Landform Types
Michigan State University Agricultural Experiment Station
Technical Bulletin
Louis A. Wolfanger, Soils and Conservation
Issued February 1941
23 pages

TECHNICAL BULLETIN 175 FEBRUARY 1941

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A Method of Quantitative and Graphic Analysis and Classification

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ACKNOWLEDGMENT

Grateful acknowledgment is due W. D. Baten, Associate Professor of Mathematical Statistics, for his helpful suggestions relative to the trigonometrical considerations involved in the analyses; and to L. R. Schoenmann, Director of the Conservation Institute, and to Ivan F. Schneider, Research Assistant in Land Use, for critically reviewing the manuscript.

LANDFORM TYPES

A Method of Quantitative and Graphic Analysis and Classification[1]

LOUIS A. WOLFANGER

From a century or two of pioneering which sought to bring the land into *some kind* of use, America has lately turned to a keen interest in *good* land use. This interest has naturally led to a more careful observation of the really significant characteristics of land, to more critical distinctions between one kind of land and another, and in turn to more exacting definitions of terms employed in describing land differences.

Of the various characteristics which land possesses, the detailed nature of the surface configuration is a feature that has especially captured attention. The concern over soil erosion and the proper use of supramarginal as well as submarginal lands, in which the minor or more secondary aspects of the topography play a significant role, are but a few of the many problems that have developed interest in the subject. Geographers, of course, have long been active students of landform, and have made various attempts to analyze and classify the surface configuration. While important progress has been made that has led to an extended understanding of the nature of the land surface, both in a broad way and in respect to individual components, yet the methods

[1]The beginnings of a scientific study of landforms may be largely identified with the broad and comprehensive types of studies initiated by von Richthofen and Penck, the so-called "fathers" of modern geomorophology, in the latter part of the nineteenth century. While Hermann Wagner had long advocated and utilized the inclusion of quantitative and measuremental considerations in geographic analyses, (see Norbert Krebs, "Mass and Zahl in der Physicien Geographie," Petermanns Mitteilungen 209, 1930, pp. 9-16 for an appreciative evaluation of Wagner's position) yet the chief interest of most students of landforms has been largely concentrated on the genetic, and only in part, as a whole, upon the equally important attributive aspects of surface configuration. The limitation, "in part," refers, of course, to the quantitative aspect of analysis, since qualitative descriptions are legion.

Recent years have witnessed a revival of interest in quantitative analyses on the part of geographic students, but they have been concerned mainly with slope and relief as such, and have overlooked the interesting possibilities of clarifying, through the help of quantitative determinations, the long pending question as to the more exact and critical differences between the surface configuration of one body of land and another. European students have been particularly active in the field of slope and relief analyses. Typical of their work are such studies as those of Partsch, Krebs, Slanar, Sidaritsch, Bruening, Schrepfer, Kallner, Wendiggensen, Paschinger, Weverinck, Schläfer, Burckhardt, Grano, and Sonntag. See A. Schläfer, "Die Berechnung der Reliefenergie und ihre Dedeutung als graphische Darstellung," Mitteilungen der Ostschweizerischen Geographisch-Kommerziellen Gesellschaft in St. Gallien, 1937-1938, 1939, pp. 1-59 for a brief summary of their work; also Guy-Harold Smith, "The Relative Relief of Ohio," Geogr. Rev., Vol. XXV, 1935, pp. 272-284, reference on pages 272-275. The latter is representative of American studies. Reference may also be made to V. C. Finch, "Montfort, A Study in Landscape Types in Southwestern Wisconsin," Geographic Surveys, Geogr. Soc. of Chicago, Bull. 9, 1933, pp. 15-44; to Robert M. Glendinning, "The Slope and Slope-Direction Map," Mich. Papers in Geogr. Vol. VII, 1937, pp. 359-364; and to the references noted in footnotes 8 and 12.

of analysis utilized and the results obtained have neither revealed nor set forth in a clear and well-defined manner the critical details of surface configuration that fundamentally and decisively distinguish one landform area from another and are so highly significant in studies of land geography and land utilization.

This paper approaches the analysis of surface configuration from a slightly different angle than has heretofore been attempted. Following a brief discussion of one or two of the more critical elements of configuration, it proposes a QUANTITATIVE and GRAPHIC system of analysis that may be coupled with a qualitative characterization for the identification and classification of landform types, and suggests some of the utilities of such analyses. Most characterizations up to the present time have been primarily qualitative. But qualitative characterizations without quantitative limitations are not sharply definitive.

INEXACT TERMS

Certain gross differences between land surfaces have long been identified. Such phrases as "the surface is flat," "the land is level or undulating," "the country is rolling," or "the region is hilly" are descriptive terms common to ancient as well as to modern chronicles, to scientific as well as to popular treatises. Various degrees of refinement have also been recognized. A region may not only be regarded as flat, but as nearly flat or very flat; not only as rolling but as gently rolling, moderately rolling, or strongly rolling. Additional support may likewise be lent by a score or more of pictorial adjectives —steep, precipitous, sharp, rough, hummocky, uneven, even, undulating, uniform, and similar terms.

Such qualitative terms are helpful in distinguishing land surfaces from one another. But they lack exactness in meaning. The degree of undulation embraced in the term, "gently undulating," for example, is subject to a wide range of personal interpretation. A resident of the Great Plains of Colorado will picture in this phrase an entirely different type of surface from that envisioned by the till plain dweller of southern Michigan or the coastal plain inhabitant of Georgia. Indeed, one or the other is certain to insist that his environment is not even undulating at all, but level or even flat!

This lack of agreement arises from several situations. In part, it arises from an inadequate terminology, and therefore an effort to make a limited vocabulary fit every type of surface configuration. In part, it is the result of cursory observation and a failure to recognize important differences. It is primarily due, however, to an almost exclusive dependence upon qualitative descriptions without support of quantitative relationships. Unless the comparative magnitude of the elements which make up a surface are indicated, their frequency of occurrence within unit areas stated, and similar quantitative facts set forth, the degree of undulation, the levelness or the nature of other surface characteristics are merely indefinite relationships.

ELEMENTS OF LANDFORM

An approach to a technique of quantitative and graphic analysis of landforms was first suggested to the writer by some of the analytical work of J. O. Veatch on land types in Michigan. Feeling a need for a quantitative basis to support his differentiation of types, he determined their proportion of "highland," "lowland," and four slope classes; and by integrating the slope classes developed a simple three-line curve for their graphic representation.[2]

This procedure suggested the principle that must underlie a scientific analysis and definition of all landform types, viz., that a whole cannot be clearly characterized or defined until its component parts are not only described but are also measured, and both the broad relationships and the inter-relationships of these parts are determined. The general principle is not new, but its application to the quantitative aspects of land form analysis has been comparatively limited, except for such specialized types of analysis as were noted in footnote one.[3]

What are the elements on which quantitative analyses may be based? A number of components may be recognized, ranging from minute detail to integrants of the first magnitude. While each element must be taken into account in a complete detailed analysis, only one has been selected as the basis for this study since it contributes so materially to the broad objective. It may be termed the surface plane.

The peculiarities of form or configuration which any land area *in toto* presents is primarily a function of the innumerable individual surfaces of which it is composed. These surfaces comprise the primary elements or components of form. Although their shape varies from roughly convex to concave, in detail they may be viewed as a series of plane-like surfaces that range from large to small in size. These planes are not planes in the geometric sense but parts of the curved surface of the earth. The distribution or pattern which they assume from region to region extends from relatively simple to very complex. A peculiar or distinctive association of planes conjoined in given patterns and in given proportions is the fundamental basis for distinguishing one landform area from another.

The varied patterns which the surface planes assume, however, challenge description. Descriptions are possible but are limited in exactness owing to lack of terms that are clearly definitive of pattern. Probably a score or more could be marshalled — rectangular, zigzag, stripped, linear, dendritic and similar adjectives — but no comprehensive system of terms exists, and even the few we have are hardly exact enough in meaning to adequately serve objective analyses.

