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What is a Hill? An Analysis of the Meanings of Generic Topographic Terms

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This report is part of the effort to generate artificial intelligence systems for aerial photo interpretation. Such a system requires symbolic definitions of generic topographic terms, especially if the system is to interact with a human operator. The author analyzes the meanings of terms such as "hill," "plain," and "terrace," and adjectival descriptors such as "blocky," "rugged," and "large." A review of literature on topography, geomorphology, and terrain analysis reveals that generic topographic terms occur frequently in descriptions of terrain, especially those intended to communicate the perceptual form of terrain. Yet such concepts--rooted in perception, judgment, and experience--are rarely defined.

A terrain analysis data base of over 1,000 propositions about the knowledge of expert aerial photo interpreters was analyzed to extract and categorize approximately 100 generic terms and 250 generic descriptors. The author's approach to defining these terms is based on concepts from ecological optics and the psychology of perception. The definitions themselves are built on concepts from the literature of terrain analysis and topography. This study has implications for practicing terrain analysts and aerial photo interpreters, as well as for the field of artificial intelligence. It suggests some new methods for describing terrain and some clarifications of traditional terminology.

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PREFACE

This report was prepared for the U.S. Army Engineer Topographic Laboratories (ETL), Fort Belvoir, Virginia 22060, through the Battelle Institute, Research Triangle Park, North Carolina 12297, under the U.S. Army Research Office's Scientific Services Program.

The work was performed at the Engineer Topographic Laboratories by Dr. Robert R. Hoffman of the Department of Psychology of Adelphi University, Garden City, NY 11530, under the technical supervision of Mr. Olin W. Mintzer, ETL, who was also the Contracting Officer's Representative.

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SUMMARY

This Report is one "piece of the puzzle" of how to generate artificial intelligence systems for aerial photo interpretation. Here I present an analysis of the meanings of generic topographic concepts---terms such as "hill," "plain," and "terrace," and adjectival descriptors such as "blocky," "rugged," and "large." A review of some of the literature on topography, geomorphology, and terrain analysis reveals that such terms are relied upon heavily in descriptions of terrain, especially those that are intended to communicate the perceptual form of terrain. Yet rarely, if ever, is an attempt made to define such concepts. They are rooted in perception, judgment, and experience. Any artificial intelligence or expert system for dealing with topographical information or aerial photo interpretation should be able to "understand" such terms, especially if it is to interact with a human operator. Hence, it will be necessary to have symbolic definitions of such terms.

First, the terrain analysis data base (Hoffman, 1984) of over 1,000 propositions about the knowledge of expert aerial photo interpreters was analyzed to extract and categorize the generic terms (about 100 of them) and the generic descriptors (about 250 of them). The listings and categorizations were used as the starting point for an attempt to provide some of them with definitions. My approach to the definition problem relies on concepts from ecological optics and the psychology of perception. The definitions themselves rely on concepts from topography. This Report has implications that should be of interest to practicing terrain analysis and aerial photo interpreters, as well as implications for artificial intelligence. The definitions suggest some new methods for describing terrain and some clarifications of traditional terminology.

INTRODUCTION TO THE PROBLEM

The basic problem or starting point of the present work was aptly described in a recent paper on photointerpretation by Hall and Benz (1985):

> "How can we increase the throughput of the [process of exploiting remote sensing imagery] and, at the same time, improve or at least maintain the current quality of the output products? On approach is to train and equip enough photointerpreters to exploit all the imagery data. Unfortunately, the current training facilities could not produce the required number of photointerpreters even if enough qualified people were available for the training. In addition, a substantial amount of practical experience is required to achieve competence as a photointerpreter. This approach, then, delivers too little too late. An alternative solution is to develop automated systems which will reduce the number of required photointerpreters. . . However, the promise of a fully-automated photointerpretation system, or even portions of one, still remains elusive. . . there is a place for a man in the loop, now and for some years to come. An important part of [the concept of coupled man-machine interfaces] is to complement the computing and data-handling powers of the machine with the inferencing and reasoning abilities of the human operator" (Pp. 54-55).

