided little contrast to values obtained by evaluating slope and relief characteristics of sharply-defined map representations of the same formations. The choice of the six-square-mile 2 1/2-minute unit area size is crucial to this finding; experimentation with the 24 square-mile 5-minute unit area and the 36 square-mile 7 1/2-minute unit area, at an early stage in the research, failed to achieve good agreement with the morphometric character of individual landforms, in situ, and the aggregates of landforms in unit areas.

Recessional moraines and outwash, with reference to the

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(4)Note statement of exception regarding eskers (p. 81).

histograms, constitute the most common landforms above 1000 feet of average elevation and the presence of till plains on the northern highland accounts for virtually all of the remaining upper-level surfaces. Ground moraines, recessional moraines, and outwash flats also account for more than 90% of all intermediate surfaces (800-1000 feet) although certain minor topographic features, e.g., eskers, proglacial lacustrine formations, and drumlins are also concentrated at this level. Clay and sandy lake beds, major components of the inventory sample, and minor areal groups of sand dunes, waterlaid moraines, and boulder belts occur in 95% of all cases at elevations of less than 800 feet.

Clay lake bed formations constitute the largest areal category of landforms without visible slope or relief (Figs. 28 and 29). Recessional moraines contain the largest area of steep slope (3^{o} or more) and strong relief (more than 200 feet) although the smaller drumlin sample exhibits a greater percentage in the foregoing relief category. Paradoxically, a greater percentage of the recessional moraine sample has steeper slopes than the drunlin sample. This is no doubt related to the gentle back-slope characteristic of drumlins in the absence of a counterpart slope in the typical morainic formation.

Outwash formations not only occur over a greater range of average elevations than ground moraines (till), but also have more pronounced relief and slope characteristics. This attribute may be due to the role of differential erosion in sculpting the fluvioglacial materials into landforms of greater topographic expression as well as to the fact that the outwash summit elevations of the northwestern rim of the northern highland have experienced pronounced dissection. Sand dunes produce strongly-marked local landforms, but they have less relief and slope than drumlins -- due possibly to the transformation of a nucleated series of coastal dunes into an arete-like ridge of coalescing dunes with a net loss of steep slope.

Ponded water formations (partially filled glacial channels) share similar morphometric values with eskers which, in turn, may be thought of as form-reversals (on a smaller scale) of proglacial troughs. Sandy lake-bottom topography approaches the morphometry of either proglacial lake forms or esker-marked topography; as a result, sandy lake bed terrain exhibits significantly greater relief and steeper slope than clay lake bed topography.

The microrelief produced by elevated beach ridges and wavecut cliffs along the inner or western reaches of the Saginaw Lowland is not susceptible to morphometric analysis from a study of even the largest scale topographic base maps (1:24,000). Although the M.S.F. map contains symbolic representations of these locally conspicuous features, their planimetric outlines are indeterminant to the point of precluding the acquisition of unambiguous values of slope and local relief.

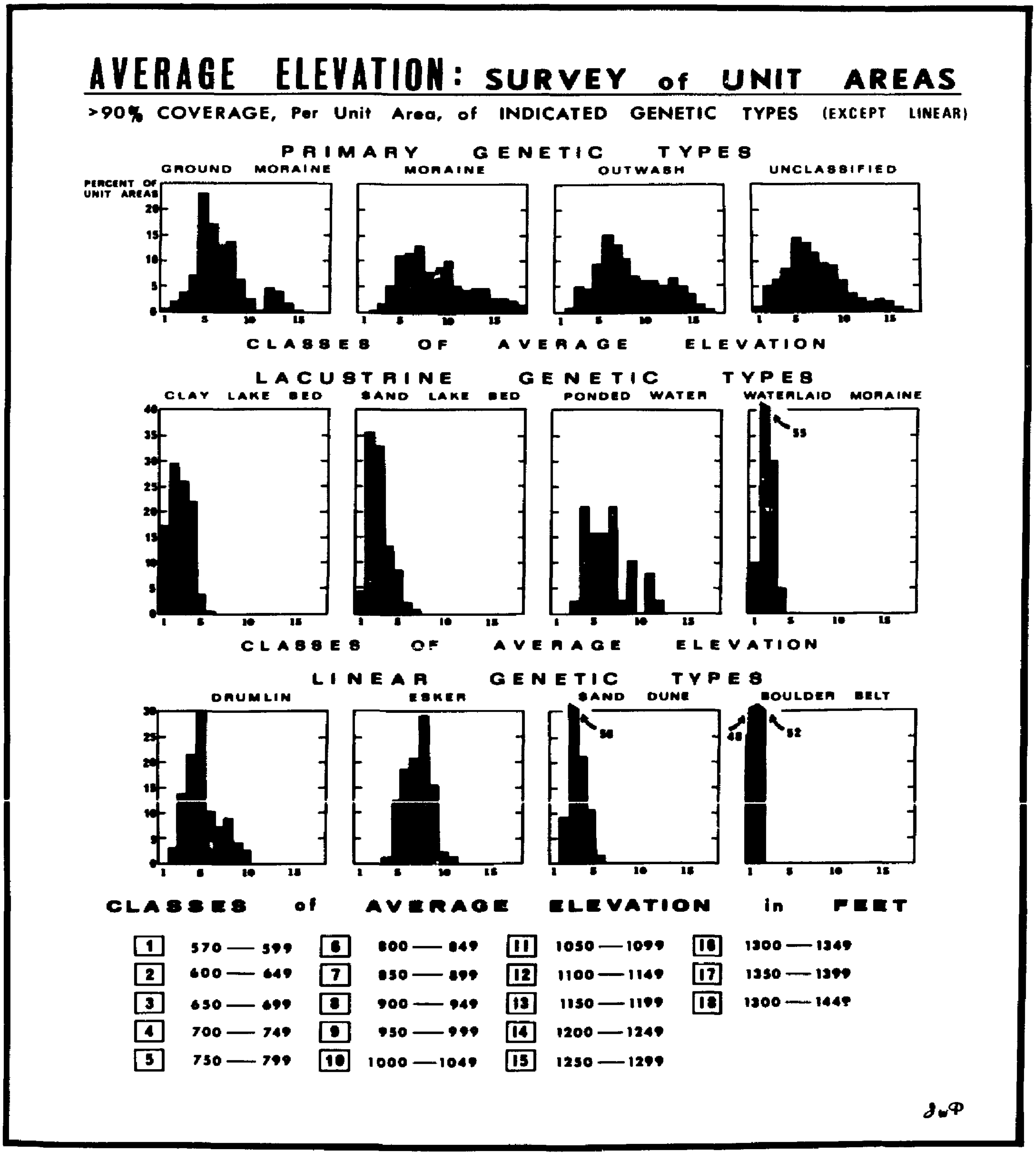
AVERAGE ELEVATION: SURVEY of UNIT AREAS
>90% COVERAGE, Per Unit Area, of INDICATED GENETIC TYPES (EXCEPT LINEAR)
PRIMARY GENETIC TYPES
GROUND MORAINE
MORAINE
OUTWASH
UNCLASSIFIED
PERCENT OF UNIT AREAS
CLASSES OF AVERAGE ELEVATION
LACUSTRINE GENETIC TYPES
CLAY LAKE BED
SAND LAKE BED
PONDED WATER
WATERLAID MORAINE
55
CLASSES OF AVERAGE ELEVATION
LINEAR GENETIC TYPES
DRUMLIN
ESKER
SAND DUNE
BOULDER BELT
56
48
52
CLASSES of AVERAGE ELEVATION in FEET
1 570 — 599
2 600 — 649
3 650 — 699
4 700 — 749
5 750 — 799
6 800 — 849
7 850 — 899
8 900 — 949
9 950 — 999
10 1000 — 1049
11 1050 — 1099
12 1100 — 1149
13 1150 — 1199
14 1200 — 1249
15 1250 — 1299
16 1300 — 1349
17 1350 — 1399
18 1300 — 1449

Fig. 27

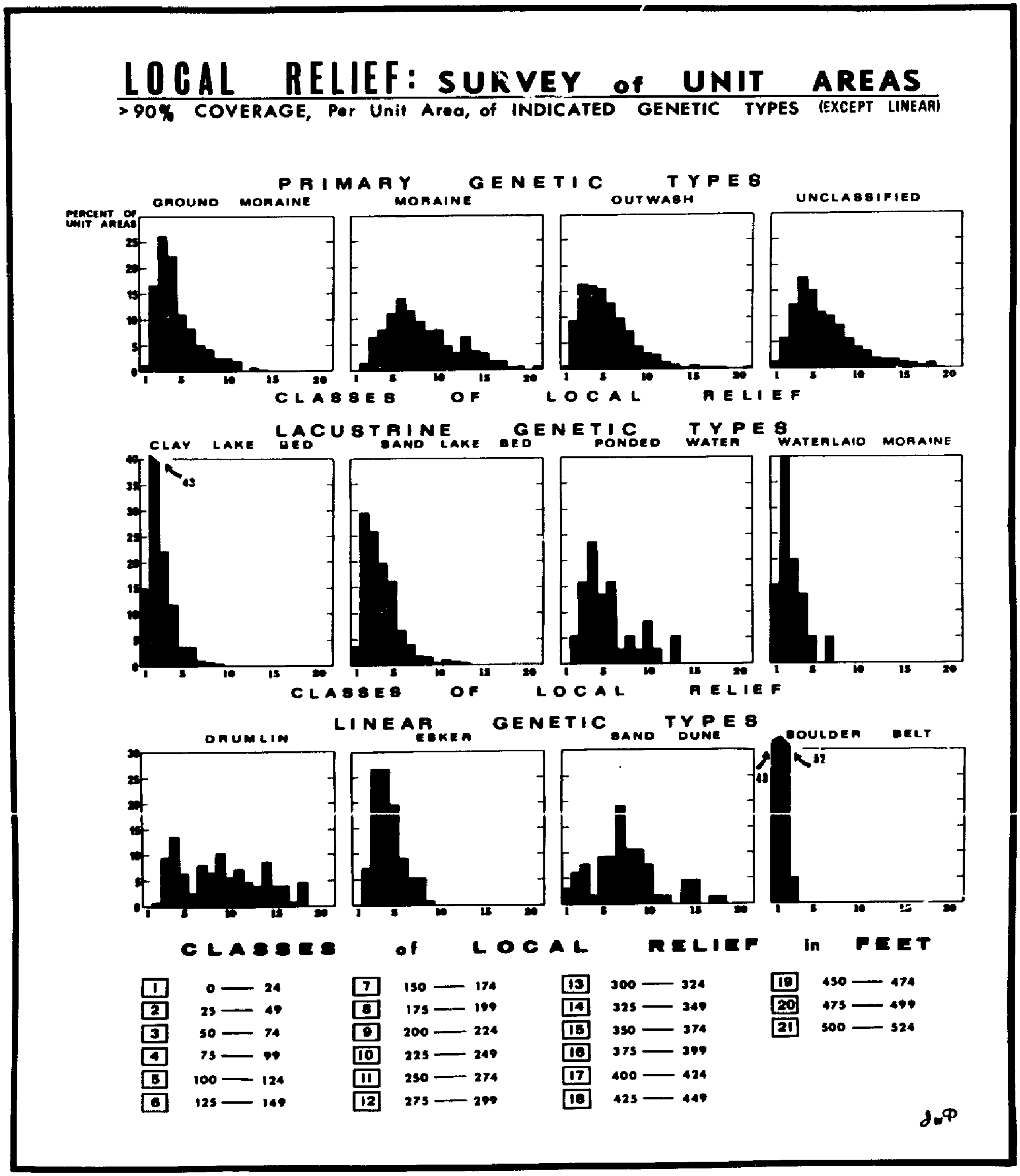
LOCAL RELIEF: SURVEY of UNIT AREAS
>90% COVERAGE, Per Unit Area, of INDICATED GENETIC TYPES (EXCEPT LINEAR)
PRIMARY GENETIC TYPES
GROUND MORAINE
MORAINE
OUTWASH
UNCLASSIFIED
PERCENT OF UNIT AREAS
CLASSES OF LOCAL RELIEF
LACUSTRINE GENETIC TYPES
CLAY LAKE BED
SAND LAKE BED
PONDED WATER
WATERLAID MORAINE
CLASSES OF LOCAL RELIEF
LINEAR GENETIC TYPES
DRUMLIN
ESKER
SAND DUNE
BOULDER BELT
CLASSES of LOCAL RELIEF in FEET
1 0 — 24
2 25 — 49
3 50 — 74
4 75 — 99
5 100 — 124
6 125 — 149
7 150 — 174
8 175 — 199
9 200 — 224
10 225 — 249
11 250 — 274
12 275 — 299
13 300 — 324
14 325 — 349
15 350 — 374
16 375 — 399
17 400 — 424
18 425 — 449
19 450 — 474
20 475 — 499
21 500 — 524