On the other hand, a quantitative analysis lends itself more readily to known or established tools. Size, gradient, number and proportions are measurable relationships. The size and gradient of each plane of a region, or of a representative sample of a region, may be measured, the planes grouped into classes, and comparisons made with other regions. Means or averages may be determined and compared. In fact, the data may be manipulated to obtain a variety of relationships. The procedure that may be employed and the value of the results obtained will be made clearer when applied to specific illustrations than if further generalized upon at this stage of the bulletin.

[2] J. O. Veatch, "Graphic and Quantitative Comparisons of Land Types," Jour. of Am. Soc. of Agron., *(27)* 7: 505-510. 1935.

[3] The concept on which this method of analysis is based was originally presented as a paper before the Geography Section of the Michigan Academy of Science, Arts and Letters in March 1940, under the title, "Flat or Level, Rolling or Hilly?" Later, while teaching in the summer session of Columbia University, the writer had the opportunity to utilize the more extensive literature of the American Geographical Society; his attention was called, through the courtesy of the librarian, Miss Elizabeth T. Platt, to the work of several other investigators who had also undertaken a quantitative and graphic analysis of certain aspects of surface configuration, noteworthily, as outlined in footnote 1, the characteristics of slope and relief. Reference to these studies has been made at appropriate points in the text.

Coupled with such qualitative descriptions as our limited vocabulary relative to pattern and form permits, such quantitative analyses should provide us with a more precise basis for identifying, defining and classifying landform types than has so far been devised.

GRADIENTS AND GRADIENT CLASSES

The innumerable planes which form the earth's surface vary in gradient or slope from horizontal to vertical. Grouping them into classes has accordingly been found to be the most serviceable first step. Such groups may be based upon either of two considerations. Group limits may be set (1) at arbitrary uniform intervals of gradient, such as 0 to 5, 6 to 10, 11 to 15 per cent, and so on; or (2) on their appropriateness to the gradients of the land under consideration, such as 0 to 2, 3 to 7, 8 to 15 per cent. Both methods possess advantages and disadvantages. The latter is the more natural, but it may handicap comparisons where land areas exhibit different natural limits and the group limits overlap.

Whatever limits may be selected, the gradient classes in turn fall naturally into two distinct types, (1) those of low gradient which approach a true horizontal plane and (2) those of higher gradients that comprise the so-called slopes.[4] The low gradient planes occur characteristically in two positions. They comprise the local, level, lower "flats," such as the basin floors and valley bottoms, and the local, level, higher "flats," such as the upper levels of upland swells, ridge crests, divides. To avoid confusion in nomenclature, two new micro-relief terms are proposed for the planes occupying those positions: INFRAPLANES for the lower or depressed "flat" or near-horizontal areas *within* a region, and SUPRAPLANES for the corresponding higher "flats" or upper levels. The importance of this distinction will become apparent later in this bulletin.

It is more difficult to affix a definite nomenclature to the planes of higher gradient because their limits are more flexible. Gentle, moderate, steep, very steep, suggest themselves as practical terms, although they possess no universal applicability unless their limits are agreed upon by common consent.

PROPORTIONS OF GRADIENT CLASSES

The simplest quantitative comparisons that may be made in the analyses of two land areas are in their proportions of gradient classes.

The proportion of each gradient class within a landform type may be obtained EXACTLY, by laborious measurement of the actual area occupied by each class and computing its percentage of the whole, or APPROXIMATELY, and quickly by running a series of traverses across the region, measuring the

[4]Cholnoky recognizes somewhat analogous components of surface forms. "The surface forms of the earth are constituted of two elements. The first part of these is the horizontal plane, the second the slope. There are no other components. Planes are termed horizontal if the direction of terrestrial gravitation is perpendicular to each of their elementary surface points . . . Every surface to which the direction of gravity is not perpendicular is a slope." Cf. Jeno Cholnoky, "On Slopes," Bull. Int'l. de la Soc. Hongroise de Geogr., LXVI, 1938, pp. 77-89. Unless broadly construed, however, his definition is too rigid and unreal inasmuch as many land surfaces are identified as "horizontal" planes although the surface may possess a decided gradient, i. e. not be truly perpendicular to the direction of gravity.

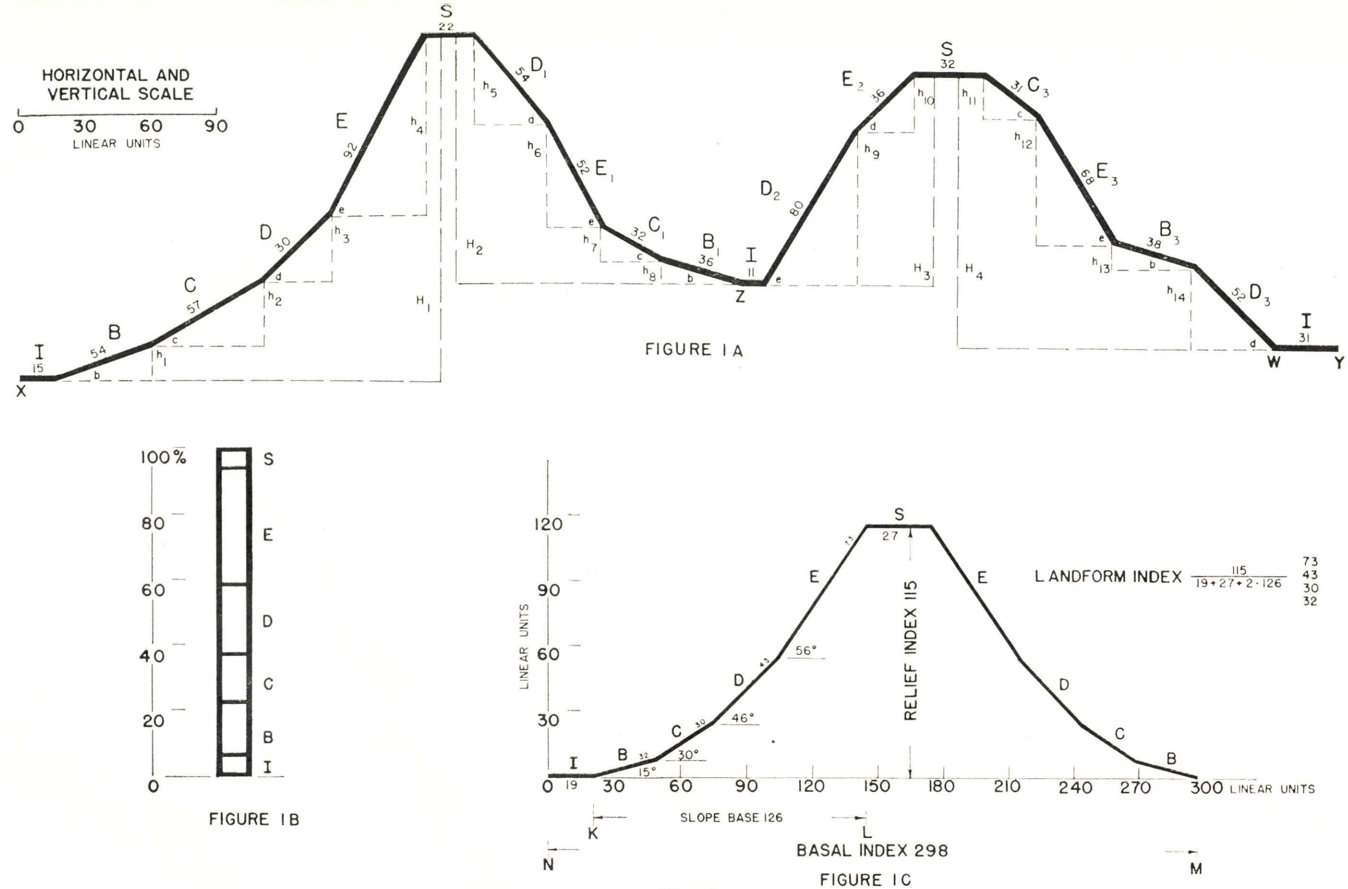

Fig. 1.