In order to develop such a man-machine complement, specification of the knowledge and reasoning skills of expert photointerpreters is necessary. In a previous report (Hoffman, 1984) I described some methods that can be used to extract the knowledge and reasoning processes of the experts. Those methods yielded a corpus of information about photo interpretation called a "terrain analysis data base." The more than 1,000 propositions in that data base consisted of descriptions of various landforms and terrain features. Example exerpts from that data base are included here as Table 1.

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insert Table 1 about here

TABLE 1

Extracts from Hoffman's (1983) terrain analysis data base. Included here is one an example of each of the major sections of the data base.

Context #3 - TROPICAL CLIMATE
- very rugged topography
- lush vegetation growth
- highly eroded in deforested areas
- little agriculture in areas of low population density
- deep soils except on slopes

Rock Form #3 - DOMES
- raised rock defined by closed topography
- can be small
- can be circular, linear, or ellipsoid in shape
- can be compound
- can be clustered
- structural disturbances at the flanks imply tilted beds, faulted beds, hogback ridges, rugged mountains
- can have radiating fractures
- radial drainage, annular at base
- undissected implies it is young
- can be composed of salt, gypsum, intrusive bedrock

Rock Type #1 - FLAT SHALE
- gently rolling, irregular plain
- rounded contours
- symmetrical finger ridges
- branching rounded hills with saddle ridges
- usually lowlands
- uniform gradients imply homogeneous rock
- uniform gradients imply uniform erosion
- tonal bands imply bedding
- compound slope gradient implies thick bedding
- flared at base implies thick bedding
- scalloped hill bases
- V- and U-shaped gullys
- landslides
- escarpments, very sharp ridges, steep pinnacles, steep slopes, V-shaped gullys, and a medium to fine drainage net imply sandy soils
- humid climate
  - implies valleys, rounded hills
  - implies dendritic drainage
  - implies fine drainage net, ponds, meanders, especially if bedded
  - implies forested, dense on hill slopes
  - implies tonal bands

(table continues)

implies row crops in rectangular arrays
implies intense agriculture
arid climate
implies steep, rounded hills and ridges
implies intermittent drainage
implies asymmetrical slopes
implies steep gullys
implies shrub land, barren land
implies light or mottled tones

Soil Type #2 - SILT
light tones
silky texture
high water-holding capacity
U-shaped gullys
highly erodable
less permeable than sand
water causes instability

Fluvial Landforms #17 - PLAYAS
dry, low relief lakebeds in arid regions
very flat surface in the region of a val! y
scrabbled surface implies alkaline deposits
can include beach ridges
few drainage features
no vegetation, unless scattered scrub
irrigation and intense cultivation
rectangular field grid
includes salt flats

Drainage Patterns #5 - THERMOKARST
g[illegible]ys form polygons and hexagons
polygons linked by meandering streams
streams link small depressions like "beads on a string"
implies permafrost

Gully Shapes #2 U-SHAPED GULLYS
moderately steep side slope
curved channel bottom
implies loess soil

Agriculture Type #4 - ORCHARDS
lattic pattern
repeated uniform rows
porous, well-drained soils
level terrain plus trees arranged in a rectangular pattern implies
nuts, citrus
rolling, uneven terrain plus trees arranged in a contour pattern
implies fruits, peaches, apples

The present Report takes this analysis one step further by examining the meanings of the various terms that appear in the data base. There, and throughout the literature on terrain analysis and photo interpretation, a host of relativistic generic terms and concepts appears. Such terms are generic in that they apply to many different situations. For example, a plain can take on many different forms and have many different features. It might be smooth and rolling, or it might even be rugged in situations where it is elevated and highly dissected by erosion. One would ordinarily not think of a plain as the kind of thing that can be rugged, but since the concept of a plain is a generic one, it can take on many different forms and appearances. On the other hand, an outwash plain is a specific type of plain and has only certain specific features. Generic topographic concepts are not limited to noun-terms, but also appear as adjectives or descriptors that are used to modify or qualify the meanings of the nouns. For example, hills can be described as "blocky" or as "rugged."

While they are certainly descriptive, such generic terms are relative to the perceptions, judgments, and experience of the photo interpreter. Such terms will have to be defined as explicitly as possible if they are to be incorporated in any "expert system" for computer-assisted photo interpretation.