Fig. 28

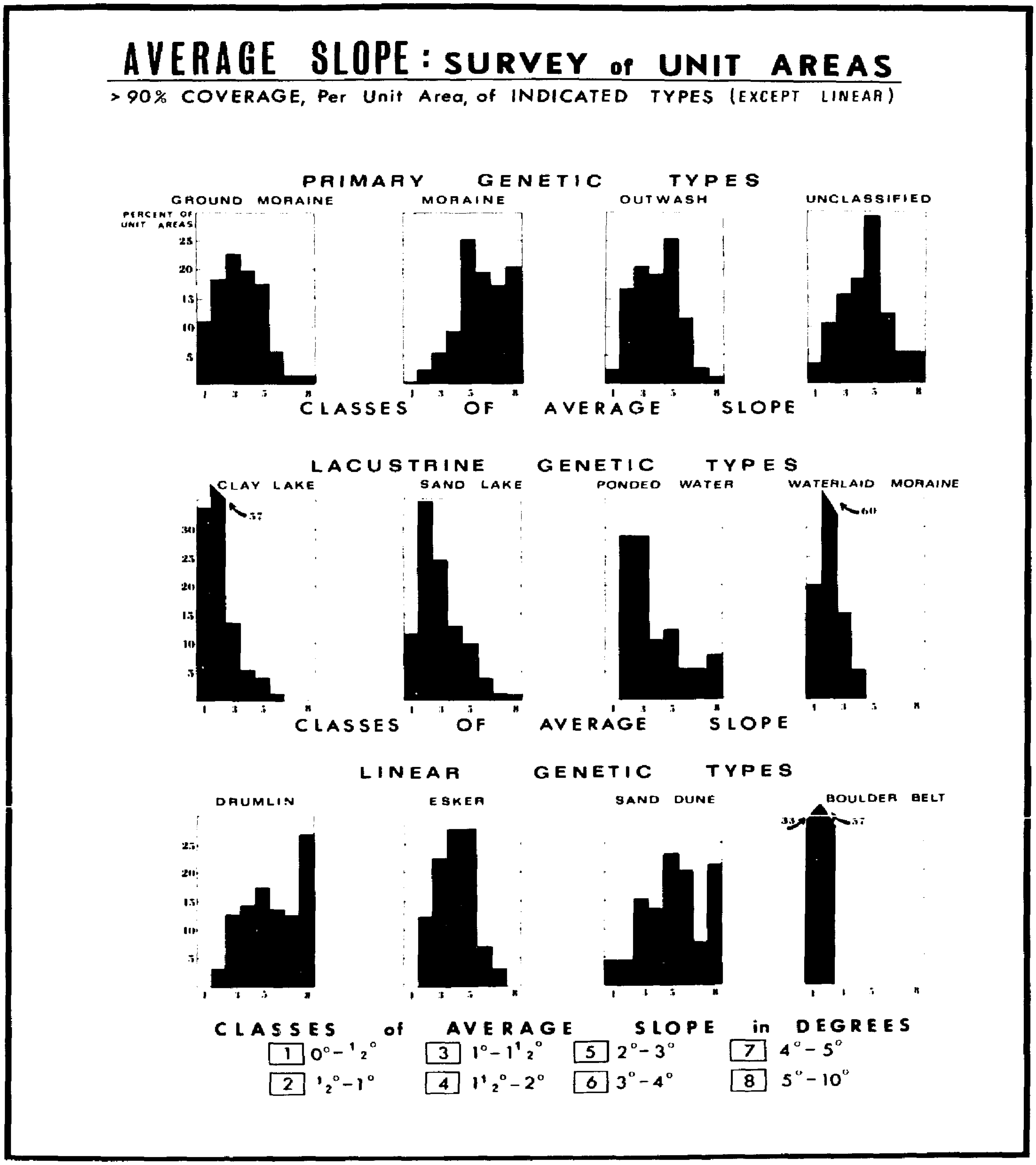
AVERAGE SLOPE: SURVEY of UNIT AREAS
>90% COVERAGE, Per Unit Area, of INDICATED TYPES (EXCEPT LINEAR)
PRIMARY GENETIC TYPES
GROUND MORAINE
MORAINE
OUTWASH
UNCLASSIFIED
PERCENT OF UNIT AREAS
CLASSES OF AVERAGE SLOPE
LACUSTRINE GENETIC TYPES
CLAY LAKE
SAND LAKE
PONDED WATER
WATERLAID MORAINE
CLASSES OF AVERAGE SLOPE
LINEAR GENETIC TYPES
DRUMLIN
ESKER
SAND DUNE
BOULDER BELT
CLASSES of AVERAGE SLOPE in DEGREES
1 0°-½°
2 ½°-1°
3 1°-1½°
4 1½°-2°
5 2°-3°
6 3°-4°
7 4°-5°
8 5°-10°

Fig. 29

CHAPTER IV

TERRAIN REGIONALIZATION FOR SOUTHERN MICHIGAN

Introduction

The following discussion is concerned with the delineation of morphometric regions and subregions for the southern peninsula of Michigan. The identification of essentially homogeneous terrain surfaces must be organized in a manner which affords recognition of the three primary topographic levels of the study area: (1) a discontinuous peripheral lowland with subsections of unlike relief and different glacial landforms, (2) a northern highland characterized by greater extremes of topographic roughness than (3) a southern highland of relatively lower average elevation. Consequently, the recognition of morphometric compartments -- called regions and subregions -- is based on the a priori recognition of these primary topographic provinces.

The identification of morphometric compartments is based on relatively small changes in elevation and relief because only restricted fluctuations of the morphometric data characterize the subdued topography of the peninsula. The limited range of the data is not unexpected in view of the youthfulness of the post-glacial erosion surface, the topographic simplicity of the pre-glacial surface, and the virtual absence of differential erosion in the unconsolidated drift materials.

The Problem of Terrain Regionalization

The initial problem in the identification of terrain regions is concerned with the selection of appropriate class intervals for the purpose of grouping elevation, relief, and slope data into fractional subgroups. The range and frequency of all terrain data must be accommodated in a sequence of value-classes so that collections of unit areas of one class may be compared with collections of unit areas of different class. This intent is explicit in Hammond's (1954:36) statement:

> "Their purpose [class or group boundaries] is to promote objectivity in classifying a piece of terrain, to make possible the comparison of different regions, and to insure the comparability of results by different people. No attempt has been made, as yet, to employ statistical analysis as an aid in choosing the most valuable boundary values. This could possibly vary depending on the regions and the purpose for which the classification is made."

Consequently, the determination of specific class limits may be arbitrary, according to the purpose of the regionalization, but this procedure need not be a subjective one.

Success in the selection of appropriate class intervals of the terrain data can only be measured by the validity of the regions or subregions which they represent; the primary goal in devising class limits for the data used in this study was to obtain results which would delineate previously undefined regional terrain types.

The three main topographic levels of the study area, as described earlier, consist of two highlands of differing dimensions and a discontinuous, peripheral lowland. The vertical component of this peninsular landscape is taken as the primary agent for regional differentiation: unit areas with a stated average elevation range are sought to establish the altitudinal planes of each highland. With only one or two exceptions, the selected class intervals produce continuous planes of a single, rigorously defined altitudinal level.

Four altitudinal levels are defined for each highland. They are based on unequal elevation intervals because of the differences in general elevation of the two. Each level is called a "terrain region" for descriptive purposes, and a nomenclature suggests the increasing elevation of each level: the three-dimensional character of each highland and the aforementioned increase in elevation is implied in the terms (1) Foreland, (2) Intermediate Upland, (3) Upland, and (4) Highland.

The determination of elevation values for the four hypsometric levels of each highland is both arbitrary and systematic in nature; it is precisely stated in observable values of elevation, and justified on the basis of the identification of such unlike regional topographies as the Cadillac Highland and the Lansing Foreland. Because the altitudinal designations serve to compartmentalize the cross sectional levels of the two highlands, they are called "morphometric" regions in the sense that they delineate subsections of a landform province in terms of discrete and objective terrain measurements.

Each of the thirty-four morphometric <u>sub</u>regions is located entirely within one of the five regional levels (including lowlands).

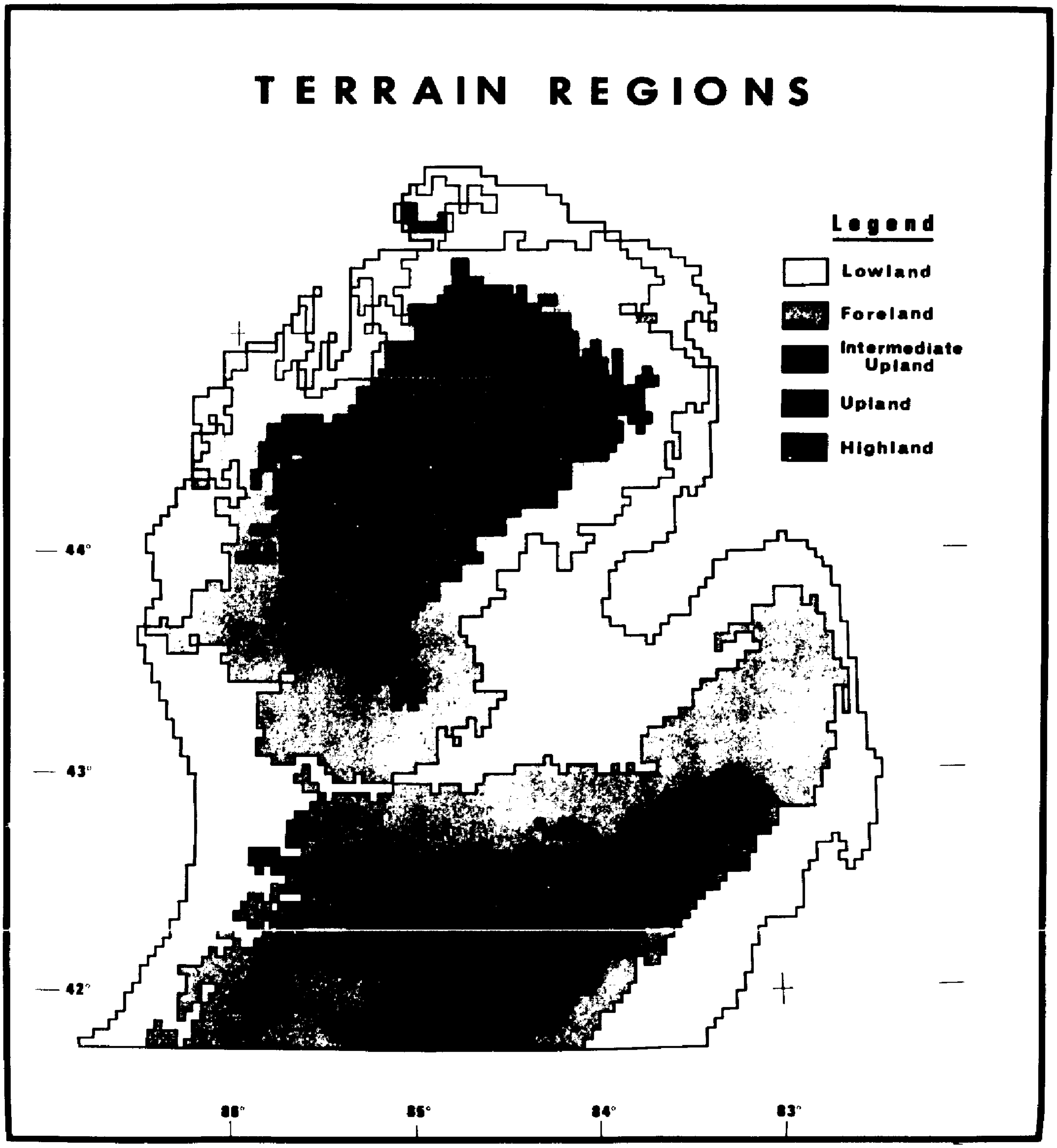
TERRAIN REGIONS
Legend
Lowland
Foreland
Intermediate Upland
Upland
Highland
44°
43°
42°
86°
85°
84°
83°

Fig. 30

The identification of a subregion is based upon the recognition of a group of unit areas with a given class of local relief in a limited area of a given altitudinal level. The grouping of such unit areas is not based on the existence of a continuous or homogeneous relief pattern; Figs. 32-26 verify core areas of nearly homogeneous relief surrounded by zones of transition consisting of unit areas with anomalous relief values. The problem of devising subregional boundaries is resolved by laying out boundaries which bisect the transition zone, approximately, of anomalous relief values between core areas of unlike but nearly homogeneous relief.

The resultant subregional boundaries have, as a minimum, at least one-third of all the included unit areas in the same relief class and at least one subregion has three-fourths of its unit areas in a single relief category.[1] The identification of a predominant relief class, in subregions, serves to adequately differentiate sectors of the various hypsometric levels and leads to such valid subregional topographies which, for instance, distinguishes the Lansing Foreland from the Boyne City Foreland (Map 23, 6D and 2B). The anomalous unit areas of all subregions are depicted in Figs. 32-36 according to relief value and grid location within the subregion; this presentation is more objective than an alternate method which "absorbs" all unit areas of a different class of relief. A method for summarizing the total relief differential of all such anomalous

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[1] It should be noted that Hammond (1957) meets this problem by use of the arbitrary but objective "four-contiguous-unit-areas" rule: anomalous unit areas, up to a maximum of four contiguous units, may be absorbed in the delineation of a homogeneous relief subregion.

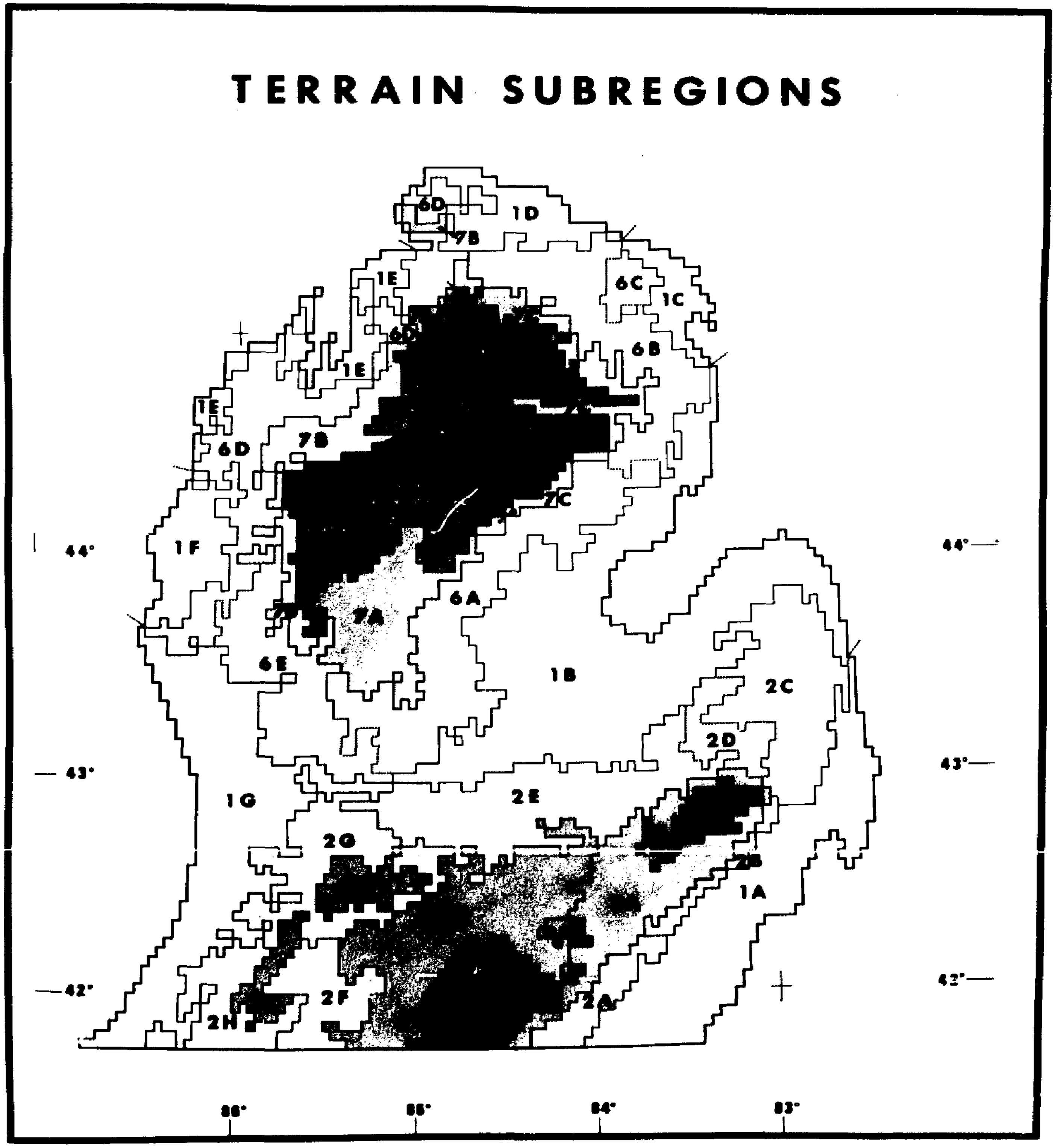
TERRAIN SUBREGIONS
1D
6D
7B
1E
6C
1C
6D
6B
1E
1E
7B
6D
7C
1F
44°
44°
6A
7A
6E
1B
2C
2D
43°
43°
1G
2E
2G
2B
1A
42°
42°
2F
2A
2H
86°
85°
84°
83°