Fig. 1A. Traverse of two imaginary hills and their associated lowlands to show the classification and lengths of their gradient classes and the trigonometric relationships of the slope classes.

Fig. 1B. Bar graph showing the percentage of gradient classes in the two imaginary hills of Fig. 1A. The percentage is based upon the proportion which each class forms of the total traverse.

Fig. 1C. Mean landform curve of the two imaginary hills, including the method of constructing angles for plotting the mean gradient classes, the quantitative relationships of the curve, and the fraction, or landform index, setting forth these relationships.

linear intercepts of each gradient class on the line of traverse, totaling the linear intercepts of each class, and computing the proportion which each total comprises of the entire traverse. The traverse method, owing to its lower cost, was used in obtaining the results reported in this publication. The degree of accuracy will necessarily depend upon the length of the traverse in relation to the size and shape of the area and the pattern of its form elements.

The use of the traverse method and the manner of analyzing the data may be illustrated with the aid of the two imaginary hills drawn to scale (Fig. 1A). Table 1 defines the classes, symbols, and other items appearing on these hills or used in subsequent analyses. While the analysis of a thousand hills would appear more impressive, the procedure would be analogous and the data only more cumbersome to handle. It should be noted that both infraplanes and supraplanes lie at several elevations, and that one of the hillsides consists of only two grades of slope.

The six gradient classes listed in column 1, Table 1, are those that have been found generally applicable to the glacial and lacustrine lands of Michigan, the source of the data utilized in later analyses of actual situations. In the case of the imaginary hills, however, the slope classes, B to E, were first fixed at their respective class means, column 4, and then plotted at five times this mean, *viz.,* at 27.5, 57.5, 102.5 and 150 per cent respectively, or at the angles of 15°, 30°, 46° and 56°, column 5.

TABLE 1.

1 Gradient Classes	2 Gradient Class Symbols	3 Gradient Limits (Per Cent)	4 Mean Gradients (Per Cent)	5 Angles of Plotting	6 Angle Symbols
Infraplane	I	0–3	....	....	....
"Gentle Slope"	B	4–7	5.5	15°	b
"Moderate Slope"	C	8–15	11.5	30°	c
"Steep Slope"	D	16–25	20.5	46°	d
"Very Steep Slope"	E	26+	30.0	56°	e
Supraplane	S	0–3	....	....	....

The mean gradients listed in column four are the arithmetic averages of the gradient limits shown in column three with the exception of the very steep slope class which was arbitrarily fixed at 30 per cent, inasmuch as this conforms to the average Michigan conditions for this class.

The fifth column shows the angles at which gradient classes B to E are plotted in constructing the mean landform graphs described on a later page. These angles are equal to a five-fold exaggeration of the actual mean gradients of these classes as shown in column 4 (i.e. 5.5 x 5, etc.) in order to increase their graphic effectiveness; plotted at their actual means, these slope classes tend to produce graphs, the contrastive characteristics of which are not readily discernible, unless large scaled graphs are employed. The magnitude of each angle is obtained by looking up the value of the actual gradient multiplied by 5 in the tangent column of an ordinary trigonometric table and noting the angle to the nearest degree (fractions of a degree are difficult and generally impracticable to plot). For graphic purposes, it is assumed that the infraplanes and the supraplanes have zero gradients.

Traversing the surface from X to Y, each slope would be classed according to its gradient, measured and recorded. Table 2 gives these tabulations, including the calculated proportions which each gradient class forms of the whole. Intraplanes (I) aggregate 57 units and form 7 per cent of the total traverse of 823 units; gentle slopes (B) aggregate 128 units and form 16 per cent; and similarly.

The broadest characteristic of surface configuration which these percentages reveal is the comparative levelness or unevenness of the land as a whole. Combining the percentages of infraplanes and supraplanes and com-

TABLE 2.

Gradient Classes and Tabulated Gradient Lengths							Total Traverse	
I	B	C	D	E	S		Units	Per Cent
15 11 31	54 36 38	57 32 31	30 54 36 52	92 52 80 68	22 32	I.... B.... C.... D... E.... S....	57 128 120 172 292 54	7 16 15 21 35 6
57	128	120	172	292	54		823	100

paring their sum, 13, with the sum of the slope classes, B to E, 87, it is apparent that sloping surfaces predominate more than 7 to 1. Each gradient class, in turn, indicates the relative distribution of the several types of surface planes: levelness is about equally divided between the supraplanes and the infraplanes; over one-half of the area, 56 per cent, consists of steep (D) and very steep (E) slopes; only one-third, 31 per cent, is made up of gentle and moderate slopes.[5]

A simple bar of the type shown in Fig. 1B has been found the most serviceable by which to depict the proportionate occurrence of each gradient class graphically. It is easily constructed and read, and facilitates comparison when aligned in, or matched with, a series of similar bars for other landform types.

MEAN GRADIENT LENGTHS

While the proportionate extent of gradient classes may be used as a measure of comparative levelness, it does not reveal relative differences in the magnitude of relief or form. Exactly the same proportions of gradient classes as those shown in Fig. 1B would materialize were the units of measure in yards, rods, or furlongs—for example, were these low hills, high hills, or mountains of identical form. This is one of the major limitations in the method of analysis proposed by Veatch to which reference has already been made.

These differences can only be set forth in real magnitudes, and not in proportionate terms only. They reveal themselves in the lengths and the mean lengths of the gradient classes. An easy method to determine these means proved elusive for a time, but was eventually discovered in some simple trigonometric relationships.

The mean lengths of the two level plane classes, the infraplanes and the supraplanes, may be obtained by dividing the aggregate length of each in the traverse by its frequency. Referring to Fig. 1A, and Table 2, the infraplanes, I, had an aggregate length of 57, and a frequency of 3; the mean infraplane is therefore 19 units. Only two supraplanes, S, were recorded, however, so that the average length of this class is 27.

The mean lengths of the slope classes, B, C, D, and E, on the other hand, are obtained by dividing their aggregates by the total number of ascents and

[5]Raisz suggests several interesting methods of reducing levelness to a single coefficient or to flatland-ratios. Cf. Erwin Raisz, General Cartography, McGraw-Hill & Company, Inc., New York, 1938, pp. 273-274. See also Veatch, *op. cit.*

descents between the infraplanes and supraplanes *regardless of whether each slope class is always present.* This divisor would be 4 in the case of the two hills, and the mean lengths would be 32, 30, 43 and 73, respectively. Offhand, it would appear that the divisor for each of these classes would also be its frequency in the traverse; however, it should be noted that even though one or more gradient classes be visibly absent in the case of an ascent or descent (such as the right-hand hill), yet each is trigonometrically present as zero in length, necessitating its inclusion in the divisor.[6]

A MEAN LANDFORM GRAPH

The significance of these several means becomes most apparent if their relationships are graphically depicted. Since each mean represents the average length of its class, (19, the mean length of the infraplanes; 27, the mean length of the supraplanes, and similarly, in the case of the two hills) they may be used to construct a mean landform graph. Such a graph appears in Fig. 1C for the two imaginary hills drawn on the same scale as the hills to facilitate comparisons.

Coordinate axes were set up and the mean infraplane (I), 19 units, laid off parallel to the abscissa. Next, the mean "gentle slope," B, was plotted by constructing an angle of approximately 15 degrees beginning at the right end of I and laying off the mean length of B, 32, on the ascending arm. The angle, 15 degrees, is the angle corresponding to the mean gradient of this class (Table 1, column 5).

Slopes C, D, and E were similarly appended in order to form a continuous curve, utilizing the angles 30, 46, and 56 degrees, respectively. The supraplane, S, is plotted parallel to the abscissa. The curve is returned to the base by the addition of the same mean slope lengths, E, D, C, and B to the graph.