Suppose we have the following situation. A non-expert is interpreting an aerial photo stereopair with the assistance of a computer expert system. Also available to the interpreter is a topographical map which covers the area of the photos. The computer system would ask the interpreter a series of questions about the coverage and the map information. As a result of the analysis, the computer system might inform the interpreter that the coverage consists of "gently rolling hills and plains," or some such description. But how does either the computer or the interpreter know what a "rolling" hill is, or by implication, what a non-rolling hill is? How does the computer or the interpreter know what the difference between a hill and a plain is? As should be obvious from this example, the computer system will have to be able to perform operations that allow it to apply generic terms (hill, plain) and descriptors (gentle, rolling). Furthermore, the interperter will have to be informed of the meanings of these terms, so s/he will know what to look for when going from the topographic maps to the aerial photos. Both the interpreter and the computer will have to be able to translate from topographic information about relief and slopes to perceptually relevant information, information about the appearance of terrain forms.

To help achieve this end, the present Report describes a method for defining the meanings of the relativistic, judgmental, perceptual terms that are used in terrain analysis and photointerpretation. It also includes a preliminary attempt at defining many of the terms. In sum, the main goal of this Report is to make some inroads into this problem of perceptual relativities---to find some links between such relativities and symbolic descriptions.

First I must show in this Introduction that terms like "rugged," "blocky," etc. are heavily relied upon in the literature on terrain analysis and photo interpretation, and that rarely, if ever, is an attempt made to define the terms, since the terms are subjective and their meanings are hard to capture in words. Indeed, in some cases, relativistic descriptors are defined using other relativistic descriptors!

RELATIVISTIC DESCRIPTORS IN REFERENCE WORKS ON TERRAIN ANALYSIS

All the available major reference works on terrain analysis, geomorphology, and photo interpretation rely on generic topographic terms and descriptors. While some generic terms, such as "hill," "plain," and "mountain" are sometimes defined in terms of topography, they are usually not defined. Furthermore, generic topographic descriptors such as "blocky," "rugged" and the like are relied on and yet are very rarely defined. For instance, Lobeck's classic work on geomorphology (1939) includes an occasional definition for some generic terms (e.g., hills are elevations with relief less than 300 meters), but it does not include definitions of the relativistic descriptors that are used to describe the terms (e.g., "ribbed" topography, "canoe-shaped" mountains). Generic descriptors do not even appear as entries in its index.

Reference works do tend to offer definitions of topographic and terrain terms, but only for specific types (i.e., for landforms), not for generic concepts. For example, Way's (1978) standard reference work on terrain analysis, like Lobeck, offers definitions for such specific forms as dune types, delta types, gully types, glacial forms, and the like. It too relies heavily on generic terms and descriptors, and like Lobeck, offers only the occasional definition for such terms (e.g., a butte is an isolated hill or mountain with relatively steep side slopes and a flat or rounded top). Also like Lobeck, Way offers no definitions for generic descriptors. Generic descriptors do not appear as entries in his index or in his glossary. The Reader is left to rely on his own perceptions to understand the meanings of such terms as "blocky" and "pitted." In those rare instances where a generic descriptor is defined, the definition is in terms of geodynamic formation processes rather than in terms of perceptual appearance. For example, an "exfoliated" form is defined as one for which there has been "the breaking or spalling off of thin concentric shells, scales or lamellae from rock surfaces" (p.384). But how does this look in an aerial photo? What is "thin?".

The texts by Lobeck and by Way are by no means isolated examples.

Mintzer and Messmore's (1984) terain analysis guide relies heavily on generic terms and descriptors, and yet offers definitions only for specific topographic types (e.g., glacial forms, fluvial forms) and for a few generic types (e.g., the relief ranges for hills and mountains). The Reader is left to his own devices to determine the meaning and perceptual significance of such things as "bench-like elevations", "long, narrow, snake-like ridges", "parallel, terraced ridges", and "irregular, star-shaped hills". Similar statements can be made about about Frost et al.'s (1953) photo interpretation guide. Its glossary offers some definitions for specific topographic types (e.g., a kame is a "short, irregular ridge, hill or hillock of stratified glacial drift," an esker is an "elongated, serpentine ridge," sandstone can give rise to "broad, V-shaped, sharply-crested ridges," a plateau composed of a certain type of rock can involve a "flat-topped plain with shelves or benches as walls"). Note, however, that such definitions themselves rely on generic descriptors and terms which go largely undefined.