Fig. 31

TABLE 8

Key to the Identification and Nomenclature of Terrain Subregions

Regions	Code	Subregions	Prevailing Relief Class: Percent of Unit Areas
Lowland:	1A	Detroit-Huron	1:62%
	1B	Saginaw	1:48%
	1C	Alpena	2:41%
	1D	Cheboygan	4:33%
	1E	Traverse City	4:48%
	1F	Ludington	3:41%
	1G	Muskegon	3:33%
Southern Highlands			
Foreland:	2A	Adrian	3:57%
	2B	Salem	2:72%
	2C	Sandusky	2:62%
	2D	Lapeer	3:60%
	2E	Lansing	2:74%
	2F	Schoolcraft	2:55%
	2G	Wayland	4:43%
	2H	Niles	4:36%
Intermediate Upland:	3A	Ann Arbor	1:48%
	3B	Jackson	2:70%
	3C	Kalamazoo	3:39%
Upland:	4A	Pontiac	4:73%
	4B	Addison	2:44%
Highland:	5A	Hillsdale	4:48%
Northern Highlands			
Foreland:	6A	Mount Pleasant	2:49%
	6B	Onaway	3:61%
	6C	Posen	2:71%
	6D	Boyne City	5:44%
	6E	Sparta	4:48%
Intermediate Upland:	7A	Muskegon	4:48%
	7B	Manistee	4:52%
	7C	Au Sable	4:51%
Upland:	8A	Grayling	4:58%
	8B	Houghton Lake	2:45%
Highland:	9A	Gaylord	4:66%
	9B	Cadillac	4:57%
	9C	Ogemaw	4:56%

unit areas, not studied here, should be developed for the purpose of measuring the relief heterogeneity of a given subregion; this index could serve just as well as relief homogeneity in the identification of morphometric subregions.

Average slope classes and prevailing surface formations are included in the description of morphometric subregions although they are not determining factors in delineating these compartments. Because slope classes have a good correlation with relief categories (Table 11) and because specific genetic landforms are known to occur within selected classes of both slope and relief, these areal characteristics are included in a fractional key of terrain factors supporting the subregions set forth on Figs. 32-36.

The Hypsometric Factor

The change of altitude in various parts of a land mass constitutes a primary basis for differentiating areal segments of that land mass. Because the average elevation parameter sets forth the principal or first-order topographic formations of any study area, the map of terrain regions (Fig. 30) delimits the extent of the two major morphometric features of the peninsula: a northern and a southern highland.

Veatch (1953) utilizes the 750-foot isohypse to distinguish between the highland and lowland areas of the peninsula. This isohypse is also used in this study (Table 9) because rapid increases in slope and relief, to the interior, occur along this line of demarcation -- a correspondence which is best illustrated (Figs. 13 and 14) along the southeastern margins of the northern and southern highlands. The delineations of the two highlands are compact in form with few outliers separated from their nuclear cores (Fig. 30).

In contrast to the continuum of the foreland regions, the highland and upland regions occur as non-continuous morphometric levels of the northern and southern highlands; these darkened areas of Fig. 30 stand out as peninsular heights (or islands) and a comparison of the northern and southern highland confirms the greater areal extent of higher elevations in the northern highland.

The cross sectional profiles of the northern and southern highlands reveal important differences in their general or prevailing elevation: more than 75% of the northern highland has average elevations in excess of 1000 feet whereas this is true for less than 25% of the southern highland. For the purpose of creating meaningful internal differentiations, the two highlands are divided into foreland, intermediate upland, upland, and highland levels; because of the profile differences of the two highland provinces, different isohypses are used in each highland to identify these internal compartments. The choice of these critical isohypses is entirely subjective, but seems justified in view of their delineation of such regional topographies as the primary and secondary cores of the southern highland, the continuous nature of the Saginaw-Maple trough, the riverine incursions of the northern highland, and the morainic rimland of both highlands.

TABLE 9

Table of Hypsometric Levels Selected for the Differentiation of Terrain Regions

Regions	Northern Highland	UAC*	Southern Highland	UAC*
Foreland	750- 899 ft.	1268	750- 849 ft.	1080
Intermediate Upland	900-1099 ft.	490	850- 949 ft.	193
Upland	1100-1249 ft.	502	950-1099 ft.	696
Highland	1250-1468 ft.	261	1100-1206 ft.	44
	Total:	2521	Total:	2013

*UAC: Unit Area Count

The regional terminology of Table 9 is descriptive of a series of altitudinal surfaces of increasing elevation; however, the terms are also objective statements of absolute elevations and are used in this dual context in the remainder of this chapter. In addition, they relate to the physiography of the peninsula insofar as they represent logical divisions of the two highland provinces. The principal hypsometric belts of the peninsular study area are illustrated on Fig. 31 and listed on Table 13 by individual subregions.[2]

The Relief-Slope Factor

A six-fold classification of local relief intervals was

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[2] The arabic numeral indicates the gross morphometric type, e.g., the figure "1" specifies lowlands, and the accompanying capital letter identifies subregions based on a concentration of a given class of local relief. Similarly, forelands are indicated by the figure "2," intermediate uplands by "3", and so on. A list of urban place names and river basins is included as a guide to the geographic location of the subregion within the study area.

used for the purpose of identifying terrain subregions (Table 10). Because of the good correlation (see below) between local relief and average slope, local relief classes alone were used in the delineation of these subregions. The consolidation of relief units into relief subregions is based on the grouping of proximate unit areas of the same relief class so that the group of like relief units represented at least one-third of all the units included in the subregion. The success of this approach is based upon the recognition of significant breaks in the regional patterns of maximum-minimum elevation change. The compartmentalization of the prevailing subdued relief of the study area, and the included anomalous unit areas, is shown in Figures 32-36.

The first three increments of the relief classification have intervals of 50 feet each while the latter three are disparate and reflect, in ascending order, the decreasing number of unit areas involved (see "Total," Table 13). Class 2, 3, and 4 have almost equal concentrations of unit areas -- 29.5%, 27.7%, and 26.4% respectively -- and Class 1 (14.4%) occurs in a 1:2 ratio to these categories but twice as often (2:1) as the combined upper categories in classes 5 and 6.

TABLE 10

Classes of Local Relief and Average Slope

Classes:	1	2	3	4	5	6
Local Relief (feet)	0-49	50-99	100-149	150-299	300-499	500-622
Average Slope (degrees)	0-.99	1-1.99	2-2.99	3-3.99	4-4.99	5-10

Only 7.3% of the units have a relief value in excess of 300 feet and the use of Class 6 relief (in excess of 500 feet), constituting less than 1% of all units, succeeds in producing the areas of maximum relief within the study area. Because only 14.4% of the units have a relief of less than 50 feet and because the lowland province occupies 37% of the peninsula, it was anticipated that lowland compartments would be recognized on the basis of either Class 1 or Class 2 relief and no other. Subsequent investigation of the regional patterns of relief in the lowland regions proved that more than one-third of all the included unit areas occurred in the relief categories of Classes 3-5. With respect to the entire study area, only four subregions are marked by assemblages of less than 40% of the included unit areas in a single prevailing relief class -- in no case does the predominant relief class constitute less than one-third of all such units. More importantly, 20 of the 34 subregions are characterized by the same relief class over 48% or more of their areas (Table 13).

Although slope characteristics have not been used to differentiate the morphometric subregions, a good correlation exists between the increasing orders of local relief, defined above, and average slope.

The high correlation between slope and relief increments is obvious from Table 11. Thus, 77.8% of all unit areas with a relief of less than 50 feet also have an average slope of less than $1/2^{\circ}$. The fact that 1.1% of this relief class also has an average slope of 2° - 3° is an indication that the Wentworth method produces a "roughness index" rather than discrete measure-

TABLE 11

Local Relief Classes as a Percentage of Average Slope Classes

Average Slope	Local Relief Classes in Feet 0-49	50-99	100-149	150-299	300-499	500-622
0°-1/2°	77.8	20.6	.9	.5	.2	--
1/2°-1°	39.4	49.7	8.1	2.7	--	--
1°-1 1/2°	9.0	58.9	23.5	18.5	.3	--
1 1/2°-2°	2.3	41.5	37.3	18.5	.3	--
2°-3°	1.1	15.9	36.3	44.8	1.9	--
3°-4°	.5	4.4	21.7	65.6	7.7	.1
4°-5°	--	.5	8.1	68.2	23.2	--
5°-10°	--	.4	1.3	31.5	60.7	6.0

ments of real slopes. It follows, then that low relief values do not ordinarily produce topographic knobbiness.

The slope factor is not expressed in descriptive terms such as "steep," "gentle," or "undulating" because (1) it was necessary to use topographic maps with different scales and contour intervals, (2) of the contrasting detail of contour-line expression on maps compiled over a period of sixty years, and (3) of the difficulty of obtaining repeatable contour-counts in areas of topographic roughness.

The Genetic Factor

Glacial landform types are included in the description of discrete subregions because they convey an impression of the physical appearance of the landscape. However, genetic landforms are not used as criteria to delimit terrain regions. Their often diverse morphometric character yields too wide a range of local relief values, as is the case in a consideration of drumlin fields which vary from 50-450 feet in local relief and provide little evidence of clustering in a given relief class (Fig. 13). Nevertheless, genetic landforms frequently produce slope and relief values which can serve as the basis for connoting the physiographic aspect of delineated morphometric subregions.

Analysis of Morphometric Provinces

The identification of morphometric provinces is based on the utilization of the 750 foot-isohypse to delineate three first-order provinces of approximately equal areas (Fig. 30):

(1) Lowland: 32.1% of the study area,
(2) Northern Highland: 30.9% of the study area,
(3) Southern Highland: 37.0% of the study area.

Each of the highland provinces consists of four morphometric regions, i.e., a foreland, an intermediate upland, an upland, and a highland in a sequential order of increasingly higher elevation surfaces (Table 9). Each of these second-order regions may include from one to eight subregions based on coherent groupings of units with similar slope and relief factors. Thirty-four third-order subregions, or compartments, have been identified and designated after names of important settlements or, in sparsely settled areas, by major hydrographic features.

A fractional key, described below, is used in conjunction with Figs. 32-36 to quantify the surface geometry of each of the

34 subregions. The key also indicates the number of unit areas in each subregion. The placement of each terrain factor is illustrated in the following example:

$$2B \quad \frac{M.41/2.72}{3.47} \quad 36$$

The individual digits stand for the following characteristics:

(2) hypsometric factor,
(B) subregion code,
(M) prevailing surface formation,
(.41) percentage of unit areas with prevailing surface formation,
(/2) prevailing relief class,
(.72) percentage of unit areas with prevailing relief class,
(3) prevailing class of average slope
(.47) percentage of unit areas with prevailing slope class,
(36) number of unit areas in the coded subregion.

The prevailing landform type for each subregion is specified according to the following code:

M = Moraine	O = Outwash	D = Drumlin
T = Till	L = Lacustrine	U = Unclassified

Eskers and sand dunes have been omitted because neither occurred as a dominant genetic type in any subregion.(3) The category of lacustrine formations, for the purpose of this code, consists primarily of lake plains of either clay or sandy materials (87% of all lacustrine units of the study area) but also includes smaller areas of boulder belts, upland or interior lacustrine formations, and waterlaid moraines.

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(3)It must be pointed out that the identification of prevailing landform types is based on counts of unit areas with 50% or more coverage of the indicated landform. Unit areas with no single formation amounting to 50% are entered in the unclassified category.

The Lowland Province

The Lowland Province of the southern peninsula of Michigan, in spite of its generally low absolute elevation, is diverse in both terrain morphometry and topographic configuration. Seven lowland compartments may be identified at elevations of less than 750 feet on the basis of contrasting patterns of regional relief and slope. Marking the periphery of the study area, these lowlands encircle the peninsula with the exception of the Emmet County littoral in the extreme north, which is without a discernible lowland at the scale of the study map (Fig. 32). The lowlands of the Lake Michigan borderland contrast markedly with the eastern flatlands of the Lake Huron-Erie coast: in no sense of the word may the former be termed "flatlands" and it is equally misleading to infer generally lower elevations for the latter.

The Saginaw Lowland (1B in Fig. 31) is the largest of the lowlands and is related genetically to the third largest lowland, the Detroit-Huron (1A); both lowlands consist of extensive lacustrine plains formed by the ablating ice masses of the Huron, Erie, and Saginaw lobes. It is not surprising, therefore, that both lowlands display relief of less than 100 feet over more than 85% of their respective areas. Furthermore, slopes of less than 2° characterize more than 95% of each lowland.