RELIEF INDEX

This curve is a diagrammatic summation of the general shape and magnitude of these hills. It is, after a fashion, a profile of a "mean hill" and its associated mean infraplane. Its altitude, 115 units, is the mean local altitude of the hills and may be termed their RELIEF INDEX (R_i) Fig. 1C. This number, 115, is not the maximum relief as measured by the vertical distance between the lowest infraplane and the highest supraplane, but is an arithmetic average which weights the position of all of the infraplanes and supraplanes in the traverse in the matter of relief. This index has a number of important relationships. When determined in actual situations, it offers a basis for comparing the sum total relief of two areas of land in terms that are more significant, in general, than comparisons based upon maximum relief only inasmuch as the topographic position of each infraplane and supraplane is considered. This

[6]It is important, in running a traverse to record or tally the number of infraplanes, supraplanes, ascents and descents in order to obtain the proper divisors. This is particularly essential where hill or mountain tops, or valley bottoms are too narrow to be deemed worthy of measure.

does not imply that maximum relief is of little or no interest; it merely indicates that average relief is a more inclusive basis for comparisons.[7]

BASAL INDEX AND STEEPNESS INDEX

The mean landform curve also reveals significant horizontal as well as vertical relationships. Thus, the horizontal distance between the initial point, N, Fig. 1C, of the mean infraplane and the end point, M, of the second descending B slope is a measure of the mean breadth or basal extent of the hills and their associated infraplanes. This may be termed the basal index (B_i). It facilitates comparison of size in a horizontal plane. For example, land areas may be compared as to the number of "mean hills" in unit distances such as per hundred miles of traverse.

The horizontal distance between points K and L, Fig. 1C, may be termed the slope base (S_b). Combined with the relief index as a fraction, $\frac{\text{Relief Index}}{\text{Slope Base}}$, it provides a general steepness index, an approximate measure of the angle of slope or the steepness involved in making the ascent from the mean intraplane to the mean supraplane. If the ratio is less than one, the general steepness of the land area under consideration will not exceed a gradient of 100 per cent or an angle of 45 degrees and the ascent, taken as a whole, may be described as relatively gentle; if greater than one, relatively steep. The steepness index of Fig. 1C is $\frac{115}{126}$ or 90 per cent (42 degrees). Although

[7]The trigonometric relationships involved in determining the mean lengths of the slope classes and the mean altitude or relief index embrace the following considerations, using the two large hills for illustrations:

$$\text{Mean Altitude} = \tfrac{1}{4}\,(H_1 + H_2 + H_3 + H_4)$$

$$\text{But } H_1 = h_1 + h_2 + h_3 + h_4 = B \sin b + C \sin c + D \sin d + E \sin e\text{; and}$$

$$H_2 = h_5 + h_6 + h_7 + h_8 = B_1 \sin b + C_1 \sin c + D_1 \sin d + E_1 \sin e\text{; etc.}$$

Substituting, condensing and simplifying, and replacing 4 with n, the total number of ascents and descents, to derive a general equation:

$$\text{Mean altitude} = \frac{\Sigma B}{n} \sin b + \frac{\Sigma C}{n} \sin c + \frac{\Sigma D}{n} \sin d + \frac{\Sigma E}{n} \sin e$$

Note, as already shown, that the mean slope lengths of B, C, D, and E classes are the sum of each divided by n and not by their individual frequencies. Substituting the known values of the mean slope lengths, B to E, determined in Table 2, and the known angles 15, 30, 46, and 56 degrees respectively in the general equation, the mean altitude sums up to 115. This value, 115, however, may be read directly from the mean landform graph, if reasonable care is used in its construction.

Quantitative methods for determining a mean or representative relief from topographic maps have particularly engaged the attention of German and Polish geographers during the last decade or two. All of the maps used have been relatively large scaled, however. A series of studies employing the term, RELIEFENERGIE, has been published. The term does not lend itself to exact translation, because the connotation varies somewhat with different authors. Some writers use it to signify "maximum," some "average" and others "typical" relief. There are also differences in the criteria employed in measurement. Some measure relief between adjacent low and high points, while others determine the differences between lowlands and uplands as a whole, or only between genetically related low and high points.

A. Schläfer, *op. cit.*, gives the best critical review of the several viewpoints and their relative values. See also Guy-Harold Smith, *op. cit.* and Erwin Raisz and Joyce Henry, "An Average Slope Map of Southern New England," Geogr. Rev. XXVII, 1937, pp. 467-472.

primarily an approximate measure, the determination of this value is a helpful additional factor in characterizing a landform type. A more exact concept of the nature and form of the average ascent (or descent) may obviously be derived from examination of the mean landform curve, or by noting the length and proportion of each slope class, B to E.[8]

THE LANDFORM INDEX

The relief index may be combined with the basal index, B_i, to produce the landform index, $\frac{R_i.}{B_i.}$ This index, L_i, is of greatest service, however, if the basal index is written as the sum of the value of its separate components, the infraplane, the supraplane and the slope base, *i.e.*,

$$\frac{\text{Relief Index}}{\text{Infraplane} + \text{Supraplane} + 2\ \text{Slope Base}} \text{ or } \frac{R_i}{I + S + 2S_b}$$

Written in this form, the index is an algebraic summation of the major features of the mean landform graph in that it sets forth the magnitude of each major component except the individual slope classes, B to E, which affects the gross form of a given land surface: the relief, the size and proportion of infraplane and supraplane, and [by noting the ratio of the relief index (R_i) to the slope base (S_b)] the general character of the ascent from infraplane to supraplane (*i. e.* the general steepness). Where information relative to the length of the individual slopes classes B to E is desired, their magnitudes may be entered adjacent to the fraction in some appropriate order, such as a vertical column starting with the slopes of highest gradient and descending to the class of lowest gradient:

$$\frac{R_i}{I + S + 2S_b} \begin{matrix} E \\ D \\ C \\ B \end{matrix}$$

The usefulness of the landform index may in part be demonstrated by substituting the values derived from Fig. 3A:

$$\frac{115}{19 + 27 + 2 \times 126} \begin{matrix} 73 \\ 43 \\ 30 \\ 32 \end{matrix}$$

From this expression, it may be noted that the two hills have an average

[8]Various methods for determining the average slope of a given body of land *as a whole* have been advanced which the reader may be interested in comparing with the local steepness index as here proposed. In general, they seek to establish quantitative relationships between either the area of sloping surface or the volume of land and the area occupied by the body of land. See, for example:

A. Penck, Morphologie der Erdoberfläche, I, Stuttgart, 1894.

S. Finsterwalder, "Uebber den mittleren Boschungswinkel und das wahre Areal einer topographischen Flache," Sitsungsber, Akad. der Wiss., Math-phys. Kl. Vol. 20, 1890, pp. 35-82.

Leopold Reincke, "Average Regional Slope, A Criterion for the Subdivision of Old Erosion Surfaces," Jour. of Geol., XXIV, 1, 1916, pp. 27-46.

John L. Rich, "A Graphic Method of Determining the Average Inclination of a Land Surface from a Contour Map," Ill. Acad. Sci., Trans., 9, 1916, pp. 195-199.

Chester K. Wentworth, "A Simplified Method of Determining the Average Slope of Land Surfaces," Amer. Journ. of Sci., 20, 5 Ser., 1930, pp. 184-194.

Erwin Raisz, *op. cit.*, pages 269-274.

local altitude of 115 units, a mean steepness of 90 per cent $\left(\frac{115}{126}\right)$, mean tops (supraplanes) of 27 units and are separated by lowland floors (infraplanes) averaging 19 units in width. The relatively high proportion of the steeper classes, E (73) and D (43), together totalling 116 units, compared with the gentler sloping classes, C (30) and B (32), totalling 62 units, shows a ratio of 2 to 1, and indicates that twice as much of the ascent consists of steep slopes rather than gentle slopes. Each of the slope classes in turn presents conditions of land utilization in relation to both its gradient and length.

