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Final Report

PROCEDURES IN THE DESCRIPTIVE ANALYSIS OF TERRAIN

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FOREWORD

The project on "Procedures in the Descriptive Analysis of Terrain" originally grew out of the principal investigator's efforts to find, primarily for teaching purposes, an approach to land form study that would be of maximum use to geographers and to other students who are interested in the use of the land. One obvious need appeared to be a method for systematically characterizing the land form in terms of its inherent nature. While many individual steps had been taken in this direction, and while in some countries, most notably Germany, a relatively broad advance had been made, there did not appear to be available an integrated study or presentation of the principles or methods of objective descriptive analysis, especially for use at medium and small scales. It was with the hope of partially filling this gap that the present investigation was conceived and proposed to the office of Naval Research in 1953.

Clearly such an investigation could not presume to be wholly, or even largely, original in specific content. There is little that is new in the general principles of geographical description. The literature of land form characterization is extensive, and has grown significantly more so in the last few years. It is, therefore, inevitable that much that appears in this resulting report will be somewhat familiar. Taken as a whole, however, the endeavor does not appear to duplicate what has been done before. Such originality as it possesses must be found somewhere within (1) its attempt to apply to the description of land form a body of principle

consistent with geographical description generally, (2) its preoccupation with methods applicable to the fairly rapid analysis of large areas, and (3) its effort to bring together under a single cover an essentially integrated system of description applicable to all kinds and aspects of terrain.

The principal investigator wishes to make special acknowledgement of the invaluable contributions made by his assistants: Jerry B. Culver, M. James Edie, Norman J.W. Thrower, Malcolm Lewis, Theodore Schmudde, and Allen L. Smith, all of whom were graduate students in the Department of Geography, University of Wisconsin, at the time of their appointment.

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I. Introduction

A. Statement of Purpose

Those who study phenomena based upon the land may be as diverse as agriculturalists, military tacticians, city planners, climatologists and geomorphologists, but all have in common a need for objective characterization of the land's surface form. Each of these students must know what surface form exists in specific locations, for that form either influences directly the phenomenon he is studying, or else it is a condition that must be taken into account by man in planning those activities that are being studied. For the geomorphologist the connection is, of course, most direct, for the existing land form commonly represents the very object of his study; the thing he is striving to explain.

Since objective characterization is needed, it is reasonable that methods of formulating and presenting such characterizations should be studied, with a view to determining whether existing methods are satisfactory or can be improved. Examination of many descriptions that have been presented suggests that methods of land form description are highly diverse, seldom systematic, and not always effective. While diversity is not of itself an evil, and while no methodology can of itself guarantee effectiveness, it seems worthwhile to investigate methods or approaches that might at least reduce the likelihood of missing the mark badly and, when best applied, might satisfy exacting standards of effectiveness.

As suggested, objectivity has been one keyword for the present investigation. Only through objective characterization can pre-conceived interpretative notions be prevented from coloring the description. A major aid to objectivity in description is the use of quantitative measure, which, throughnot always worth the effort involved in obtaining it, can sometimes free the describer from the vagueness and lack of comparability that are the frequent concomitants of verbal characterization. Also contributing to objectivity are system and balance, which make certain that neither oversight nor pre-judgement of value permits significant aspects of description to be omitted or slighted. Like quantitative measure, system and balance are especially important in comparative studies, for they guarantee that comparable data will be available for all the various areas being analyzed. It is, then, the primary task of the current study to investigate possible methods for improving areal characterication of land form with particular regard to these qualities of system, balance, and quantitative measure that are particularly valuable as guardians of objectivity.

It would be misleading to imply that an investigation of the sort proposed represents a revolutionary approach to the study of land form, or even to land form description. Many students have recognized the importance of objectivity in description, and the literature on objective and quantitative characterization is extensive. [1] It may however, be stated

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1. Neuenschwander's study of morphometric concepts, published in 1944, offers a bibliography of 640 items, and many additional papers have appeared since then. E. Neuenschwander, "Morphometrische Begriffe", Arbeiten aus dem Geographischen Institut der Universität Zürich, Serie A, No. 2, Zürich, 1944.

that in general earlier works on descriptive methods have, when broad in coverage,[2] been relatively unsystematic and non-quantitative, or, when quantitative, have been confined to

2. See, for example, S. Passarge, Beschreibende Landschaftskunde, Friederichsen, de Gruyter and Co., Hamburg, 1929.

one or two specific indices.[3] Furthermore, the objective

3. Papers of this group are numerous. A familiar American example is G. H. Smith, "The Relative Relief of Ohio", Geographical Review, v. 25, pp. 272-284. Probably the most important American departure from this single-item approach is the recent work by A. N. Strahler, summarized in "Quantitative Analysis of Watershed Geomorphology", Transactions, American Geophysical Union, v. 38, 1957, pp. 913-920.

approach has had a limited following, stronger allegiance having been given to the "explanatory description" so effectively advocated by Davis and others.[4] The difficulties and short-

4. Something of the continuing appeal of the Davisian approach is exemplified by the remarks of the French geographer Henri Baulig in a recent discussion published in part in "Geomorphology, Geomorphography, Geomorphogeny and Geography", New Zealand Geographer, v. 12, no. 1, April 1956, pp. 89-93. In the textbook field the idea is expressed in Kendall, Glendimming and MacFadden, Introduction to Physical Geography, Harcourt, Brace and Co., Inc., New York, 1952, pp. 197-198.

comings of this attempt to describe the surface form by telling how it originated have been suggested in an earlier paper and will not be reviewed here. However, the degree to which this approach has been accepted and is still practiced by teachers and students of landform implies that continued development and advocacy of objective techniques is still needed, in spite of the valuable work of Passarge, the European morphometrists, Linton, Smith, Kesseli, Strahler and many others.

An additional consideration that recommends further study of objective descriptive techniques involves the complex problems of scale of study. Many of the works on objective description, especially the European morphometric studies, have been large-scale, detailed investigations of a single mountain massif, a single valley, or a single small drainage basin. No criticism of such studies is intended, but smaller-scale studies of larger areas, measuring many tens of miles in either direction, are often desirable. Techniques of analysis and description that are applicable to very detailed small-area studies may prove entirely too time consuming, and too much directed toward individual features to be feasible or satisfactory for the study and characterization of sizeable regions. For these broader-scale investigations, minor details and individual features must be subordinated to assemblages of features or to summary characteristics that prevail over larger areas. And in particular, because of the large area that must be covered, the methods of analysis that are used must not be unduly consumptive of time. This latter point is especially important when quantitative measure (morphometry) is involved, for many of the morphometric techniques that have been proposed are excessively tedious.[5]

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5. Note, for example, C. Wentworth, "A Simplified Method of Determining the Average Slope of Land Surfaces," American Journal of Science, v. 20, Ser. 5, 1930, pp. 184-194. This, one of the simplest methods heretofore proposed for determining average slope, requires perhaps two hours for the calculations of the average slope of a single 5-minute rectangle.

Because techniques applicable to these intermediate-scale characterizations have received limited attention, particularly in terms of balanced and systematic treatment, and because descriptions on these scales are particularly needed by geographers, among whom the principal investigator is numbered, the present study is directed largely toward the investigation of procedures that are applicable to descriptive analysis at these scales. No specific attention is given to techniques of highly detailed description, though some ideas useful for that purpose may be forthcoming.

B. Approaches and Procedures

An approach to objective description that seems especially promising is that which endeavors to resolve the phenomenon being studied into component parts or aspects. This approach has been successfully employed and has become standard procedure for the characterization of such complex phenomena as climate and soil, and it may be expected to prove similarly useful in the analysis of land form. Efforts in this direction, chiefly the development of numerous morphometric indices, have, of course already been made.

In a previous paper [6] a scheme has been suggested by

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6. E. Hammond, "On the Place, Nature and Methods of Description in the Geography of Land Form", ONR Contract Nonr 1202(01), Procedures in the Descriptive Analysis of Terrain, Technical Report No. 1, 1957, pp. 8-13.

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which the land form may be so resolved into specific characteristics. Four major groups of characteristics were identified: those being slope, surface materials, dimensions, and arrangements. In the present study each of these principal groups

will be examined, with an eye to selecting certain specific properties that are significant and diagnostic and that, as well, are capable of being readily determined from topographic maps or from the field, and that may be simply and concisely expressed. Sources of data, and methods of determining and expressing these characteristics will be briefly explored and exemplified.

Since the description of an area requires the use of a well-balanced series of characteristics, attention has been given also to the problems of completeness and balance in description, and especially to the selection and expression of combinations of relatively few characteristics for purposes of concise, comparable small-area descriptions. The unit-area method of study is examined and some examples of brief small-area descriptions are offered.

Descriptions of large areas may thenbe built up from large numbers of small unit area characterizations. The process of accomplishing this, however, involves problems of scale change and generalization, some of which are complex and difficult to handle. Some of these problems have been examined, and simple solutions are suggested. The concepts of land form types and land form regions are explored from the point of view of the concise, multi-element, unit-area system of small-area description. Examples of generalization and regionalization are offered, using the state of Missouri and several areas in the American West as testing ground.

II. DETERMINING AND EXPRESSING THE CHARACTERISTICS OF AREAS

A. Characterising Slope[7]

7. Since this chapter was originally conceived and set down a considerable time ago, the writer has had the opportunity to read A. N. Strahler, "Quantitative Slope Analysis", Bulletin of the Geological Society of America, v. 67, 1956, pp. 571-596. Strahler examines many of the same problems in the light of much more rigorous statistical analysis than has been employed here. However, since the aims are somewhat different and the ideas independently conceived and are not strongly controverted by Strahler's work, the chapter has been included in essentially its original form. It thus serves as a reporting of the ideas derived in the course of the present project.

1. The General Problem - The Nature of Slope Data

Among the various elements or component attributes into which the form of a land surface may be resolved, the slope or inclination of the surface must be reckoned as one of the most fundamentally significant. For almost every conceivable purpose for which evaluation of the terrain may be made, though those be as diverse as geomorphological development, agricultural utility, or significance to the production of precipitation, the slope of the land enters as a major consideration. It is not surprising then that in the literature of careful descriptive analysis of terrain, consideration of slope occupies a prominent place. Nor, since the slope of the land is a measurable angle, expressible by number, is it remarkable that slope has been characterized with the aid of numerical expression and mathematical processing to a greater degree than most other terrain elements.[8]

8. For a summary of techniques to 1944, see Neuenschwander, op. cit., 1944, especially pp. 7-22.

In the simple terminology of solid geometry, the slope or inclination of a surface may be defined either as (1) the angle between a line drawn on the surface normal to the contour, and the horizontal plane, or (2) the tangent of that angle. By the methods of the calculus, the slope is defined for each point on a given surface, the value being the inclination of the line drawn tangent to the surface at that point and normal to the contour. This value is expressed by the derivative (dy/dx) of the equation of the line on the surface that passes through the given point, normal to the contour. On a three-dimensional surface, the slope has, in addition to its numerical value of inclination, a further quality of direction, but this aspect is not included in the definition of slope employed here.

The important thing is that slope is a point value. Since any finite surface is made up of an infinite number of dimensionless points, one must, theoretically, measure and list an infinite number of slope values in order to characterize precisely the slope conditions of any surface whose slopes do not very according to some simple system. In practice, land slopes are measured not for true points, but for short lines of finite length. This represents a significant degree of generalization, but so long as the lines are kept short relative to the length of slope segments of reasonably constant inclination, the procedure is valid as well as unavoidable. Even with this simplification, in making a rigorous analysis of the slopes

of a land area a few miles across, it will still be necessary to make many thousands of individual measurements. For practical purposes this number may be further reduced by sampling techniques, but for surfaces as complex as most land surfaces, the number of individual measurements will still be so large that a listing or map-spotting of their values cannot be readily digested. For this reason, abstracting or summarizing the data is absolutely nesessary, and techniques by which such summarization can be accomplished are worthy of careful study. Attention here will be directed principally toward those techniques that, by logic and experimentation, seem best adapted to the rapid analysis of areas measuring several tens of miles across. The scale is thus <u>choregraphic</u> rather than <u>topographic</u>, in line with the geographer's most abundant interest.

2. The Sources of Slope Data

The most direct way of obtaining slope data is by measurement in the field, for as many points as may be desired, using some sort of clinometer. The advantage is that the information so obtained is firsthand. It is therefore free from generalization or possible inaccuracy on the part of a topographer or cartographic draftsman. On the other hand, field measurement of hundreds or thousands of points over a large area is an extremely arduous, time-consuming, and hence costly process. It is a method scarcely to be considered unless a high degree of accuracy is required and topographic maps of good quality are not available.

If convenience and quickness are prime considerations nothing can rival an accurate contour map as a source for slope information. By means of a simple slope scale based upon the spacing of contour lines, the slope at any point (or, actually, for any short segment) can be very readily determined, and data for large numbers of points can be obtained and recorded in a relatively short time. For most geographical purposes, contour maps are by far the most valuable source of slope data, if they are available. Caution is necessary in using such maps. First, the representation of slopes on contour maps of a scale smaller than 1:125000 is usually quite unreliable. Second, many contour maps, even of larger scale, are rather highly inaccurate, especially in their rendition of slopes. This is true, for example, of many of the earlier sheets of the USGS series, as may be clearly seen, where re-survey has been undertaken, by comparing the old sheet with the newer one derived from air photos by multiplex or similar methods,[9]

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9. A striking example is provided by the Crawford Notch, N. H., Sheets of 1896 and 1950, both on scale of 1:62,500.

An especially common fault of the older sheets is a tendency to draw steep slopes as less steep than they actually are, in order to keep the contour lines from running together. Contours are also commonly smoothed and rounded out. Thorough familiarity with contour maps will often permit a user to distinguish maps on which the contouring has an

implausible or over-generalized appearance.

Stereoscopic aerial photographs can also serve as sources of slope data, but only at the price of either gross inaccuracy or excessive time in processing. Slopes can be determined from such photos by photogrammetric methods, but the time and effort required renders these methods wholly impractical for most geographical purposes. If it is deemed worthwhile to use photogrammetric analysis, it might prove worthwhile to construct a contour map from the photos first, and then to use that map as the direct source for slope data, as well as for other types of information that may be desired.

Some experimentation has been carried out, by the writer and others, along the lines of estimating slope from direct examination of a stereo pair. However, the techniques tried, which involve the subjective visual comparison of the unknown slope with some sort of known standard, have not proved sufficiently reliable or accurate to make them worthy of consideration in the body of this paper. [10] A

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10. Appendix 1.

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given device may "work" for one individual or on one area of coverage, but not for another.

3. Techniques of Summarization for Expressing the Slopes of an Area

The summarizing or generalizing that is necessary in order to reduce the myriads of point data to practicable

and comprehensible numbers and forms may be accomplished either in the collecting process, or in organizing the data for presentation. Generalization is done at the collecting stage by means of sampling techniques or by grouping of data by eye. At the reporting stage, generalization and summary are done by means of statistical, diagrammatic and cartographic methods.

a. Generalizing during collection of data.

No attempt will be made here to review the extensive literature dealing with sampling methods. Suffice it to say that for slope analysis from contour maps three principal types of samples have been employed: area samples, linear samples, and dot or point samples. Each is quite amenable to this type of use, the problem for each being the determination of the size of sample required. In the present project a kind of dot sampling was employed, with results that are sufficiently promising to warrant a brief discussion.

Basically, the system involves simply the determination of the slope at each of a series of points, sufficient in number and so placed as to give a representative sample of the slope conditions within the area under consideration. In practice, the dots were inscribed on a large sheet of clear plastic which was then tossed with random orientation upon the topographic sheet. With the aid of a slope scale the slope was determined by contour spacing at each point where one of the superimposed dots fell. The aggregate data for all the points that fell within the area under

consideration represented the slope sample. Since the need is for a representative sample rather than a truly random sample, and since landform features are rarely placed according to anything resembling a rigid system, there seems no reason why the dot pattern employed should not be systematic,[11] The patterns used in this study

11. Strahler, op. cit., pp. 591-592, presents the arguments in favor of truly random sampling from the point of view of statistical theory. The method suggested here can easily be adapted to the use of random dot patterns when the purposes demand them.

were, in fact, ones in which the dots were located at the corners of triangles, squares or parallelograms. Such patterns assure even coverage, are easy to construct, and make control of the number of dots in the sample relatively easy.

The results of comparisons between dot sampling and planimetering of areas were somewhat surprising, in that the number of dots needed to give reasonably accurate values for the slope areas, even in patterns of wide scattering or great complexity, does not appear to be large. A sample of 90 to 100 dots in a 7½-minute rectangle will rarely yield values for the areas of slope classes that depart by more that 2 % from the measured values, and a sample of 50 to 60 dots will rarely yield values departing by more than 5% from the measured figures. These are eminently reasonable numbers, for with a slope scale, sixty or even a hundred slope values can be obtained in a reasonably short time.

It is felt, then, that dot sampling, with a relatively small number of dots, will yield slope data that are sufficiently representative and accurate for most geographical purposes. The method is further recommended by the relative quickness with which it may be carried out.

A still more rapid, though less accurate, method is available for obtaining slope data from contour maps. This is the method of eye estimate, used in conjunction with the grouping of slopes into classes. With the aid of a slope scale which shows the contour spacings corresponding to the boundary values of the slope classes used, the portion of the map under consideration is scanned, and an estimate is made of the percentage of the total area that is occupied by slopes of each class.

As an aid to the estimating process, it is convenient to employ a transparent plastic overlay, on which an area equal to that of the map area under consideration has been ruled off into ten or twenty equal parts. When superimposed on the map, this grid makes it easier to estimate the area of a given slope class to the nearest five or ten per cent figure.

Successful use of the eye estimate method requires both care and practice. Rapidity and degree of accuracy increase markedly as familiarity wth the method is gained. Once a fair degree of facility has been achieved, very useful results may be obtained, though the degree of

precision is not high. In the present project, no attempt has been made to estimate percentages within less than a five percent range, and a ten per cent range is the smallest that can be estimated with any reasonable degree of regularity. However, it is rarely necessary to obtain data of greater precision than this, and when it is necessary, other methods, such as dot sampling, should be used.

Granted reasonable facility with the method, the degree of accuracy of estimate depends upon several factors, principally the character of the terrain. Terrain samples in which there are strong and abrupt contrasts in slope or in which one or two slope classes occupy most of the area offer little difficulty. On the other hand, complex and fine-textured surfaces, or those in which slope changes are subtle, or those in which a large portion of the slopes have a steepness that is very close to one of the class boundary values offer a much greater chance for error. For such surfaces, it is well to resort to a more precise method, or at least to check one's estimate carefully.

In the current project, the eye estimate method has been employed much more extensively than any other, largely because it combines an unparalleled rapidity with at least the modest degree of precision that the work requires. The checks and tests which have been made

confirm both the strengths and weaknesses of the method, as stated above.[12]

12. Seven hundred 7½ minute rectangles in Missouri were examined independently by two individuals, both inexperienced in the method at the outset, for the purpose of determining the percentage of each rectangle occupied by slopes gentler than 8%. Estimates were made only to the nearest ten percent. Of the seven hundred pairs of estimates, 60% coincided, 37% differed by one class and 3 % differed by two classes. Results suggested that coincidence was considerably greater in the later estimates than in the earlier ones.

Thus there are available at least two relatively quick methods for obtaining useful slope data from contour maps. One is applicable only if slopes are being grouped into a small number of classes and if no more than very modest precision is required. The other, that of dot sampling, can, by increasing the number of dots in the sample, be made to serve for almost any desired degree of exactness. Line samples (traverses) and area samples can also be adapted for rapid and useful slope analysis.[13] They were, however, not

13. For an example of the use of linear traverses for slope sampling see L. Wolfanger, "Landform Types", Michigan State College, Agricultural Experiment Station, Technical Bulletin 175, East Lansing, 1941.

experimented with, and it is doubtful that they would prove more useful, in terms of combined precision and speed, than the dot samples.

The dot-sample method is also applicable to use in the field, provided that a representative pattern of dots can be established and located on the ground. Slopes would be measured by clinometer rather than by slope scale.

The same method could be used on aerial photographs if only it were possible to determine the inclination readily from the photographs. Attempts to estimate the slope angle by comparison with measured slopes on small stereo-pairs of the same scale and spacing have not proved successful. For somewhat obscure reasons, much more favorable results have been obtained from using the same comparison technique for an overall eye estimate of the per cent of area occupied by slopes of various classes. Apparently the comparison method serves well when one is scanning the entire stereo field of a pair of photos, but breaks down badly when one concentrates on single slopes of limited extent. Further experimentation along this line seems advisable.

b. Generalizing after collection of data.

Once the slope data have been obtained, from whatever source and by whatever method, they must then be summarized, generalized or abstracted in some way that will make them readily comprehensible to the user. It has already been suggested that certain types of generalizations, such as grouping into classes, may be done at the same time the data are collected. In order that all methods may be discussed, however, it will be assumed for the present that the data are in the form of rather precise inclination figures for each of a large number of points. In this raw form they are distinctly cumbersome to use, being comparable to a long series of monthly temperature figures for some climatic station. The problem is then to reduce

drastically the number of figures presented to the user, so that he will need to consider no more than a few digits or index designators, a simple diagram or a very brief verbal characterization. There are many familiar types of statistical summaries, but surprisingly few of them have been utilized in discussing slopes. This is probably due largely to the fact that slope data have rarely been collected slope by slope or point by point in numerical form. The quantitative slope analysis methods used in the past have commonly attempted to proceed directly from the map to a summary value, rather than to measure smaple slopes and then summarize. Wentworth's rather familiar method for determining the average slope of an area is an example in point. [14] By

14. Wentworth, op. cit., 1930.

counting contour intersections along a set of measured traverses and applying a mean correction for the angle of crossing, he obtains the average slope without ever having measured any actual slope angles. Because the mean is about the only familiar statistical summary that can be obtained by such direct methods, the mean or average slope has received more attention than any other type of slope data, and probably a great deal more than its value warrants.

With a mass of point slope data available for an area, however, many other sorts of summaries can be easily obtained, and many of these are far more revealing and useful than the mean slope.

Undoubtedly the simplest and most direct means of summarizing slope data is to present, in tabular or graphic form, the frequency with which slopes of each degree are represented within the sample. This frequency distribution may be presented by simply plotting or tabulating frequency of occurrence against degree of slope. However, unless slopes are grouped into a relatively small number of classes, the frequency curve accomplishes little in the way of simplification, for the variety of inclination present within a given area may be very large. If slopes are grouped into a few classes, a graphic, tabular or coded summary of the frequency curve may be offered that can be comprehended at a glance. For all its simplicity this is one of the most revealing, realistic and versatile of all slope summaries.

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15. Strahler, "Quantitative Slope Analysis", 1956, examines a number of sets of such slope frequency distribution data and comments on methods of analysis.

The establishing of a system of classes into which to group slopes may be done according to an almost unlimited number of schemes. The main principle to be followed is that the classes chosen must be suitable to the specific purpose at hand. If, for the particular purpose, there are definite critical or limiting slope values, then these should be used as class boundaries. For example, if the slopes are being classified for land-use

planning, and it is felt that in the area being studied, slopes in excess of 10% cannot be cleared without danger of erosion, while lesser slopes can safely be cleared, then the figure of 10% should be used as one of the dividing lines between classes. If the purposes of the study are less specific, or if the values that are "critical" for the purpose are not known, then arbitrary class limits must be set. These may be such as to give an equal range of values to each class, to fall at minimal points in the distribution curve, to encompass roughly the same number of individuals in each class, or to serve any of various other goals that do not involve specific critical values. In any event, the number of classes must be sufficient to give the desired degree of subdivision. If arbitrary class limits are set, there is always the tendency, when the data are being evaluated, to forget that the limits were but arbitrarily chosen and to invest them with a significance they do not really possess.

When even the class frequency data are too cumbersome for the purpose if given in complete form, it is sometimes valuable to give the data for one or two classes that seem particularly significant. Surprisingly useful, for example, is the figure that gives the percentage of the total area that is occupied by the gentler slope class or classes. Not only are gentle slopes usually the ones in which man is most vitally interested and which he finds most useful for the largest number of purposes; their degree of prevalence is also a highly

graphic descriptive index. To know that 65% of the slopes of a given area are within the limits of what may be termed "gentle" is probably to know more of value about the slopes of that area than could be provided by any other single figure. The choice of an upper limit for "gentle" slopes will depend somewhat upon purpose. For certain types of land use in a given area there may be a critical upper value beyond which the slopes cannot be used. For certain types of irrigation farming, the critical slope may be no more than one or two per cent. For non-irrigated machine-cultivated field crop agriculture, the critical slope beyond which erosion or mechanical difficulty becomes serious may be seven to ten per cent. For relatively few purposes are slopes in excess of ten per cent reasonably termed "gentle".

The fraction of the total area occupied by the especially steep slope classes is another useful index of slope conditions, giving some indication of the ruggedness of the land, and, if the lower limit of the class is reasonably chosen, also suggesting the amount of land that is hopelessly outside the bounds of usefulness to man. If coupled, this value and that for gentle slope together give an excellent brief summary of slope conditions of an area.

For many types of statistical data a very useful summarizing index is the prevalent or modal value or class, that is the class containing the largest number of individuals. In slope analysis, however, the

modal class is not necessarily very meaningful, because frequency distribution curves for slopes often do not rise from either extreme toward a well-defined maximum. Instead, the distribution is sometimes multimaximal or relatively even, class-for-class. Therefore the modal class may actually have only a slight degree of prevalence over one or more other classes. Thus the prevalent slope class is an index of limited value, not so much because it is misleading, but because it often reveals so little.