In contrast, the Traverse City Lowland (1E) is marked by exceptionally strong relief and is one of only two subregions which have as much as 42% of their respective areas in the steepest slope category (5°-10°). No other subregion has the abundance of

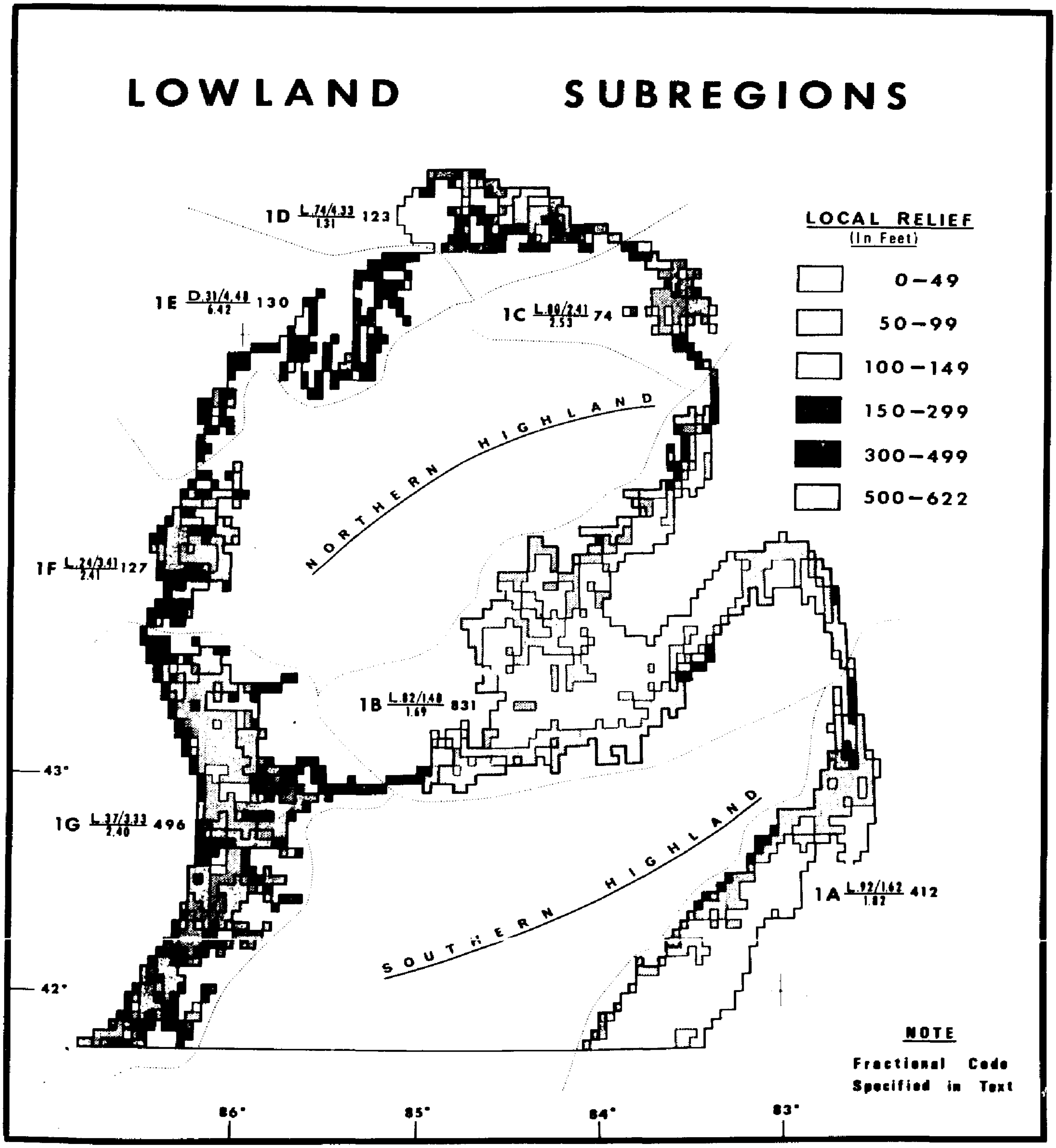
LOWLAND SUBREGIONS
LOCAL RELIEF
(In Feet)
0–49
50–99
100–149
150–299
300–499
500–622
1D L.74/4.33 / 1.31 123
1E D.31/4.41 / 6.42 130
1C L.80/2.41 / 2.53 74
1F L.24/3.41 / 2.41 127
1B L.82/1.48 / 1.69 831
1G L.37/3.33 / 2.40 496
1A L.92/1.62 / 1.82 412
NORTHERN HIGHLAND
SOUTHERN HIGHLAND
43°
42°
86°
85°
84°
83°
NOTE
Fractional Code Specified in Text

Fig. 32

relief energy of the Traverse City Lowland: 87% of its unit areas have local changes in elevation in excess of 150 feet. Unlike the other six lowlands, most of the Traverse City Lowland is non-lacustrine in origin and exhibits a distinct linear grain due to the presence of large complexes of drumlin hills and numerous intervening water-filled depressions.

The Muskegon (1G) and Ludington Lowlands (1F) have prevailing slope and relief intermediate in value between the flatness of the Saginaw Lowland and the roughness of the Traverse City Lowland. The lake-border portions of these lowlands are marked by north-south belts of interlocking sand dunes which produce most of the slope and relief noted above. Proglacial sandy lake bottoms characterize much of the Muskegon Lowland, whereas outwash plains are the most common landforms of the Ludington Lowland; postglacial erosion in both instances has produced nearly identical slope characteristics (Table 15, 1F, 1G). The Lake Border recessional of southwestern Michigan, extending from New Buffalo to Grand Rapids, is a provincial anomaly; with the exception of the Caro Moraine of Tuscola County, no other lowland contains a sizeable recessional moraine.

The Cheboygan and Alpena Lowlands (1D and 1C), the two smallest lowlands, are characterized by rolling lake plain topography with approximately half of each lowland having relief of 100-300 feet and slopes of less than 2°. These values are somewhat higher than those for similar topographic forms in the south (1A, 1B), but significantly lower than values obtained from lacustrine formations of the Muskegon and Ludington Lowlands. Six major lakes (Grand, Long, Douglas, Black, Burt, and Mullet), complemented by six large lakes of the Traverse City Lowland (Charlevoix, Torch, Elk, Leelanau, Crystal, and Glen), form a crescentic array of water-filled troughs at lowland elevations along the northern coast of the peninsula.

The Southern Highland Province

Compared with the Northern Highland, the Southern Highland is characterized by lower average elevations and reduced slope and relief values. It contains slightly less than one-half (48%) of the total peninsular relief of 50-99 feet; however, less than 3% of this available relief is in excess of 300 feet (Table 16). Although the combined area of all the lowland provinces accounts for nearly two-thirds of the available flatlands (less than 1°) of the peninsula, forty-two percent of the next slope class (1°-2°) occurs in the Southern Highland and serves to distinguish it from the Northern Highland (Table 15).

The Foreland Region of the Southern Highland

Forelands comprise 56% of the Southern Highland Province (cf. Table 12, Number of Unit Areas) and the changing patterns of slope and relief, over such a large area, necessitated eight third-order terrain compartments to adequately portray these differences. Certain non-contiguous subregions, on the other hand, are remarkably similar in the case of slope and relief; for instance, the Sandusky (2C) and Schoolcraft (2F) subregions have a local relief of less than 100 feet over more than 80% of their respective areas. The

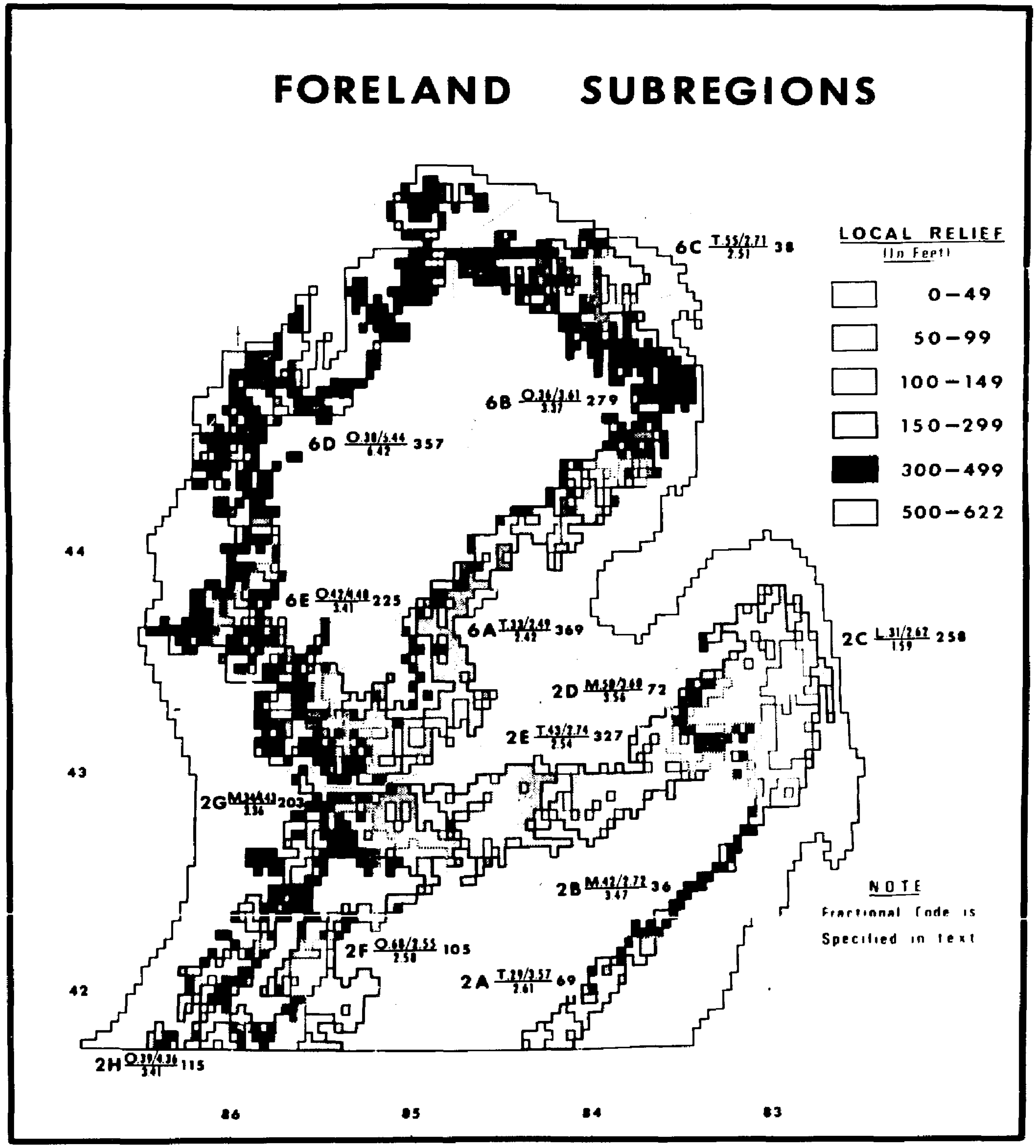
FORELAND SUBREGIONS
LOCAL RELIEF
(In Feet)
0-49
50-99
100-149
150-299
300-499
500-622
NOTE
Fractional Code is Specified in text
6C
6B
6D
6E
6A
2C
2D
2E
2G
2B
2F
2A
2H
44
43
42
86
85
84
83

Fig. 33

fact that they also have more than 90% of their surfaces in average slopes of less than 2^{o} further emphasizes the similarity of these two compartments.

Stratified lacustrine deposits and the tenuous recessional moraines of the Port Huron system characterize more than half of the Sandusky subregion, whereas two-thirds of the Schoolcraft compartment is made up of outwash. Except for the Houghton outwash plains (8B), the Schoolcraft outwash plains are morphometrically the most subdued examples of this landform type for the peninsula as a whole. Adjacent outwash trains at higher elevations in the Jackson subregion (3B), including the Marshall-Climax-Coldwater triangle, occur consistently with 150-199 feet local relief.

The Lansing Foreland (2B), second largest subregion of the 14 compartments of the Southern Highland, consists of the east-west trending moraines of the Saginaw system and the most extensive till plains of the study area. Because less than 1% of these formations have relief in excess of 150 feet and because a relief component of 50-99 feet prevails over 75% of the area, the Lansing Foreland is distinguished by abundant but only moderate changes in local elevations. In contrast, the Lapeer (2D), Wayland (2G), and Niles (2H) subregions exhibit relief in excess of 150 feet in more than one-third of their unit areas. The topography of these compartments provides a sharp contrast to the more moderate relief of the conterminous Sandusky, Lansing, Schoolcraft, and Adrian (2A) subregions (Fig. 33).

The Adrian (2A) and Northville (2B) compartments represent a relatively narrow zone of altitudinal and relief transition between the nearly flat Detroit-Huron Lowland and the dissected southeastern rim of the Ann Arbor Intermediate Upland (3A). This transitional belt is an area of rapidly rising values of elevation, relief, and slope and is marked by the topographic dominance of the Defiance Moraine. As mentioned earlier, this morainic system rises abruptly out of the lacustrine plains and produces one of the most distinct physiographic boundaries of the southern peninsula.

The Intermediate Uplands of the Southern Highland

Three intermediate uplands (Fig. 34) make up one-third of the Southern Highland area and occur at elevations of 850-949 feet. The Jackson compartment (3B) is the largest of these subregions and is characterized by a surface geometry similar to that of the Lansing Foreland, at lower elevations, to the north. Because three-fourths of the Jackson subregion has slopes of less than 2° and a relief of less than 100 feet, it contrasts sharply with the adjacent Ann Arbor (3A) and Kalamazoo (3C) compartments. Both of the latter have more than 70% of their units in slopes of 2° or greater and more than 75% of their units have relief in excess of 100 feet.

Although morainic hills are the dominant formations in both the Kalamazoo and Ann Arbor subregions, they occur at the lowest elevations (except for the Lake Border and Caro Moraines) and are among the most subdued examples of their genetic type. Significantly greater slope and relief values are obtained for similar proportions of moraine and outwash types in the Boyne City Foreland (6D) and the Cadillac Highland (9B) of the Northern Highland (Tables 12 and 13).