Were the value of S of this expression increased, say 20- or 30-fold, then the landform index would lose its dominantly hilly form and be representative of a more level plain. Corresponding changes in landform would be signalled by similar changes in the values and relationships of any of the other components.

While the landform curve is indicative of general shape and magnitude, it is neither a genuine cross-section profile nor exactly representative of the mean shape of the hills. The sequence in which the slope gradients, B to E, are appended may or may not be representative of their relative or actual distribution. This limitation is common to all generalizations. However, a "mean hill" (or other type of landform) may be easily constructed which more nearly approaches the average shape, if care is used in recording the data. In place of arbitrarily plotting the slope classes in the order B, C, D and E, the basal or first gradient may be selected on the basis of its frequency of occurrence in this position; similarly for the second, third and other levels. At the same time even such a mean landform curve is not necessarily a complete approximation of a "typical" or "mean" hill because it is a "profile" in only one direction, whereas the hill or landform under consideration is three dimensional. Whichever curve is employed, it can be nothing more than a mathematical or diagrammatic generalization, although a highly useful one for comparative studies.

THE MEAN LANDFORM UNIT

The landform curve suggests the representation of what might be termed the mean local topographic or landform unit. Described in terms of its surface planes, a landform unit may be defined as the association of an infraplane, a supraplane, and its descending slopes, the combination forming the local unit or ensemble of surface configuration. In traversing the hills of Fig. 1A, for example, one encounters such a unit between X and Z, a second between Z and W, and similarly. An aggregation of such units would be combined to form an area of hills and give it a distinctive surface configuration. Inasmuch as the landform curve is constructed from the mean lengths of the several components which go to make up a landform unit, it may be viewed as the graphic representation of the mean local landform unit.

An area of plains may be similarly interpreted. Despite its "level" character, a plain consists of a series of infraplanes, supraplanes and their connecting slopes. A landform unit in this instance extends, as in the case of the hills, from the initial point of one infraplane to the initial point of the subse-

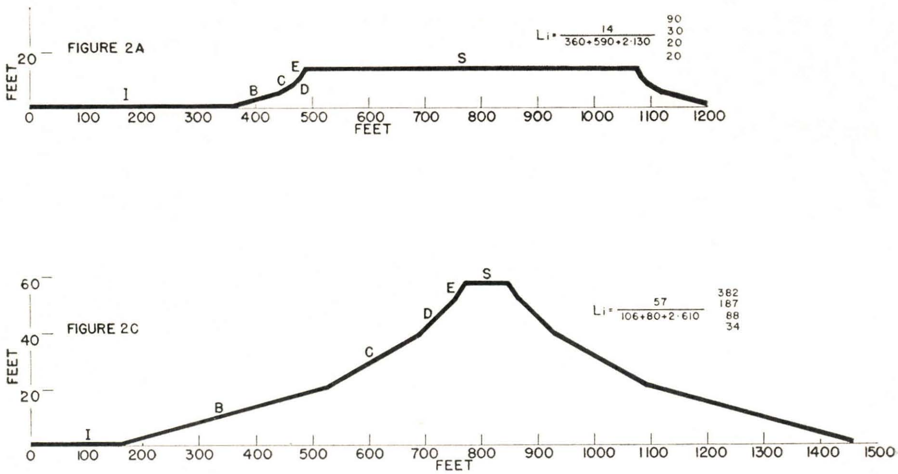

Fig. 2. Mean landform curves of four contrastive types of surface configuration in Kent County, Michigan. The elements upon which Fig. 2A is based are averages derived from the analysis of traverses aggregating approximately 25 miles over so-called "flat" land; Fig. 2B, "level" or "gently undulating" land; Fig. 2C, "moderately rolling" land; Fig. 2D, "hilly" land. Note the five-fold exaggeration of the vertical scale.

quent one. The same concept may be applied to any surface configuration with slight modifications or adaptations to unusual types of topography.[9]

The mean landform unit, therefore, embodies the major local characteristics of surface configuration. Its size and shape as a whole and in detail, the magnitude of its components, and its relative density or frequency within unit distances may be used as a basis for distinguishing one landform area from another in so far as surface configuration is concerned.

FLAT, UNDULATING, ROLLING AND HILLY COUNTRY

If the mathematical relationships and the terminology appear involved, the actual use of the procedure is extremely simple in operation and interpretation. Once mastered, it entails the simplest calculations: addition, division, and simple plotting. A concrete application to several real situations will demonstrate its utility.

During the course of some land utilization studies in Kent County, Michigan, a series of road traverses were run to determine the significant gradient characteristics of each of the land types that had been recognized. Natural

[9]These units will recall the textural units proposed by Johnson as indicators of topographic texture. He defines these units as the land mass lying between drainage lines. While the net relationship is essentially similar, except for the basis of demarcation, his unit tends to be somewhat broader and more inclusive in certain types of topography, such as in youthful glacial topography where the infraplanes consist primarily of enclosed basins without drainage outlets—an important topographic feature in the analysis of this land type. Otherwise a landform analysis based upon his textural unit would produce a mean landform curve in which the infraplane would be divided into two equal parts flanking the slope bases. Cf. Douglas Johnson: "Available Relief and Texture of Topography: A Discussion," Journ. of Geology, Vol. 41, 1933, pp. 293-305; reference on page 296.

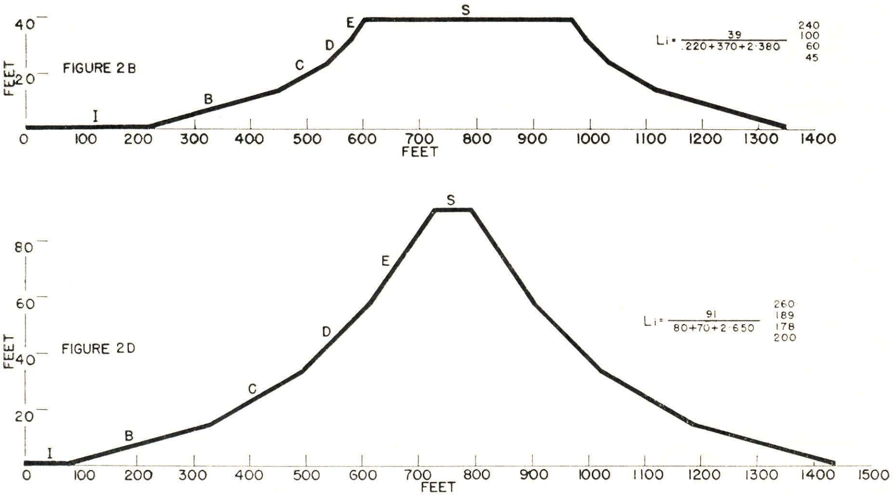

Fig. 2. (Legend on opposite page.)

planes and slopes (not the roadbed) intercepting the line of traverse were noted, allocated to one of the six gradient classes indicated in Table 1, and the length of interception of each measured.

Figures 2A, B, C, D show the mean landform graphs for four contrastive topographic types that had been observed in the county. Gradients were plotted at the angles shown in column 5, Table 1. Figs. 2A and 2B represent land surfaces in which the proportions of "level" land, supraplanes and infraplanes, aggregate relatively high; Figs. 2C and 2D, in which the proportions of slopes, B to E, aggregate high. The land depicted by Fig. 2A is a "flat" till plain; it is made up of a succession of low, broad, flattish upland swells alternating with shallow saucer-like basins. Fig. 2B represents a "level," "undulating," or "smooth" till plain. The surface exhibits a "level" aspect, but is made up of low flattish swells and numerous flat-bottomed dips, basins and shallow drainage valleys, all of which average deeper than those of the "flat" plain.

Fig. 2C is a moderately "rolling" country; it includes a complex of morainic hills of relatively moderate relief, interspersed with basins or level areas of more limited extent. Fig. 2D is a rough "hilly" morainic country, slopes are steep, maximum relief approximates 100 feet or more, and flat-floored basins, level tracts and valley lowlands comprise only a minor part of the surface aspect.