Also obtainable from the raw point-by-point data are various indexes showing the degree and scheme of variation of slopes within the area. Apparently little has been done with this topic previously, and no specific attention has been given to it in the course of the present investigation. Experience gained through rather cursory examination of frequency distributions of slopes in the state of Missouri and several areas in the western United States suggests that much of value can be learned from the careful analysis of such distributions. Slopes in any given area of erosional terrain commonly group themselves into two or more rather distinct ranges of steepness, often with marked minima or even discontinuities separating one from the other. The slopes of one area may differ from those of a nearby area only by the addition of a single range of, perhaps, steeper slopes, the rest being virtually the same. For example, the interstream uplands in much of the Ozark area have virtually the same slope characteristics as the rolling

or undulating prairie sections of central or western Missouri. The distinguishing feature of the Ozarks is the addition of the steep slopes of the lower valley sides. Considerations of this sort, frequently noted by geomorphologists, are worthy of much more systematic study than they have attracted up to now. Characterizations of individual areas, area-to-area comparisons, correlations with the nature of the underlying materials or of the vegetation cover, and various other valuable types of analysis can all be made from the raw slope data and should prove highly significant.

The mean or average slope has been used more often than any other single index to characterize the slopes of a given area, probably because of the basic simplicity of the concept and the frequency with which it has been used in other statistical analyses. It is so fraught with shortcomings, however, that its value for slope characterization is small.[16] In somewhat similar

16. See W. Calef and R. Newcomb, "An Average Slope Map of Illinois", Annals of the Association of American Geographers, v. 43, no. 4, Dec., 1953, pp. 305-316. The authors, after making and analyzing an average slope map of Illinois, reach the same conclusions. Their extension of this conclusion to all statistical maps of terrain (p, 316), however, seems unwarranted.

manner to the mode, the mean is most effective as a summarizing index if the frequency distribution curve rises from either extreme toward a pronounced maximum.

Slope frequencies commonly do not exhibit this pattern. It is entirely possible for the mean slope value for an area to be wholly unrepresented among the slopes that actually occur in the area. This would be true, for example, in an area of canyon-cut tableland, where all slopes were either very gentle or very steep. The mean value would be that of a moderate inclination which did not exist in the vicinity. The mode, for all its weakness, at least has the virtue of indicating something that actually does occur, and with greater frequency than any other one thing, condition or class of that type. While there are surfaces for which the mean would yield a representative value, that representativeness cannot be depended upon; it is not inherent in the concept of the mean.

Many methods, most of them exceedingly tedious, have been devised for determining the mean slope. One of the simplest is that of Wentworth, mentioned earlier. With point-slope data, however, the mean can be found directly and with no difficulty. Admittedly the degree of accuracy would not be as high as that obtainable by the various methods of greater complexity. However, there are probably few instances in which a high degree of precision is really needed, and in view of the questionable value of the mean as an index, the expenditure time and effort required by the more exact methods is rarely justified.

For an individual area or for comparison among areas, any of these values or summaries may be presented in tabular form. Summaries involving several values, such as frequency distribution of classes, may also be shown by line, bar, or pie graphs.

If it is desired to show the distribution of slope characteristics over an area, cartographic representation of some sort must be used. Slope distribution within a small area shown on a large scale may, of course, be shown by a slope-for-slope map, on which the actual areas occupied by slopes of each class are outlined and distinguished by tone or color. In geographical studies, however, the area under consideration is usually too large and the scale that must be used is too small to permitmapping of this sort. For these large-area, small-scale studies, it is suggested that the total area be subdivided into many unit areas of relatively small size. For each of those unit areas the slopes are analyzed by the methods suggested above. With these data at hand, individual slope indices may be mapped over the whole area by choropleth or isopleth techniques, or by various sorts of cartograms. Multiple-value summaries, such as class frequency distribution, are difficult to map effectively, just as are similar summaries in climatology, soil science, economic geography, or any other field. Most of the techniques that have been employed involve the recognition and mapping of recurrent combinations of values.

3. Conclusions

The fact that slope is the property of a point (or in practice, the property of a short line), and therefore offers untold numbers of values for any finite area of the land surface, makes some form of generalization or summarization necessary, both in the collecting and the expressing of data intended to characterize the slopes of an area of any considerable size.

Collection of data is accomplished by any of various techniques of sampling. Especially valuable because of the rapidity it affords, and surprisingly accurate in its results is the dot sampling method, which may be applied either in the field or on accurate contour maps. By this method a representative set of slope values from the area is obtained, and from these data many types of summary indices may be derived. For an area measuring about 7 by 9 miles, a sample of 60 to 100 slopes is sufficient for most purposes, though the sample can be increased to give almost any desired degree of precision. A less reliable but quicker method for obtaining class distribution data is that of eye estimate with the aid of a slope scale and overlay grid.

Presentation of slope data in summary form may be accomplished in many different ways. For simple characterization of phenomena for which numerical data are available, probably nothing yields a greater amount of information than a table or graph showing the class frequency distribution of values. If, for purposes of

extreme conciseness, a single index is desired that will convey the most useful information about the slopes of the area, one may use the percentage figure for any given class, may indicate the modal class or may compute the mean value. Especially useful for many purposes are the percentage of the sample that falls into thegentle slope class, and that that falls into the steepest slope classes. The prevalent or modal class is less indicative, and the mean value may be non-representative and misleading.

Any of these numerical values and indices permits a direct quantitative comparison among areas as well as correlations between slope characteristics and possible causal or resultant phenomena. Each is also capable of being expressed cartographically by choropleth or isopleth techniques. If representation is to be on a sufficiently small scale, further generalization will have to be made by grouping and boundary-smoothing.

B. Characterizing Surface Materials in Land Form

Like slope, surface material is essentially the property of a point on the land surface (actually a small finite area and extending to some limited depth beneath the actual surface). Thus the problems and techniques of sampling and summarizing its occurrence in an area are basically the same as those encountered in the study of slope. There are, however, some quite different problems involved in the practical applications of the techniques.

The chief theoretical problems are those of defining surface material, choosing what aspects of it will be considered, and setting up classes of differentiation. The answers will depend almost entirely upon purpose. In general, for relatively small-scale studies, the principal focus of attention would be on the gross physical nature of the uppermost few inches, or at most few feet, of soil or regolith. More specialized consideration of the physical structure or chemical composition of the regolith carries one into the realm of soil science which, however important, is outside the scope of the present investigation. Similarly the underlying rock structure, while a major control of the development of land form, is best omitted from a list of land form elements.

A reasonable approach for small-scale study would seem to be to subdivide surface materials into a number of distinctive major classes, such as ice and snow, water, bedrock, boulders and gravel, sand, and soil (in the broad sense of regolith made up largely of materials finer than

sand). Within a unit area, the occurrence of these classes of material is determined by dot sample or by eye estimate, as was suggested for slope. The same sorts of summaries may also be used, namely tabulation of the relative frequency of occurrence, the degree of occurrence of any single class, or the prevalent class. Since material does not offer a continuum of value, the mean, of course, is not defined.

The principal practical problem involved in the characterization of surface material is the obtaining of data. Except for water, ice, and sometimes sand, the necessary information cannot be obtained from topographic maps. Where available, detailed soil maps usually offer very useful data, but the extent of areas for which they are available is relatively small. Aerial photography is also a useful source of information, at least in the hands of an experienced examiner. In the last analysis, however, the surest source, though by no means the quickest or most convenient, is the field, especially for distinguishing fixed sand, stony soil, and stone-free soil, three very common materials.

c. Characterizing Vertical Dimensions in Land Form

Unlike slope, which is a property of a point, vertical dimensions naturally are properties of three-dimensional surfaces of finite area. In the complex geometry of land surfaces, there are many different vertical

measurements that can be made that may be interesting and significant.

Perhaps the most apparent of all vertical dimensions of land form is the height of the individual slope. Such heights (height of hills, ridges or interfluves above the base; depth of valleys and depressions below adjacent crest or lip) are obvious and readily perceived characteristics that give distinctive character to a given landscape. When one thinks of vertical dimensions in land form, it is these easily-seen individual slope heights that come first to mind. However, they are not the only vertical dimensions that are important to land form analysis.

As well as the total heights of major slopes, it is often of interest to consider the heights of lesser features or parts of slopes, such as cliffs or crags, river banks, terraces and benches, or waterfalls. It may be highly desirable to know the range of elevation along a given crest or divide, along a given stream valley or segment thereof, or along a pass route from one valley floor across the divide to the next valley. It may be worth considering the range of elevations on a given upland quite apart from the depths of valleys incised into it, or that of a lowland apart from isolated peaks that stand above it.

Finally, one may measure the total range of elevation present within a given area; that is, the difference in

elevation between highest and lowest points. This quantity, familiar as the "local relief" or "relief energy" of an area, has received much attention in the literature of morphometry, perhaps more than any other single item. It is a more "artificial" property than individual slope height, particularly if the area for which it is determined has been arbitrarily bounded. It is possible for the highest and lowest points in an area of some size to be incapable of being encompassed in a single view, and thus the local relief may be notably larger than the elevation differences one would actually notice if he were in the area. In spite of these shortcomings, the ease and objectivity with which the maximum elevation difference may be determined, in comparison to a summarization of individual slope heights within the same area, recommend it strongly as an index of vertical dimension.

In the current project, attention has been given to but two of the various possible measures of vertical dimension: maximum difference in elevation and individual slope height.

In principle there seems no need to depart from the method of determining maximum elevation difference that has been made familiar in this country by Guy-Harold Smith.[17]

17. G.-H. Smith, "The Relative Relief of Ohio", Geographical Review, v. 25, 1935, pp. 272-284.

By this method, the large region under study is subdivided into numerous rectangles of uniform size, and the maximum

elevation difference is determined for each rectangle. The method is simple, quick and objective.

The only significant problems involved in the application of this method are those of choosing size and shape for the unit areas. Because they are used as mapping units in the U.S.G.S. topographic series, it has been customary in this country to use as unit areas rectangles bounded by parallels and meridians. The extreme convenience of using these rectangles largely offsets their disadvantages, which are that they are not equidimensional, and that they change size with latitude. The latter point becomes too significant to overlook if the latitude range of the areas studied is great. It can easily be adjusted, however, by increasing the east-west dimension by a given number of minutes in higher latitude zones. The size of unit area chosen for local relief determination is difficult to set. Generally speaking, it should be large enough to insure that the full length of at least one typical slope is included, but not so large as to include diverse landscapes or to permit broad regional slopes to affect strongly the relief figure. Where slopes are short and crests and valleys are closely spaced, a small rectangle would be most desirable, while coarse-textured terrain demands a larger unit area. But if local reliefs are to be compared for diverse areas, it is desirable to keep the unit areas constant, which necessitates a compromise. Experimentation suggests that within the United States

a rectangle measuring 7½ minutes on a side (approximately 7 by 9 miles) serves reasonably well as a compromise unit for this purpose. However, this is somewhat too large for most of the eastern part of the country, where a 5-minute rectangle would be preferable, and rather too small for some parts of the Southwest, where 10 minutes would be a better figure.

For maps bearing a military grid, the 10,000-yard or 10,000-meter grid squares serve admirably as unit areas for relief determination in areas of not-too-coarse texture. They have the slight advantage of being equi-dimensional and the greater advantage of being constant in size, but they are awkward to use on maps on which the grid is not already printed, or on which a given square may be divided among two or three map sheets.

Criticism of the index is based chiefly on the quite reasonable feeling that to be representative and meaningful, the local relief index should approach as closely as possible the figure for heights of typical single slopes within the area. Local relief, then, becomes a "second-best" index, employed simply because it is so easy to employ. It is hard to quarrel with that view. Accordingly, any means whereby the local relief can be made to approximate the actual slope heights most closely appears desirable. Keeping the area as small as is feasible is the only device available, for only by that means can the effects of excessive diversity of terrain or marked regional slope

be minimized. However, it must be kept in mind that for a unified comparative study, the same size unit area should be used throughout, or comparability and objectivity are lost.

If a summarization of individual slope heights is indeed the most desirable single index of vertical dimension in an area, methods by which it can be derived are worthy of consideration.

Since there is in any area an infinite number of slopes (measured from crest to adjacent valley axis), the problem of deriving an index is similar to that for slope. Some form of sampling is necessary, and, as with slope, this can be done by various methods. Since a system of dot sampling has already been recommended for slope analysis, it seems worthwhile to consider the applicability of a similar system to the study of relief. This naturally requires an adaptation, for unlike slope, slope height is not a point quantity. It is rather the difference in elevation between the two ends of a line drawn normal to the contours and extending from crest to adjacent valley bottom. Through any point, placed at random on the surface, there is one such line that may be drawn. Thus if a given number of points are placed within the study area, they will locate an equal number of slopes whose height may be measured. Conceivably then, the same dots that were used for sampling slope may be used also for sampling slope height. However, in most instances, especially in long-sloped terrain, it is reasonable to use a smaller number of dots than are needed for slope analysis.

Once obtained these slope height data may be summarized in any of the ways usable for slope. It is probable, however, that the mean height, the modal height class, and the maximum height would be much more meaningful that are the corresponding values for slopes. The class distribution is, none the less, a more revealing and complete type of summary than any one of the single indices.

In the application of this method a practical problem is encountered in the definition of the end points of any given slope. It is not satisfactory to place these points invariably at the first crest or valley to either side of the sampling point, for travel normal to the contour frequently brings one onto the plunging crest of a spur or into the bottom of a steep ravine that is no more than a subsidiary feature on the major slope under consideration. While there is probably no wholly satisfactory way of eliminating this difficulty and at the same time maintaining objectivity, it will help to keep certain principles in mind while deciding where the top and base of a given slope should be. Generally speaking, the base of the slope should be located at the axis of a valley with essentially parallel sides and with a longitudinal gradient notably less steep than adjacent slopes and spur ends. In the majority of cases this valley axis will be oriented in a direction sharply different from that of the measured slope. The upper end of the slope should be on a summit from which

slopes of significant length radiate in all directions, or on a ridge top of very gentle inclination and marked by essentially parallel contours. It should not be on an insignificant projection on the side of an otherwise continuous slope. The upper end of the slope should be a dominant point in the small area in which the sampling point lies.

It should be mentioned that in some types of terrain, especially areas occupied largely by gently sloping plains but with a few prominent peaks or ridges rising above, or deep canyons falling below, individual slope heights are difficult to define and almost meaningless to summarize. In a basin-and-range landscape, for example, if a sampling dot falls on a mountain side, is the base of the slope to be placed at the foot of the mountain face, or far out in the middle of the basin at the ultimate foot of the piedmont plain? And conversely, for a dot falling on the piedmont plain, should the top of the slope be set on some miniature divide between rills on the plain, or should it be at the crest of the mountain range at the head of the piedmont? The choice would depend upon the purpose for which the analysis is being made. In most instances it would probably be best to consider and describe the mountain slopes and the piedmont slopes separately.

D. Characterizing Horizontal Dimensions in Land Form

The variety of horizontal dimensions that may be measured in a land form area is at least as great as the

variety of vertical dimensions, and many of the possible measurements are significant and useful. Among these are the distances between adjacent crests or summits, between adjacent valley axes or depressions, and between adjacent streams. Others are the breadths or areas of various kinds of features; such as lakes, streams, patches of gentle (or other) slope, patches of ice, sand, exposed bedrock, etc. Or one may measure the lengths of such linear features as ridge crests or streams.

In considering the dimensions of such features as patches of gentle slope or lakes or patches of permanent ice or snow, the concern is not with the total area of these within the unit, but with the size of the individual features of the kind. We have, for example, already discussed the importance of the percentage of the unit area that is occupied by gentle slope, but it is also significant to know whether this gentle slope occurs in many tiny plots or in one or two large ones. This difference would be critical to the utility of the land for purposes as diverse as mechanized agriculture and airport development.

These dimensions of patches of slope of a given class or material of a given kind may best be obtained by direct measurement from a map upon which the patches have been outlined. For each individual patch one may measure the maximum and minimum breadth and may find the area by planimeter or by grid method. If the number of patches is small, no difficulty exists, but if the number is large (frequently

true for patches of slope), some form of sampling may be necessary. If numerous, the data may be summarized by tabulation of frequency distribution or by the various single indices such as the mean. In the present project no specific attention was given to horizontal dimensions of this type, and nothing more than the foregoing general statements can be made.

Some work was done, however, on methods of obtaining data concerning the spacings of crests and valleys. It is these spacings that give to an area one of its most distinctive characteristics, that which has sometimes been called the "texture" of the terrain. In stream eroded country it is one aspect of the "degree of dissection" of an area. Differences in coarseness of texture have long been recognized, but the concept is a difficult one to define precisely, which is perhaps one of the reasons why it was relatively little studied, either quantitatively, comparatively or genetically, until rather recently.

Basically the determination of the texture of an area of land form requires no more than the sampling and measurement of crest-to-crest or valley-to-valley distances. These might be accomplished with the aid of a dot-sampling device, as previously suggested for slope and slope height. In this instance, for each point, one would determine and measure the shortest line segment passing through that point from a crest (or valley) on one side of the point to a crest (or valley) on the opposite side. There one

would amass a representative group of crest-to-crest distances, which could than be summarized as desired.

However, application of this method leads quickly to practical problems that are difficult to solve with complete objectivity. The most pressing of these problems has already been encountered in the discussion of slope height. This is the question of which crests (or valleys) to use and which to ignore as insignificant. If one considers every crest that is distinguishable from the contours, he will obviously obtain a very different value for the texture than he will obtain if he considers only "significant" or "major" crests.

This problem suggests that one may in fact wish to consider more than one degree or scale of texture. In general terms, one might wish to consider separately the spacings of "major" crests or valleys (which may be called the "gross texture") and the spacings of all crests or valleys (which may be called the "complete texture"). The contrast between these is illustrated by the San Gabriel Mountains, in southern California, in which major crests are high and widely spaced, giving a distinctly coarse gross texture, but in which the slopes of all valley sides are scored by a dense system of gullies and ravines, giving a complete texture that is very fine. On the other hand parts of the Ozarks in south-central Missouri or of the Appalachian hills in northeastern Kentucky display a remarkably close spacing of major crests, but show little

development of ravines or gullies on their forested slopes. This in comparison with the San Gabriel Mountains these areas possess a much finer "gross texture", but a somewhat less fine "complete texture".

An approach to a reasonable though not strictly objective distinction between these two indices is suggested by the discussion of slope height. The straight-line distance between the top and base of a "major" slope as delimited for slope-height determination could be used in the determination of gross texture. This distance would be the valley-to-crest distance or, ideally, half the distance between major crests. The usual frequency-distribution or single index types of summaries could be used to give concise characterization of the phenomenon over the unit area.

As with slope heights, this method yields confusing data if applied to mountain-studded or canyon-cut plains. In such areas the gross texture is most reasonably defined as the spacing between mountain crests on the one hand, or between canyons on the other. Therefore the slopes sampled should reach from a mountain crest to a major drainage axis of the plain between ranges, or from a canyon bottom to the crest of the major divide between that canyon, and the next. The minor crests and valleys on the smoother lowland or upland would be disregarded.

In the current project another method was devised to increase the objectivity of gross texture determination by

insuring that the crests and valleys whose spacing is measured are "major" ones. A "major" crest or valley was arbitrarily defined as one that rose above its base or fell below its brow by an amount equal to more than one-third of the maximum elevation difference within the unit area in which it lay. Several sample points were arbitrarily placed within the unit area and a straight line was then pivoted about each point. By this device it was possible to determine the shortest distance, along a line passing through the point, separating adjacent crests between which the surface dropped more than one-third of the local relief of the area. From the sample distances a simple mean was calculated, and this was used as a texture index for the unit area. Texture variation was mapped on this basis for the state of Missouri.[16]

16. Appendix 2

Most values fell between one and two miles, with extremes of 0.7 miles and 4.0 miles. Since time has permitted neither the testing of this method in areas of more diverse terrain, nor the comparison of its results with those obtained by other methods, its value can not yet be assessed, but it does offer distinct promise.

Analysis of the "complete texture" of an area, in which even small gullies are considered, offers fewer difficulties, because no selective decisions are necessary.

One method of measurement would be to examine the contour line passing closest to the sampling point, mark the first salient (or re-entrant) to either side of the sampling point, and measure the distance between. Various acceptable systems of sampling and measurement could undoubtedly be devised. For the unit area as a whole, the usual forms of summaries could be employed.

The most commonly employed technique of analyzing texture of an area has been that of computing the drainage density, that is the total length of streams or drainage channels divided by the area. This method was apparently devised by Neumann , and has been extensively used by Horton, Strahler and others. It need not be discussed at length here, but there is no question of its usefulness for detailed analysis of the drainage net. Its principal drawback for large-area studies is the tediousness of stream-length measurements. The method also faces the familiar problems requiring decisions about whether or not very small drainage lines are to be considered.

E. Characterising Horizontal Arrangements (Patterns) in Land Form

Without question, the most difficult aspects of land form to characterize objectively are the arrangements of features, both in the horizontal and the vertical planes. Many of the specific arrangements in which one might be interested, such as the pattern of crests and summits, are so complex and offer such a great range of variation as to be extremely elusive for systematic characterization. Not

only are individual patterns difficult to describe concisely, they are also difficult to compare systematically with other individual patterns, so that classification becomes doubly difficult.

In the present investigation, while considerable thought has been given to the possibilities of simple characterization and classification of arrangements, they have not been principal topics of study, and in any event, positive results have been small, especially so for arrangements in the horizontal plane.

Examples of patterns in the horizontal plane that may be of interest are that of crests and summits, that of valleys and depressions, that of hydrography, that of gentle slope (or of any other slope class), and that of exposed bedrock (or any other class of surface material). Such patterns may be, with varying degrees of difficulty, drawn from map study, from aerial photographs, or from field survey, but once they have been drawn, the task is only begun. The problem is how to describe the pattern in summary form, and how to compare it objectively with others of the same kind. Theoretically, it should be possible to express any pattern in mathematical terms, but for few, if any, of the significant patterns in land from analysis is such expression remotely feasible, though certain specific aspects of the pattern can be isolated and expressed in simple terms (e.g. the prevalent orientation of major ridge crests). Probably the only way patterns

could be strictly objectified or quantified would be by the same route of resolving them into component aspects that has been used in this general investigation of land form as a whole. But since each type of pattern would have to be broken down in this way, and since strict objectivity in pattern analysis is not needed for the majority of purposes, it does not seem that the time and effort required are worth expending unless the specialized purposes of a given study demand it.

On the other hand, it does seem feasible to develop somewhat subjective classes into which individual patterns could be placed by inspection and comparison with an example. Such a method has been utilized, in rather rudimentary and unsystematic fashion, by various writers, especially in the descriptive portions of textbooks.[18] Usually only

18. See, for example, S. Passarge, Beschreibende Landschaftskunde, 1929, op. cit.

a few sharply contrasting types have been mentioned and a similar number of well-marked examples offered.

A systematic attack on the problem would require the collection of a large number of actual examples. These would then be carefully examined and sorted into as many distinctive groups as seemed necessary, and for each class a middle-of-the-range example would be set aside as a model. When one wished to characterize a new individual, he would compare it with the various models and place it in the class whose model it most closely resembled. Clearly this process

involves a considerable degree of subjectivity, both in establishing the classes and in matching individuals with the models. It is, however, probable that such a method would prove sufficiently meaningful and accurate to serve all but the most exacting purposes.

A very simple classification of patterns of major crests, summits and divides constructed on this basis might look something like the following:

1. Parallel - Major crests essentially parallel, with no significant side branches.
2. Trellis - Principal crests essentially straight (and parallel), with significant lateral branches normal to the principal crest.
3. Feather - Principal crests essentially straight (and parallel), with significant parallel lateral branches that meet the principal crest at an acute angle.
4. Comb - Principal crests essentially straight (and parallel), with significant lateral branches on only one side and nearly normal to principal crest.
5. Dendritic - Principal and lesser crests are widely branching, with no marked parallelism or prevalent orientation.
6. Elongated dendritic - Crests extensively branched, but drawn out in one direction, so that except near their junctions, crests are at least roughly parallel.

7. Radial - Crests radiate from a well-defined node.

8. Fragmental - Crests are points or short ridge segments, essentially unconnected with one another.

It should be emphasized that this list has not been carefully worked out by the process suggested above and is not intended to serve as a finished product. It does, however, illustrate the sort of thing that can be done, and suggests certain problems that are likely to be encountered. Two of these may be mentioned briefly.

Anyone attempting to use the suggested list would, in all probability, be quickly dismayed by its brevity, for he would encounter patterns that appeared utterly distinct from any of those mentioned. Since the list was not experimentally worked out and does not purport to be complete, this is to be expected. However, a major problem that must be guarded against in almost any attempt to formulate a classification of natural phenomena of any complexity is the tendency to proliferate excessively the number of classes. Unless one consciously resists this tendency, he will almost certainly find himself burdened with more classes than he can reasonably handle.

A second difficulty is the ever-troublesome one of scale, perhaps best illustrated by an example. If one studies the patterns of crests (or of valleys) in northwestern Missouri in terms of small unit areas, he finds that most of the areas display patterns that might be called

dendritic, elongated dendritic, or a strongly branching version of the feather class. If, however, he looks at a small-scale map of northwestern Missouri, he is immediately struck by the remarkable north-south parallelism of the master streams and divides, a characteristic he might well have missed entirely in working with the smaller units. The same disparity of pattern in features of differing order can sometimes be found even in very small areas, where small tributaries of perhaps first, second and third order may form perfectly dendritic patterns, while the larger streams, of fourth or fifth order are distinctly parallel, thus giving a combination drainage pattern that is more or less a feather pattern with frayed-out laterals. Such combination forms are troublesome to deal with, and may, if the purpose demands their inclusion, require special mention apart from the concise characterization that is offered in map or brief summary.