The Uplands of the Southern Highland

The Pontiac (4A) and Addison (4B) uplands (Fig. 35) are characterized by intermediate slope and relief categories. The Pontiac subregion has 73% of its area in relief of 150-299 feet and the Addison tract has 76% of its area in relief of 50-149 feet. These two compartments, at elevations of 950-1100 feet, comprise only 9% of the area of the Southern Highland. (This is only half the area of the corresponding hypsometric level, 900-1100 feet, of the Northern Highland.)

The larger complex of interlobate moraines in the Pontiac subregion accounts for the fact that slopes in excess of 3° occur at a ratio of 2:1 compared to the Addison compartment. Although the Kalamazoo moraines (3C) are topographically rougher, with 21% of all slopes in excess of 4°, the morainic hills of the Pontiac compartment have the greatest share of pronounced relief (80% of all units in excess of 150 feet) of any subregion of the Southern Highland.

The differentiation of the eastern and western sectors of the Addison compartment (Fig. 35) is apparent in the greater relief and more extensive moraines of the eastern half as compared to the reduced relief (less than 150 feet) and substantially larger areas of outwash and till of the western half.

The Hillsdale Highland of the Southern Highland

The Hillsdale Highland (5A, Fig. 36), delimited by a basal elevation of 1100 feet and a summit elevation of 1284 feet,

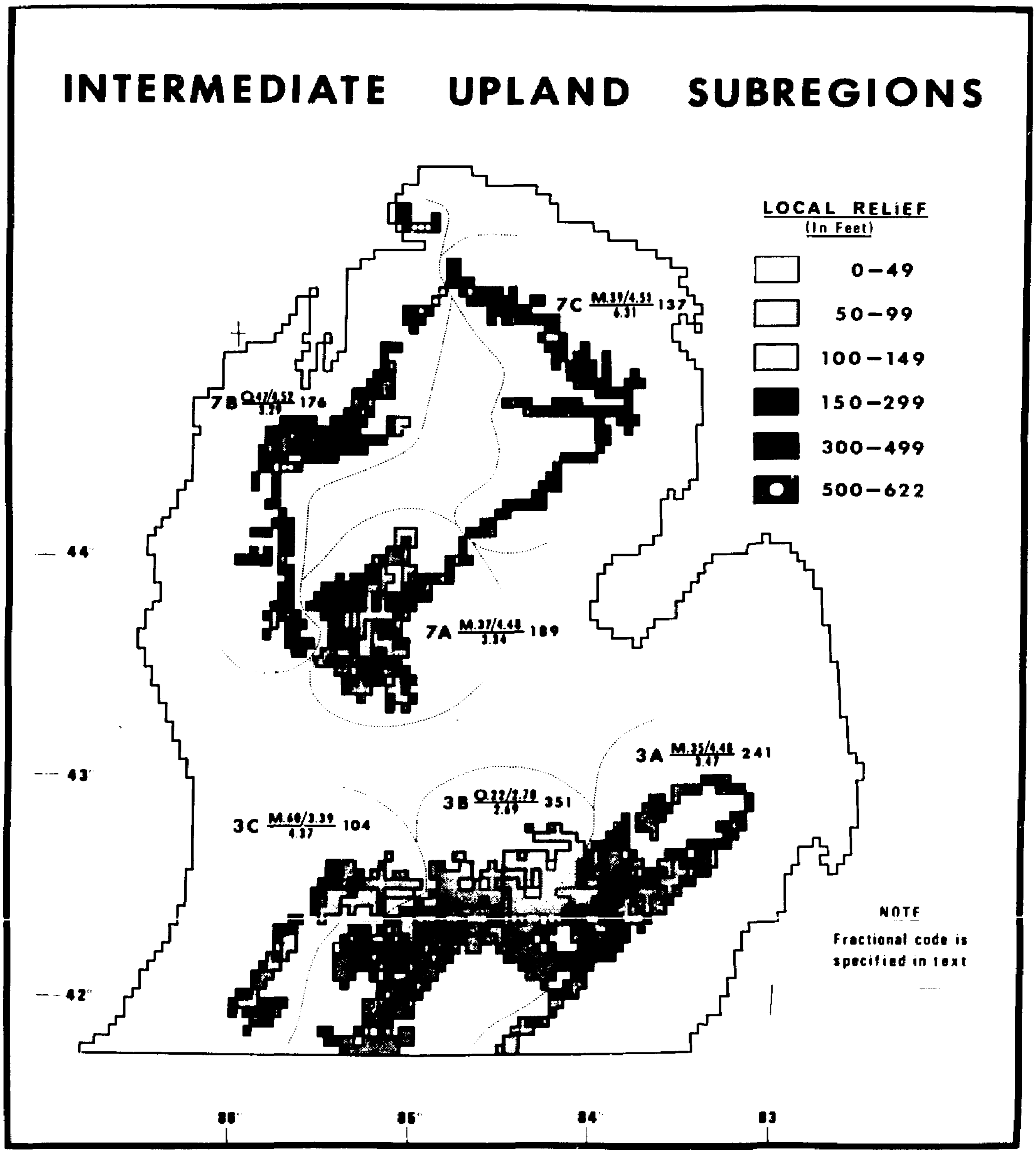
INTERMEDIATE UPLAND SUBREGIONS
LOCAL RELIEF
(In Feet)
0-49
50-99
100-149
150-299
300-499
500-622
7C M.39/4.51 / 6.31 137
7B 176
7A M.37/4.48 / 3.34 189
3A M.35/4.48 / 3.47 241
3B Q.22/2.70 / 2.69 351
3C M.60/3.39 / 4.37 104
NOTE
Fractional code is specified in text
44°
43°
42°
86°
85°
84°
83

Fig. 34

is less rugged than the interlobate Pontiac subregion. The presence of moderate relief (84% of all units in the range of 100-299 feet) and moderate slope (93% in the 1^{o}-3^{o} range) makes it comparable to the Lapeer subregion (2D) in the foreland region (Tables 15 and 16).

The small number of units (44) of the Hillsdale Highland attests to lower absolute elevation of the Southern Highland when compared to the 751 units of the Northern Highland above the 1100 feet isohypse. The utility of adopting a higher basal elevation (1250 feet) to classify the highlands of the Northern Highland is supported by the face that highlands of both the Northern and the Southern Highland are then characterized by morainic formations over 55-59% of the resultant areas. Such agreement would not be possible if identical hypsometric categories were applied to both of the first-order provinces.

The Northern Highland

The Northern Highland has both a larger area and a greater amount of upland/highland surfaces than the Southern Highland. Table 11a summarizes the greater concentration of higher slope and relief values (Classes 5 and 6) in the Northern Highland.

TABLE 11a

Percentages of Unit Areas in Specified Classes of Slope and Relief in The Northern and Southern Highlands

Slope:	Class 1 0°-1°	Class 2 1°-2°	Class 3 2°-3°	Class 4 3°-4°	Class 5 4°-5°	Class 6 5°-10°
Northern	13.1	27.1	43.5	55.3	72.1	81.1
Southern	21.4	42.7	39.2	28.2	14.6	3.2
UAC*	1609	2101	1488	767	402	465
Relief (ft.)	0-49	50-99	100-149	150-299	300-499	500-622
Northern	11.1	19.3	38.1	56.1	83.5	96.6
Southern	14.4	47.7	36.7	24.3	2.3	--
UAC*	961	2016	1552	1801	473	29

*UAC = Unit Area Count

The Northern Highland contains 72.1% of all Class 5 and 81% of all Class 6 slope and relief units of the study area; the Southern Highland does not exceed 15% of either class. Conversely, the Southern Highland includes between 62% and 64% of all units in Class 1 and Class 2 of local relief and average slope. The fact that neither highland province includes more than 50% of the lower three classes of slope and relief is an indication of the greater frequency of these three categories in the peninsular lowlands.

The Foreland Region of the Northern Highland

The foreland region of the Northern Highland, consisting of five separate subregions, comprises the largest second-order region of the study area and accounts for 20% of the area of the peninsula. The size and diversity of these subregions is considerable, an indication of the heterogeneous and transitional character of the land surrounding the highland core of the peninsula.

The western foreland is divided into two compartments, Sparta (6E) and Boyne City (6D), on the basis of contrasting slope and relief factors. Of the two, the Sparta subregion contains considerably less relief and less topographic roughness: 51% of its units have a relief of less than 150 feet and only 25% have slopes of more than 3^{o}. The Boyne City area shows 83% and 75%, respectively, in the same registers of relief and slope. In spite of the quite similar mix of landform types in both subregions, the morphometric character of the two subregions is clearly different.

The Boyne City compartment (6D) consists of six separate parcels or segments, the greatest fragmentation of any subregion, extending over 175 miles from Levering in the north to Shelby in the south. Although this subregion is bound together by certain hypsometric characteristics, a northern component (from Petoskey to Rapid City) of extreme ruggedness must be distinguished from a southern component (Rapid City to Shelby) of slightly less rugged slope and relief conditions (Fig. 33). Sixth largest of the 34 subregions of the study area, the Boyne City subregion has greater surface roughness than any other compartment, followed, in order, by the Traverse City (1B) and the Ogemaw (9C) subsections. This finding is supported by the fact that no other subregion exceeds the proportion of total area in rugged slope and relief which characterizes the Boyne City compartment: 38.5% and 54.6% of its units occur in Classes 5 and 6 (combined) of relief and slope, respectively (Tables 12 and 13).(4)

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(4)The ruggedness of terrain in the northern component is reflected in the construction of ski runs in the "Boyne Mountains." It is interesting that these and other winter sport areas are not

The northeastern foreland is divided into two contrasting terrain surfaces: the poorly-drained till plains of Posen (6C), with relief of less than 100 feet over 82% of its area, and the lake and swamp-studded till and outwash plains of Onaway (6B) with a relief in excess of 100 feet over 95% of its area. The Posen compartment contains fewer inclined surfaces and less relief than the nearby Alpena Lowland (1C) while the Onaway compartment is differentiated from the adjacent Mt. Pleasant Foreland (6A) on the basis of greater slope and relief (Fig. 33). Isolating the Onaway subsection serves to emphasize its prevailing outwash formations which do not occur in the adjoining subregions (6C, 1C, 1D).

The southeastern foreland of the Northern Highland is made up entirely of the Mt. Pleasant subregion (6A). This compartment is the largest morphometric unit of either highland province, comprising 2,450 square miles, approximately, and ranks as the third largest subregion of the study area. The subdued or undulating topography of this compartment is indicated by the fact that (1) no unit area has a relief in excess of 300 feet or a slope of more than 5°, and (2) approximately two-thirds of all units have a relief of 50-149 feet and slopes of 1°-3°.

A preponderance of the Mt. Pleasant subregion consists of undulating till and outwash plains as well as extensive lacustrine bottomlands with a relief of 50-149 feet. Two intracompartmental anomalies are apparent from an inspection of Figs. 13 and 14: (1) all units with a slope of less than 1° and a relief of less than 50 feet are associated with the nearly flat sandy lake plains near

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located on the topographic heights of the Northern Highland, but marginal to it.

Alger, and (2) all units with a relief in excess of 150 feet, 11.1% of the compartment area (Table 13), contain prevailing surface expressions of the Gladwin, Owosso, or Port Huron moraines.

These findings illustrate the control of various terrain dimensions by the presence or absence of specific landform types; however, these results apply to the Mt. Pleasant subregion alone and, because of the range of parametric values for any given landform type, one may not assume the same topographic expression of slope and relief for moraines, till and outwash, and sandy lake plains in other compartments of the study area.

The Intermediate Upland Region of the Northern Highland

The intermediate upland region is made up of three subregions which bear the names of three major river systems: the Muskegon (7A), the Manistee (7B), and the Au Sable (7C). Each of these rivers, because of headward erosion, is cutting back into surfaces of higher elevation and collectively they mark the greatest impact of fluvial erosion in the study area. These riverine incursions manifest themselves as finger-like indentions of the Northern Highland in the cases of the Manistee and Au Sable rivers (Fig. 34). The Au Sable forms the longest continuous penetration while the Manistee occupies the deepest valley of the peninsula (Fig. 10).

The Manistee and Au Sable compartments, in that order, feature drainage surfaces of increasing slope and relief when compared with the Muskegon subregion. The Muskegon segment contains an even distribution, approximately, of relief values on either side of the 150 foot-interval; in this respect, it is comparable to the Ann Arbor (3A) subregion. This morphometric parallel may indicate a similar degree of dissection of the recessional moraines common to the two intermediate upland surfaces.

Although all three subregions of this province have about the same relative area of moraines (37%-39%), the Au Sable area has more than twice as much outwash (47%-20%) as that of the Manistee. The latter, however, has 20% of its area in sandy lake plains formed during the high-water stages of glacial Lake Michigan. The morphometric contrast between the sandy lake plains and the Au Sable outwash plains is discernible in Fig. 14 which shows a relief of less than 100 feet for the former, but of 100-300 feet for the latter.

Although isolated segments of the Lake Border and Port Huron moraines (Lake Michigan Lobe) exceed 500 feet in local relief in the Manistee subregion, the West Branch (or Roscommon) Moraine produces a relief of 150-500 feet in 93% of the Au Sable unit areas. The corresponding frequency for the Manistee district is 73%, high in itself, and reinforces the morphometric uniformity of the Muskegon (7A) -- Manistee (7B) -- Au Sable (7C) relief slope ranking mentioned above (p. 116).