The manner in which each graph suggests the landform type upon which it is based is striking. Fig. 2A reminds one of "flat" land; Fig. 2B, of "level" or "undulating" plains; Figs. 2C and 2D, of "rolling" and "hilly" lands. The form of the curve and its relationships are easily remembered, even though, as previously explained, the curve is not a true cross-section but merely a composite diagrammatic representation. At the same time, the terms, flat, undulating, rolling and hilly begin to assume measurable concreteness and some graphic order and meaning. The landform indices state these relationships in precise and comparable quantities.

Attention may now be drawn to the four graphs of Fig. 3. Each of these is based upon traverses over similar terrain, so-called level or undulating land.

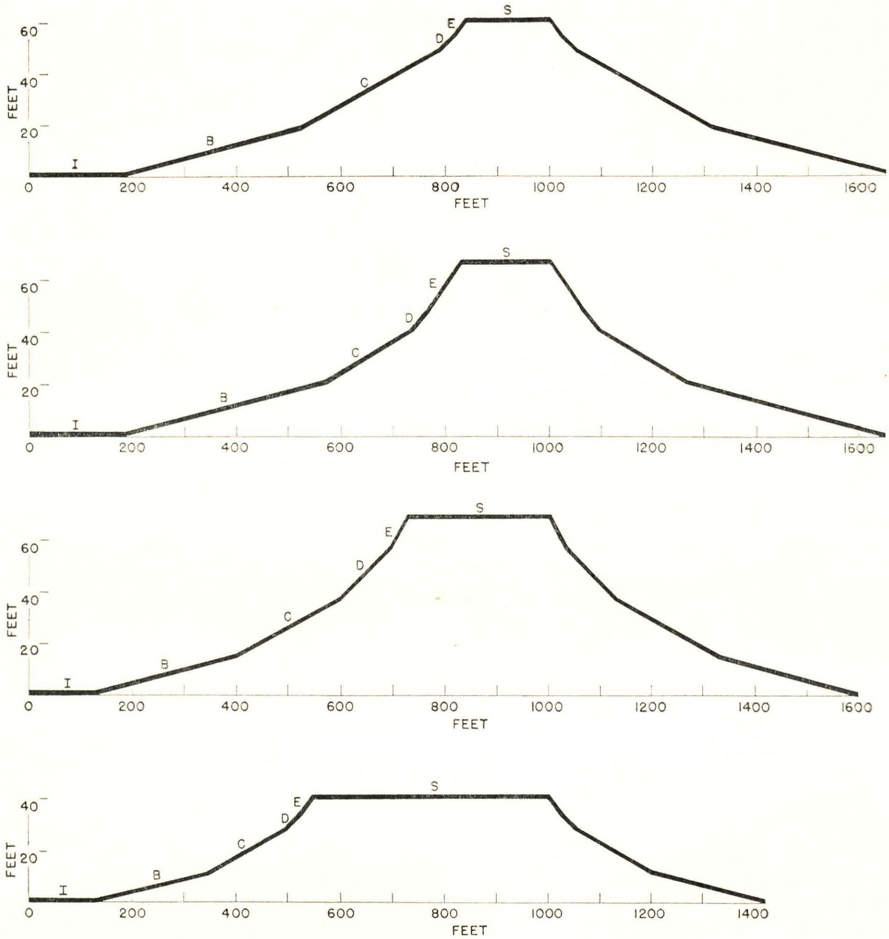

Fig. 3. Mean landform curves showing some of the variation of so-called "level" or "undulating" land in Kent County, Michigan. Each curve is based upon a single traverse totalling some 10 to 15 miles. Note the high proportions of surface of low gradients, I, B and S. Each curve displays variation in the length of its slope classes at the same time it exhibits broad similarity to the others. The lower curve is approaching "flat" land.

The similarity between these curves is as striking as the contrast between the four graphs of Fig. 2. In developing concepts and in building up appropriate definitions of landform types, a number of such curves could be averaged to form a normal or type graph. The individual curves, in turn, would indicate or suggest the limits within which a given definition is applicable. The chief landforms that would create difficulties in classification would be those lying near the extreme limits where one type merges into another. But this is a problem imposed upon all systems of classification, and is practically resolved by reaching general agreement as to specific limiting criteria. Were graphs constructed for every type of landform the earth possesses and arranged in order of ascent from the horizontal, the curves would in all probabilities vary from a nearly flat horizontal line to a steeply ascending curve with little or no intraplane and supraplane and with relief indices ranging from near zero into thousands of feet.

The appropriateness of assigning any of the commonly used terms to a given type of land surface will be long debated. Whether there is such land as "flat" or just what kind of land should be designated as flat is beside the point. All such terms are rather firmly ingrained in everyday speech, and the geomorphologic student will have the same difficulty in fixing their limitations as the pedologist has had in the popular use of the terms, soils, subsoil, clay, loam, sand, and similarly. He will be obliged to tolerate their loose use on the part of laymen, and invent new appropriate terms for scientific considerations.

TERMINOLOGY AND CLASSIFICATION OF LANDFORMS

The difficulties attending the use of popular terms or cumbersome phrases has tempted the writer to propose a group of new terms and to suggest an outline for a system of classification despite the hardships entailed in this type of pioneering. The terms and system are ventured in the interest of stimulating thought and of ultimately obtaining agreement as to appropriate nomenclature and a useful system of classification.

1. The first or highest category differentiates on the basis of what may be termed form viewed in its entirety. It takes into account the broader or more panoramic aspects of surface configuration. PLANETERRAINS include land areas that are dominantly "level"; the landform index shows a dominant proportion of infraplanes and supraplanes; a relatively small proportion

Comprehensive Form	Gross Magnitude of Form	Regional Form	Local Magnitude of Form
Planeterrain (plane + terrain)	Plains	Planoplains (plane + plains)	Types and Subtypes (Geographical nomenclature)
		Undulplains (undulating + plains)	
	Plateaus	Planoplats (plane + plateaus)	
		Undulplats (undulating + plateaus)	
Slopeterrain (slope + terrain)	Hills	Acutohills (acute + hills)	
		Obtusohills (obtuse + hills)	
	Mountains	Acutomounts (acute + mountains)	
		Obtusomounts (obtuse + mountains)	

of slope base (S_b) in relation to the basal index; slopes are chiefly B_n and C_n types with only relatively small percentages of D_n and E_n.[10] Slopeterrains include land areas dominated by the slope classes, B to E; the landform index shows a small proportion of infraplanes and supraplanes, and a high proportion of slope base. In studying surface configuration at this categorical level a series of bar graphs of the type shown in Fig. 1B is helpful in depicting differences in the proportion of slope and plane classes. This figure is representative of slopeterrain; a high proportion of infraplanes and supraplanes would indicate planeterrain.

2. The second category differentiates the two major divisions on the basis of what may be termed gross magnitude of form. Hills and mountains are similar in form but differ in magnitude. Thus slopeterrains with low relief indices are hills; of high indices, mountains. Similarly, planeterrains of low relief indices are plains, and of high indices, plateaus.

3. The third category recognizes more local or regional form. It differentiates one plain from another, or one plateau from another, chiefly on the basis of secondary differences in the proportions of the plane classes, I and S. Hills and mountains are similarly distinguished from one another chiefly on the basis of secondary differences in the proportions of slope classes.

PLANOPLAINS are plains the general surface of which lies prevailingly horizontal, approaching a geometric plane; approximately two-thirds or more of their area consists of supraplanes and infraplanes and slopes are almost wholly of the B_n and C_n type; D_n and E_n are permissive but incidental; the general steepness index of the slope classes is low; mean landform curves are analogous to Fig. 2A. UNDULPLAINS are undulating plains with roughly less than two-thirds of their area in supraplanes and infraplanes; slopes include chiefly B_n and C_n types and relatively small proportions of D_n and E_n; the general steepness index is low, but not as low as in planoplains; mean landform curves are analogous to Fig. 2B. PLANOPLATS and UNDULPLATS are plateau surfaces corresponding to planoplains and undulplains. It is impossible to indicate the exact limits of the several elements involved in the definition of any one of these plains and plateaus until experience with this type of analysis is more extended.