P. Characterizing Vertical Arrangements in Land Form

Arrangements of features in the vertical plane are as numerous and as varied as horizontal patterns, and are only slightly less difficult to treat objectively. Included under this heading would be transverse profiles of valley sides, longitudinal profiles of crests, valley axes and streams, and vertical distribution of surface area, of gentle (or other) slope classes, of lakes, or of given classes of surface material, and numerous other such profiles and vertical distributions. It should be noted

that there are two rather distinct but related types of information involved here: (1) vertical distributions, that is, positions of certain features in the vertical scale, and (2) profiles, that is, the manner of variation of elevation of the surface along a given line. Analysis and characterization of the first type is basically simple, requiring no more than the sampling and plotting of values along a uni-dimensional scale of elevation. Description of profiles, on the other hand, is likely to be a complex and difficult task, somewhat comparable to that of characterizing horizontal patterns. Fortunately, for certain purposes vertical distributions can be made to serve in place of the more difficult profile characterizations, thus easing the problem somewhat.

In the present study, attention has been given to only two related vertical arrangements: (1) transverse valley-to-crest profile and (2) vertical distribution of gentle slope. However, the methods employed in the analysis of these two properties can be applied to many other arrangements as well.

The characteristic profile that extends from a major valley axis directly upslope to the adjacent major crest is a significant and diagnostic item in the nature of a small section of terrain. Reproducing or describing it not only shows in graphic fashion something of the "picture" that an observer would actually see in the area, but it also shows more clearly than any other single index the vertical

organization of the terrain, the arrangement of slopes and flats in the vertical plane. Though it is independent of scale and dimension, the transverse profile by itself goes far toward expressing the essential gometry of an area. This is especially true for surfaces composed of sharply contrasting steep and gentle slopes, such as canyon-cut tablelands and mountain-studded plains. On a more detailed scale, the transverse profile brings out the existence of cliffs, terraces and shoulders that may be both characteristic of the area and significant to the purpose of the study.

As with other characteristics, the analysis of transverse profiles has two parts, each of which offers important practical difficulties. The first part is that of collecting the profile, the second is that of describing it.

Though one would hardly expect it to be so, the collection of transverse profile samples is probably more beset by practical problems than is the characterization of the profiles once they have been drawn. There is no particular difficulty in choosing the location for sample profiles in a general way; this may be done by the dot patterns previously suggested for other properties. The real difficulty is the <u>specific</u> location of the profile, and an appreciation of this problem requires some familiarity with terrain details.

Ideally, the profile of a slope is drawn along the line that would be followed by a stream of water or a large rolling ball, that is, the line so drawn as to be everywhere

normal to the contour. On laterally straight slopes, that is, slopes that have straight, parallel contours, such a profile would clearly portray the slope form, and would represent the profile that an observer would see in the field. But laterally straight slopes of any breadth are rare. On most slopes the contours are highly irregular, with numerous convexities or spurs, between which are concavities or ravines. On such slopes, three significantly different kinds of profiles occur. The first is the profile that may be drawn down the crest of a spur. The second is that drawn down the axis of a ravine. The third is one that, starting from the crest, finds its way down the flank of a spur, eventually reaches the axis of the adjacent ravine, and continues down the ravine to the base of the slope. In the same small area these three types of profiles, particularly the first and second, may be utterly different, and one's impression of the characteristic profile of the area will depend heavily upon which type of profile has been drawn.

In irregular country the profiles one is most likely to notice in the field are the profiles of the projecting spur crests. But such spur crests sometimes occupy but a small percentage of the area, and are in such instances not truly representative. The more hidden profiles of the intervening hollows are in these cases actually more "typical" of the area. An illustration is offered by the granite-knob country of the St. Francois Mountains in the

eastern Ozarks of Missouri. The visitor to this area is impressed by the marked convexity of the rounded knobs. A study of the contour maps, however, reveals that this convexity is representative only of the spur crests and certain broad slopes without ravines. A large percentage of profiles taken completely at random, however, would fall into the ravines and hollows between spurs, and would be convex only near the crest, the middle and lower sections being slightly to strongly concave. Concavity is, of course, characteristic of the majority of profiles that follow the axes of ravines and hollows in erosional topography.

In sampling profiles, than, one must decide and must clearly state whether he is going to draw his samples from spur crests, from hollows, or indiscriminately from both. It is suggested that the last-named choice will yield relatively meaningless information. If one must choose between the other two he should do so on the basis of his purpose. There is no question but that spur-crest profiles better convey the appearance of the area than do the others.

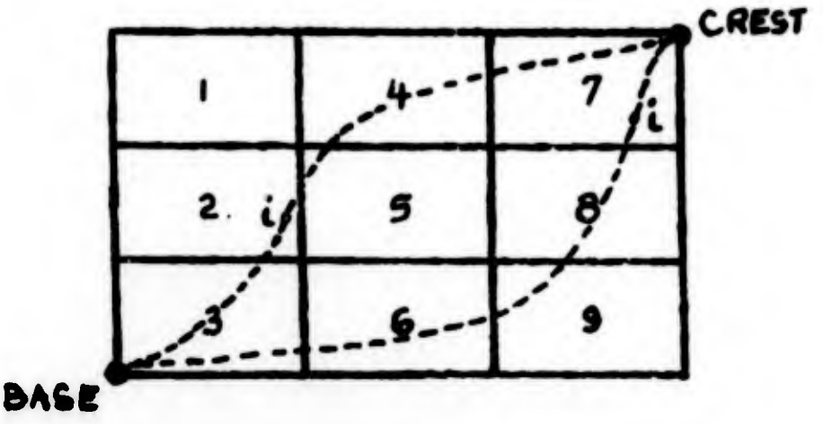
Once it has been decided what type of profile is to be studied, the sample profiles may be collected by various methods. One method would be to draw the profile of the spur (or hollow) nearest to each of a pre-arranged series of sampling dots. The collected profiles would then have to be described and probably summarized for the unit area.

Since a profile is often a rather complex curve, this involves some difficulty, and there are many techniques than can be used, ranging from simple subjective classification, as suggested earlier for patterns, to mathematical curve fitting. A promising method is suggested by the work of Cholnoky, [19] who noted that the majority of slopes

19. J. Cholnoky, "On Slopes", International Review of the Hungarian Geographical Society, 1938, pp. 77-89.

consisted of an upper convex section and a lower concave section, separated by an inflection point. Cholnoky discussed several types of profiles that differed from one another on the basis of the relative lengths and heights of these upper and lower sections. With profiles that extend from major crest or divide to major valley axis, it appears feasible to systematize Cholnoky's profile distinctions in terms of the horizontal and vertical position of the inflection point relative to the crest and base of the profile.

Such a scheme, in which nine profile types are distinguished, is shown in the accompanying illustration.



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The upper right-hand corner of the diagram represents the crest of the profile and the lower left-hand corner the base. The vertical distance separating the two points is subdivided into three equal parts, and the horizontal distance is similarly divided. The inflection point of any profile of the Cholnoky type will fall into one or another of the nine rectangles so formed, and the particular rectangle into which the point falls can be used as a basis for classifying the profiles. Thus a characteristic gross profile from the Basin-and-Range country would have its inflection point in the upper right-hand rectangle, while in one of the less-dissected parts of the Ozark upland, the inflection point of a typical profile would fall into the middle rectangle of the left-hand column. It should be noted that the use of the diagram is independent of both vertical and horizontal scales. Eye inspection of a drawn profile will usually suffice to determine into which rectangle its inflection point would fall. With practice it should be possible to classify relatively simple profiles from inspection of the contour map, without the necessity of actually drawing the profile at all.

This scheme is highly generalized, as any simple profile classification must necessarily be. It does not take into account complex profile types that may have two or even more inflection points. If the irregularities that produce these supernumerary inflections are small,

they may, for the sake of simplicity, be generalized out of existence. If, however, they are great, as will not infrequently be true, it may be necessary to establish one or more additional classes, perhaps loosely defined, to accomodate the profiles possessing them. Since the method has not been extensively tested, it is not known how often it would be necessary to resort to this device, nor how many additional classes would be needed. It is,however, entirely clear that many profile details and local oddities cannot be encompassed by any general characterization, and can be portrayed only by actual drawings or detailed verbal descriptions of the specific profiles in question.

As suggested earlier, it is often possible to give the most needed information about vertical arrangements in terms of vertical distributions rather than actual profiles. Sometimes the vertical distribution itself is actually the sort of data specifically sought. Thus one might be concerned, in an alpine mountain area, with the vertical distribution of permanent snow and ice, or, in a formerly glaciated range, with the vertical range of existence of glacial lakes. In these instances the concept of profile does not enter into consideration. In other instances however a vertical distribution may provide data that are valuable in their own right, but that may also furnish at least a rough idea of the characteristic profiles. This is, for example, true of vertical distributions of area and of slope.

Data concerning the vertical distribution of area may be obtained by dot sampling of elevations or by measuring with a planimeter the areas enclosed by successive contour lines. Either the size of the sample or the interval between planimetered contours may be adjusted to give the desired degree of accuracy and precision. The data may be expressed in tabular form or by any of several graphic devices. Perhaps the most familiar graphic device is the hypsometric curve, in which elevation is plotted against the area that lies above the corresponding contour.[20] The use of the polar planimeter for

20. The uses of this curve have been discussed by various authors. See A. N. Strahler, "Hypsometric (Area-Altitude) Analysis of Erosional Topography", Bulletin of the Geological Society of America, v. 63, 1952, pp. 1117-1142.

determining the elevation-area distribution is so very slow as almost to rule it out for the relatively rapid, smaller-scale study with which the present investigation is concerned. Dot sampling affords much greater rapidity and a sufficient degree of accuracy for most purposes.

Closely related to the area-elevation determination is the slope-elevation relationship. By any of various means of sampling, one can determine the vertical distribution of any particular slope class, or can determine what are the slope characteristics of any given elevation zone or band.

In the current project, considerable experimentation was done with a very simple index of the vertical distribution of gently-sloping land. The total elevation range of the unit area was divided into an upper and a lower half. By eye estimate or dot sampling it was then determined whether the major portion of the gently-sloping land lay above or below that median contour. Three classes were recognized: (1) areas in which more than two-thirds of the gently-sloping land lay in the lower half of the elevation, (2) areas in which more than two-thirds of the gently-sloping land lay in the upper half of the elevation range, (3) areas in which the gently-sloping land was relatively evenly divided between the upper and lower halves, neither half having as much as two-thirds of it.[21] This index is almost absurdly simple

21. In practice a fourth class was also recognized, in which the entire area was occupied by gentle slope. This definition, however, is not strictly comparable to the other three.

and is quick to determine, but it yields a very rough first approximation of the essential profile type of the area. Experience suggests that it might be improved by subdividing the vertical range into three parts instead of two and by lowering the qualifying fractions from two-thirds to one-half. Crude though it is, this method probably offers the quickest objective method of expressing something of the essential vertical arrangement of the

surface of an area, and it gives the information in terms of what is undoubtedly the most commonly significant slope class.

III Sources of Land Form Data

Objective and systematic characterization of terrain cannot, as a rule, be done accurately without access to at least one of three sources of material: (1) field observation made for the specific purpose; (2) aerial stereophotograph coverage; or (3) accurate contour maps having a sufficiently small contour interval. Single aerial (or ground) photographs and accurate topographic maps other than contour maps will often yield much valuable information, but do not permit most types of quantitative data to be determined. Verbal accounts and maps prepared by field observers with other purposes in mind are of more limited value. And no one of the three most useful types of sources will usually by itself satisfy all of the investigator's needs or interests.

A. Field Observation

Field observation can be made to yield all conceivable kinds of information for objective analysis of land form, but only at the cost of great time and expense if extreme accuracy is desired. For such accuracy the field investigation must take the form of a topographic survey, including mapping of the surface material. If such high accuracy is not required, field study can be brought within reasonable limits of time and cost, but even at best it is

expensive and slow in comparison with the other methods of obtaining data. Of course, for many areas contour maps and aerial photographs are not available, and if these areas are to be studied, they must be studied in the field.

If the areas to be characterized are large, the field methods used can scarcely go beyond the level of careful reconnaissance methods. These would involve some sort of sampling, which might be either highly systematic or relatively unsystematic. Systematic sampling, which alone would insure precision, would presumably take the form of a thorough inventory of desired elements at each of a large number of pre-set points or along pre-established traverse lines, in the same manner in which data are sampled from contour maps. The collecting of a significant sample, perhaps more than fifty points within a 7½ minute rectangle, may still require a great deal of time, especially so if the sample points are located (as they should be) without regard to their accessibility. In smooth, open country with a close network of roads, such a sample might be taken in a day's time, but in areas with few or no roads, or with rugged or marshy or densely-grown terrain, the task could require a week or considerably more. In some instances merely locating the points themselves would be a major task. At best the area that could be worked in a single field season might be somewhat more than a one-degree square. Under difficult conditions

it could well be considerably less than one quarter of such a square. The data obtained should permit reasonably precise characterization of the area studied.

If only a modest degree of precision is required, field investigation can be much more brief and less strictly systematic. Instead of collecting a formal sample, the investigator simply endeavors to "cover the ground" to the extent that he has not failed to see, at reasonably close range, any part of the surface that could be significantly different from its surroundings. During his informal traverse he observes carefully all important characteristics. He measures example slopes, notes the character of surface materials, observes profile characteristics, estimates slope heights and lengths, and endeavors throughout to arrive at a balanced picture of the whole area. At the end of his reconnaissance he should be able to synthesize a clear, reasonably thorough and objective description of the area, including even some of the simpler types of quantitative information. Thoroughness and balance can be furthered by the use of a check list.

While less precise and reliable than the characterization that would be possible with formal sampling, this description may still be adequate for many purposes, and can be accomplished in a fraction of the time. Such a reconnaissance method was tested by the writer in several areas in Missouri and in the Great Plains and Middle Rockies,

with generally favorable results.[20] Naturally progress is

20. See examples in Appendix 2.

least rapid and the results least satisfactory in rugged or heavily wooded country when visibility is limited, and in areas where road accessibility is low. Most of the areas studied had fairly good nets of roads that were passable (though sometimes no more than that), and it was found that a half day usually sufficed for the reconnaissance of a 7½ minute rectangle. In difficult areas even this simple type of reconnaissance would require several days for an area of comparable size.

Not all elements of land form lend themselves equally well to field study. Perhaps the simplest to observe in the field are slope, profile and surface materials. Surface materials are especially marked as objects for observation in the field, for only there are definite data usually available. Field observation is also particularly valuable in bringing out lesser details of the terrain, often lost between contours or through generalization on contour maps. This is perhaps most striking for details of profile, i.e. such items as terraces and benches, or other small slope breaks on the valley sides, and small irregularities in the longitudinal profiles and in the patterns of streams. Finally, there is no substitute for field study to fix in the investigator's mind the firm visual impression needed to make the terrain "come to life"

in a way that even the most skilled and practiced scanning of a contour map or quantitative analysis of the features shown thereon cannot do.

On the other hand such elements as dimensions and horizontal arrangements are quite elusive in the field. Through practice, slope heights and distances can be estimated with a modest degree of precision, but occasional errors of surprising magnitude creep in. As anyone with experience can testify, an unaccustomed clarity of the atmosphere or an entry into terrain having features of an unfamiliarly large scale can, for a time, at least, throw large errors into an observer's estimates of distance and height. Patterns in the horizontal plane are often very difficult to perceive on the ground, especially in wooded lands of gentle relief where points of vantage are not available. These arrangements may, on the other hand, be most obvious from a glance at a topographic map or an aerial photo.

In summary, field investigation, while theoretically the most complete and reliable source of terrain information, offers numerous difficulties to large-area study. These are principally slowness and hence costliness, but also involve the difficulty of field perception of certain elements, most notably dimension and pattern. Rapid field reconnaissance, especially if aided by aerial photos, can, however, serve well as a source of information, provided great precision is not required. If greater precision is required, formal field sampling can be used, but at considerably increased cost.

It should be borne in mind that this very brief assessment of the value of field study is aimed only at its usefulness for descriptive analysis and not its value for studies of origin or significance of the terrain. For studies such as these, field investigation can in no way be omitted, and may well supply the major portion of the interpretative evidence.

B. Aerial Photographs

Since aerial photography suitable for stereoscopic study is now available for large areas of the world that are not adequately mapped and that are difficult of field access, it is important to consider the usefulness of this medium as a source of objective land form information.

Aerial stereophotographs can be utilized for land form study in two significantly different ways. (1) They may be analyzed photogrammetrically, that is as survey data that may be converted into topographic maps of high accuracy and precision, provided that some ground control has been established in the area. (2) They may be used directly, in their existing form, as a visual source of information. For rapid studies of large areas, photogrammetric methods are, in general, excessively slow. And in any event, they simply serve the purpose of converting the photographs into contour maps, and most of the interpretation is then made from the contour map, not directly from the photographs. For present purposes, then, attention will be given only to the usefulness of photographs as direct sources of information.

From direct reading of aerial stereophotographs one may obtain valuable and reasonably precise information concerning such items as crest and valley patterns and various horizontal dimensions. A practical observer can often distinguish many types of surface materials, such as water (including swamps), ice and snow, bare rock, boulders, and sometimes sand. This is one of the few kinds of information for which aerial photographs are better sources than contour maps. Another is topographic detail, such as minor (especially first order) drainage channels, ledges, terraces, and small irregularities in slope and stream gradient. Somewhat less satisfactory is the information concerning profiles and other vertical arrangements. Generalized profile types can usually be determined by inspection, but quantitative evaluation is not possible with any great degree of accuracy or precision. At least equally unsatisfactory are determinations of vertical dimensions and of slopes. While these can be made accurately by photogrammetric measurements, they do not lend themselves to rapid direct determination. Experimentation suggests that the most useful results are those that are obtained by a scanning type of slope or slope-height comparison over the whole area of overlap of a stereo-pair. In this way, one can arrive at an approximate picture of the apportionment of slopes among various classes of <u>relative</u> steepness or height. And if it has been possible to measure a few

sample slopes in the field or from maps, it may be possible to assign approximate values to the steepness or height classes. However, attempts to measure individual slopes from stereophotographs by various sorts of comparison keys have not been very successful, but have shown excessive variation from place to place on the photographs and from observer to observer.[21] Thus it

21. Appendix 1

appears that aerial photographs fall short of the mark as sources of certain of the most important sorts of quantitative data. For other types of quantitative data, however, they can serve well, and they are quite useful sources of qualitative information.

It should also be emphasized that there are certain very practical difficulties to the use of aerial photographs for large-area analysis. How important these problems become depends upon the availability of money, personnel and space. In the current project, which was conducted with a limited budget and few personnel, they proved troublesome. One problem is that of cost. At present in this country prints of aerial photographs cost fifty cents or more apiece. Complete stereo-coverage of a seven-and-one-half-minute rectangle may require more than thirty prints, so that the cost may be fifty times as great as that of a topographic map of the same area. Clearly, if it proves necessary to use aerial photographs, analysis of a large area will be a costly undertaking, too costly for

most private researchers. To reduce the cost to reasonable figures, a rather coarse sampling technique must be employed.

The second practical problem is that of the time required to sort out the photographs, to identify and mark on them the study units and any sampling points that may be desired, to mark on each pair the area of overlap unique to that pair, and finally to examine them stereoscopically and make the needed observations and measurements. While no specific timings were made, it is probable that the use of photographs requires more than twenty times as many man-hours as are needed for comparable analysis from contour maps. For the private researcher this is again a costly matter.

In summary, aerial photographs are useful sources of qualitative information concerning most elements of land form, and may be used for quantitative studies of certain elements, especially those, such as patterns, dimensions, and materials, that are developed in the horizontal plane. Slopes and vertical dimensions and arrangements cannot be effectively handled without recourse to excessively timeconsuming photogrammetric methods. For the limited budget study of large areas the requirements of cost of photographs and the much greater man-hour requirements make the use of aerial photographs prohibitively expensive unless coarse sampling of the large area is acceptable. For relatively

low-cost projects selected stereo-pairs may be profitably studied for clarification and supplementation of contour map or field reconnaissance observations. If cost is not so critical an item, or where photo coverage is accessible through an interested government agency, aerial photography provides by far the most complete and most useful land form information available for large sections of the globe.

C. Contour Maps

Contour Maps of high accuracy represent by far the most convenient and inexpensive sources of terrain information for the areas for which they are available. Since most of the earlier discussion of the determination of various land form characteristics was keyed to the use of such maps, there is no need here to do more than summarize the principal strengths and weaknesses.

Provided they are responsibly accurate and are drawn to suitable scale and contour interval, contour maps can provide nearly all kinds of land form information except for surface material (other than water and permanent ice) and finer details of the surface. For these characteristics other sources, such as field observation or photographs must be utilized. But with these significant exceptions thorough terrain descripti s of high quality can be derived from contour maps in a small fraction of the time and at a small fraction of the cost required by field study or the use of aerial photographs.

The major obstacles to the use of contour maps are obvious, practical and highly restrictive. Large-scale contour maps (one inch to the mile or larger) are available for only a small portion of the world, and many of the maps that are available are below the needed standards of accuracy. These problems are so familiar as to require little elaboration. Suffice it to say that contour maps must be used with caution unless the investigator can obtain reasonable assurance that they are accurate enough to give a good representation not only of certain critical elevations and of general patterns of features, but of actual slope steepnesses as well. Many maps drawn on the contour principle are in fact little more than form-line maps drawn to an open framework of horizontal and vertical control. Sometimes this can be detected from the improbable appearance of the contours, but sometimes it is masked by skillful rendering. The absence of high-quality contour map coverage of such vast areas of the world is beyond a doubt the greatest obstacle to systematic and comparative land form study.

IV. The Formulation of Land Form Descriptions of Large Areas

A. The Unit Area Approach

In somewhat similar manner to the way in which the complex phenomenon of land form in a given area may be systematically analyzed by resolving it into component elements, so the systematic description of a complex

area be attacked by breaking the area up into small units, each one of which may be characterized as an individual. These individual characterizations may then be combined and summarized in an orderly manner to afford a meaningful description of the larger area and its internal differentiation. This approach to large-area description and regionalization thus involves two distinct steps: (1) the subdivision of the larger into many small unit areas and the systematic characterization of each of these units in terms of a chosen set of elements or differentiating characteristics, and (2) the synthesizing of these unit area descriptions in such a way as to make clear the variations and similarities from place to place over the larger area.

The unit area method has its greatest value when the unit area is very small relative to the size of the whole area under consideration. Since the method is intended to reveal as clearly as possible the nature and pattern of internal variation within the larger area, a large number of small individuals, within each of which there is relatively little chance of marked variation, will serve much better than a small number of large individuals that can be but vaguely defined. The comparison is similar to that of a photograph reproduced with a very fine half-tone screen and the same photograph with a coarse screen. The fine screen gives notably sharper definition.

On the other hand, the unit area must be sufficiently large to permit all desired characteristics to manifest themselves and to be measured or described. Local reliefs, textures and patterns simply cannot be meaningfully defined or characterized except for areas large enough to include the entire length and height of at least one major slope, and preferably more than one. As a rule this would require that the area measure at least one or two miles across, and preferably somewhat more, especially in areas where coarse texture is common.

In the present study, a rectangular area was used measuring 7½ minutes of latitude or longitude on each side (slightly less than 7 by 9 miles in Missouri; about 6 by 9 miles in North Dakota). For most of the areas studied a 5-minute rectangle (about 4½ by 5 3/4 miles in Missouri) would have been preferable.

The use of a uniform, arbitrarily located grid for delimiting unit areas has much to recommend it, for it is wholly objective and assures that all data are collected for areas of the same size and shape. For certain specific purposes, however, non-uniform units may prove more valuable. An excellent example is provided by the numerous recent studies, by Strahler and others, of stream-eroded terrain, in which the unit areas chosen have been drainage basins, usually of third to fifth

order.[22] To my knowledge the studies made on this basis

22. See, for example, A. N. Strahler, "Quantitative Analysis of Watershed Geomorphology", Transactions of the American Geophysical Union, v. 38, 1957, pp. 913-920

have involved only analysis of and comparison between isolated individual units, and have notattempted to use such units in systematic characterizations of large areas or delimitation of regions, although this could undoubtedly be done.

B. The Analysis of Unit Area Data

1. The Areal Variation of Individual Elements.

Once all of the unit areas have been characterized in terms of the selected list of elements, the next problem is to analyse the variation of land form characteristics from place to place over the largerarea. This may be done in two distinctly different ways: (1) by considering the variation of each characteristic separately, or (2) by combining all elements within each unit area to define land form types, whose distribution over the larger area is then plotted. The first of these two approaches is straightforward and familiar, and requires but brief discussion.

Certainly the simplest way of analyzing the areal variation of any complex phenomenon is to map the variations of individual elements separately. When based upon the unit area approach, this would involve the use of a base map on which the unit areas were shown. In each

unit area would be entered the quantitative value or class index number or symbol for the particular element being mapped. Then for purposes of visual clarity each unit area could be colored or shaded according to its value or type, resulting in a choropleth map. Or, for continuously varying quantities, isopleths might be drawn to the values plotted. For most land form indices choropleth representation is more strictly correct, since the indices represent summaries for the unit areas and not properties that vary continuously across the surfaces.

For many purposes this element-by-element study of variation is precisely what is needed. It is especially helpful in studies of the genesis of specific aspects of the land form or in studies of functional significance, in which it is advantageous to be able to compare areally the occurrence of different individual elements that may be causally related. Furthermore, the cartographic representation of a single element is much simpler than the representation of the simultaneous variation of several elements. Thus, for example, Thornthwaite, in presenting his second scheme of climatic classification, chose to map the four selected elements separately rather than to combine them into a map of climatic types, though in presenting his earlier classification he had done the latter.[23]

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23. C. W. Thornthwaite, (1) "the Climates of North America According to a New Classification", Geographical Review, v. 21, 1931, pp. 633-655. (2) "An Approach Toward a Rational Classification of Climate", Geographical Review, v. 38, 1948, pp. 55-94.