The Upland Region of the Northern Highland

Accounting for only 10% of the Northern Highland area, this second-order highland includes the Gaylord (9A), Cadillac (9B), and Ogemaw (9C) subregions at average elevations 50-250 feet above the highest average elevation of the Southern Highland. Interlobate moraines occupy 55%-59% of each subregion and, together with the Traverse City and Boyne City compartments, produce the most

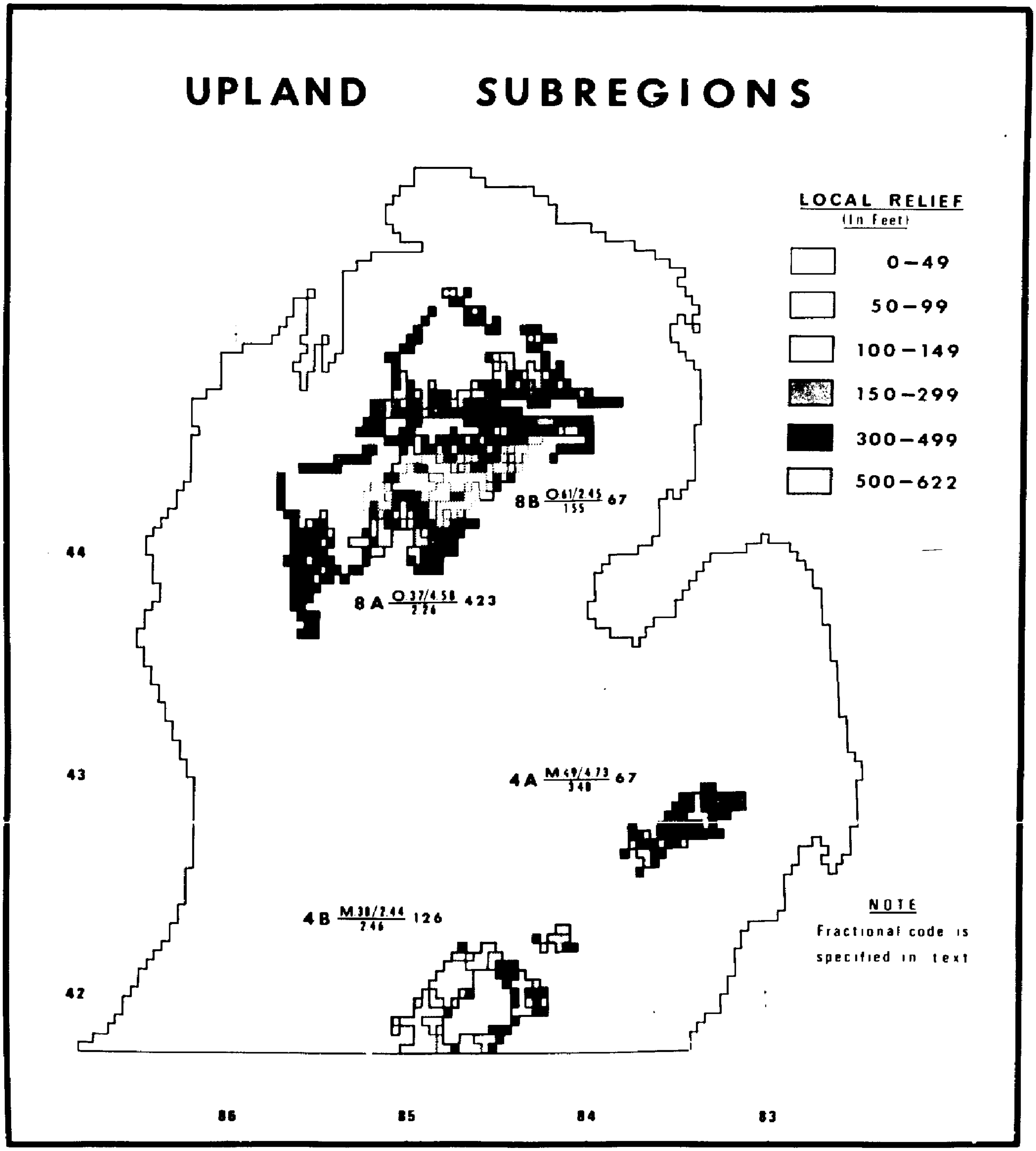
UPLAND SUBREGIONS
LOCAL RELIEF
(In Feet)
0–49
50–99
100–149
150–299
300–499
500–622
8B O61/2.45 155 67
8A O37/4.58 2.76 423
4A M49/4.73 3.48 67
4B M38/2.44 2.46 126
NOTE
Fractional code is specified in text
44
43
42
86
85
84
83

Fig. 35

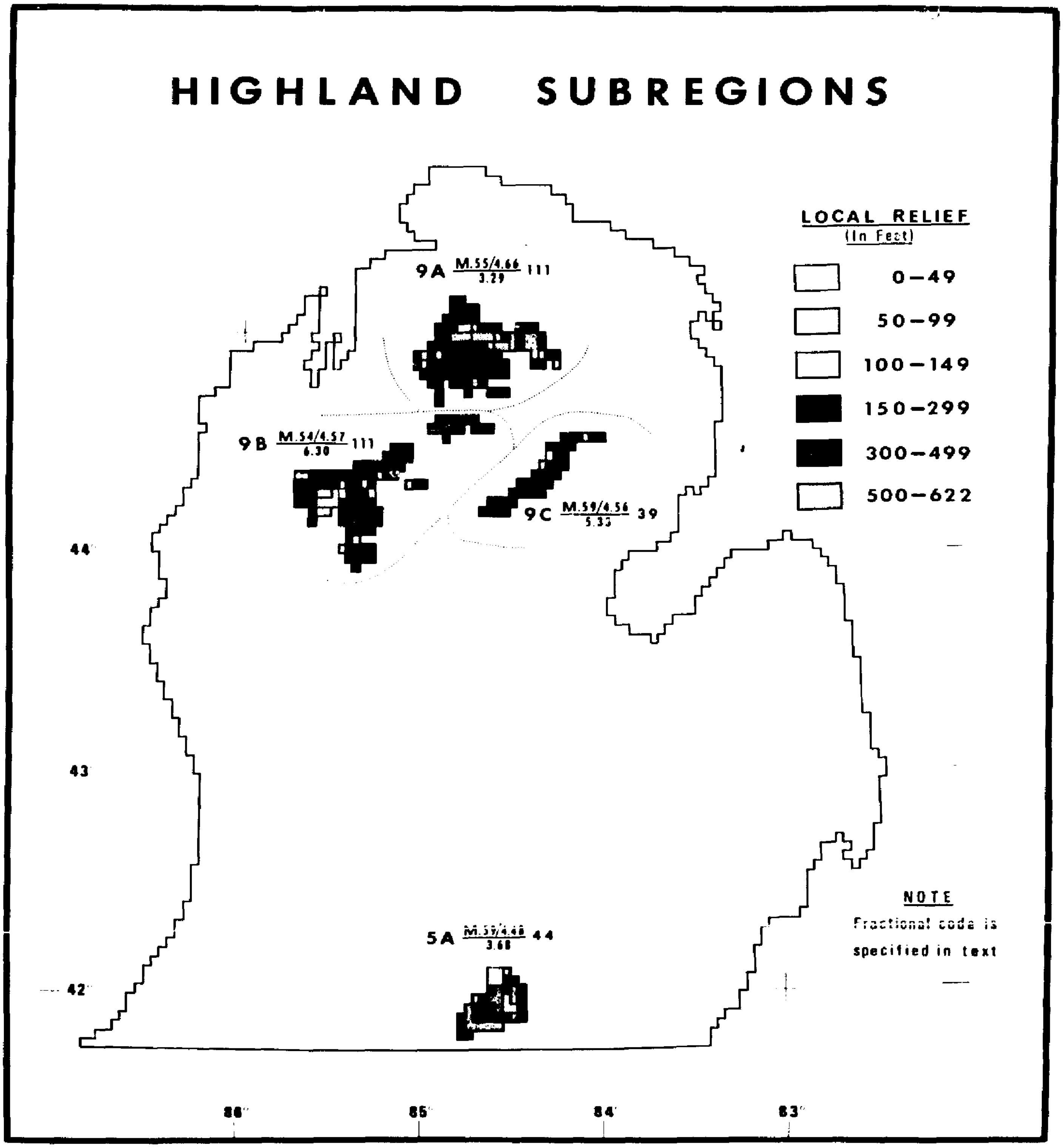
HIGHLAND SUBREGIONS
LOCAL RELIEF
(In Feet)
0-49
50-99
100-149
150-299
300-499
500-622
9A M.55/4.66 / 3.29 111
9B M.54/4.57 / 6.30 111
9C M.59/4.56 / 5.33 39
5A M.59/4.48 / 3.68 44
NOTE
Fractional code is specified in text
44
43
42
86
85
84
83

Fig.36

rugged topography of the study area.

Although the Cadillac Highland has 30% of its units in slope of more than 5^{o} and includes the highest elevation of the peninsula (1706 feet), the Ogemaw sector has slightly more area in relief of 300 feet or more and slope in excess of 4^{o}. The Gaylord Highland, with less broken topography, has considerably less area in 4^{o} slope, or 15%-19%, and relief of more than 300 feet, or 18%-25%, than either the Cadillac or Ogemaw Highlands.

Assessment of Regionalization and Comparison with Other Works

A major objective of this study concerns the differentiation of the topographic surface of the southern peninsula of Michigan into morphometric provinces, regions, and subregions. The morphometric provinces -- a discontinuous, peripheral lowland surrounding a northern and a southern highland -- are established by use of the 750 feet-isohypse to designate an upper and a lower register of changing average elevation values over the entire peninsula.

The first-order highland provinces are described in terms of four dissimilar altitudinal levels, called secondary morphometric regions, and labelled with an identifying set of descriptive terms. Homogeneous altitudinal levels, based on average elevation in a mosaic of unit areas, facilitate the study of the gross features of the peninsula considered as a physiographic entity.

Morphometric subregions, a third-order of terrain generalization, are based on the changing relief and slope characteristics within the peripheral lowland and at each of the altitudinal levels of the two first-order highlands. Because of the limited ranges of relief and slope data within the generally subdued terrain of the peninsula (and the resultant narrowly-defined class intervals of the data), the subregions display only diminished concentrations of the same class of relief and slope increments in their respective area-mosaics. However, the identification of relief-slope nodes may be verified from an inspection of the regional maps; the same maps point up the difficulty in constructing boundaries between such nodal areas when the change in relief and slope character is only gradual across significant horizontal distances. In such cases, subregional boundaries are drawn in a manner that equally apportions the anomalous unit areas to either of the morphometric nodes.

In concept, the present work is closer to Hammond's (1957) approach than to any other in the literature of regional morphometry. Hammond seeks the delineation of landform regions through the integration of slope, local relief, and profile characteristics. Slope description is based on the differentiation of steep and gentle slopes; profile traits are determined by the appearance of a minimum of two-thirds of all gentle slopes in either the upper or lower register of a unit's local relief. A third profile category allows an approximately equal distribution of gentle slope in both registers of relief.

Hammond overcomes the problem of creating terrain regions with homogeneous phenomena by absorbing all anomalous units, up to a maximum of four contiguous units, within any one of the 62 possible regional combinations of three terrain parameters (slope, relief, and profile). The approach used in the present work seems to be more objective in stating the percentage of prevailing classes of relief and slope and the mapping of the locations of all anomalous units. Although Hammond includes the percentage of stoniness of Missouri soils as a morphological indicator, this parameter is not used in delineating landform regions. In contrast, the eleven glacial landform types of the present study greatly facilitate the physiographic description of morphometric compartments.

Veatch's (1957) brief outline of the physical regions of the southern peninsula, without the benefit of morphometric parameters, is remarkably consistent with the results of this study. This is undoubtedly the result of his use of Leverett's earlier work in differentiating glacial formations of the study area, his careful analysis of terrain types, and his rich field experience and knowledge of the soils and vegetation patterns of the peninsula. Veatch's list of 21 subregions, compared with the 34 subregions of the present study, is notable for its lack of compartmentalization within the province of the Northern Highland.

As an integrative morphometry, the present work may be compared with Pike's (1963) thesis which incorporates eight weighted morphometric parameters in delineating 10 generic landform regions for New England. However, Pike's work is based on isoline constructions within a discontinuous network of 142 sample points representing regions of presumably homogeneous terrain character. These representative samples serve to quantify 100 square mile (average) terrain surfaces whereas the standard six square-mile unit area of this study provides a total inventory of the peninsular landscape.

Calef's and Newcomb's (1953) slope map of Illinois, a single-factor morphometric study, applies the Wentworth formula to irregularly shaped tracts of unlike slope characteristics. These tracts were isolated on topographic maps in a purely arbitrary manner as areas of either greater or lesser contour densities which contrast with other proximate slope tracts. Because of the difficulty in assigning transitional slope zones to either the higher or lower adjacent slope tract, the authors conclude that the arbitrary or "irregular" unit area method is virtually useless in areas of minor slope change (which characterizes much of the present study area).

It has been shown, in Chapter 3, that recessional moraines are consistent relief-makers in the array of glacial landform types common to the morphometric subregions of the southern peninsula; conversely, lacustrine landforms are often without visible slope or relief. Till and outwash formations in the study area display a variety of morphometric values but tend to cluster below the mean of such ranges of the data. It was also demonstrated that moraine-and-outwash combinations of both highland provinces have steeper slopes and greater relief than the moraine-and-till associations of other locations of either highland. Finally, the coincidence of reduced values of slope and relief with the lower elevation of lacustrine features contrasts sharply with the normally greater values obtained for the non-lacustrine regions of the peninsula.

CHAPTER V

EVALUATIONS AND PROSPECT OF TERRAIN REGIONALIZATIONS BY MORPHOMETRIC METHODS

Geomorphic processes of mainly a glacial character have sculpted the peninsular landscape and a variety of constructional landforms and terrain regions remain in place as topographic relics of a past climate. The two-fold objective of the present study seeks a morphometric assessment of the genetic landform types and the terrain regionalization of the southern peninsula of Michigan.

Parametric characterizations (slope, relief, and elevation) of eleven glacial landform types relate to the morphometry of terrain surfaces rather than to the morphometry of individual landform types. This is accomplished by reference to the smallest standard graticule, forming a network of more than 6,800 unit areas. Because of the relatively narrow spectrum of landform dimensions found in the morphometric data, it is extremely important that grid cells be small enough to effectively isolate the limited areas of slope and relief anomalies which give geometric contrast to the abundance of subdued topographic surfaces: many maps of the study area, at similar scales, depict an undifferentiated southern peninsula as simply a 'plains' area.

The relatively small 2 1/2-minute graticule also minimizes the displacement of regional boundaries caused by placing such boundaries along unit perimeters rather than as isolines plotted between data points. The resultant mosaic patchwork of quadrangular units produces a continuity of the morphometric data which compares favorably with that on contour or hypsometric maps of a similar scale.