Even if one were to consult Parker's (1984) dictionary of earth sciences, Gary et al.'s glossary of geology (1972) and Fairbridge's (1968) encyclopedia of earth sciences, one would be hard-pressed to come away with a significant understanding of the meanings of such terms as "jagged," "blocky," "sawtooth," and the like. One certainly would find no indication of the perceptual referents and importance of such terms.

One exception to this state of affairs is the photo interpretation manual by Rinker and Corl (1984). Of course, they too rely heavily on generic terms and descriptors (e.g., "closely spaced hills," "pockmarked plain," "teardrop-shaped hills," "sharlpy rounded crests"). They also provide an occasional definition for a generic term. For example, "basins and valleys are depressions that are sufficiently large to provide a significant separation between the adjecent higher elevations" (p. 17).

Faults are defined as a "perceptible displacement between the sides of a fracture along the fracture plane, ranging from small cracks to trans-continental lineations" (p. 33). Plains are defined as "any relatively flat surface of sufficient extent to be a mappable unit" (p. 63). An escarpment is defined as "a significant and obvious boundary that separates landform units" (p.64). They even offer an occasional definition for a generic descriptor (e.g., lumpiness is "small-scale roundness" or a "blocky and choppy profile"). However, these definitions themselves rely on other generic terms and descriptors (as can be seen in the above examples). The distinguishing feature of the Rinker and Corl manual is its awareness of the fact that there is indeed a problem of deiniftion here. In their extensive cataloging of landform features they mention that the definitions are relative to the perceptions and experience of the interpreter. To illustrate their point about perception, they offer a number of profile diagrams, some of which are reproduced here in Figure 1. Each profile relates to a different descriptor or set of descriptors. In every case, they mention that the description is based on the visual impression of the landforms (Pp. 266-281) and they define the descriptors ostensively, that is, by pointing to an illustration of the visual appearance of the form profile.

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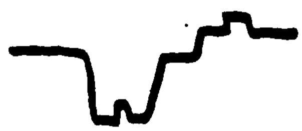
insert Figure 1 about here

FIGURE 1

Examples from Rinker and Corl's (1984) photo interpretation "logic sheets" which involve ostensive definitions of some generic topographic terms (reproduced with permission).

GENERIC DESCRIPTORS	PROFILE ILLUSTRATION
(1) Sharply angular, jagged, irregular, inconsistent, asymmetric	
(2) Smooth slopes, uniform gradient	
(3) Stepped, sloping faces, interrupted slopes	
(4) Blocky, fin-like projections and pinnacles, box-like valleys	
(5) Gentle slopes, deep pits, vertical walls, rounded contours	
(6) Rounded angularity, lumpy surfaces	
(7) Smooth slopes, very gently rounded profiles	

A ridge can be long, but so can a stream gully. So can a canyon. How is "long" for a canyon different from "long" for a stream? Can one definition of "long" work for both cases? A mountain range can be rugged, but so can a plain. Can "plain" be defined in such a way that the word "rugged" will apply to it without negating its meaning as something that is flat? A small mountaint in a cluster of larger mountains can appear to be a hill. What's a hill?

The stage has been set for an attempt to fill in what appears to be a major gap in the literature on photo interpretation and terrain analysis. The literature abounds with generic terms such as plain, hill, ridge, knob, mound, and the like. It abounds with generic descriptors such as rough, blocky, rolling, scalloped, and the like. Such generic terms and descriptors appear to be absolutely necessary in the description of landforms and terrain. Yet, little or no concentrated effort has been applied to defining these terms.