On the other hand, the element-by-element analysis of a large area possesses the major deficiency of not being able to present adequately the areal variation of the complex characteristics that actually is the land form. The different elements do in fact exist together, and what the observer sees in any area is the complex, not the individual elements separately. However valuable they may be, Thornthwaite's separate maps of the four individual elements of his classification leave the reader somewhat unsatisfied, and one finds himself trying to superimpose the four maps in his mind's eye, so that he can picture what climatic types occur and how they vary from place to place.

2. The Combining of Elements in the Unit Area--Classification and the Recognition of Land Form Types.

If several or many elements are to combined in a synthesized characterization, the procedure becomes much more complex and difficult, involving not only problems of description, but of classification and generalization as well. For if numerous small-area characterizations are to serve as the basis for large-area description, they must be limited in scope and strictly systematic and comparable in content.

The description of a small unit area may, of course, be made as thorough as desired. With the guidance of a check list or comparable study outline one can be reasonably

sure that he has not failed to note some significant aspect of the land form. He may present his information as a relatively informal but cohesive verbal statement, or as a strictly ordered point-by-point cataloging of characteristics. If the goal is purely the description of that one area for its own sake, the characterization need be neither brief nor highly formalized. But if the description is to provide but a single stone in the broad wall of a large-area characterization, it must be both concise and systematic. This suggests that in that circumstance it should be restricted to a selected smallgroup of characteristics and that the information with regard to those characteristics should be very brief, preferably a quantitative index or a placement in one of several well-defined classes.

Such a concise characterization in terms of a few properties requires a careful selection of which properties are to be used. This selection will depend entirely upon the purpose for which the particular study is being made, and can differ greatly from study to study. Strahler and his associates have suggested a considerable list of properties that are of interest in the study (especially of the genesis) of stream-eroded topography.[24]

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24. A. N. Strahler, "Quantitative Analysis of Watershed Geomorphology", op. cit.

The student of depositional surfaces of late glacial drift or of sand-dune areas would choose a very different group of

properties for consideration, and one concerned with the relationships of agricultural practice to land form would select still another set. It is not possible to recommend any specific selection of properties without consideration of the purpose of the investigation. And even if the purpose is clearly defined, the selection of characteristics is not necessarily simple, for the relationships between land form and the phenomena to which it is being related may be imperfectly understood. Where this is so, any final, thoroughly defensible solution must await extensive systematic studies of the cause-and-effect relationships involved. If this is not feasible, then the selection can, of course, only be made as best it may according to the understanding of the moment. It is uncertainty about what properties are really important for the purpose that has been at the base of a great deal of the criticism that has been levelled at particular mapped classifications (such as Köppin's climatic classification). One must be careful, in criticizing any classification or selection of pertinent properties, that he is using it with the same purpose in mind as that for which it was originally devised.

Once the selection of properties has been made, each unit area is then described in terms of those particular characteristics. The description must be brief, preferably no more than a number or a word or simple phrase. Since large numbers of individuals are to be compared,

It is highly desirable that the number of possible descriptions, under each property, be restricted in number. That is, it is desirable to set up, for each property, a small number of classes into which the numerous individuals can be grouped. For properties having numerical values (such as dimensions or slope) these can be specified ranges of values; for non-quantitative properties (such as arrangements or materials) they can be specified types, perhaps subjectively determined.

Thus each unit area becomes characterized by a series of numbers or indices, one for each property that has been selected for inclusion. It is then possible to compare each unit with any other in terms of any desired property. But the complete set of indices or designators for each area also constitutes a highly concise description of that unit, which may then be compared and contrasted with those for other units. Each specific combination of values that occurs defines a land form type, which may be represented in the large area by one or by many individuals.

This element-by-element characterization of unit areas and its use as a means of defining and recognizing land form types that may recur elsewhere is nothing more than a systematic classification of land form. The individuals being classified are the unit areas; the differentiating characteristics are the specific properties selected.

In terms of each characteristic a series of classes has been established. Another part of the classification process that has not yet been discussed, is the establishment of the hierarchy of categories,[25] which will be

25. The terms "individual", "differentiating characteristic", "class", and "category" are here used in the sense employed in M. G. Cline, "Basic Principles of Soil Classification", Soil Science, v. 67, 1949, pp. 81-91.

treated below in the discussion of the problems of regionalizing. It will be clear that there can be devised at least as many different perfectly legitimate classifications of land form as there are legitimate purposes for land form study.

The number of types of land form that may be defined by even a simple systematic classification is very large. A classification based upon no more than five different properties, and making room for only five degrees of distinction with respect to each property would still define 3125 different land form types. To be sure, many of the types might not actually occur, and some, because of interdependence of properties, might not be possible, but even with these deletions, the number of types is likely to be extremely large.

For general descriptive and analytical purposes there need be no concern about such a large number of resultant types. Indeed, a classification much more detailed and ramified that this can be utilized handily, with the aid of proper nomenclature or a simple codification of type designation. The classifications used in the biological

sciences are examples. However, if a classification is to serve as a basis for small-scale mapping or regionalization, a multiplicity of classes becomes an embarrassment. The map will be exceedingly fragmented, for few types defined in such detail will be repeated over sizeable contiguous areas, and neither large numbers of types nor dozens of tine areas are conducive to cartographic representation. The recognition and mapping of regions then requires that by some means the number of different types that are to be dealt with must be drastically reduced.

C. The Identification and Delimitation of Land Form Regions from the Unit Area Approach

1. Basic Problems of Generalization. Generalization is an integral and inescapable part of all small-scale mapping and of all regionalization. Somehow the mass of data, with all the detailed variation that it defines, must be greatly simplified in such a way as to permit a few regions of relatively simple outline and uncomplicated characterization to be identified and mapped, without doing more violence to the truth than is absolutely necessary.

Generalization for this purpose may be of two distinct types: (1) it may involve a reduction in the amount of information offered about the individuals and the regions they compose; or (2) it may involve a simplification of boundaries once the regions have been outlined. Commonly both types are employed.

In terms of the unit area classification method being discussed here, the first of these processes of generalization would be most directly accomplished by (1) reducing the number of different properties with respect to which each unit area is characterized, or (2) reducing the number of classes in each property-category (i.e. making fewer, but more inclusive classes). Each of these methods decreases the amount or precision of the information made available for each individual and hence for the regions of which the individuals are a part. With a given purpose in mind, it is often possible to simplify the detail by combining the many classes at a given level of the classification into a small number of groups that are sufficiently homogeneous for the purpose at hand. Such an arrangement, called a technical grouping,[26] is almost necessary if extreme simplicity is required.

26 M. O. Cline, op. cit., pp. 84-85

The second process of generalization, that of simplifying outlines, is accomplished after the classification or technical grouping has been plotted in full on the map. Basically this consists of the elimination of enclaves and peninsulas that are deemed too small to show on the finished small-scale representation. One must decide, more or less arbitrarily, just what degree of cartographic complexity he is willing to allow, and must

therefrom arrive at the minimum dimensions of the smallest area he can permit to remain on the map. In the unit area system this might, for example, be decided to be an area containing no fewer than four contiguous units, or perhaps an area measuring not less than two units wide in its smallest dimension, or something of that sort. All enclaves smaller than that, or salients narrower than that would then automatically be eliminated, and would be incorporated into the surrounding area.

However, this process is sometimes less easy than at first glance it seems to be. A frequent occurrence is a single unit or small patch of a given type sandwiched between large areas of two other types. Obviously the small patch must go, but into which of the bordering masses shall it be incorporated? The logical solution is to take it into the one whose type it most closely resembles. But how is this determined, except in the most obvious cases?

Suppose an isolated unit differs from the first of its larger neighbors only by one degree in regard to property A, and from the second neighbor by one degree in regard to property B. With which neighbor shall it be incorporated? The answer would be either that it does not matter, or that it depends upon which of the two one-stage differences is considered to be the more significant, in the light of the purpose. If property A is considered more critical than property B, then the break

between the isolated unit and the first neighbor is the more important, and the "orphan" is housed with the second neighbor.

Thus one must (preferably in devising his classification) determine not only which properties he will use as a basis for differentiation, but also the order in which those properties shall appear in the scheme of differentiation. If property A is the most significant property to the purpose, it should appear at the highest level of the classification. Individuals should be grouped according to that property before being further subdivided on the basis of other properties, and so on through the list of characteristics, in descending order of importance. Once this hierarchy is established the task of dealing with borderline units is simplified.

Even then, however, a difficulty remains. Suppose, in our example, the "orphan" unit differs from the first neighbor by one degree in regard to property A, but from its second neighbor by two or three degrees in regard to the less significant property B. Which is the more significant degree of difference? If these seemingly trivial matters are decided ahead of time, they will make the final regionalization proceed much more smoothly and quickly.

In attempts to regionalize land form on the basis of a systematic classification of unit areas, experience suggests that even though the classification is very simple, perhaps no more than a three-category system with

relatively few classes, the plotted pattern of types is likely to be so fragmented that there are almost no large contiguous areas of any one type. One is forced to start consolidating more-or-less unlike neighbors immediately and extensively. Instead of having the problem of fitting a few small anomalous areas in with one or another large neighbors, the problem is that of simplifying a pattern made up of nothing but small areas, most of them too small to show separately. Therefore the techniques of generalization are of the greatest importance. Without simplification of the classification, possibly including technical grouping, and establishment of a clearly defined hierarchy of properties, the establishment of regions is almost hopeless.

D. The Formal Description of Regions

The final major problem in the characterization of land form is that of presenting to the reader a more-or-less formal description of the area analyzed, including its regional subdivisions. This is, then, a problem of communication, and one of such size and scope that it would be presumptuous to attempt to encompass it here. The brief discussion that follows is intended only to emphasize those aspects that seem most directly pertinent to the systematic, objective approach under consideration.

For the sake of simplicity in discussion, regional descriptions may be divided into two types: (1) those that are highly concise, involving very little verbal

characterization, and (2) those that are more extensive, involving many techniques of presentation, including verbal.

1. Concise Regional Descriptions. In general, the devices most fundamental to concise descriptions are statistical and graphic, often combined. These permit the presentation of data in the briefest possible form. They are usually organized on the basis of specific elements and give their information in either quantitative or systematically qualitative form. Thus they are especially well adapted for use with the objective and systematic analysis that has been treated here. For purposes of careful areal comparison, a major concern of the geographer, concise presentations of this sort are highly valuable.

The description of a region (comprising many unit areas) can be done entirely by means of statistical tabulations, either giving summary indices for the region as a whole, or tabulating the frequency of occurrence of values in the various unit areas that comprise the region. Such characterizations may be offered on an element-by-element basis, or on the basis of the occurrence of landform types (previously defined) that combine several characteristics.

Thus it is possible to characterize a region of considerable size by a series of numbers or code figures.

that summarize for that region the occurrence of values or classes of a chosen set of land form properties. Such a characterization could not be surpassed for conciseness except by combining all of the indices, by means of a classification, into a type, which may be named or given a code designator. A description of this kind permits direct and quick comparison of one area with another, on the basis of as many properties as may be desired.

If a considerable number of regions is being shown on a single map, it is desirable to show the characteristics of each region by some means other than a statistical tabulation or series of code letters or numbers entered in the appropriate place. However, this is not readily possible unless the characterization is exceedingly simple. If the regional descriptions have been simplified into type designations, then, of course, regions of different types may be shown by different colors, symbols, etc. But if the descriptions are more complex, involving several characteristics, these cannot ordinarily be shown other than by codal designator. With descriptions involving no more than two or three elements, graphical representations can sometimes be devised that are more eye-catching than a coded designator, but the possibilities are limited.

If the map is at a sufficiently large scale, it may be possible to show the distribution of minor variations

within each major region. The problems and methods of showing these are no different from those involved in showing the larger regions on a smaller scale.

2. Fuller Regional Descriptions. For more intensive study of regional land form characteristics, the statistical summary is insufficient. As previously suggested, certain properties, such as patterns, profiles, various topographic details, and the place-to-place variations in co-existence of various characteristics, do not lend themselves well to quantitative expression or other brief summary treatment. The concise, largely statistical summary, for all its utility, does not provide a fully fleshed portrait of an area.

Such a thorough characterization can be made successfully only by the use of many different techniques. Probably the most frequent cause of deficiency in regional characterizations is the failure to employ all of the useful media. Statistical data, maps, sketches and diagrams, photographs, and verbal descriptions can all contribute significantly to the effectiveness of regional description, and therefore none should be slighted.

If the unit area method has been used in making the regional analysis, one must be especially careful to bring out in his regional description those broadscale features that may have been unduly fragmented and hence probably overlooked in the unit-area study. Major divides, drainage systems, escarpments, etc. must be made clear in

the overall description. These and other internal variations within the region must all be made clear by the use of maps, illustrations and detailed sample or small-area characterizations.

Although it has often been said that objective description cannot be made palatable and interesting,[27] there

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27. Thus: "If an observer is compelled to depend on experience, that is, to use only empirical terms in his descriptions of topography, every feature he discusses must be unique in all respects...If, then, all the elements of the landscape are similarly treated the account will be almost interminable and utterly wearisome." O. D. von Engeln, Geomorphology, The Macmillan Company, New York, 1942, p. 7.

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seems no reason to believe that this is a valid general criticism. So long as one is careful to impart to his objective portrayal those qualities of clarity, illustration, system and summary that are the hallmarks of any scientific description, there is no inherent reason why it should be either dull or otherwise ineffective. Perhaps only the individual of unusual talent can make a description come vividly alive to his reader, but if his analysis has been thorough and careful, any trained student can, by full and judicious use of all the techniques at his disposal, present a regional description that will be clear and effective.

APPENDIX 1

A Suggested Method for Direct Measurement of Slope from Aerial Photographs

Because of the availability of aerial stereophotograph coverage of extensive parts of the globe for which good contour maps do not exist, it is important to develop techniques whereby specific land form information may be derived from the photographs. Through the use of photogrammetric methods, nearly all desired types of data can be obtained, but these methods are in general too slow or require too much costly equipment for most private research projects. Even without precise photogrammetric techniques, many varieties of data can be gotten from photos by direct examination and simple measurements. However, to the writer's knowledge, no satisfactory method has been devised for direct visual determination of slope. The following is a brief account of a method that was devised and tried in the course of the present investigation. While the tests made are too limited to be conclusive, they suggest that the method, though inherently imprecise, merits further study.

Basically the method involves the use of keys, in the form of small stereo-pairs cut from the coverage being studied, on which are known slopes having inclinations corresponding to the boundary values of four slope classes. The keys are then superimposed, under the stereoscope, upon the photo pair being studied and are used as comparison scales for determining the steepness of slopes on that pair.

The keys were prepared by selecting centrally located portions of adjacent photos which exhibited slopes having the values of 8 %, 15% and 30%, as checked by the contour maps or, in some instances, by field measurement. In practice, field measurement should be used if at all possible. Two types of keys were tried. Each was a small stereo-pair cut from the central portions of adjacent photos, the area of the cut-out sections being less than one square inch. The first keys used contained, on a single cut-out, examples of all three of the critical slopes. Later keys, and generally the more satisfactory, were made by cutting a separate pair for each of the critical values. These little pairs were then mounted, at the proper spacing, on a small sheet of clear acetate. This was placed over the photo pair being studied, under a bench stereoscope. By moving the key about, the slope being measured could be compared successively with each example on the key, and thus its steepness could, theoretically, be determined.

For testing purposes, two different techniques were employed.

1. The first tests that were made involved the visual estimation of the percentage of an area that was occupied by each slope class. Stereo coverage was obtained for each of several 7½-minute rectangles in Missouri. The limits of the rectangle were marked off on the appropriate photographs. Then, on successive stereo pairs, the area of overlap

unique to that pair was outlined, and this area was then examined under the stereoscope. With the aid of the comparison key, an estimate was made of the percentage of the area occupied by each slope class. After all pairs had been so examined for the entire 7½-minute rectangle, the data for all the unique areas were added together. The resulting sums were then divided by the number of areas, and thus figures were obtained for the apportionment of slopes among the four classes for the entire rectangle. These data were then compared with figures obtained by dot planimeter from the contour maps.

2. The second set of tests involved slope-by-slope comparisons, rather than the estimates of percentages over sizable areas. In each of two quadrangles, about 30 slopes were measured from the photographs and compared with measurements made from the topographic maps.

The results of the first method are shown in tabular fashion below.

Quadrangle	0-8% P	0-8% M	8-15% P	8-15% M	15-30% P	15-30% M	30+% P	30+% M
Round Spring SE	14	12	6	11	41	42	39	34
Ironton C	48	45	16	23	27	28	7	3
Ava NE	30	22	30	32	30	29	10	17
Meta NE	44	34	15	*42	36	22	5	3
Augusta C	44	*28	13	21	16	25	26	26
Green Ridge SW	99	100	1	0	0	0	0	0
Centralia NW	91	94	9	6	0	0	0	0
Seymour SE	48	62	49	*31	3	8	0	0
Brookfield SW	88	91	12	9	0	0	0	0
Bethany NW	11	*44	74	*38	15	18	0	0
Maitland-Craig S	79	82	8	9	6	9	7	0
Elmer SW	60	71	17	15	14	11	9	2
Grandin NE	67*	39	14	*44	12	17	7	0
Vienna-Redbird N	71	69	11	15	14	12	4	3
Salem SW	80	*61	19	*34	1	5	0	0
Rocky Comfort NE	66	*42	12	25	16	22	7	12
Des Arc NE	28	33	23	30	35	38	14	0

Of the 60 comparisons which did not involve double zero values, 34 were within 5%. This degree of error is of the same general order of magnitude as that for eye estimates of slope percentages from contour maps as made by a relatively unpractised person, and somewhat greater than map estimates made by a practised observer. Undoubtedly with practice the accuracy would be significantly increased, though it is doubtful that estimates should be attempted with greater precision than a 5% or preferably a 10% range.

The occasional very large errors (starred in the table) appear to represent two principal situations. Some, such as those in Meta NE, Bethany NW, Grandin NE and Salem SW, apparently arise from the fact that there are large areas of land with inclination very close to a class boundary value, so that a systematic error in estimating could produce a large discrepancy. The Augusta C, Seymour SE and Rocky Comfort NE rectangles are characterized by fragmentation and complexity in the pattern of occurrence of gentler slopes, and are thus difficult to handle.

Results of the second system of testing, in which individual slopes were classified, from observation of the photos, and then compared with values derived from the contour map, are at best inconclusive, but not especially encouraging. The data were collected only by class values, and therefore the degree of error cannot be meaningfully evaluated.

Of 189 slopes for which data were compared, 117, or 62% were placed in the same class by both determinations. While this is not a high degree of coincidence, it may be misleading, for there may have been many slopes that were close to the boundary values, so that the errors of estimate might in fact be small. Clearly, additional testing would be necessary in order to determine the true value of the method.

In summary, the stereo-pair comparison key method for measuring slopes on aerial stereo-photographs is a somewhat promising but insufficiently tested technique. Results

thus far obtained suggest that its application through estimates of slope-class percentages in successive areas of unique overlap yields better results than the sampling and measurement of individual slopes, though such a conclusion would be difficult to explain and is highly tentative.

Considering the method as a whole, its entire validity depends upon the answer to the question of the degree to which slopes occurring toward the edges of stereo-photographs are distorted. Obviously they are distorted on the individual photographs, but this is not necessarily so for the stereo image as perceived by the observer. Unless slope distortion in the stereo image is significantly large in specific parts of the overlap area, the method would seem to be sound in theory, though necessarily imprecise in application. It deserves further consideration and testing.

APPENDIX 2

Land Form Characteristics, Types and Regions in Missouri

1. Introduction

The state of Missouri was used as a testing ground for many of the principles and techniques that were developed or employed during the course of the investigation. The reasons for choosing this particular area were several. First, it offers a considerable variety of terrain, ranging from flat alluvial plains to high hills. Second, it is an area that was already somewhat familiar to the principal investigator through long residence and travel. Third, most of the state is topographically mapped on a scale of 1/62,500 or larger, and the majority of the mapping is at least moderately recent.

Since many of the concepts and techniques discussed in the body of the text were developed during the investigation, and in some instances quite late in the period of study, it has not been possible to apply all of them to the Missouri area. Thus the Missouri study is not intended as an example of what an ideal descriptive analysis should be. It is intended to bring out some of the problems that one encounters in trying to describe the complex terrain of a large area and to illustrate the application of a few of the suggested techniques for dealing with these problems.

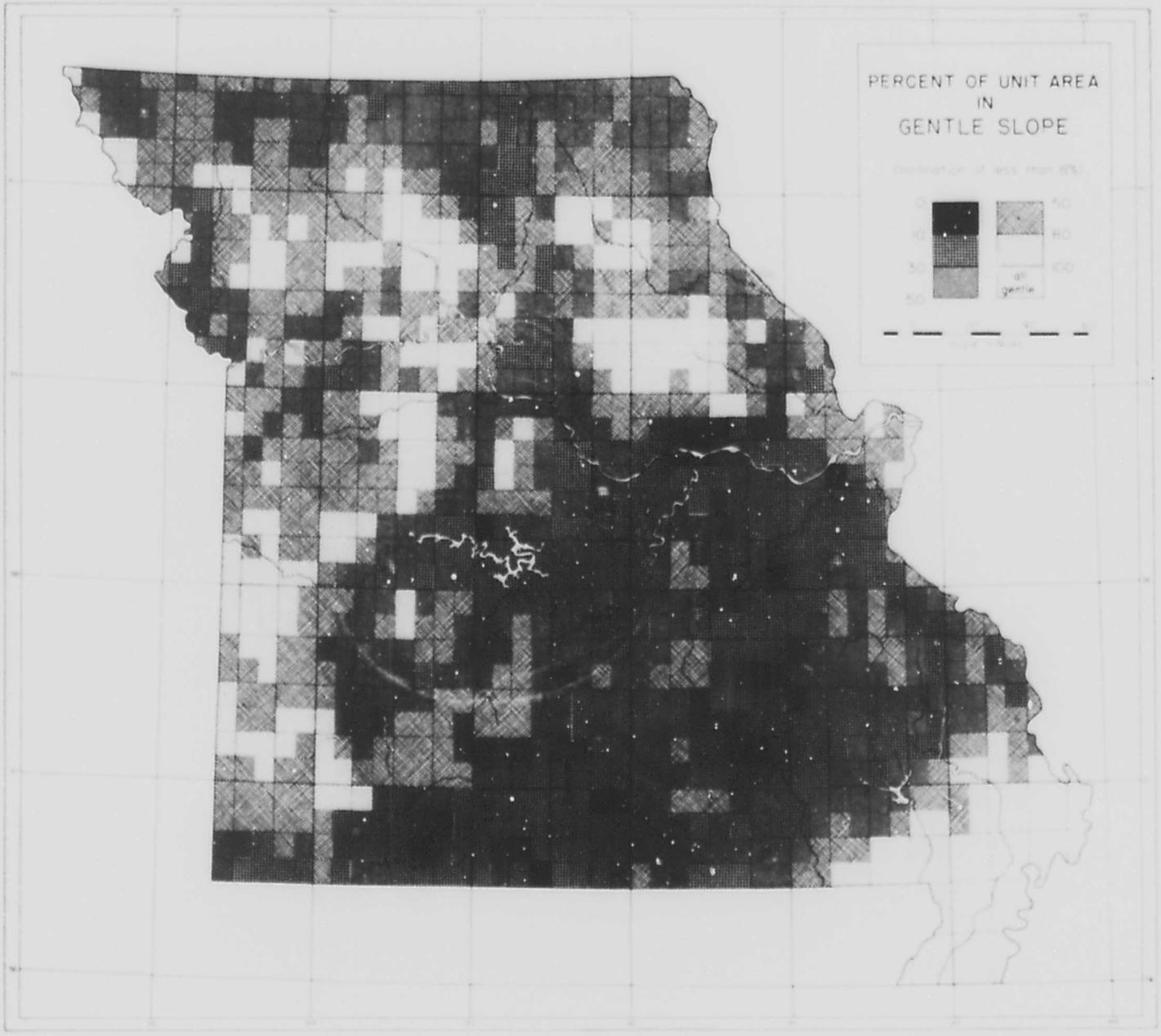
Specifically included are (1) a series of maps, made from unit-area analysis, showing the variation, over the state, of several individual elements of land form; (2) an

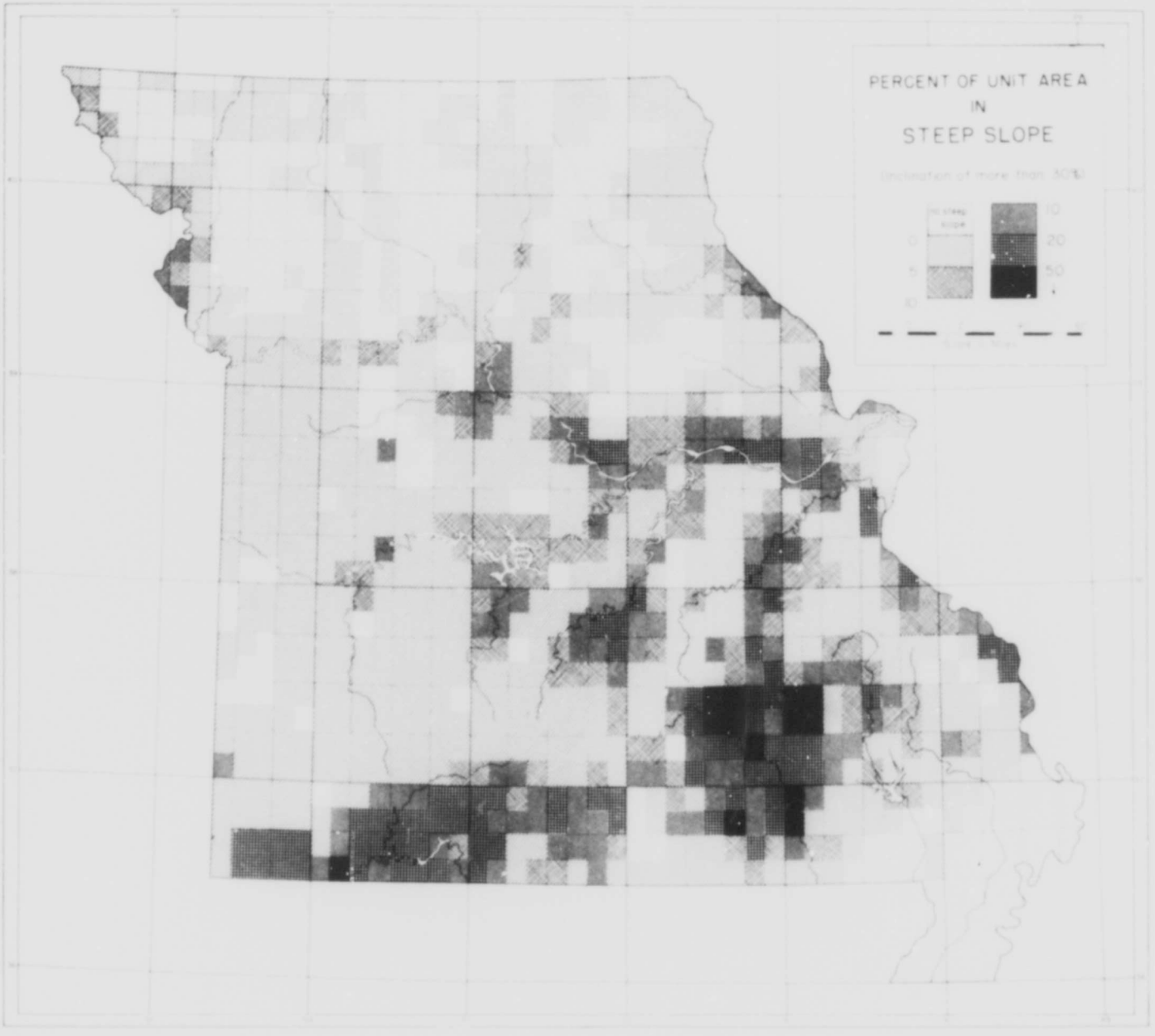
example of the derivation of a system of land form types and a land form regionalization of the state, on the basis of a selected set of characteristics; (3) examples of descriptions of individual unit areas, both in brief summary form and in reasonably full form; (4) an example of a description of a larger region, both in brief summary form and in fuller form.