ACUTOHILLS connote hill areas of relatively sharp and narrow outline. Slopes are largely of the D_n and E_n types, the prevailing gradients forming chiefly acute angles with a vertical plane. The general steepness index is greater than one. OBTUSOHILLS comprise the counterpart group. They are hill areas of gently to moderately rolling character with slopes chiefly of the B_n and C_n types, and a general steepness index of less than one. Mean landform curves are analogous to Figs. 2C and 2D.[11] ACUTOMOUNTS and OBTUSOMOUNTS are mountainous areas corresponding to acutohills and obtusohills.

4. The fourth category takes into account a more local magnitude of form. Entities at this level may be termed types. Differentiation of local magnitude is expressed in secondary differences in relief indices and the length of gradi-

[10] B_n, C_n, D_n, and E_n refer to "gentle," "moderate," "steep," and "very steep" slopes respectively but are not limited to a stated range of gradient. This range, implied by the subscription, is variable and can only be fixed in the analysis of given local landform types. It may also prove desirable to add additional slope classes in the analysis of certain landform types.

[11] It is important to note the steepness index in examining a mean landform curve because the five-fold exaggeration employed in plotting the slope classes, B to E, tends to give an erroneous impression as to the steepness of ascent.

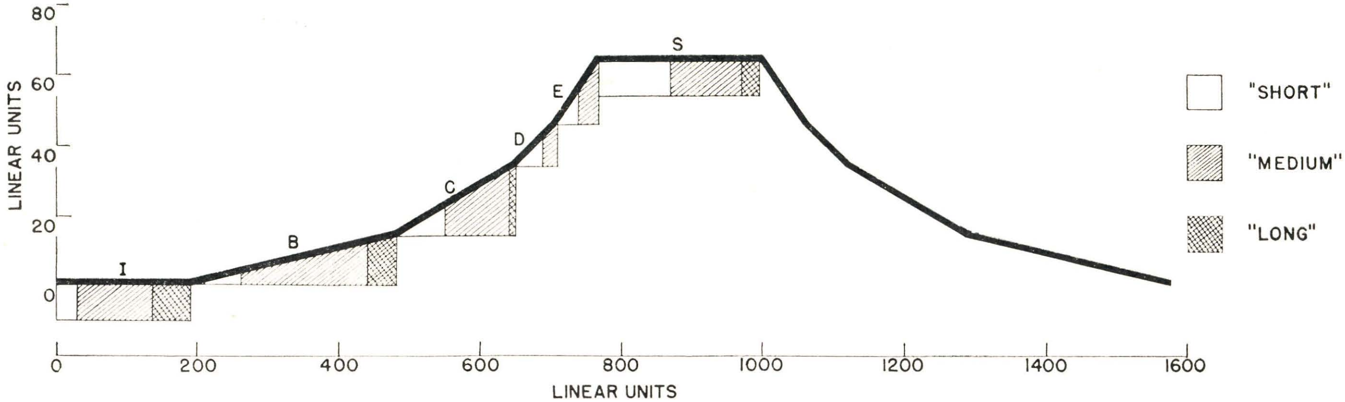

Fig. 4. Mean landform curve of "level" or "undulating" (undulplain) land, Kent County, Michigan, indicating a graphic method to show the proportion of "short," "medium" and "long" slopes which make up each of the gradient classes. The graph indicates that the surface is made up chiefly of "medium" and "short" or choppy slopes with only a sprinkling of "long" slopes.

ent classes, and is measurable in terms of mean gradient lengths. Reference to Fig. 3 reveals differences in these undulplains in the matter of mean lengths of intraplanes, supraplanes, and each of the four slope classes. Members of this category are best designated by local geographic names selected from communities that serve as type illustrations.

Subtypes within the fourth category or a fifth category may be identified on the basis of the frequency of slope lengths of given magnitudes. These facts are as significant in land surface analyses as length of showers and their relative frequency is to rainfall investigations. Slopes within a type may be grouped into "short," "medium," and "long" and the relative extent of each class determined. Fig. 4 suggests a method for including these relationships on a mean landform graph. In the case of the intraplane and the supraplane the line representing their mean length was apportioned between "short," "medium," and "long"; in the case of the slope classes, perpendiculars were dropped from the ends of each and the horizontal distance between them similarly apportioned. In reading this aspect of the graph it should be noted that the horizontal width measured along the abscissa and not the areal extent of each block or segment indicates the proportionate extent of slope length in each class.[12]

LANDFORM MAPS

Classification of types in itself serves only a limited purpose unless the types are given areal expression (Fig. 5). Such maps may be constructed, moreover, to show the distribution of types at any or all of the categorical levels. A series of this character would prove useful in many ways. Data for such analyses are available from two sources: (1) field traverses or (2) cartographic traverses employing the topographic map. The topographic map would be the ideal in cost and time, but unfortunately most maps employ too great contour intervals to furnish the degree of detail that should be incorporated, especially in a study of the lower landform categories. Nevertheless, a series of such traverses has been initiated in an attempt to discover the nature and distribution of the broader landform groups, utilizing the serviceable angle of slope scale devised by Cozzens and supplementing this data with such field traverses as resources permit.[13]

UTILITY OF THE METHOD

The mean landform graph and map have a wide range of scientific and practical potentialities. They not only facilitate analyses of landforms and a clearer understanding of their fundamental character, but they also offer a hope for more accurate comparisons of land surfaces in widely separated areas. The level character of the Great Plains of Colorado, of the till plains of

[12] The mean landform curve may now be compared, or perhaps better contrasted, with the hypsographic curve and the related hypsographoid and clinographic curve (see Raisz, *op. cit.*, pp. 269-271 for a brief description) as methods of landform analysis. These curves are primarily designed for landslope analyses, or the distribution of the earth's surface or volume according to altitude. See Karl Sonntag, Studien Ueber de Hypsographische Kurve, Leipzig, 1932, for an extended discussion of the hypsographic curve.

[13] Arthur Cozzens, "An Angle of Slope Scale," Journal of Geomorphology, (3) 1: 52-56. 1940.