I believe that it is possible to generate definitions of generic terms and descriptors, definitions that do not eleminate the relativities, but that anchor the relativities in measurable and perceptually informative topographic features of terrain. The fact that relativistic descriptors are relied on heavily in terrain analysis, combined with the fact that they seem to be used in a consistent way by various expert photointerpreters, implies that there is sufficient information available in photos and topographic maps to allow for precise definitions of the generic terms. Countless hours of debate have been spent by expert photointerpreters on such questions as, "What do we mean when we say that a hill is blocky?" The usual answer is to throw up one's hands and say "It's blocky because it looks blocky!" Indeed, it does look blocky, and my claim is that the reason that people can agree that it looks blocky is because there actually is sufficient information available in the optic array to specify such perceptual judgments. Furthermore, if the information is available in the optic array, then it can be specified in topograpghic terms.

In the next section I will describe the method I used to catalog and analyze the meanings of generic topographic terms and descriptors. Following that will be an analysis and discussion of the results, which will lead in turn to my attempt at defining some of the generic terms.

METHOD

MATERIALS

The materials which were analyzed were Hoffman's (1984) terrain analysis data base and eight specific terrain analysis programs developed at the Center for Physical Sciences of the Engineer Topographic Laboratories using the KES expert-systems development package.

The terrain analysis data base consists of 1,233 propositions about landforms. It was derived from standard reference works on terrain analysis and photointerpretation (Frost, et al., 1953; Lobeck, 1939; Mintzer and Messmore, 1984; Rinker and Corl, 1984; Way, 1978) and from a structured interview of an expert photointerpreter. The data base has a number of categories, including climate context, rock forms, rock types, soil types, fluvial lanoforms, drainage patterns, gully shapes, agriculture, and cultural forms. Example exerpts from each category were presented above in Table 1 (with the exception of cultural forms, which fall outside of the focus of the present analysis).

The KES programs are small routines for assisting photointerpreters in the analysis of specific forms, such as metamorphic rocks, glacial forms, and drainage patterns. In the use of a KES program, the operator is asked a series of multiple-choice questions about the coverage being analyzed. An example is:

Formtype:

(1) mountains

(2) low hills

(3) high hills

(4) low plains

(5) high plains

(6) depressions

(multiple answers are permitted).

The operator answers each question with reference to the aerial photos at hand, and after the series of questions has been answered, the KES program offers its analysis, a landform categorization such as "outwash plain" or "lakebed."

METHOD

In order to conduct a meaning-full analysis of the data base and the KES systems, the following terminology was adopted, based on traditional concepts in linguistic semantics.

PROPOSITION - Any statement in the data base or KES system. For example, under the category of drumlins is the proposition: "Smooth, long, oval, rounded, cigar- or teardrop-shaped low-lying hills."

PREDICATION - Any binary statement consisting of a property that is asserted of some object. For example, the above proposition consists of the following seven predications:

"The hills are smooth," "The hills are long," "The hills are oval," "The hills are rounded," "The hills are cigar-shaped," "The hills are teardrop-shaped," "The hills are low-lying."

Since all of the predications that occur in the data base and the KES programs take the form of adjectives, the term "adjectives" is used to refer to the descriptors that are used to identify the properties in the predications. Counting of adjectives is not equivalent to the counting of predications, however, since one adjective can serve in more than one predication. For example, under the category of basalt forms it is asserted that there are "terraced hill slopes, canyon walls, and gorges." In this proposition, the single adjective "terraced" occurs in three predications, one about hill slopes, one about canyon walls, and one about gorges. Thus, the number of predications in the data base should be greater than the total number of propositions. Any one proposition can contain more than one "chunk" or predication.

Note that not all propositions need to contain predications. For example, under the category of glaciers, one proposition asserts that "moraines are at the glacier edge." In this proposition, the presence of a form is asserted and nothing is predicated of the form except for its presence. Thus, not all of the propositions in the data base contain adjectives.

Armed with this terminology, one can perform a meaning-full analysis of a set of linguistic propositions such as those that occur in the terrain analysis data base or the KES programs. One can ask, How many predications occur in the propositions?---in other words, how "dense" are the propositions? One can ask, How many adjectives are used in the propositions?---in other words, how much reliance is there on relativistic perceptual judgments, in contrast with simple assertions about the presence or absence of features?

The terrain analysis data base and the KES systems were analyzed in terms of their number of propositions and predications. Frequency counts were made of the occurrence of particular adjectives and particular generic terms. The analysis was straight-forward, even though over a thousand propositions and hundreds of generic terms and descriptors were involved.