2. Maps Showing the Areal Variation of Individual Elements

The accompanying maps (1 to 6) are presented as examples of the application of unit-area analysis to the variation of individual elements of land form over a large area. Except for the surface materials map, the data were derived entirely from contour maps, and the unit area is a 7½-minute rectangle. There are several patches, chiefly in the central northern and central western parts of the state, for which adequate maps do not exist. For most of these areas old, small-scale reconnaissance maps were used as the basis for rough estimates. For a few rectangles in northern Missouri for which not even these are available, estimates were derived from the character of the surrounding sheets and from planimetric maps of the drainage net. For all the obvious weakness of such estimates, it is highly probable that the data shown are not significantly in error, for the likely magnitude of error is not large in comparison to the class intervals used.

Maps 1 and 2, showing respectively the percentage of unit area in gentle and in steep slope, were derived largely


PERCENT OF UNIT AREA
IN
GENTLE SLOPE

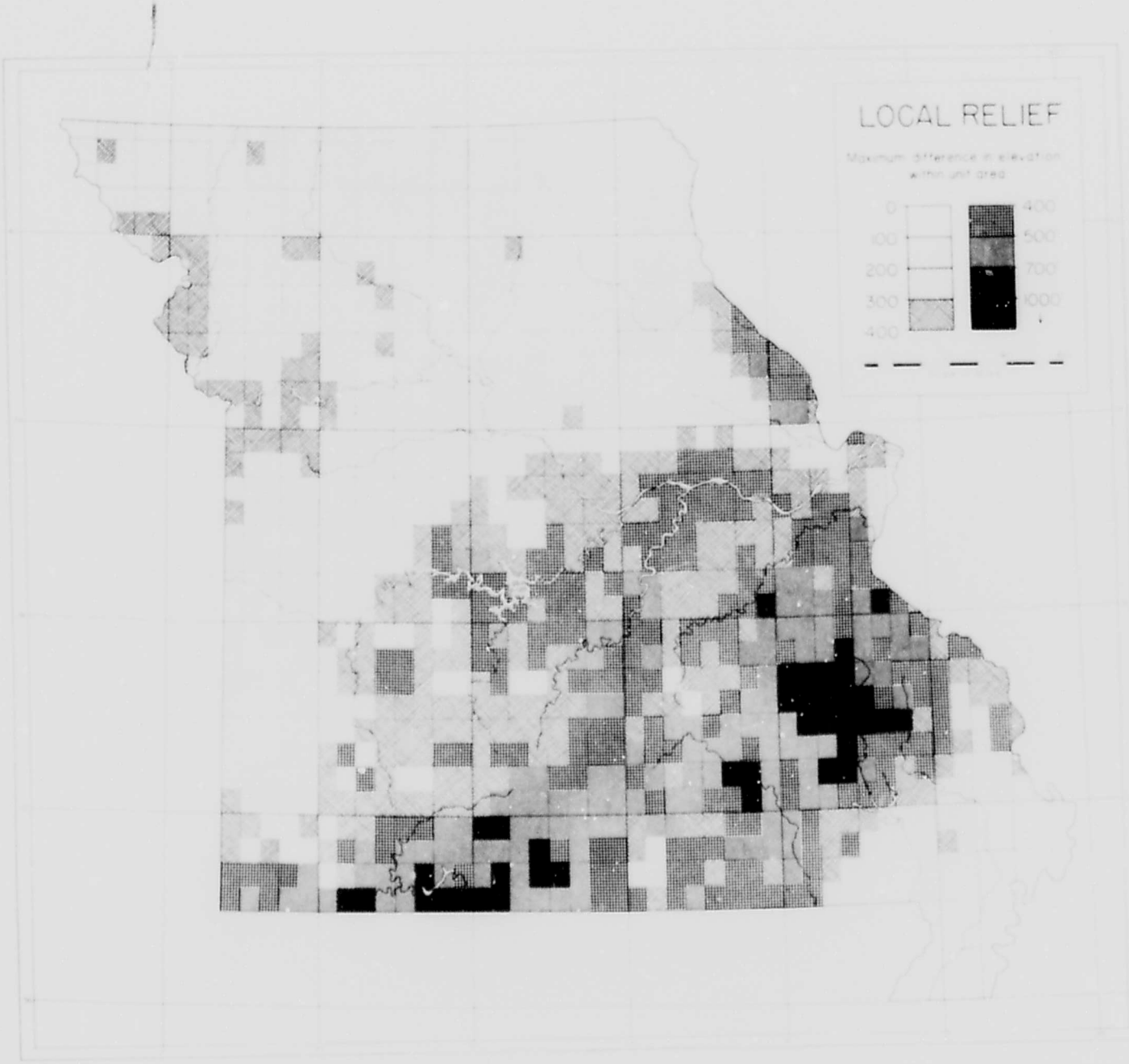

PERCENT OF UNIT AREA
IN
STEEP SLOPE
Inclination of more than 30%
10
20
50

from data obtained by eye estimate. Estimates were made independantly by two people, and all significant differences were re-checked. Percentages were estimated by ten per cent intervals, greater precision being deemed unnecessary. Because of the large number of individuals possessing a small percentage of steep slope, a finer subdivision was made in that range.

The two slope maps are felt to be highly successful in showing the most striking and, for may purposes, most significant variations in Missouri terrain. They are especially effective in bringing out two important features that are rarely shown on maps, but that are recognized by those who know the state well. One of these is the prevalence of strongly rolling land (but with little truly steep slope) along the northern margin of the state and in the north-central area. The second is the distinction between what may be called the "open" and "closed" sections of the Ozarks, the former possessing much gently-sloping land (generally on uplands) and the latter having little smooth land and much steep slope.

Map 3, that of local relief, requires no explanation. It was derived by the method made familiar by Smith. It yields few surprises, serving principally to show the degree to which local relief sets the Ozark area apart from its surroundings.

Map 4, showing generalized profile type, will be seen to be based upon the simple index indicating where, in the


LOCAL RELIEF
Maximum difference in elevation within unit area
0
100
200
300
400
500
700
1000


GENERALIZED
PROFILE TYPE
Based on vertical position of gently sloping land
All land is gently sloping
Gently sloping land divided between upper & lower half of elevation range
More than 2/3 of gently sloping land is in lower half of elevation range
More than 2/3 of gently sloping land is in upper half of elevation range

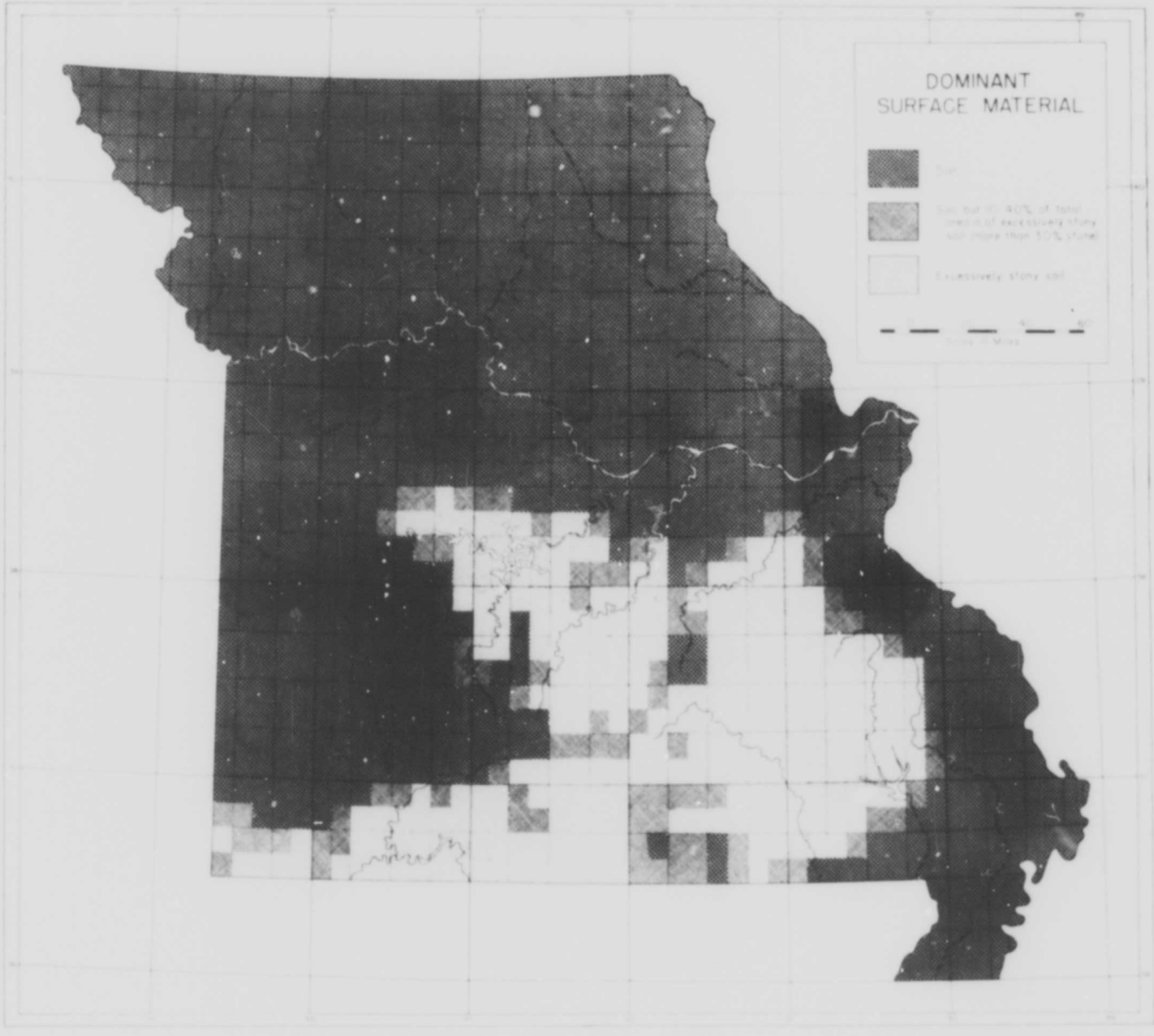
vertical range, the gently-sloping land occurs. The data were collected at the same time as those for slope. Once the extent of gentle slope had been determined, it was then further estimated, by inspection, what percentage of that gently sloping area lay above (or below) the median contour. Three classes were established, as shown in the legend. In order to give distinction to those featureless areas (chiefly in the alluvial delta plain of the southeast) that are occupied by nothing but gentle slope and have negligible relief, a fourth class was set apart.

Again the map offers few surprises, but makes some important distinctions. Most of the state will be seen to fall into either the upland class or the split-level class, thus emphasizing the concept of the area as a variously-dissected upland surface. With one significant exception the lowland profile occurs along or adjacent to the valleys of the major streams. That exception is in the St. Francois area, in southeast-central Missouri, one of the most distinctive sections of the Ozarks.

The map of surface material (Map 5) was constructed from a soil map of the state.[1] The only extensive variation

1. From M. F. Miller and H. H. Krusekopf, "The Soils of Missouri", University of Missouri Agricultural Experiment Station Bulletin 264, 1929.

in surface material in Missouri is the occurrence of excessively stony soil in much of the Ozark area, as distinct from the reasonably stone-free soils of the remainder of the state. There are no major occurrences of other materials


DOMINANT
SURFACE MATERIAL

such as sand, exposed bedrock, standing water, etc. Accordingly, with the aid of soil descriptions, the excessively stony soil classes were identified on the map, and their pattern of occurrence was transferred to the unit-area grid. Wherever stony soil classes occupied more than forty per cent of a unit area, the unit was classed as having "excessively stony soil" as a dominant material. If stony soil classes occupied less than ten per cent of the unit, it was classed as dominantly "soil", and a third class encompassed the intermediate values. The value of forty per cent was chosen as the lower limit of a "stony" unit in preference to fifty per cent, because throughout the hilly areas of southern Missouri the steeper slopes are stony even in areas where the gentler slopes are not occupied by excessively stony soil classes. Thus the amount of stony soil is always greater than the soil class map alone indicates.

The surface material map emphasizes the remarkable stoniness of the Ozark core, a characteristic familiar to all who know the area, and a matter of great importance to the utility of the land.

Map 6, mean spacing of major crests, represents an attempt to characterize the "gross texture" of the area. The method employed is that described in the text on page 38. Because of the virtual non-existence of "major crests", the alluvial delta of southeastern Missouri could not be classified. The numerous open spaces in the map represent areas for which adequate topographic maps were not available at


MEAN SPACING
OF
MAJOR CRESTS
less than 10 mile
10-15 miles
15-20 miles
greater than 20 miles
no significant crests

the time of drawing. Time did not permit subsequent filling in of those spots by estimate.

The value of this map is difficult to determine. There are not major variations of gross texture within the state, and the opportunity to test the method in coarser-textured areas of the West did not materialize. The index does serve to bring out some of the wider valleys of major streams and the broader tracts of undissected upland, but in general it is not as valuable a diagnostic index for the internal differentiation of Missouri terrain as are the others of this series.

3. Land Form Types and Regions

For the purpose of testing and illustrating methods of identifying land form types and grouping them into regions of dominant occurrence, the data collected and entered on the maps just discussed were used as the basis for a simple land form typing and regionalization of Missouri. The selection and the categorical order of the differentiating characteristics employed should, in any such undertaking, be dictated by the purpose for which the description is made. Since there was no clearly-defined purpose of description inherent in the present investigation, it was possible to choose freely. In order to provide results of relatively broad interest, it was decided to select a group of characteristics that would be especially diagnostic in portraying the visual appearance of the land surface and that would at least vaguely suggest the agricultural utility of the land, insofar as that is causally related to the surface form. Since it was also desired to keep the problem as

simple as possible, the number of differentiating characteristics was held to three (or for some purposes four). After some experimentation it was decided to use (1) the per cent of the area in gentle slope (inclination less than 8% , (2) the maximum difference in elevation, and (3) the generalized profile type. In order to reduce further the complexity of the resultant map, the number of classes for gentle slope was reduced from six to four and the number of classes for local relief from eight to five.

Data from the maps of gentle slope, local relief and profile type, simplified as indicated, were then superimposed on a single work sheet, by entering the appropriate class number for each element in the proper unit area. When the three sets of data had been entered successively, each unit area contained a three-digit figure that characterized it according to the three elements and defined its type.

On the basis of the classification employed, it is theoretically possible to obtain 62 types (note that profile type "A" can occur only with class 1 of gentle slope, and probably only with class 1 and class 2 of local relief). In Missouri it was found that only 40 types actually occurred, and that only 27 types occurred in more than 5 different units. In fact 88% of the 1247 unit areas in the state are accounted for by only 21 types.

Once this map was available, it was used as the basis for the establishment of a system of land form regions. This was done in the following manner.

First, heavy lines were drawn on the sheet, separating areas of occurrence of the four different classes of percentage of gentle slope. This pattern was then simplified by "absorbing" isolated patches of one class into larger adjacent areas, following the principles mentioned in the text on p.78. No areas were permitted to remain unless they contained at least five contiguous units.

Second, these areas, essentially homogeneous with respect to gentle slope, were subdivided according to local relief. Again the simplification process was employed, still following the "five contiguous unit" rule.

Third, the profile type was used as the basis for further subdivision of the resultant regions. Again the same method of simplification was employed. It was discovered that in areas of less than 30% gentle slope (class 4), the occurrence of profile types was much scattered or fragmented. It also was felt that in such areas the vertical location of the small amount of gentle slope is a less significant aspect of the terrain than it is in those areas where large amounts of smooth land occur. For these reasons it was decided to disregard profile distinctions in the areas of gentle slope class 4.

During the development of the regional map several areas were found in which there was so much fragmentation of types that it was extremely difficult to arrive at the best scheme of generalization. For such areas the pattern of boundaries and groupings offered is only one of several

that could be used, and readers familiar with the areas may disagree with the particular choice. This is inevitable in small-scale maps. In each of these problem areas, however, the scheme that is shown was arrived at by careful weighing of the degree of "violence" done by each of several boundary arrangements. Some of the most difficult areas to handle are (1) the river-breaks northwest and east of Kansas City; (2) the hilly country in north-central Missouri near Moberly; (3) the Mississippi River section from the vicinity of St. Louis northwestward; (4) the eastern and southeastern fringes of the Ozarks; (5) the western border of the Ozarks near the Osage River, and (6) the margin of the Ozarks in the southwestern corner of the state. It will be seen that all of these are areas of transition from one major terrain class to another. As is common in erosional topography, the types interfinger in complex pattern along the border zone. On a much smaller-scale map, these sections would usually define the zones through which major boundaries would be drawn, and would not merit an independent existence.

The resultant map of regions of occurrence of land form types is presented as map 7. Map 8 and the accompanying outline represents an attempt to arrange those same areas in an orderly system of major regions, sub-regions and sections. In the outline a name has been assigned to each division,[2] and the index designator of the dominant

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2. As a rule the names assigned are either descriptive or, for the smaller sections, are taken from a principal

town, river, or county in the area. With few exceptions, no attempt was made to adjust them to previous regional nomenclature. They are intended merely as devices of convenience and are not put forth with strong recommendations for their use.

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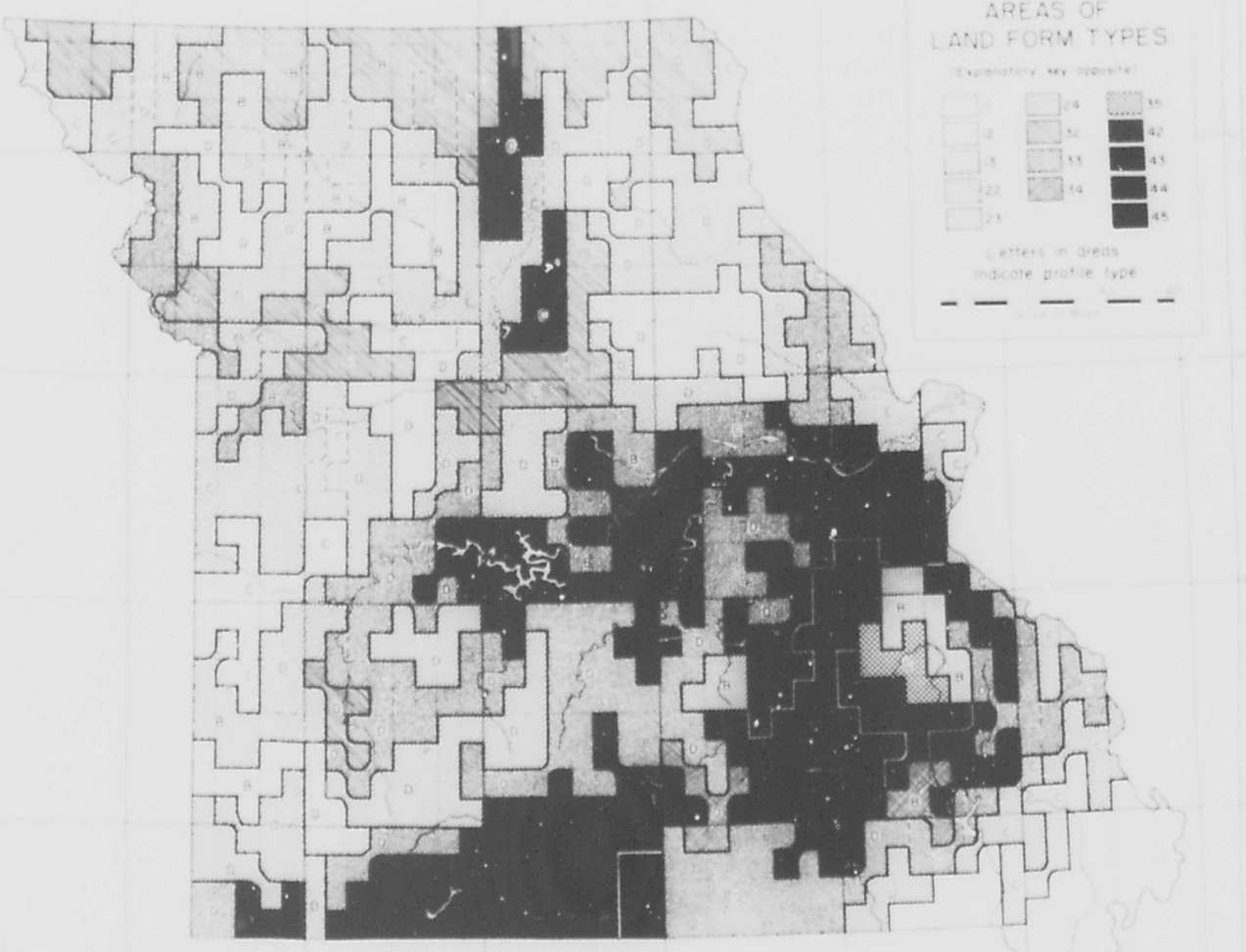
type or types in the division is listed, together with a suggested verbal designator corresponding to the indexed type.

Assessment of the value of this particular regionalization of Missouri land form can be made only after it has been used. Since the purpose for which it was designed was intentionally a general one, it would be unexpected for it to serve adequately for the study of highly specific functional or genetic relationships. To those of us who have been working on the Missouri portion of the project, it is, however, an encouraging product, for it does bring out in systematic fashion important place-to-place variations in the terrain that have not been made evident by pre-existing maps. It shows variations that actually exist, that are visible in the field, that need to be taken into account by those using the land, and that warrant explanatory study by those interested in the genetic aspects of land form study.

It should be re-emphasized that this is only one of the many regionalizations of Missouri land form that could be made. For other, more specific purposes, other characteristics could be used as the bases of differentiation, other class boundaries could be chosen, and other schemes of generalization employed. The construction of this particular

map was intended primarily to illustrate the methods, principles and problems involved, and only secondarily to yield a product that may prove useful for rather general descriptive purposes.

The map presented is of the choropleth type, in which the integrity of the rectangular unit-area boundaries has been preserved throughout. It could be converted into a smoothed-boundary map if desired. The smoothing of boundaries could be done mechanically, but more meaningfully it should be done in accordance with the actual location of the terrain changes as determined from the topographic maps. Time has not permitted the completion of such a map for inclusion in this report.