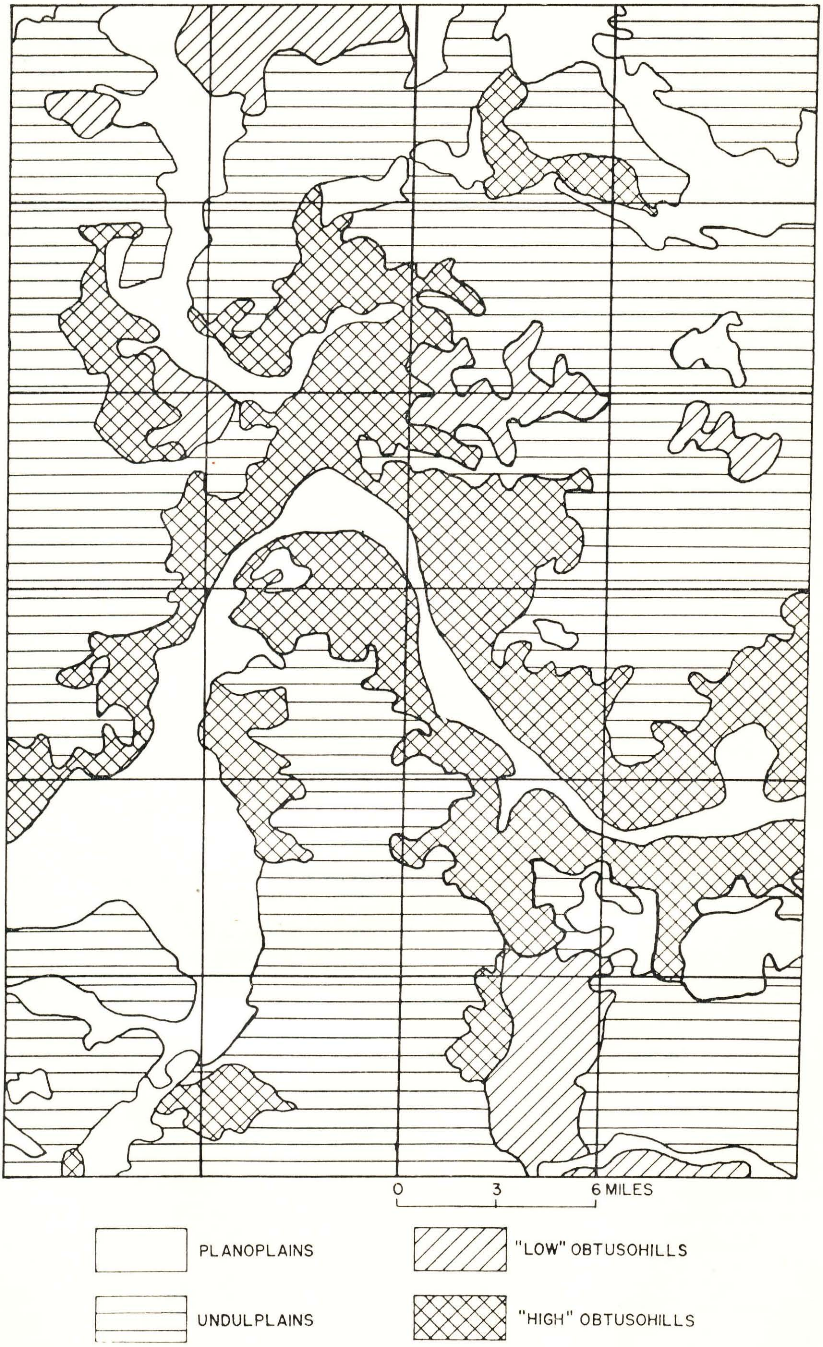

Fig. 5. Landform map of Kent County, Michigan. The mean landform curves for the planoplains, the undulplains and the "low" and "high," obtusohills shown on the map appear in Figs. 2A, B, C, D, respectively. The areas of "low" obtusohills would be popularly designated as rolling, and the "high" obtusohills as hilly country. The narrow belt of planoplains extending from east to west across the south central part is the floor of the Grand River. It is bordered by a belt of rough hills ("high" obtusohills) with a relief index approximating 90 feet. Rolling land ("low" obtusohills) with a relief index of 55 to 60 occurs in the northern and southern tier of townships. The greater part of the county consists of undulplains (level to undulating land) with a relief index of 35 to 40, except for local areas of planoplains which are chiefly outwash or "flat" till plains.

Michigan, and of the coastal plains of Georgia may not only be more easily and effectively compared one with another, but also with the reported level Karoo country of South Africa, the Murray-Darling plains of New South Wales and the Yangtze lowlands. Such comparisons, moreover, need not only be in the matter of form alone, but may also be employed to measure significant differences in the influence of rock structure or other genetic relationships. It should be borne in mind, moreover, that comparisons based upon this method of analysis may be made at any level of generality or detail—broad and comprehensive to include extensive provinces or entire continents, or very local to study landform differences within a small area.

Aside from its more scientific value, a county, state, or national map showing the distribution of landform types would contribute materially to an inventory of our land resources. We are more or less ignorant as to the real nature and magnitude of the different types of surface configurations which condition to such a degree the use of our land resources. Such maps would prove of inestimable value to the agricultural and soil conservationist, to the horticultural, forest or grazing specialist, and to others interested in land use and planning. Moreover, if the distribution of landform types were compared with the distribution of other phenomena, it would lead to the discovery of land uses and other geographic relationships that are now unknown or unverified. Conjoined with the ordinary physical or topographic map, it would also prove a highly valuable tool for appraising both current and proposed uses of land, since not only the magnitude of the landform involved, but also its proportion of level land (infraplanes and supraplanes) and slope classes and the average length of these plane classes—all of which have a marked bearing upon land potentialities—are quantitatively set forth. So-called level lands, for example, with given soil and climatic conditions and showing a high proportion of short slopes of even gentle or moderate gradients create very different problems of use, management, and erosion control from types possessing long slopes of like gradients; similarly for landform areas of identical character but combined with different soil or climatic conditions.

One of the more effective uses of the landform curve is to link it with a generalized soil section, to show both surface and soil characteristics and the general nature of their association, since both surface and soil condition the use of land. Such a composite diagram could be prepared by first constructing the mean landform curve and then sketching in appropriate soil profiles under the curve. The combination would prove helpful to studies in many phases of land geography. Problems of land use and management may be deliberated in their duel relationship of soil and surface.

LIMITATIONS OF THE PROCEDURE

The accuracy of the data obtained by the field traverse method is subject to at least three types of limitations:

1. *The Length and Method of Traverse.* This is a difficulty common to all problems of sampling. Both the minimum length required for an adequate sample and the pattern of traverse employed will vary with the complexity of the landform. While a road traverse will ordinarily be preferred as more economical of time and resources, yet certain gradients may be disproportionately represented if the roads traversed tend to follow such gradients more

or less exclusively, as for example the infraplanes or the supraplanes in rough hill or mountain country. In such situations a foot or other type of traverse will have to be substituted or included. Account must also be taken of the grain or trend of the topography. In the Appalachian Ridge and Valley Province, for example, traverses should be carried both across and parallel to the grain. The data obtained may either be worked up into separate graphs for each direction or merged into a single one.

2. *Measurement of Gradients.* Gradients may be measured with engineering precision, with the clinometer or Abney level, or approximately classed on the basis of mere judgment after some experience is gained through actual measurements and familiarity with the characteristics of the region. Where the road pattern is such as to facilitate the use of an automobile, a plumb bob suspended in the automobile and provided with an easily read scale may be used to supplement or check judgment whenever the road bed conforms with the natural slopes.

3. *Measurement of Slope Lengths and Horizontal Planes.* Measurement of length of slopes and planes may also vary from precision to approximation. An ordinary speedometer can be easily read within 250 feet and within 100 feet with experience; the special speedometer devised by the writer some years ago and now widely used in soil, geologic and other surveys registers in five-hundredths of a mile and can easily be read within 5 feet and within 1 or 2 feet with experience.

The ideal data would obviously be that derived from profiles or traverses run with engineering precision. But it is extremely doubtful if the final results would be proportionate to the almost prohibitive costs. Differences of a few feet in gradient lengths and slopes are lost or tend to become relatively inconsequential in the ultimate determinations, analyses and comparisons that are made. At least the methods, utilized in even their cruder aspects, reveal information and important relationships between land areas that are extremely interesting and have been largely obscure if not wholly unattainable. No other method has as yet been devised that determines and sets forth the detailed topographic characteristics of a region more effectively.

It is believed that if gradients are classed and measured with reasonable care and accuracy appropriate to the level of analysis, the results will prove surprisingly serviceable. The degree of accuracy required will necessarily vary with the use to be made of the data: whether an overview as a whole is desired or the region is to be studied in great detail as to its geomorphologic, social, economic or other characteristics. A traverse intended to analyze and compare two closely related types or subtypes obviously calls for a much higher degree of accuracy than one designed to compare the Virginia Piedmont Upland as a whole with the New England Upland or the Coastal Plain Province. The similarity in the four curves of Fig. 4 is an approximate measure of the accuracy obtainable with the use of an ordinary speedometer and identification of gradient classes by simple observation. The higher percentage of supraplane in the case of the lower curve, based upon a traverse in the southeastern township of Kent County, is in keeping with the actual character of the land. This township is noticeably flatter than the southwestern and western clay plains upon which the other three curves are based.

In planning the use of our land resources there is genuine need of an inventory covering the details of form, including their nature, the manner of their association, and the distribution and extent of given types of surface