Small scale terrain subregions, differentiating the peninsular landscape according to precise combinations of landforms with known dimensions, are produced from large scale topographic maps of a 5:1 ratio to the included morphometric maps (1:2,000,000 scale research maps to 1:62,500 scale topographic maps). Consequently, it was necessary to use area symbols in a grid network at the microscale because point or line symbolizations, in the fine-mesh data network of unit areas, become area symbols at the scale of the completed maps.

It is true that many of the subregional differentiations are based on patently minor fluctuations of the slope and relief data; it is similarly apparent that the resultant subregions do not represent totally homogeneous terrain regions within the narrowly defined class intervals of the diagnostic indices. However, this is the product of a subdued topographic surface without marked ranges in the morphometric data; it is also the concentration of slope and relief characteristics in area (rather than the exclusion of anomalous terrain examples) which provides the best approach to the delineation of significantly different terrain compartments within the constraints of only limited fluctuations of the data.

The adoption of the unit area as a reference frame is a conventional approach in the study of regional morphometry; however, the rectangular format is deficient in dealing with the varying sizes and shapes of non-geometrical parcels of homogeneous landform types, slope, or relief. When rectangular grid units are used, however, the topographic grain of the textured landform types is the determining factor in the selection of a proper unit-size; the determination of unit-size seems more critical when dealing with extensive surface formations of restricted changes of the included terrain dimensions.

Although Michigan landform types with a definite shape or grain, viz., eskers, drumlins, sand dunes, and kames, are commonly smaller than any other which has been applied to an extensive geographical area in the literature of regional morphometry. Despite the fact that a limited check of unit areas with textured landforms failed to produce significant parametric differences from the average of all the grains in a given unit area, additional research is required to establish the relationship between grain-size and the size of unit areas. The determination of a proper unit-size, in application to a diverse topographic surface, remains as a vexing problem in the literature of systematic morphometry (Thompson, 1959).

The results of this study are founded on the recency, accuracy, and scale of the appropriate series of topographic maps and the M.S.F. map (Martin, 1955) of the surface formations of the southern peninsula. Thrower and Cooke (1968) have discovered subdued drumlin and river terrace formations on updated (1959) versions of older (1902) topographic maps drawn with field-sketching techniques. They note that "a great deal more is said about technique and form than the quality of the contouring itself (in slope studies)."

Despite the improved expression of contours on topographic maps produced by photogrammetric methods, the requirement of contour accuracy remains far below the capabilities of modern photogrammetric plotters. Unchanged in more than half a century, the United States Geological Survey requirement for the placement of contours states that as many as 90% of the data points along a contour line may contain an error of as much as one-half the value of the contour interval; the remaining 10% of data points, by implication, may sustain errors of even greater magnitude.

The M.S.F. map (Martin, 1955) was drawn from topographic and county-road work maps, utilizing a scale of 1:63,360; and then reduced to a scale of 1:500,000. The map identities for the various glacial landform types was first accomplished by Leverett (1915) from one-inch to the mile reconnaisance maps; his published map, scale 1:750,000, was revised and updated on the basis of "detailed field work and the use of air photos."

Area, profile, and genetic characteristics of certain glacial landforms are crucial to the findings of this study. For instance, the areal extent of microfeatures, such as eskers, is so limited as to warrant study only as discrete, individual landforms. The difficulty in differentiating recessional and ground moraines

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(1) Personal correspondence: Helen M. Martin, August, 1963.

is yet another problem and the determination of such boundaries introduces a subjective element in the genetic classification of area landforms.

Suggestions for Future Research

There is a need to discover the morphometric character of specific formations on a chorographic basis. This approach might be extended to include, for instance, a detailed morphometry of the moraines of a given substage of the Wisconsin glaciation and their changing dimensions at different locations of the peninsula. The derived terrain data of these or other formation types could lead to certain conclusions regarding the rates of glacial ablation in various locations, and, possibly, the influence of a previous glacial or non-glacial topographic surface on a subsequent, superposed surface.

Because most of the parameters utilized in the present study were developed for the purpose of quantifying "alpine" terrain surfaces, their application to the lacustrine flats of the eastern coastal plain has produced relatively narrow ranges of the morphometric data. With the possible exception of parameters dealing with the order and texture of drainage (Strahler, 1957), there is a notable lack of terrain indicators which could serve to detect the subtle topographic differences which occur in different sections of these flat bottomlands. Of the parameters used in this study, the index of average slope displayed the greatest sensitivity to these intraregional differences.

A perusal of the appropriate topographic maps supports the contention that (1) the bank slopes of individual stream courses, and (2) the abrupt, but minor, changes in elevation along the face of the various beach benches make up the principal diagnostic features of extensive portions of the lacustrine plains. Because of the lack of specific techniques designed to quantify these kinds of subtle and extremely localized changes in slope and relief, the need for the innovation of flat-land parameters is crucial to future research. It is conceivable that such indices might express these "concentrated" relief and slope changes in a ratio to the total increment of slope and relief for the entire unit area.

A study of the peninsula's major drainageways is needed to complete the analysis of its gross landforms. Such a study should include a longitudinal survey of trunk valleys using the mean valley depth parameter (Pike, 1961). This indicator, actually an adaptation of Wentworth's formula, provides an index value (in feet) of the average depth of valley surfaces below the crest elevations of bounding ridge lines. In practice, 10-mile traverses (perpendicular to the channel) are analyzed for counts of slope direction changes and contour crossings. A comparison of such index values, taken at predetermined intervals along the longitudinal stream profile, should provide a formulatory basis for characterizing the basin character of each major stream or river; comparisons with the profile characteristics of other discharge channels should produce meaningful regional differences.

The Need for an Automated Morphometry

The tedious and time-consuming nature of collecting morphometric data is either directly stated or implied (on the basis of parameters used) in this and each of the regional studies mentioned in the text. It is unfortunate that a direct correlation exists between the size of the study area and the complexity of the parameters used; studies involving larger areas were based either on sampling techniques or on relatively simple terrain parameters. Research should be initiated to develop new parameters which can make use of unsophisticated terrain data to describe more abstract characteristics of the topographic surface; these new methods might provide such indices as the total area of a deformed surface compared to the area of the geometric plane surface of the unit itself.

In the absence of new concepts, ordinary data can be manipulated quickly and accurately with the use of automated equipment. The quantity and precision of computer-produced maps provide a powerful tool for the analysis of data and serve as a logical adjunct to the present calculations of local relief, average slope, the Index of Comparative Relief, and the Elevation-Relief Ratio. Future research will come to rely on the speed and load-bearing potential of computers manipulating data from formats on punched cards or magnetic tapes.

It is now feasible for computers to produce a multitude of work maps on ordinary line printers utilizing a variety of class intervals, representative symbols, and numerical transformations of the data. The perception of the various data distributions in a sequence of computer-produced maps will allow the researcher a choice of options not available previously because of the time/cost limitations in producing the maps or calculations by hand.

The SYMAP computer program, composed at the Laboratory for Computer Graphics (1968), can produce choropleth and isopleth maps on ordinary line printers and allows the user much flexibility in imput and output specifications. The recent introduction of the calculating computer adds a new dimension to computer-produced graphics: the coded data of a matrix imput is utilized in a three-dimensional representation given either as a histogram format or a topographic surface.

These programs have meaningful cartographic applications in the presentation of morphometric data, but the actual production of research maps is limited at the present time because of the lack of access to computers with very large memory cores, expensive coordinate plotters, and a technical staff needed to operate and maintain the diversity of program variations. However, the feasibility and increased tempo of morphometric research is virtually assured as cost-reductions occur and as the availability of trained programmers increases.

The application of primary scanners to conduct contour counts and of densitometers for assessing contour densities, however, might be even more fundamental to morphometric research than computer analysis of data. The time-consuming nature of data-collection remains as the largest single impediment to increased morphometric research.

APPENDIX

Morphometric Data for Regions, Subregions, and

Landform Types --

In Unit Areas Containing 50% or more

of the

Indicated Genetic Landform Type

TABLE 12 : NUMBER OF UNIT AREAS IN THE VARIOUS REGIONS(1) AND SUBREGIONS AND PERCENTAGES OF UNITS OCCURRING IN SPECIFIED CLASSES OF SLOPE

Subregion:	Number of Unit Areas:	Classes of Average Slope: (In Degrees) 0-0.99	1-1.99	2-2.99	3-3.99	4-4.99	5-10	TOTAL
1A	(412)	82.0%	15.1%	2.2%	0.7%	---	---	100.0%
1B	(831)	69.0	27.0	5.1	1.9	---	---	"
1C	(74)	23.0	52.7	18.9	4.1	1.3	---	"
1D	(123)	30.9	30.6	20.3	4.9	1.6	1.6	"
1E	(130)	11.5	4.6	6.2	23.1	13.1	41.5	"
1F	(127)	14.2	41.0	25.2	10.2	6.3	3.1	"
1G	(496)	15.7	40.4	25.2	11.1	5.0	2.6	"
Subtotal	2193:32.1%							
2A	(69)	10.1	60.9	29.0	---	---	---	"
2B	(36)	11.1	27.8	47.2	11.1	2.8	---	"
2C	(258)	58.5	40.3	1.2	---	---	---	"
2D	(72)	---	41.7	55.5	2.8	---	---	"
2E	(327)	28.2	53.6	18.1	0.1	---	---	"
2F	(105)	33.3	58.0	6.7	1.9	---	---	"
2G	(203)	4.6	20.8	35.6	23.7	13.3	2.0	"
2H	(115)	12.2	23.7	40.9	16.5	1.7	---	"
Subtotal	1185:17.3%							
3A	(241)	2.1	27.8	45.6	21.2	2.5	0.8	"
3B	(351)	6.9	68.6	22.2	2.3	---	---	"
3C	(104)	1.0	16.4	25.0	36.5	14.3	6.7	"
Subtotal	696:10.2%							
4A	(67)	---	9.0	47.7	32.8	9.0	1.5	"
4B	(126)	2.4	46.0	34.9	14.3	1.6	.8	"
Subtotal	193: 2.8%							
5A	(44)	---	25.0	68.2	6.8	---	---	"
Subtotal	44: .6%							
6A	(369)	24.7	42.3	26.0	6.2	0.8	---	"
6B	(279)	2.5	23.7	36.6	22.6	10.0	4.6	"
6C	(38)	13.1	60.6	23.7	---	2.6	---	"
6D	(357)	3.7	7.0	15.1	16.5	15.7	42.0	"
6E	(225)	6.7	24.9	40.9	19.1	6.6	1.8	"
Subtotal	1268:18.6%							
7A	(189)	4.2	19.6	34.4	24.3	13.8	3.7	"
7B	(176)	2.8	11.4	29.0	17.6	17.6	21.6	"
7C	(137)	---	6.6	11.7	27.0	23.3	31.4	"
Subtotal	502: 7.4%							
8A	(423)	6.4	25.8	23.6	16.8	11.3	16.1	"
8B	(67)	55.2	31.8	6.0	---	---	---	"
Subtotal	490: 7.2%							
9A	(111)	2.7	20.7	28.9	18.0	16.2	13.5	"
9B	(111)	---	16.2	18.9	16.2	16.2	29.8	"
9C	(39)	---	7.7	15.4	28.2	33.3	15.4	"
Subtotal	261: 3.8%							
TOTAL	6832:100%	1609 23.5%	2101 30.8%	1488 30.8%	767 11.8%	402 5.9%	465 6.8%	

(1) Expressed in the subtotals.

TABLE 13 : NUMBER OF UNIT AREAS IN THE VARIOUS REGIONS(1) AND SUBREGIONS AND PERCENTAGES OF UNITS OCCURRING IN SPECIFIED CLASSES OF LOCAL RELIEF

Subregion:	Number of Unit Areas:	Classes of Local Relief: (In Feet) 0-49	50-99	100-149	150-299	300-499	500-622	
1A	(412)	61.9%	28.2%	5.8%	4.1%	---	---	100.0%
1B	(831)	48.4	36.9	11.0	3.7	---	---	"
1C	(74)	10.8	40.5	27.0	20.3	1.4	---	"
1D	(123)	14.6	19.5	27.6	32.6	5.7	---	"
1E	(130)	8.5	1.5	3.1	48.4	37.7	.8	"
1F	(127)	.8	20.5	40.9	33.1	4.7	---	"
1G	(496)	4.2	32.3	32.9	29.8	.8	---	"
Subtotal	2193:32.1%							
2A	(69)	---	39.1	56.6	7.3	---	---	"
2B	(36)	---	72.2	27.8	---	---	---	"
2C	(258)	27.9	62.4	9.7	---	---	---	"
2D	(72)	---	2.8	59.7	37.5	---	---	"
2E	(327)	7.4	74.3	17.4	.9	---	---	"
2F	(105)	28.6	55.2	15.2	1.0	---	---	"
2G	(203)	---	14.8	40.4	42.8	2.0	---	"
2H	(115)	2.6	35.7	26.0	35.7	---	---	"
Subtotal	1185:17.3%							
3A	(241)	.4	17.0	34.9	47.7	---	---	"
3B	(351)	2.6	70.3	22.2	4.9	---	---	"
3C	(104)	---	23.1	39.4	35.6	1.9	---	"
Subtotal	696:10.2%							
4A	(67)	---	---	19.4	73.1	7.5	---	"
4B	(126)	---	43.7	32.9	23.8	---	---	"
Subtotal	193: 2.8%							
5A	(44)	---	15.9	36.4	47.7	---	---	"
Subtotal	44: .6%							
6A	(369)	12.2	48.8	27.9	11.1	---	---	"
6B	(279)	1.1	5.0	60.9	28.7	4.3	---	"
6C	(38)	10.5	71.1	15.8	2.6	---	---	"
6D	(357)	1.7	3.1	11.8	35.8	43.7	3.9	"
6E	(225)	1.8	15.1	33.8	47.5	1.8	---	"
Subtotal	1268:18.6%							
7A	(189)	2.6	19.1	29.1	48.1	1.1	---	"
7B	(176)	---	6.8	15.9	52.3	20.5	4.5	"
7C	(137)	---	---	5.8	51.1	43.1	---	"
Subtotal	502: 7.4%							
8A	(423)	.7	6.9	17.3	57.7	16.5	.9	"
8B	(67)	50.7	44.8	4.5	---	---	---	"
Subtotal	490: 7.2%							
9A	(111)	.9	9.0	14.4	65.8	10.8	---	"
9B	(111)	2.6	5.4	8.1	56.8	27.0	1.8	"
9C	(39)	.8	---	5.1	56.4	35.9	---	"
Subtotal	261: 3.8%							
TOTAL	6832:100%	961 14.1%	2016 29.5%	1552 27.7%	1801 26.4%	473 6.9%	29 .4%	

(1) Expressed in the subtotals.