AREAS OF
LAND FORM TYPES
(Explanatory key opposite)
1
2
3
22
23
24
32
33
34
35
42
43
44
45
Letters in areas
indicate profile type

I Ozarks (Hills)

A. Ozark Border (33-Open low hills)
1. Noel Section (33D-Broad low hills)
2. Crane Section (33D-Broad low hills)
3. Greenfield Section (32D-Broad very low hills)
4. Buffalo Section (33D-Broad low hills)
5. Stockton Section (33C-Spaced low hills)
6. Warsaw Section (33D-Broad low hills)
7. Jefferson City Section (33B-Rolling low hills)
8. Hermann Section (33C-Spaced low hills)
9. Troy Section (33D-Broad low hills)

B. Springfield Platform (23D-Low tablelands)
1. Neosho Section (23D-Low Tableland)
2. Monett Section (13D-Open low tableland)
3. Springfield Section (23D-Low tableland)
4. Wheatland Section (23D-Low tableland)

C. Central Ozark Divide (33D-Broad low hills)
1. Richland-Owensville Section (33D-Broad low hills)
2. Salem Section (23B-Broken low tableland)

D. Northern Ozark Hills (43-Low hills)
1. Lake of the Ozarks Section (43-Low hills)
2. Osage-Gasconade Section (43-Low hills)
3. Meramec-Missouri Section (43-Low hills)
4. Sligo Section (43-Low hills)

E. Southern Ozark Hills (44-Hills)
1. Elk River Section (44-Hills)
2. White River Section (44-Hills)
3. Norfork Section (43-Low hills)
4. Current River Section (44-Hills)
5. Weingarten Section (44-Hills)
6. Buckhorn Section (43-Low hills)

F. St. Francois Country (45-High hills)

1. Taum Sauk Section (45-High hills)
2. Arcadia Section (35C-Spaced high hills)
3. Farmington Section (24B-Broken tableland)

G. Southeastern Ozarks (33-Open low hills)

1. Mountain View Section (34D-Broad hills)
2. West Plains Section (33D-Broad low hills)
3. Mill Spring Section (34B-Rolling hills)
4. Wappapello Section (33C-Spaced low hills)
5. Castor Section (33D-Broad low hills)
6. Marble Hill Section (33C-Spaced low hills)

H. Mississippi Margin (23-Interrupted Plains)

1. Louisiana Section (23C-Plain with low hills)
2. Kaskaskia Section (23C-Plain with low hills)
3. Dexter Section (23C-Plain with low hills)
4. Doniphan Section (23D-Low tableland)

II. Delta Plain (Lowland Plains)

A. Delta Border (12C-Smooth lowland plains)
1. Cape Girardeau Section (22C-Irregular lowland plain)
2. Stoddard Plain (12C-Smooth lowland plain)

B. Delta Flats (11A-Flat plains)

AD 202198

III. Green Hills (Very low hills)

A. Northern Border Hills (32-Open very low hills)
1. Tarkio Section (32C-Spaced very low hills)
2. Bethany Section (32B-Rolling very low hills)
3. Unionville Section (32B-Rolling very low hills)
4. Milan Section (32C-Spaced very low hills)
5. Lancaster Section (32D-Broad very low hills)
6. Wyaconda Section (32D-Broad very low hills)

B. Chariton Hills (42C-Very low hills)
1. Mussel Fork Section (42C-Very low hills)
2. East Fork Section (42C-Very low hills)

C. Central Missouri Hills (32-Open very low hills)
1. Boonville Section (32C-Spaced very low hills)
2. Columbia Section (32D-Broad very low hills)

IV. River Breaks of Western Missouri (Open low hills)

A. Missouri Lowlands (33C-Spaced low hills)
1. St. Joseph-Independence Section (33C-Spaced low hills)
2. Liberty Bend Section (23C-Plain with low hills)
3. Richmond Section (32C-Spaced very low hills)

B. Missouri Border Uplands (23D-Low tablelands)
1. Platte City Section (32D-Broad very low hills)
2. Kansas City Section (23D-Low tableland)
3. Greenwood Section (33B-Rolling low hills)

V. Northern and Western Plains (Plains)

A. Nodaway-Missouri Lowland (22C-Lowland plains)
1. Rockport-Craig Bottoms (12C-Smooth lowland plain)
2. Mound City Section (22C-Irregular lowland plain)

B. Northwestern Upland Plains (22D-Upland plains
1. Maryville Section (22D-Irregular upland plain)
2. Hopkins Section (22B-Rolling plain)
3. Plattsburg Plain (12D-Smooth upland plain)
4. Platte Section (22B-Rolling plain)
5. Dekalb Section (22B-Irregular upland plain)
6. Polo Section (22D-Irregular upland plain)
7. Jamesport Section (22D-Irregular upland plain)

C. Grand Lowland (22C-Lowland plains)
1. Gallatin Section (22B-Rolling plain)
2. Thompson-Locust Section (22C-Irregular lowland plain)
3. Chillicothe Plain (12B-Undulating plain)
4. Carroll-Chariton Section (22C-Irregular lowland plain)
5. Waverly Bottoms (12C-Smooth lowland plain)

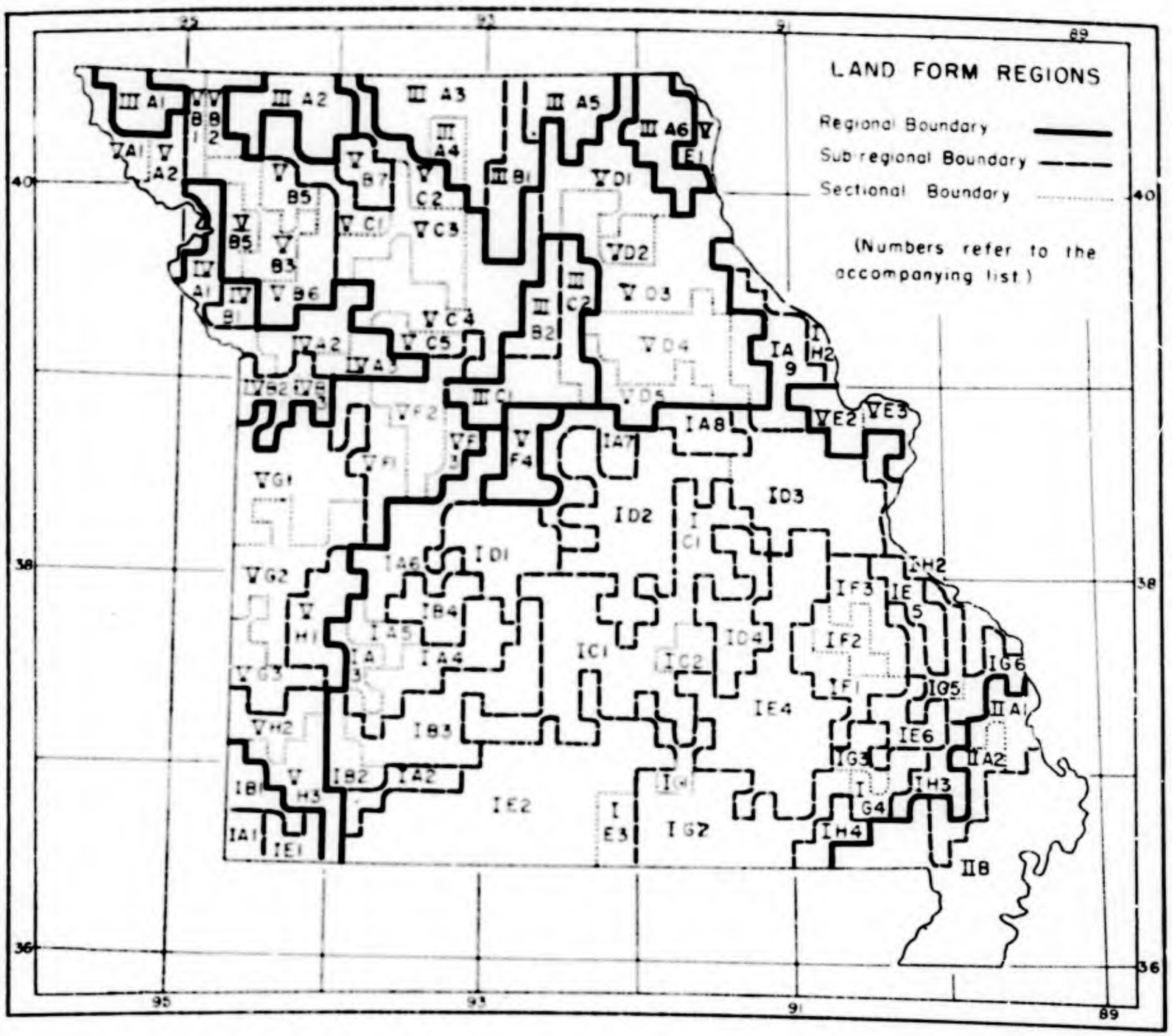
D. Northeastern Upland Plain (22D-Upland plains)
1. Edina Section (22D-Irregular upland plain)
2. Shelby Plain (12D-Smooth upland plain)
3. Monroe Section (22D-Irregular upland plain)
4. Audrain Plain (12D-Smooth upland plain)
5. Fulton Section (22D-Irregular upland plain)
6. Bowling Green Section (22D-Irrugelar upland plain)

E. Mississippi Lowlands (22C-Lowland plains)
1. Alexandria Section (22C-Irregular lowland plain)
2. St. Charles Section (22C-Irregular lowland plain)
3. St. Louis Bottoms (12C-Smooth lowland plain)

F. Central Upland Plain (22D-Upland plains)
1. Warrensburg Section (22D-Irregular upland plain)
2. Pettis Plain (12D-Smooth upland plain)
3. Sedalia Section (22D-Irregular upland plain)
4. Tipton Section (22D-Irregular upland plain)

G. Osage Lowland (22C-Lowland plains)
1. Cass Section (22C-Irregular lowland plain)
2. Butler Plain (12C-Smooth lowland plain)
3. Barton Section (22B-Rolling plain)

H. Southwestern Upland Plain (22D-Upland plains)
1. El Dorado Section (22D-Irregular upland plain)
2. Carthage Plain (12B-Undulating plain)
3. Granby Section (22D-Irregular upland plain)


LAND FORM REGIONS
Regional Boundary
Sub-regional Boundary
Sectional Boundary
(Numbers refer to the accompanying list)
40
38
36
95
93
91
89

Descriptions of Areas

The four brief descriptions that follow are intended as examples of the sorts of things that can be done in the way of objective characterization. The first three, Bethany NW, Sweet Springs NE, and Augusta C, are for 7½-minute rectangles, the unit areas of the Missouri study. The fourth is for the Andrain Plain, one of the distinctive sections set apart in the regional subdivision offered above.

The unit-area characterizations represent examples of the "building stones" of which regional descriptions can be built. The regional characterization, although it considers an area of limited extent, for which extreme generalization is not necessary, exemplifies some of the ways in which unit-area data may be combined and generalized for larger regions.

Each characterization involves two parts, a concise summary description and a fuller portrayal using verbal description, a few photographs, and simple diagrams. These were composed with the same broad general purpose in mind that governed the choice of elements used in the preceding regional discussion. For more specific purposes, other kinds of information might be offered, and other summary indices employed.

The data upon which the descriptions are based were derived from the contour maps, from aerial photographs, and from rapid field reconnaissance.

Bethany NW

The Bethany NW quadrangle (Fig. 1) is located in northwestern Missouri near the Iowa border. It lies in northwestern Harrison county, about 55 miles northeast of St. Joseph. The small town of Bethany lies ten miles to the southeast. The quadrangle forms a part of the Bethany Section of the Northern Border Hills, one of the sub-regions making up the Green Hills.

1. Brief Characterization

Slopes

0-3% - - - 1% of area
3-8% - - -43% of area = prevalent slope class
8-15%- - -38% of area
15-30% - -18% of area

Mean slope = 11%

Local relief

Max. diff. in elevation = 280 ft.
Mean height of principal slopes = 120 ft.

Basic profile type = B (gentle slope split high and low)
Mean spacing of major crests = 1 mi.
Pattern of valleys = dendritic
Surface material = soil 100%
Type designation = 32B (rolling very low hills)

2. Fuller Characterization

The Bethany NW quadrangle may be described as a rolling hill land of low relief. Few areas so well merit the designation "rolling", for slopes are everywhere gentle to moderate, without angular breaks (Fig. 2). There is very little flat land and almost no steep land. Such flat land as there is occupies narrow strips along the principal valley floors and the crests of major ridges. The small patches of steep slope occur on the sides of

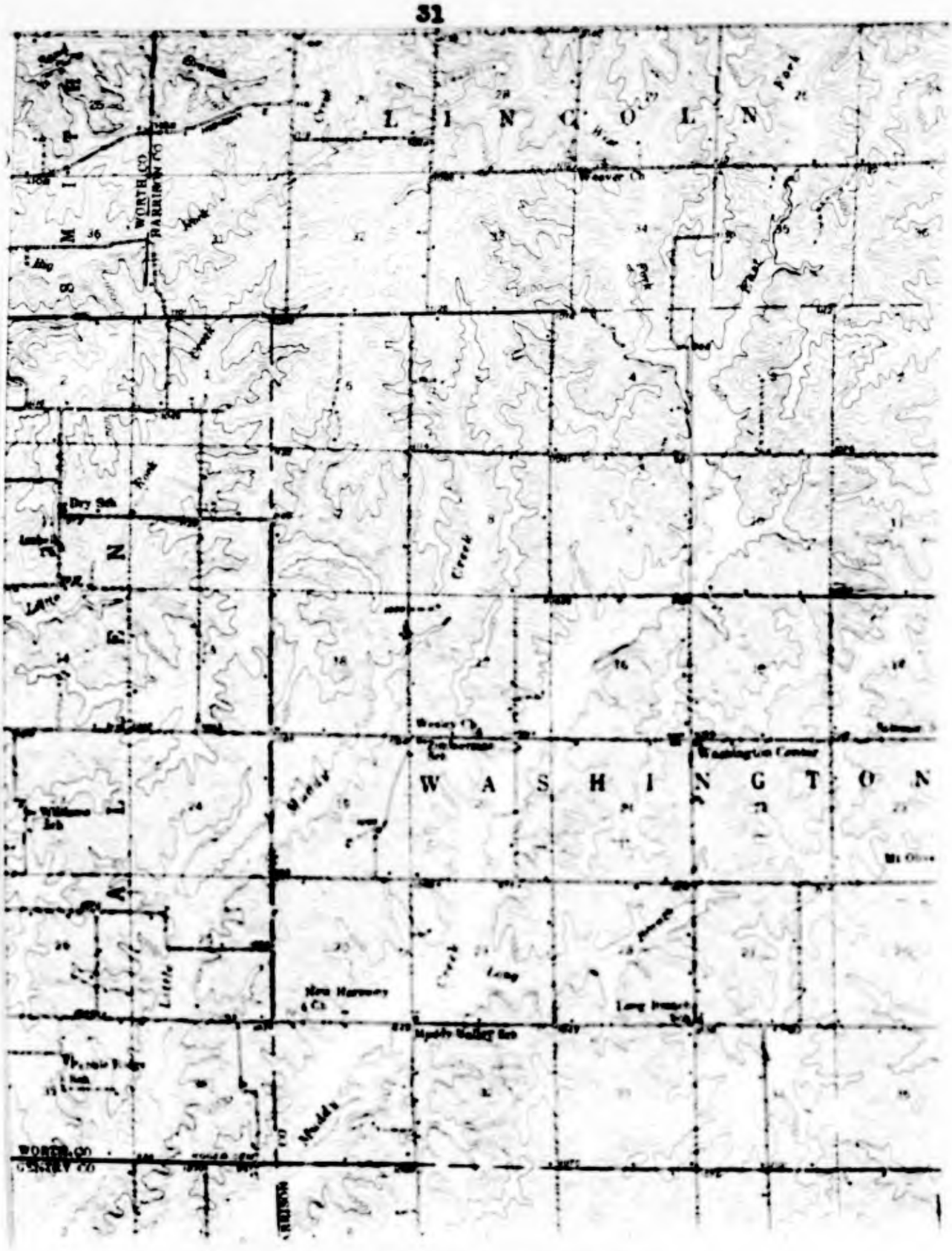


Fig. The Bethany NW Quadrangle

Contour interval 20 ft.; scale 1:62,500

Fig. 2. Characteristic landscape in Bethany NW quadrangle
View NE from point 1½ miles northwest of
Washington Center

minor ravines and as the basal sections of some slopes along the margins of the broader valley floors. Practically all of the steep slopes face northward. With the exception of these and two unusually broad, smooth ridge crests in the northwest and southeast, the various classes of slope are remarkably even in their distribution.

Slope profiles are similarly uniform throughout. The characteristic transverse valley profile shows a tendency toward convexity, the inflection point being commonly below the mid-height of the slope and closer, horizontally, to the valley axis than to the crest line. The profiles are singularly free from marked breaks and irregularities; there are no significant ledges or terraces (Fig. 3). However, most channels are shallowly incised, and gully development in the first-order channels is common.

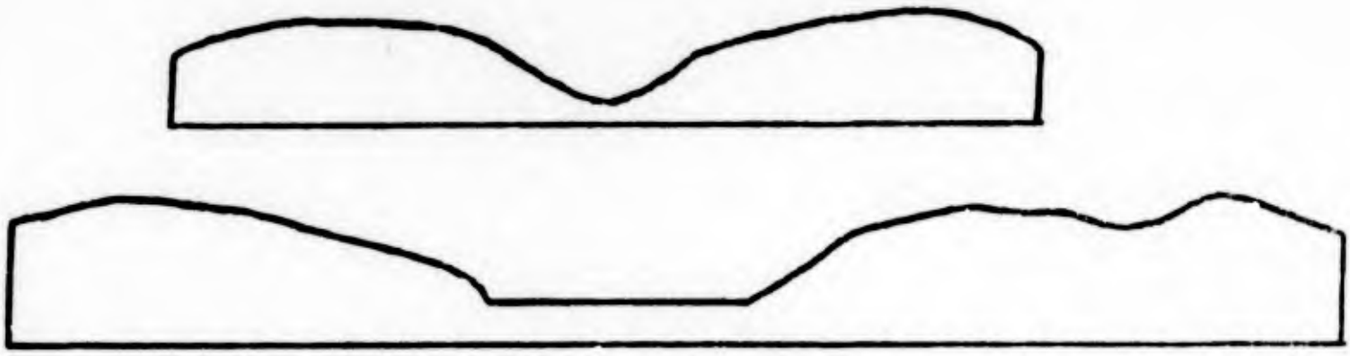


Fig. 3. Characteristic transverse profiles (vertical exaggeration 5:1).

A. Across tributary valley one-half mile east of Williams School

B. Across valley of Big Muddy Creek westward from Washington Center.

The same smoothness characterizes the longitudinal profiles of valleys, which are gently concave, and without irregularities in gradient (Fig. 4).

Fig. 4. Longitudinal profile of Little Muddy creek and tributaries (vertical exaggeration 10:1).

Crests are even and continuous, with no significant development of peaks and notches (Fig. 5). The crest of the ridge separating the two principal branches of Muddy Creek

may be followed for ten miles without encountering any longitudinal gradient exceeding 55 feet per mile. Generally the gradient is closer to 20 feet per mile.

Fig. 5. Smooth ridge crests and convex valley slopes. View SE across head of Little Rock Creek, northwest part of quadrangle.

The vertical development of the surface is modest, the maximum difference in elevation within the quadrangle being but 280 feet. Part of this relief is accounted for by a regional slope toward the south-southwest. Both crest and valley levels decline about 100 feet from the northern edge of the area to the southern. The master stream, Big Muddy Creek, has a uniform gradient of about seven feet per mile. The heights of individual slopes vary from 60 to 120 feet.

As the scarcity of upland flat would indicate, the drainage net is practically complete. The "gross" texture of the terrain is moderately fine, major crests or valleys being spaced, on the average, approximately a mile apart.

Across the widest valley the crest-to-crest distance is 1½ to 2 miles (Fig. 6). The side slopes of these major features,

Fig. 6. View across valley of Big Muddy Creek about one mile south of New Harmony Church. The slopes here are the most angular tobe found anywhere in the quadrangle.

however, are scored by ravines and between which the interval is commonly no more than 200 to 400 yards. A set of still smaller first-order channels, usually shallow, occurs over much of the area, with intervals of only 80 to 100 yards.

The widest true valley floor is from 1000 to 2000 feet wide, and most valleys do not possess significant bottomlands. The two broadest uplands, in the northwest and southeast, both measure about 3/4 mile across.

The drainage pattern is basically dendritic, only slightly drawn out in the direction of the regional slope (Fig. 4.). The pattern of crests is the simple inverse of that of drainage; there are no discordances.

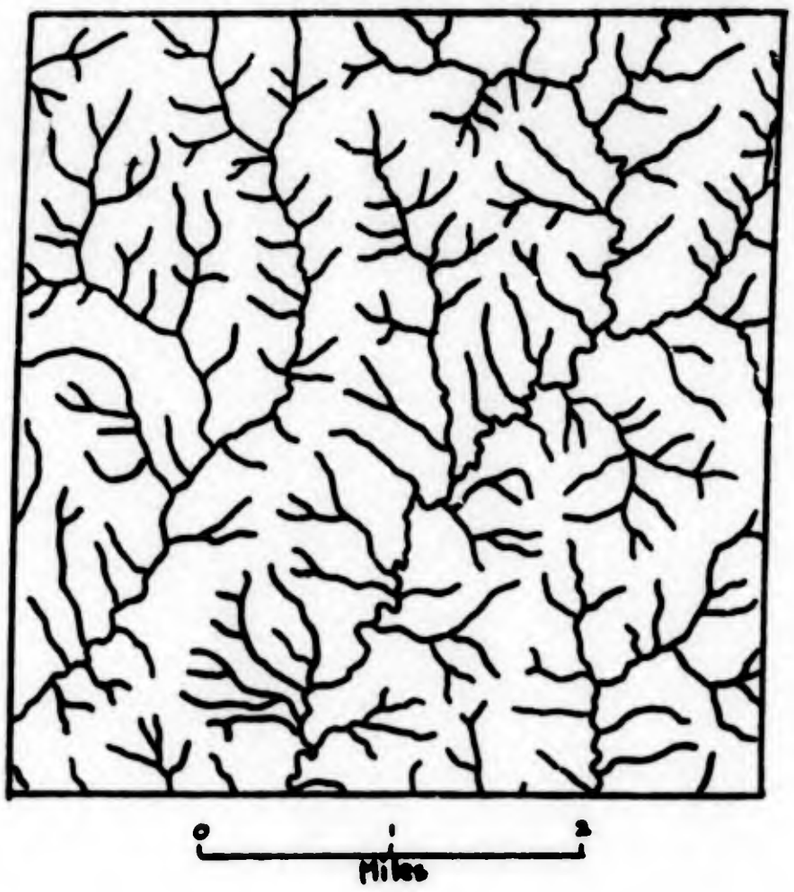


Fig. 4. Drainage pattern in central part of quadrangle. Nearly all channels shown are of second or larger order.

The hydrography is simple. There are only two permanent streams, the two roughly parallel branches of Muddy Creek. Virtually all streams of fourth or higher order and some of third order have meandering channels, in spite of the prevailing narrowness of bottomlands. The channels of shorter streams are straight or unsystematically irregular. Except for a few small artificial farm ponds there are no bodies of

standing water and no enclosed depressions.

Surface material throughout is silty soil, generally free of stones, gravel or sand. Apparently there are no outcrops of bedrock.

In summary, the Bethany NW quadrangle displays a soil covered surface of small relief, composed almost entirely of smoothly rolling slopes of moderate to gentle inclination, organized about a dendritic drainage net of moderately fine texture.

Sweet Springs NE

The Sweet Springs NE quadrangle (Fig. 1) is located in west-central Missouri about 65 miles east of Kansas City, 15 miles north-northwest of Sedalia, and 20 miles south of the Missouri River. It is a portion of the Pettis Plain, a smooth section of the Central Upland Plain.

1. Brief Characterization

Slopes

0-3% - - -43% of area (prevalent slope)
3-8% - - -38% of area
8-15% - - -17% of area
15-30% - - 2% of area

Mean slope = 5%

Local relief

Max. diff. in elevation = 230 ft.
Mean height of principal slopes = 120 ft.

Basic profile type - B (gentle slope split high and low)
Mean spacing of major crests = 2.4 mi.
Pattern of valleys = feather, dendritic tributaries
Surface material - soil 100%
Type designation = 12B (undulating plain)

2. Fuller Characterization

The Sweet Springs NE quadrangle is a plain of low relief and, in the main, very gentle slopes. Were it not for the wide shallow valley of the Blackwater River and the narrow ones of its short tributaries, the plain would have scarcely more than 100 feet of relief and would be almost devoid of slopes steeper than 5%. Even with the valleys, slopes gentler than 8% occupy more than four-fifths of the area, and slopes steeper than 15% are rare.