TABLE 14 : NUMBER OF UNIT AREAS(1) IN THE VARIOUS REGIONS AND SUBREGIONS AND PERCENTAGE OF UNITS PER LANDFORM TYPE IN GIVEN REGIONS(2) AND SUBREGIONS

Sub-regions	Number of Unit Areas	MORAINE	TILL	LACUSTRINE(3)	OUTWASH	DRUMLIN	ESKER	SAND DUNE	UNCLASSI-FIED	TOTAL
1A	(412)	1.5%	0.3%	92.4%	---	---	---	---	5.8%	100.0%
1B	(831)	3.4	6.4	82.1	1.0	---	---	1.1	6.0	"
1C	(74)	---	5.4	79.7	---	4.1	2.7	---	8.1	"
1D	(123)	1.6	0.8	74.0	0.8	4.1	0.8	4.1	13.8	"
1E	(130)	16.2	7.7	19.2	1.5	30.8	---	6.9	17.7	"
1F	(127)	11.8	12.6	24.4	30.8	---	---	10.2	10.2	"
1G	(496)	16.9	11.9	36.9	14.9	---	---	5.7	13.7	"
Sub.	2193:32.1%									
2A	(69)	27.5	29.0	16.0	5.8	---	---	---	21.7	"
2B	(36)	41.6	---	11.2	5.6	---	---	---	41.6	"
2C	(258)	26.0	19.0	31.0	5.4	---	3.9	---	14.7	"
2D	(72)	50.0	5.6	13.9	8.3	---	11.1	---	11.1	"
2E	(327)	18.4	42.8	8.3	1.8	---	7.0	---	21.7	"
2F	(105)	5.7	8.5	1.0	67.6	1.0	---	---	16.2	"
2G	(203)	34.0	14.3	14.3	18.2	---	---	---	19.2	"
2H	(115)	27.8	7.0	2.6	39.1	---	---	---	23.5	"
Sub.	1185:17.3%									
3A	(241)	35.3	25.3	2.0	18.7	---	2.1	---	16.6	"
3B	(351)	19.1	19.9	4.3	21.6	4.3	11.4	---	19.4	"
3C	(104)	59.6	7.7	1.9	24.1	---	---	---	6.7	"
Sub.	696:10.2%									
4A	(67)	49.2	6.0	---	25.4	---	---	---	19.4	"
4B	(126)	38.1	7.9	---	21.4	2.4	1.6	---	28.6	"
Sub.	193: 2.8%									
5A	(44)	59.0	11.4	---	11.4	---	---	---	18.2	"
Sub.	44: 0.6%									
6A	(369)	20.0	32.5	19.2	16.9	---	---	---	11.4	"
6B	(279)	23.3	12.2	6.1	35.5	8.6	3.2	---	11.1	"
6C	(38)	2.6	55.3	10.5	---	18.4	5.3	---	7.9	"
6D	(357)	35.3	3.1	6.2	37.5	8.1	---	0.3	9.5	"
6E	(225)	31.5	14.7	---	41.8	---	---	---	12.0	"
Sub.	1268:18.6%									
7A	(189)	36.5	20.6	---	30.2	---	---	---	12.7	"
7B	(176)	37.5	2.3	---	47.1	---	---	---	13.1	"
7C	(137)	39.4	8.8	20.4	20.5	---	---	---	10.9	"
Sub.	502: 7.4%									
8A	(423)	33.1	15.4	2.3	36.9	---	---	---	12.7	"
8B	(67)	---	22.4	1.5	61.2	---	---	---	14.9	"
Sub.	490: 7.2%									
9A	(111)	55.0	1.8	---	37.8	---	---	---	5.4	"
9B	(111)	54.1	9.9	1.8	18.0	---	---	---	16.2	"
9C	(39)	59.0		---	25.6	---	---	---	15.4	"
Sub.	261: 3.8%									
TOTAL	6832 (100.0%)	1591 23.3%	928 13.6%	1795 26.3%	1330 19.5%	127 1.9%	102 1.4%	65 1.0%	894 13.0%	

(1) Only unit areas with more than 50% of the indicated landform types were assigned in this classification.

(2) Expressed in the subtotals.

(3) Includes sand and clay lake beds, interior ponded water formations, and boulder belts.

TABLE 15 : PERCENTAGES OF SPECIFIED CLASSES OF AVERAGE SLOPE FOUND IN THE VARIOUS REGIONS(1) AND SUBREGIONS

Subregion:		0° - 0.99°	1° - 1.99°	2° - 2.99°	3° - 3.99°	4° - 4.99°	5° - 10°
1A		21.0%	2.9%	0.6%	0.4%	---	---
1B		34.1	10.7	2.8	2.1	0.2	---
1C		1.1	1.9	0.9	0.4	0.2	---
1D		2.4	2.4	1.7	0.8	0.5	0.4
1E		0.9	0.3	0.5	3.9	4.2	11.6
1F		1.1	2.5	2.4	1.7	2.0	0.9
1G		4.9	9.5	8.4	7.2	6.2	2.8
	Subtotal	65.5%	30.2%	17.3%	16.5%	13.3%	15.7%
2A		0.4	2.0	1.3	---	---	---
2B		0.2	0.5	1.1	0.5	0.2	---
2C		9.4	4.9	0.2	---	---	---
2D		---	1.4	2.7	0.3	---	---
2E		5.7	8.3	4.0	0.1	---	---
2F		2.2	2.9	0.5	0.3	---	---
2G		0.6	2.0	4.8	6.3	6.7	0.9
2H		0.9	1.6	3.1	2.5	0.5	---
	Subtotal	19.4%	23.6%	17.7%	10.0%	7.4%	0.9%
3A		0.3	3.2	7.4	6.6	1.5	0.4
3B		1.5	11.5	5.2	1.0	---	---
3C		---	0.8	1.7	5.0	3.7	1.5
	Subtotal	1.8%	15.5%	14.3%	12.6%	5.2%	1.9%
4A		---	0.3	2.2	2.9	1.5	0.2
4B		0.2	2.8	3.0	2.3	0.5	0.2
	Subtotal	0.2%	3.1%	5.2%	5.2%	2.0%	0.4%
5A	Subtotal	---	0.5%	2.0%	0.4%	---	---
6A		5.7	7.4	6.4	3.0	0.7	---
6B		0.4	3.0	6.8	8.2	7.0	2.8
6C		0.3	1.1	0.6	---	0.2	---
6D		0.8	1.2	3.6	7.7	13.8	32.3
6E		0.9	2.7	6.2	5.6	3.7	0.9
	Subtotal	8.1%	15.4%	23.6%	24.5%	25.4%	36.0%
7A		0.5	1.8	4.4	6.0	6.5	1.5
7B		0.3	1.0	3.4	4.0	7.6	8.2
7C		---	0.4	1.1	4.8	7.9	9.2
	Subtotal	0.8%	3.2%	8.9%	14.8%	22.0%	18.9%
8A		1.7	5.2	6.7	9.3	11.[illegible]	14.6
8B		2.3	1.2	0.3	---	---	---
	Subtotal	4.0%	6.4%	7.0%	9.3%	11.9%	14.6%
9A		0.2	1.1	2.2	2.6	4.8	3.2
9B		---	0.9	1.4	2.7	4.8	7.1
9C		---	0.1	0.4	1.4	3.2	1.3
	Subtotal	0.2%	2.1%	4.0%	6.7%	12.8%	11.6%
	TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

(1) Expressed in the subtotals.

TABLE 16 : PERCENTAGES OF SPECIFIED CLASSES OF LOCAL RELIEF FOUND IN THE VARIOUS REGIONS(1) AND SUBREGIONS

Subregion:		Classes of Local Relief (In Feet)					
		0-49	50-99	100-149	150-299	300-499	500-622
1A		26.5%	5.8%	1.6%	0.9%	---	---
1B		41.9	15.2	5.9	1.7	---	---
1C		0.8	1.5	1.3	0.8	0.2	---
1D		1.9	1.2	2.2	2.2	1.5	---
1E		1.1	0.1	0.3	3.5	10.4	3.4
1F		0.1	1.3	3.4	2.3	1.3	---
1G		2.2	7.9	10.5	8.2	0.8	---
	Subtotal	74.8%	33.0%	25.2%	19.6%	14.2%	3.4%
2A		---	1.3	2.4	0.3	---	---
2B		---	1.3	0.6	---	---	---
2C		7.5	8.0	1.6	---	---	---
2D		---	0.1	2.8	1.5	---	---
2E		2.5	12.1	3.7	0.2	---	---
2F		3.1	2.9	1.0	0.1	---	---
2G		---	1.5	5.3	4.9	0.8	---
2H		0.3	2.0	1.9	2.3	---	---
	Subtotal	13.4%	29.2%	19.3%	9.3%	0.8%	
3A		0.1	2.0	5.4	6.4	---	---
3B		0.9	12.3	5.0	1.0	---	---
3C		---	1.2	2.6	2.0	0.4	---
	Subtotal	1.0%	15.5%	13.0%	9.4%	0.4%	
4A		---	---	0.8	2.7	1.1	---
4B		---	2.7	2.6	1.7	---	---
	Subtotal		2.7%	3.4%	4.4%	1.1%	
5A	Subtotal	---	0.3%	1.0%	1.2%	---	---
6A		4.7	8.9	6.7	2.3	---	---
6B		0.3	0.7	11.0	4.5	2.5	---
6C		0.4	1.3	0.4	0.1	---	---
6D		0.6	0.6	2.7	7.1	33.0	48.3
6E							
	Subtotal	6.4%	13.2%	25.7%	19.9%	36.3%	48.3%
7A		0.5	1.8	3.5	5.0	0.4	---
7B		---	0.6	1.8	5.1	7.6	27.6
7C		---	---	0.5	3.9	12.5	---
	Subtotal	0.5%	2.4%	5.8%	14.0%	20.5%	27.6%
8A		0.3	1.4	4.7	13.5	14.8	13.8
8B		3.5	1.5	0.2	---	---	---
	Subtotal	3.8%	2.9%	4.9%	13.5%	14.8%	13.8%
9A		0.1	0.5	1.0	4.0	2.5	---
9B		0.1	0.3	0.6	3.5	6.4	6.9
9C		0.2	---	0.1	1.2	3.0	---
	Subtotal	0.4%	0.8%	1.7%	8.7%	11.9%	6.9%
	TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

(1) Expressed in the subtotals.

TABLE 17 : PERCENTAGES OF SPECIFIED GENETIC LANDFORMS FOUND IN THE VARIOUS REGIONS(1) AND SUBREGIONS

Subregion:		Moraine	Till	Lacustrine	Outwash	Drumlin	Esker	Sand Dune	Unclassi-fied
1A		0.4%	0.1%	21.2%	---	---	---	---	2.7%
1B		1.8	5.7	37.4	0.6	---	---	13.8	5.6
1C		---	0.4	3.3	---	2.4	2.0	---	0.7
1D		0.1	0.1	4.5	---	3.9	1.0	7.7	1.9
1E		1.3	1.1	1.4	0.2	31.5	---	13.8	2.6
1F		0.9	1.7	1.7	2.9	---	---	20.0	1.4
1G		5.3	6.4	10.2	5.6	---	---	43.1	7.6
	Subtotal	9.8%	15.5%	79.7%	9.3%	37.8%	3.0%	98.4%	22.5%
2A		1.2	2.2	0.6	0.3	---	---	---	1.7
2B		0.9	---	0.2	0.2	---	---	---	1.7
2C		4.2	5.3	4.5	1.1	---	9.8	---	4.2
2D		2.3	0.4	0.6	0.4	---	7.8	---	0.9
2E		3.8	15.0	1.5	0.4	---	22.5	---	7.9
2F		0.4	1.0	0.1	5.3	0.8	---	---	1.9
2G		4.3	3.1	2.2	2.8	---	---	---	4.4
2H		2.0	0.9	0.2	3.4	---	---	---	3.0
	Subtotal	19.1%	27.9%	9.9%	13.9%	0.8%	40.1%		25.7%
3A		5.4	6.6	0.3	3.4	---	4.9	---	4.5
3B		4.2	7.5	0.8	5.7	11.8	39.2	---	7.6
3C		3.9	0.9	0.1	1.9	---	---	---	0.8
	Subtotal	13.5%	15.0%	1.2%	11.0%	11.8%	44.1%		12.9%
4A		2.1	0.4	---	1.3	---	---	---	1.4
4B		3.0	1.1	---	2.0	2.4	2.0	---	4.0
	Subtotal	5.1%	1.5%		3.3%	2.4%	2.0%		5.4%
5A	Subtotal	1.6%	0.5%	---	0.4%	---	---	---	0.9%
6A		4.6	12.9	4.0	4.7	---	---	---	4.7
6B		4.1	3.7	0.9	7.4	18.9	8.8	---	3.5
6C		---	2.3	0.2	---	5.5	2.0	---	0.3
6D		7.9	1.2	1.2	10.1	22.8	---	1.6	3.8
6E		4.5	3.6	---	7.1	---	---	---	3.0
	Subtotal	21.1%	23.7%	6.3%	29.3%	47.2%	10.8%	1.6%	15.3%
7A		4.3	4.2	---	4.3	---	---	---	2.7
7B		4.2	0.4	---	6.2	---	---	---	2.6
7C		3.4	1.3	1.6	2.1	---	---	---	1.7
	Subtotal	11.9%	5.9%	1.6%	12.6%				7.0%
8A		8.8	7.0	0.6	11.7	---	---	---	5.8
8B		---	1.6	0.1	3.7	---	---	---	1.1
	Subtotal	8.8%	8.6%	0.7%	14.8%				6.9%
9A		3.8	0.2	---	3.1	---	---	---	0.7
9B		3.8	1.2	0.1	1.5	---	---	---	2.0
9C		1.5	---	---	0.8	---	---	---	0.7
	Subtotal	9.1%	1.4%	0.1%	5.4%				3.4%
	TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

(1) Expressed in the subtotals.

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