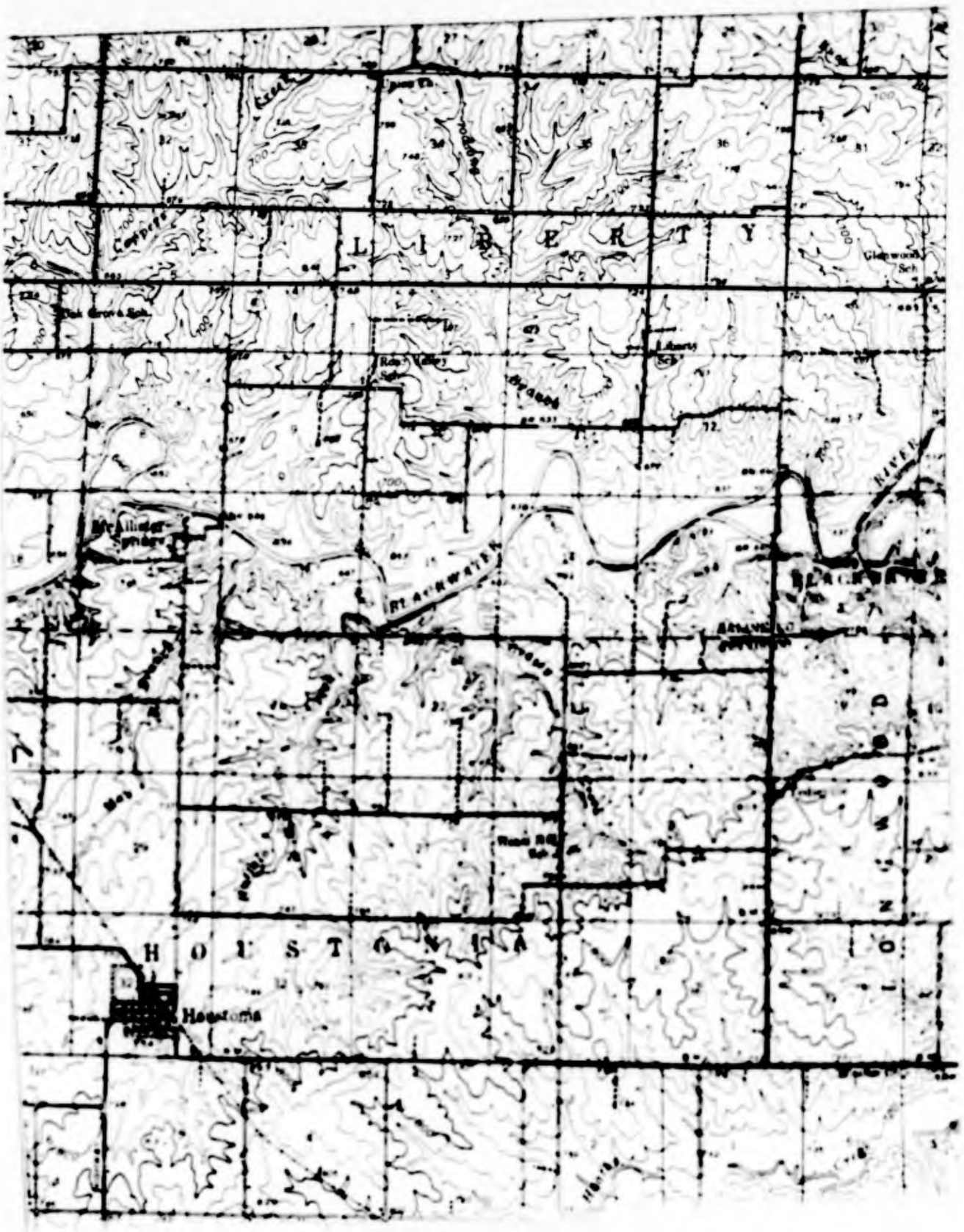


Fig. 1. The Sweet Springs NE quadrangle.

Contour interval 20 ft.; scale 1:62,500.

The surface is almost entirely soil-covered. Bedrock outcrops occur only as exposed ledges on the low bluffs and banks along the Blackwater. There is no standing water except for the many small artificial farm ponds.

The pattern of valleys is simple. One major valley, that of the Blackwater, crosses the middle of the area from west to east. Short tributaries enter the master stream at high angles from either side. Their valleys are abundantly branched in ideal dendritic pattern. In the southeast corner of the quadrangle is a portion of a second valley system, that of eastward-flowing Heaths Creek. Its tributary valleys, like those of the Blackwater, enter at high angles, but they are shorter, straighter and less branching than those of the larger stream. In total the valley and drainage pattern may be described as feather-like, that of the Heaths Creek basin being ideally so; that of the Blackwater River having dendritic tributaries (Fig. 2).

Only one primary crest crosses the area, that forming the divide between the Blackwater and Heaths Creek. Lateral spurs from this crest are inconspicuous because of the shallow incision of the small tributaries. Only on the north slope near the river do the tributary valleys become deep enough to give prominence to the spurs, which are rather abruptly truncated by low bluffs at the edge of the bottomland. North of the Blackwater the dendritic tributary systems are somewhat more deeply cut, and spurs reaching toward the River are better defined and more branching.

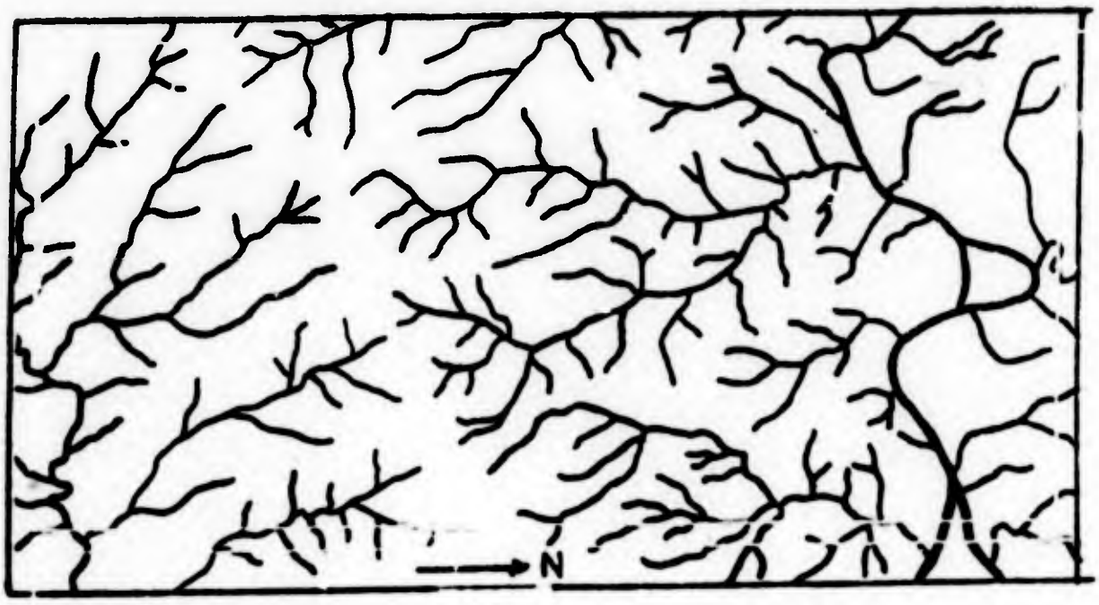


Fig. 2. Drainage pattern of area between Blackwater River (right) and Heaths Creek (left). Most channels shown are second order and above. Scale 1:62,500.

These northern spurs are less sharply cut off at the edge of the valley.

The channel of the Blackwater display a series of wide and angular bends and near-meanders (Fig.2). These bends, which have an amplitude of nearly a mile, are much wider than the bottomland, so that the valley floor itself is somewhat sinuous. The three largest bends have been artificially cut across to straighten the channel.

Most slope profiles fall into one or another of two classes. Some, particularly in the shallow drainage basin

of Heaths Creek and in the upper reaches of the tributaries of the Blackwater, are very gently sloped and essentially straight (Fig. 3A). A larger number, including most of those along the Blackwater and the lower sections of its tributaries, are convex (Fig. 3B). Those along the south side of the Blackwater are especially oversteepened at the base. Above these oversteepened sections long gentle slopes reach up southward to the principal divide (Fig. 3C). All crests

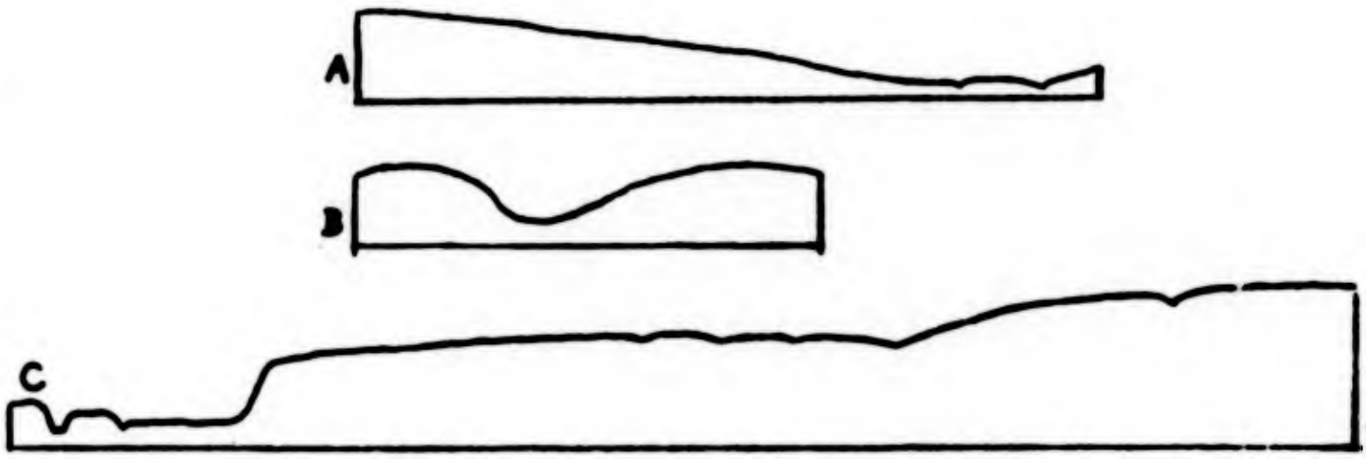


Fig. 3. Representative transverse profiles (vertical exaggeration 10:1).

A. Across valley of Heaths Creek 3/4 mile west of Mission Church.

B. Across valley of Long Branch west of Liberty School.

C. South side of Blackwater valley, southward from mouth of Buffalo Creek

are broad, and nearly all upper slopes are very gentle. Only along the northern brow of the major divide do slopes not

conspicuously gentle occur at higher elevations. Three-fourths of the sampled slopes steeper than 8% occur in the lower half of the elevation range. Conversely, 2/3 of the slopes gentler than 3% occur in the upper half of the range.

Longitudinal profiles of major crests show little departure from horizontality. The long, gentle lateral spurs sweeping down toward the Blackwater Valley are flattened toward their lower ends, and then drop more steeply into the valley bottom.

Stream and valley profiles are all gentle, unbroken, and faintly concave. The Blackwater drops less than twenty feet in its course of about ten and one-half miles across the quadrangle. Heath's Creek has a gradient of approximately ten feet per mile.

The total width of the Blackwater valley, between major divides to south and north, is from six to nine miles (Fig. 4). The north slope of the Heaths Creek basin is two to three miles long. Secondary crests in the Blackwater basin are

Fig. 4. View north-northwestward across valley of Blackwater River from crest of divide one mile east of Tedieville.

spaced at intervals of one to two miles. Thus the area as a whole is coarse textured for a region of such small relief. "Complete" texture, however, is fine, the shallow first-order channels being spaced at intervals rarely exceeding 400 yards (Fig. 5). The width of the bottomland of the Blackwater varies from less than 300 yards to about one-half mile.

Fig. 5. Road crossing successive first order channels in section north of Blackwater River. View southward from a point one mile east of Union Church.

The divide between the Blackwater and Heaths Creek rises about 200 feet above the Blackwater and only about 80 feet above Heaths Creek. 100 feet is the commonest depth for the lower valleys of tributaries to the Blackwater. Upper reaches of these tributaries and the small incisions of the first-order channels are gentle-sided, V-shaped, and are rarely cut more

than forty feet into the smooth, long slopes (Fig. 6). The channel of the Blackwater itself occupies, at low water, a steep-banked cut more than twenty feet deep.

Fig. 6. Smooth upland on divide between Blackwater River and Heaths Creek. Note slight depth of dissection. View southward from point one mile northwest of Houstonia.

In summary, the Sweet Springs NE quadrangle is a smooth soil-covered, long-sloped, gently swelling plain, shallowly incised by the Blackwater River and its short tributaries. Slopes of even moderate steepness are few, and upper slopes are especially gentle.

Augusta C

The Augusta C quadrangle (Fig. 1) lies in the river breaks along the lower Missouri in St. Charles County, about twenty miles west of St. Louis. It is a part of the Meremec-Missouri section of the Northern Ozark Hills.

1. Brief Characterization

Slopes

0-3% - - -10% of area
3-8% - - -18% of area
8-15% - -21% of area
15-30% - -25% of area
30+ % - - -26% of area = prevalent slope class.

Mean slope = 20%

Local relief

Max. diff. in elevation = 460 ft.
Mean height of principal slopes = 220 ft.

Basic profile type = C (more than 2/3 of gentle slope low)
Mean spacing of major crests = 1.2 mi.
Pattern of valleys = dendritic
Surface material = soil 97% (Small amts. water, sand, bedrock)
Type designation = 43C (hills)

2. Fuller Characterization

The central 7½ minute rectangle of the Augusta quadrangle is a hilly area of moderate relief, lying in the river breaks on the north side of the Missouri River. A portion of the floodplain of the Missouri extends along its southern edge.

The maximum difference in elevation is 460 feet, but few individual slopes approach that height. Most slope heights fall within the range of 180 to 300 feet, 220 feet representing the mean. Crest elevations are highest

Fig. 1. Augusta C quadrangle. Scale 1:62,500, contour interval 20 feet.

(840-900 feet) near the western margin, andabout 100 feet lower at the eastern edge. Valley floor elevations decline in the same direction, being 600 to 700 at the western margin, 500 feet at the eastern edge. In the southwestern corner, adjacent to the Missouri floodplain, is a distinctly lower "story" of rolling hills, with crests fully 200 feet below those of the higher divides and with slope heights of about 100 feet (Figs. 2 and 3).

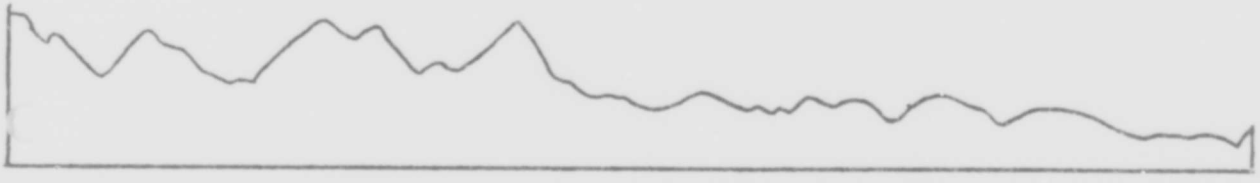


Fig. 2. North-northeast to south-southwest profile, 1 3/4 miles west of Augusta, showing the "two-story" development of hills. Vertical exaggeration 5:1.

Fig. 3. Low, rolling hills (foreground) and high steep hills northwest of Augusta. View eastward from road one mile north-northwest of St. Johns School.

The slopes exhibit a great range of steepness. Although slopes steeper than 30% are the modal class, gentle slopes (less than 8%) occupy more than a quarter of the area. Of this gentle slope, the largest contiguous area is the strip of the Missouri floodplain that is included along the southern edge. Much of the remainder is found along the bottoms of the major valleys (Fig. 4). Nearly three-fourths of the gentle slopes are in the lower half of the elevation range. However, several ridges, especially in the north and west, are flat-topped, and in the extreme northwestern corner is a broad projection of the extensive upland that stretches far to the northward and westward across eastern Missouri. Steep slopes occur throughout the hilly land, but they are especially marked in the northeastern corner, and are found sparingly in the low hills of the south-western section.

Fig. 4. View northeastward across broad valley of Schluersburg Branch, from road 1/4 mile southeast of Happy Glen School.

Through most of the area slope profiles are straight to distinctly concave, concavity being especially pronounced along those valleys that are open, but without floodplains (Fig. 5).

Fig. 5. Profile across tributaries of Femme Osage Creek, northwest of Schluersburg, showing slightly concave slopes. Vertical exaggeration 5:1.

Nearly two-thirds of the slopes steeper than 30% are on the upper portions of valley sides. Along the western edge of the area almost all steep slopes are found above the 700 foot contour, thus only on the uppermost hundred feet of the valley sides. Toward the east however the steep segments reach steadily farther down the slopes, so that at the eastern margin they extend down almost to 500 feet, and thus occupy most of the valley side. This is especially notable in the northeast, where the valley sides are very steep, straight and short (Fig. 6). Against the Missouri floodplain the hilly country ends abruptly in a smooth line of bluffs that truncate ridges and spurs.

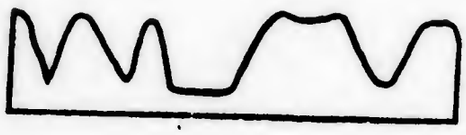


Fig. 6. Profile across Callaway Fork and tributaries about one mile from northeast corner of quadrangle. Vertical exaggeration 5:1.

Longitudinal profiles of crests are essentially horizontal and with only occasional development of peaks and notches. Longitudinal profiles of valleys have two minor peculiarities, a tendency toward abrupt steepening at the head, and a development of slight steps in the gradient just below this steep head segment (Fig. 7)

Fig. 7. Longitudinal profile of large southern tributary that enters Femme Osage Creek one-half mile southeast of Vine Hill School. Shows steep heads and minor steps (A). Vertical exaggeration 10:1.

There is little uniformity in the length of slopes or the spacing of major crests. Generally the spacing of crests

ranges from ½ mile to 1½ mile, the mean being about 1 1/4 mile. The narrowest spacings are found in the north, and especially the northeast, where the branched headwaters of tributary systems are deeply incised between steep slopes. Throughout the area secondary ravines are spaced at intervals of 200 to 400 yards (Fig. 8), and smaller channels scarcely 100 yards apart score the hillsides in the low southwestern section.

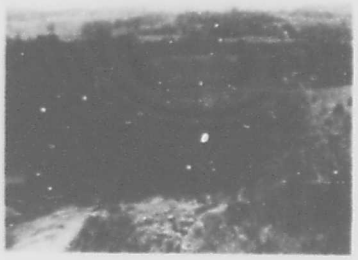


Fig. 8. Secondary ravines cutting rolling country adjacent to Missouri floodplain (left) east of Augusta. View westward from Tavern Rock Quarry.

The Missouri bottomland is over two miles in width in this section, though nowhere does its entire width lie within the bounds of the quadrangle. The principal tributary in the area, Femme Osage Creek, has a valley floor ¼ mile or more in width, and a crest-to-crest valley width of nearly a mile.

The pattern of crests and valleys is almost ideally dendritic, the principal direction of drainage being toward the east. Bifurcation angles are usually large. Stream channels are all irregular; there is no development of true meanders.

Soil, generally thin and stony on the slopes, covers nearly all of the area. Some bedrock outcrops occur on the steeper slopes and especially on the bluffs along the Missouri floodplain. Extensive strips of sand occur on the floodplain adjacent to the main channel in the extreme southeast. There are no natural occurrences of standing water except for some narrow backwater sloughs along the edges of the Missouri channel. The Missouri itself cuts across the southeast corner with a normal channel width of 1000 to 2000 feet. Besides the Missouri only the Femme Osage Creek and its two principal branches are permanently flowing.

In summary, the Augusta C rectangle is an area of open hills of moderate relief, considerable steepness, especially on the upper slopes, and dendritic pattern.

Field Evaluations

The three preceding areas were among those examined in the field by rapid reconnaissance methods. In the interest of estimating the value of the brief reconnaissance method, the following summary material taken entirely from field estimates is presented for comparison with the summary data included in the preceding accounts. Unfortunately a systematic field summary was not drawn up immediately following the reconnaissance of the Bethany NW quadrangle, so that comparable data cannot be offered for that area.

Sweet Springs NE

Slopes

0-8% - - - 80-90% of area
8-15%, 15-30% - - Abt. 5% of area, each
30%+ - - - Insignificant amount

Local relief

Max. diff. in elevation = Abt. 200 ft.
Slope heights = 80 to 160 ft.

Basic profile type = "probably D, but close to B."
Mean spacing of major crests = 1-2 mi., nearly 2.
Pattern of valleys = Dendritic.
Surface material = Nearly all soil; some rock ledges.
Type designation = 12D

Augusta C

Slopes

0-8% - - - 20-25% of area
8-15% - - Not specified, but by remainder, abt. 20%
15-30% - - 25-35% of area. Prevalent class.
30+% - - 20-30% of area

Local relief

Max. diff. in elevation = Abt. 350 ft.
Slope heights = 250 ft. generally ; 100 ft. in SW.
Basic profile type = C
Mean spacing of major crests = 1 to 2 miles
Pattern of valleys = Dendritic
Surface material = Largely soil, often stony. Some rock ledges
Type designator = 43C

The Audrain Plain

Definition and Delimitation

One of the most sharply-defined landform regions of Missouri is the Audrain Plain, a remarkably smooth section of the Northeastern Upland Plain, lying north of the Missouri River in the east central part of the state. Measuring nearly 75 miles from near Moberly in the northwest to near Warrenton in the southeast, and nearly 50 miles from New London in the north to New Florence in the south, it lies astride the major drainage divide separating the lower Missouri and the Mississippi (Fig. 1). The plain is simply an unusually broad section of the once pervasive upland of the Missouri area, as yet almost unaffected by the stream dissection that has carved most of the upland into small remnants.

The Audrain Plain is clearly delineated by a unit area analysis made on the basis of prevalence of gentle slope and amount of local relief.[1] Except for its outer fringes, the whole region is distinguished from its surroundings by virtue of having more than 85% of its area in gentle slopes (less than 8% inclination). Except for parts of the eastern and southern fringes it is also characterized throughout by local relief of less than 300 feet, though in this respect the plain is not different from the adjacent areas to north and west. It is thus the smoothness that is the distinctive characteristic.

1. The region stands out clearly as an area of smooth plains (Class 12) on the map of occurrence of land form types in Missouri (map 7, p.24). It lies about 70 miles west-northwest of St. Louis.

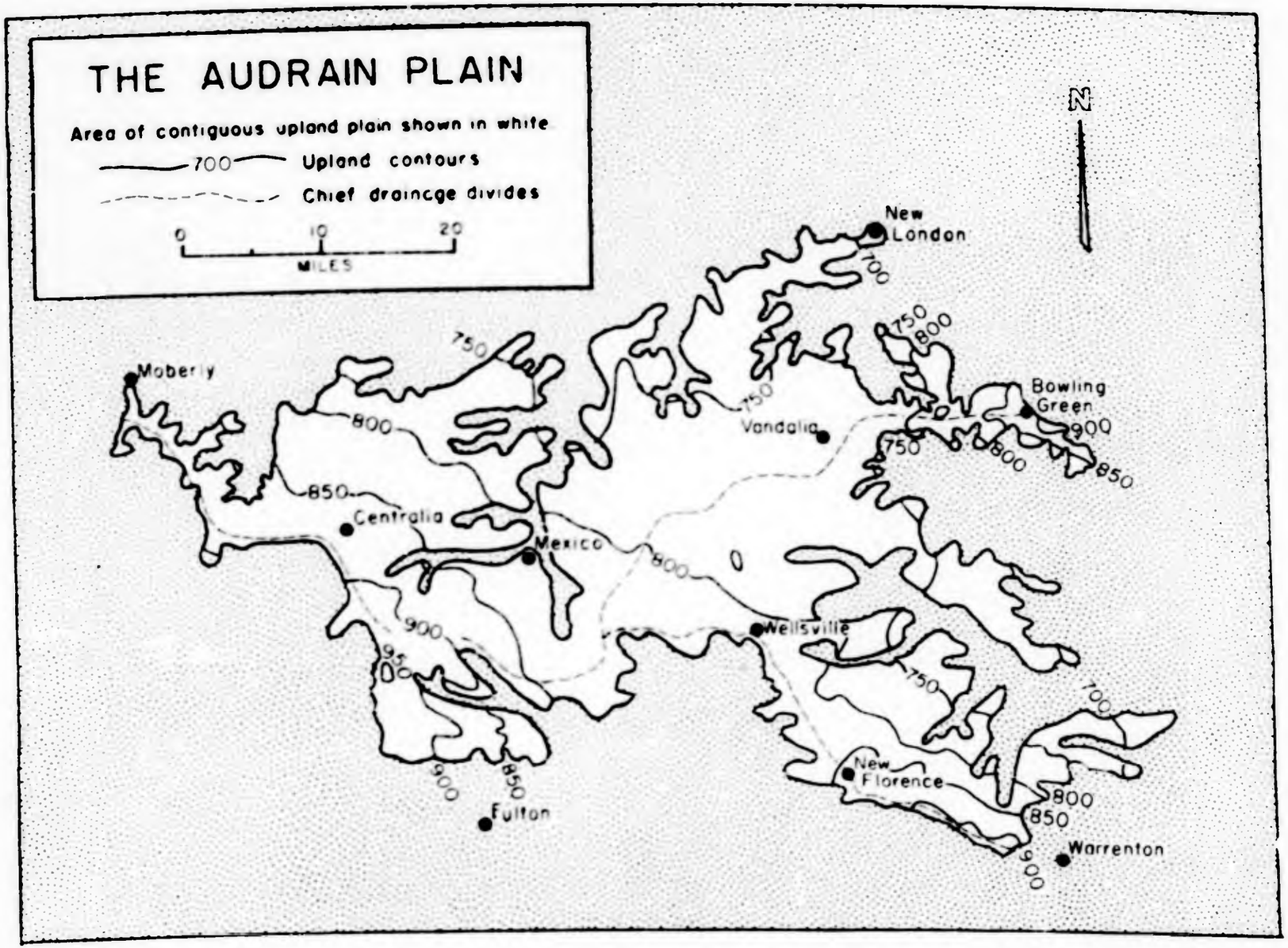

THE AUDRAIN PLAIN
Area of contiguous upland plain shown in white
700
Upland contours
Chief draincge divides
0
10
20
MILES
N
New London
Moberly
Bowling Green
Vandalia
Centralia
Mexico
Wellsville
New Florence
Fulton
Warrenton
700
750
800
850
900
950

Figure 2 compares the contiguous area of smooth upland and the occurrence of units having more than 80% of their area in gentle slope. On the basis of the unit area method, only this largely smooth core area constitutes the distinctive Audrain Plain; the surrounding area containing only fingers and outliers of the smooth upland belong either to the several areas of irregular rolling plains that occupy much of northeastern Missouri, or to the more hilly river breaks along the Mississippi and Missouri Valleys. Thus defined, the Audrain Plain contains 23 unit areas of 7½-minute dimensions.

Brief Summary Characterization (Diagnostic summaries of unit areas comprising the region).

Slope

Prevalent frequency distribution

0-3% - - - 75% of area
3-8% - - - 20% of area
8-15% - - 5% of area

Modal class = 0-3% in all unit areas (Occupies 55% to 95% of all units).

Occurrence of classes in the units

0-3% - - - Min. 55%; Max. 95%; Modal 75%
3-8% - - -Min. 5%; Max. 45%; Modal 20%
8-15% - - Min. 0%; Max. 15%; Modal 5%
15-30% - - Min. 0%; Max. 10%; (only 5 occurrences)
30+% - - - Min. 0%; Max. 2%; (only 1 occurrence)

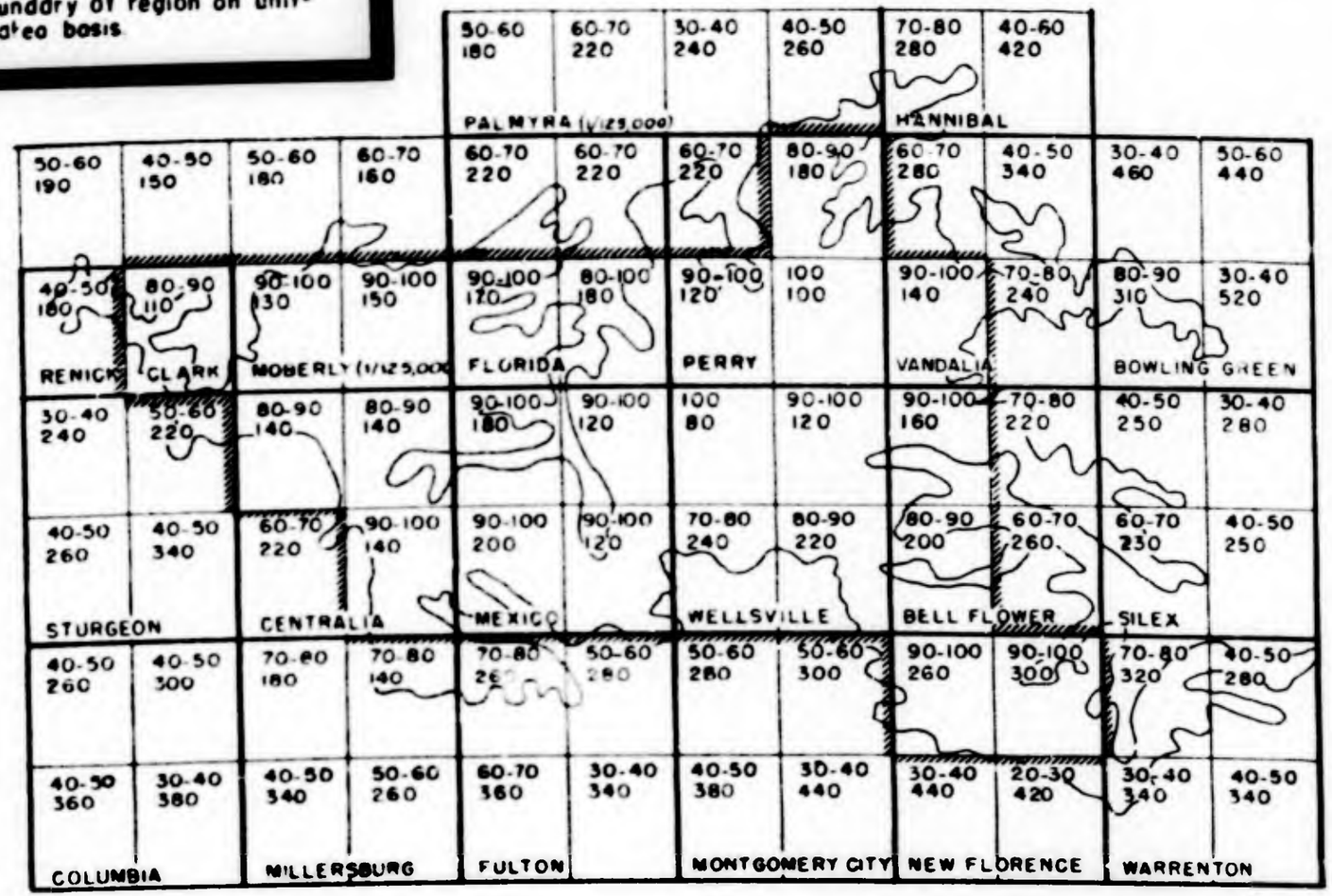
Local relief

Min. 80 ft.; Max. 300 ft.; Mean 160 ft.; Median 140 ft.

Transverse profile type = D(gentle slope high) in 23 units, A (all gentle) in 3 units.
Pattern of drainage = Dendritic throughout
Mean spacing of principal crests
Min. 0.9; Max. 2.5; Mean 1.6; Median 1.5 miles.
Surface materials = Soil 100%
Type designation = 12D (smooth upland plain).

THE AUDRAIN PLAIN

Upper figure in rectangle = % Gentle Slope
Lower figure in rectangle = Local Relief
Boundary of contiguous upland plain
Boundary of region on unit-area basis



Fuller Characterization

The Audrain Plain contains 23 unit areas, all of which have more than 85% of their area in gentle slopes, and none of which has local relief in excess of 300 feet. Three units are occupied entirely by gentle slopes, and 16 others are more than 90% gentle (Fig. 2). In only three units, all in the extreme southeast, does the local relief exceed 200 ft., and in two units (also entirely in gentle slope) the local relief does not exceed 100 feet. It is also significant that in all units more than two-thirds of the gently-sloping land lies in the upper half of the elevation-range, giving the characteristic upland plain profile.

Other features of remarkable uniformity are the valley pattern, which is ideally dentritic throughout, the surface material, which is everywhere soil, and the complete absence of enclosed depressions and of standing water (except for small artificial ponds). Only six of the 23 units show any steep slopes (inclination in excess of 30%), and in only one of these does it account for as much as one per cent of the area. It is generally confined to a few short segments of low bluff or bank along the channels of major streams.

The region displays moderately coarse "gross" texture, the spacing of major crests averaging 1.6 miles. "Complete" texture, on the other hand, is highly variable, being no more than 100 to 200 yards in areas of valley development, but reaching a half mile or more on undissected upland tracts (Fig. 3). The small first-order channels, however, are rarely incised more than ten feet below the surface (Fig. 4)

Fig. 3. Undissected upland section 2½ miles west of Centralia. View eastward along Wabash railroad.

Fig. 4. Shallow first-order valleys at head of stream system. View 1½ miles northeast of Hallsville, Centralia quadrangle.

Transverse slope profiles are almost invariably gently convex, with the inflection point near the base of the slope and with a much elongated upper segment (Fig. 5). There are

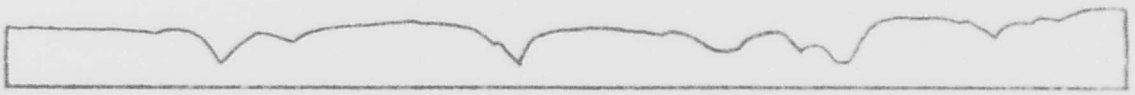


Fig. 5. North-South profile across shallow valleys in northeastern part of Centralia quadrangle. Vertical exaggeration 20:1.

no significant terraces, benches, or other irregularities in profile. Short steep bluffs, often showing bedrock ledges, occur on the lower slopes along the outsides of major bends of several principal streams. Elsewhere the basal slopes are soil covered and rarely exceed 15-25%. In the shallower valleys they are more commonly in the 8-15% range (Fig. 6).

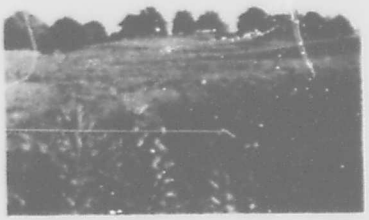


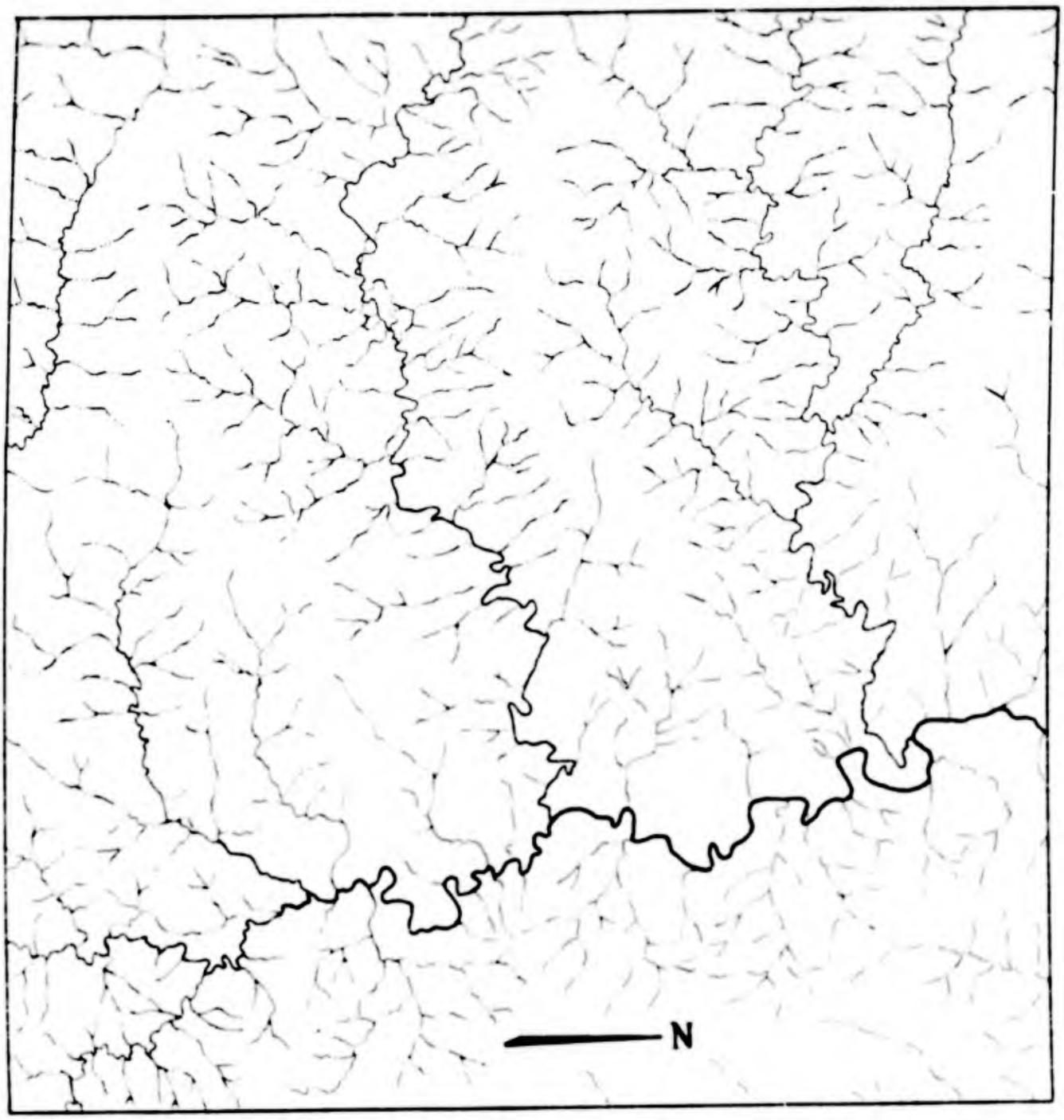
Fig. 6. Typical side of shallow valley. Maximum slope about 15%. Valley of Silver Fork, three miles southwest of Centralia.

Longitudinal profiles of valleys are similarly smooth and without significant development of steps or falls. It is common, however, for small tributary branches to display a steepening of gradient between their very gentle headwater segments on the upland surface and their still gentler segments in the major valleys (Fig. 7). This is especially pronounced along the southern and eastern margins, where the major streams are most deeply incised.

Fig. 7. Longitudinal profile of a section of Bear Creek and several of its right-bank tributaries, northeast part of New Florence quadrangle. Vertical exaggeration 20:1.

The dendritic pattern of drainage is almost ideal in its development (Fig. 8). Bifurcation angles are characteristically large; there is no significant drawing out of the pattern in any direction. Similarly, there appear to be no notable discordances or departures from the dendritic pattern within the area, though they do occur in the river-breaks section immediately adjacent to the south.

At a more detailed scale, channel patterns are more varied. Nearly all streams of fourth order and above, and



DRAINAGE PATTERN
NORTHWEST PART OF MEXICO SHEET

0 1 2 3 4
Miles

many of third order, meander extensively. As a rule these meanders are freely developed on wide bottomlands, but in the larger and deeper valleys the correspondingly larger bends impinge frequently against the valley walls. The largest stream in the area, the South Fork of the Salt River, a few miles north of Mexico enters a section in which its wide meanders are distinctly entrenched, the accompanying bottomland being narrow and sinuous. This characteristic is almost universally developed by sizeable streams around the margins of the area, but this is the only example within the region itself. These meanders are of the type often called "ingrown", in which the slopes on the outsides of bends are very steep and those on the insides much more gentle.

Considering the region as a whole, the upland surface slopes gently north-northeastward from the southern edge (Fig. 1). Along the northern and eastern margins the elevation of the upland is approximately 750 feet, but southward it increases to slightly more than 800 feet in the center of the southern edge and rises more steeply to more than 900 feet in the southwestern corner, south of Centralia, and in the southeastern corner, near Jonesburg. Another high point occurs on a projecting arm of the upland, actually outside the region proper, in the extreme northeast near Bowling Green.

Following the pattern of regional slope, drainage on the surface is almost entirely northward and eastward.

Tributaries of the Salt River, chiefly the South Fork, drain the western and northern sections of the plain. The south eastern part, however, drains eastward down the sag between the northeastern and southeastern high points via the Cuivre River system. Only in the area south and southwest of Mexico does drainage from the upland itself make its way into southward-flowing streams (Fig. 1). Elsewhere the southern margin of the upland and the major drainage devide practically coincide, and the edge of the plain is abrupt and clearly marked.

To all sides the Audrain Plain is bounded by more thoroughly dissected country, but in these neighboring areas numerous patches and fingers of smooth upland remain. Around most of the perimeter the smooth tracts are many and large and the depth of valleys is small, so that there is a circle of what may be termed irregular plains (Map 7, p. 24). In the southeastern corner, however, the ring is missing, and the plain ends directly against deeply and strongly dissected hill country of the Ozark Border (Missouri River breaks). Somewhat similar hilly land exists beyond the ring of irregular plain everywhere except in the north. There, beyond the main stem of the Salt River valley, the upland re-establishes itself to form the Shelby Plain, a similar, but less extensive counterpart of the Audrain Plain.

APPENDIX 3

Some Basic Land Form Types and Their Occurrence

For purposes of comparison and experimentation, a number of areas in the northern Great Plains and Rocky Mountains were analyzed in a manner similar to but much less than that employed in Missouri. They were studied from the contour maps and were reconnoitered in the field. The terrain involved was highly diverse, as will be evident from the following listing (See also Fig. 1).

1. North-Central Nebraska - 118 unit areas (7½-minute rectangles) in the Sand Hills and Loess Hills.
2. Southwestern South Dakota - 97 unit areas, mostly in a strip along the White River, including part of the Badlands.
3. Central North Dakota - 111 unit areas in till plains and marginal moraine land, on and east of the Coteau du Missouri.
4. West-Central Wyoming - 142 unit areas comprising most of the Wind River Basin, much of the Owl Creek and eastern Wind River Mts., and parts of the Rattlesnake, Sweetwater and Green Mts.
5. Southwestern Montana - 96 unit areas including much of the Beartooth, Madison and Jefferson Ranges and parts of the Tobacco Root, Gallatin and Centennial Ranges, together with some bordering areas.

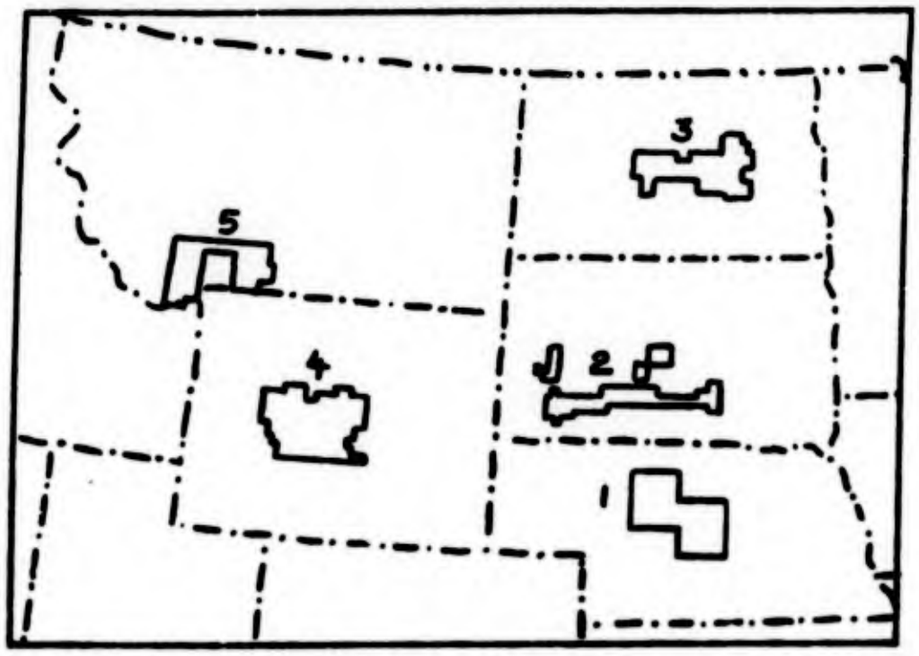


Fig. 1. Test areas in western United States.

While it has not been possible to prepare regional analyses of these areas comparable to those for Missouri, it has proved interesting to extend to them the classification scheme employed in Missouri, with an eye to determining what basic similarities and differences occur. Since in Missouri there are almost no local relief values above 1000 feet, it was necessary to add five higher classes to accomodate the mountains of Wyoming and Montana. The boundary between classes 4 and 5 was also lowered from 800 to 700 feet.

The added classes are:

6 - - - 1000 to 1400 ft.
7 - - - 1400 to 2000 ft.
8 - - - 2000 to 3000 ft.
9 - - - 3000 to 5000 ft.
Q - - - 5000 to 7000 ft.

On this basis 130 types are theoretically possible. The number actually encountered in the test areas (including Missouri) is 78. Of these, 34 occurred more than 10 times. 23 occurred more than 25 times each, but because of the much larger sample from Missouri, these are mostly types that are common there.

In addition to the data for per cent of gentle slope, local relief, and profile type that were used as a basis for classification, data were also collected for percentage of steep slope. It was originally hoped that this fourth element could be added to the classification. However, it resulted in such a proliferation of classes and such a fragmentation of areas of occurrence that it was decided to omit it from the type characterization. However, it, together with various other characteristics, as suggested in the brief summary descriptions of regions in Appendix 2, can readily be added for more detailed, but still concise characterization.

It is felt that the simple three-element classification employed here is a valid and useful one for a general-purpose regional subdivision. It must be reiterated, however, that it is not intended to serve for more specific purposes.

Below is a list of thirty land form types found recurrently within the test areas. All of these types occurred in sizeable contiguous patches in one or more of the areas, and the principal regions of their occurrences are named, together with one or more topographic sheets that exemplify the type in that region.

Should this simple general-purpose classification prove useful for large-area landform mapping and generalized regional study, it should prove valuable to extend the following catalog by analysis of other areas. In any event, it serves as an example of the way in which a land form type catalog may be developed, whatever the nature and number of the elements used in the classification scheme.

Type	Characterization	Type Localities (and Quadrangles)
11A	Flat Plains	1. Missouri - Delta Flats (Sikeston) 2. North Dakota - Ground moraine in Carrington-New Rockford-Fessenden area (New Rockford)
12A	Smoothly Undulating Plains	1. North Dakota - Ground moraine about Devils Lake (Devils Lake)
12B	Undulating Plains	1. Missouri - Chillicothe Plain (Halo, exc. SW) (Note also Sweet Springs NE).
12C	Smooth Lowland Plains	1. Missouri - Rockport-Craig Bottoms (Craig, exc. SE) 2. Missouri - Butler Plain (Metz, Horton, Harwood) 3. North Dakota - Sheyenne R. S of Devils Lake (Tokio SW, Horseshoe L.)
12D	Smooth Upland Plains	1. Missouri - Plattsburg Plain (Plattsburg) 2. Missouri - Audrain Plain (Mexico) 3. Missouri - Pettis Plain (Green Ridge, exc. SE)

14C	Open Plain with Hills	1. Wyoming - Wind River Basin NW of Riverton (Ocean Lake, Lost Wells Butte, Riverton NE)
22B	Rolling Plains	1. Missouri - Gallatin Section of Grand Lowland (Pattonsburg SW, SE, Gallatin NW, SW)
22C	Irregular Lowland Plains	1. Missouri - Carroll-Chariton Section of Grand Lowland (Rothville, Indian Grove, Bosworth) Also many rather scattered examples in eastern Sand Hills of Nebraska (e.g. Long Lake, exc. NW).
22D	Irregular Upland Plains	1. Missouri - Polo Section of Northwestern Upland Plains (Polo). 2. Missouri - Edina, Monroe and Fulton Sections of Northeastern Upland Plains (Edina, SE quarter; Millersburg, exc. SW).
23C	Plain with Low Hills	1. Missouri - Louisiana, Kaskaskia and Dexter Sections of Mississippi Margin of Ozarks (Nebo NW, SE; Puxico NW, NE). 2. Nebraska - Northwest edge of Loess Hills of C. Neb.- (Anselmo, Merna, Broken Bow) 2. Nebraska - East-central Sand Hills (Seneca NE, SE; Brownlee SW, SE).
23D	Low Tableland	1. Missouri - Neosho and Springfield Sections of Springfield Platform (Niangua)
24C	Plain with Hills	1. South Dakota - White River Valley, just east of Badlands (Conata NE, Interior, Wanblee NE).
27C	Plain with Low Mountains	1. Wyoming - Sweetwater Rocks (Split Rock NW, Savage Peak, Ft. Ridge)
32B	Rolling Very Low Hills	1. Missouri - Bethany and Unionville Sections of Green Hills (Bethany exc. SW, Galt NW).

Type	Characterization	Type Localities (and Quadrangles)
32C	Spaced Very Low Hills	1. Missouri - Tarkio, Milan and Boonville Sections of Green Hills (Tarkio exc. NW, New Franklin). 2. Nebraska - Sand Hills north and northeast of Thedford (Moon Lake exc. SE; Seneca 4 SW, SE).
32D	Broad Very Low Hills	1. Missouri - Lancaster, Wyaconda and Columbia Sections of Green Hills (Edina, NW¼; Sturgeon NW, SW).
33C	Spaced Low Hills	1. Nebraska - North-central Sand Hills in areas about Mullen and in SE Cherry Co. (Purdum exc. NE, Seneca NW, SW) 2. Nebraska - Much of Loess Hills of Central Nebraska (Lillian, Broken Bow NE, Ansley, Eddyville). Also common in scattered sections of Ozark Border in Missouri.
33D	Broad Low Hills	1. Missouri - Most of Ozark Border subregion (Long Lane exc. SE, Warrenton exc. SE). 2. Missouri - Most of Central Ozark Divide (Bado exc. NW; Redbird exc. NE).
34C	Spaced Hills	1. So. Dakota - White R. Badlands (Sheep Mtn. Table, Stirk Table, Rockyford).
34D	Broad Hills	1. So. Dakota - White R. Valley south of Murdo (Murdo SE, SW; Westover) Also scattered through Southeastern Ozarks in Missouri.
35C	Spaced High Hills	1. Missouri - Arcadia Section of St. Francois Country (Ironton exc. SW)
42C	Very Low Hills (valley)	1. Missouri - Chariton Hills (Bucklin, Bucklin NW, New Boston, New Cambria W).

Type	Characterization	Type Localities (and Quadrangles)
43B	Low Hills	1. Missouri - Northern Ozark Hills, esp. between Osage and Gasconade and between Gasconade and Maramec R. (Linn exc. SE; Union)
43C	Low Hills (valley)	1. Missouri - Lower Osage R. and Meramec-Missouri sections of Northern Ozark Hills (Meta, St. Clair exc. NW). 2. Nebraska - Thedford-Halsey section of Sand Hills (Thedford). 3. Nebraska - Southeastern part of Loess Hills of Central Nebraska, west of St. Paul (Loup City SE, Ashton, Farwell, Systed).
44B	Hills	1. Missouri - Central part White River Section of Southern Ozark Hills (Ava, Thornfield). 2. Missouri - Meingarten Section of Southern Ozark Hills (Meingarten exc. NE).
44C	Hills (valley)	1. Missouri - Eastern Current River section of Southern Ozark Hills (Round Spr. exc. NW; Lesterville exc. NE).
44D	Hills (ridge)	1. Missouri - SW and NW parts White River Section of Southern Ozark Hills (Norwood; Mtn. Grove S; Tepes NW, NE).
45C	High Hills (valley)	1. Missouri - Town Lock Section of St. Francois Country (Ste Are exc. SW; Ironton SW).
48C	Mountains (valley)	1. Wyoming - Southern margin Owl Creek and Northern Mts. (Boysen, Birdseye Pass, Rochester). Also frequent occurrences at S margins of Beartooth, Gallatin and Madison Ranges, Montana.
49C	High Mountains (valley)	1. Wyoming - Eastern and southern Wind River Mountains (Moccasin Lake) 2. Montana - Outer parts Beartooth Mts. (Mt. Wallace exc. SE; Mt. Cowen exc. SE) 3. Montana - Tobacco Root Mts. (Harrison exc. NE). 4. Montana - Centennial Range (Lower Red Rock Lake SW, SE; Upper Red Rock Lake SW, SE). Also common in Madison and Gallatin Ranges, Montana.