For the next step in the analysis, the propositions and predications were classified. The categorization which I relied on bears some resemblance to the traditional classification of "pattern elements" used in terrain analysis, however, my classification differs from it in some ways since my purpose was to develop a meaning-full categorization rather than to engage in the kinds of activities that terrain analysts engage in. In the traditional classification, features are classified into seven groups: tones, vegetation, drainage patterns, gully shapes, form or relief, land use, and special features. The present analysis departed from this traditional classification in some respects. First, the vegetation and land use categories were combined since propositions of the two types two usually referred to vegetation or agriculture. Second, drainage patterns and gully shapes were combined into one category since both refer to drainage. Second, a category of soils was included since many of the propositions in the data base referred specifically to soils. Third, a category called "formation processes" was added since many of the propositions in the data base referred to geological dynamics. For example, a proposition under the heading of arid climate was "evaporation causes surficial mineral deposits," which refers to the processes which cause a form or feature. Fourth, the traditional category of "special features" was re-named "associated implications." Examples of such entries in the database are: "arid climate implies blocky hills and ridges" and "playas can include beach ridges." An implication can be a reference to any of the other types of feature (soils, relief, tones, etc.). Since my purpose here was to analyze the propositions for their meaning content, an associated implication in the data base was counted as such, however, it was also counted as an instance of other categories depending on its content. For this reason, my category of associated implications differs from the traditional category of "special features." For example, the proposition "arid climate implies blocky hills and ridges" was counted as an associated implication and was also counted as a reference to relief. Fifth and finally, a category called "location" was included since a number of the propositions referred to the locations of various forms. For example, an entry under the heading of outwash plains asserted that they "occur at the borders of glacial forms."

An example exerpt from the data base with indications of how its propositions were scored is included in Table 2.

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insert Table 2 about here

TABLE 2

An example exerpt from the data base and an illustration of how the propositions in it were scored. The category of this entry was "Terminal moraine." Technically, the proposition in line 4 has no predications since it contains no adjectives. Nevertheless, since all propositions were scored for their content, the proposition in line 4 is categorized under the predications column.

DATA BASE ENTRY	NUMBER OF PROPOSITIONS	NUMBER OF ADJECTIVES	NUMBER OF PREDICATIONS	PREDICATION CATEGORY
Usually within a rolling prarie.	1	1	1	L,R
Undulating, linear bands of hills.	1	2	2	R
Small, concentric knobs, ridges, and depressions.	1	2	8	R
Resulting from material pushed ahead of glacier.	1	0	0	F
Many ponds, swamps, and hedgerows.	1	1	3	D,V
Deranged drainage.	1	1	1	D
Narrow, deep V-gullys.	1	2	2	D
Rounded, steep ridges, light tones, saucer gullys, forests imply coarse soils.	1	5	5	A,R,T,D,V,S

R= relief T=tones L=location
D= drainage V=vegetation F=formation processes
A= associated implication S=soils

RESULTS

TERRAIN ANALYSIS DATA BASE

The frequency counts for the terrain analysis data base are presented in Appendix 1 and Appendix 2. Appendix 1 shows the frequency of use of each of 249 generic descriptors (adjectives) and Appendix 2 shows the frequency of use of 99 generic terms.

The number of different adjectives used was 249, however this is not the same as the total number of adjectives. That is, the number of different adjectives used does not reflect the total number of predications in which the adjectives appeared. The total number of adjectives is given by the sum of the frequencies that appear in column in Appendix 1---1,695. Since the total number of propositions in the data base was 1,233, this means that there were about 1.37 adjectives per proposition. In other words, each proposition tended to include more than one adjective. Some propositions included no adjectives and some included as many as seven. An example of a proposition with a relatively large number of adjectives is an entry under the category of the schist rock type: "Long, deep, parallel U- or V-shaped gullys with light, banded tones." On the average, 2.51 different descriptor adjectives were applied to each topic (249/99) and each topic was described using an average total of 17.12 adjectives (1695/99). In other words, each generic adjective is typically used to describe more than one topic, and each topic is typically described with a large number of adjectives.

Table 3 presents a breakdown of the predications in terms of the categorization. The total number of predications (1,525) is greater than the total number of propositions (1,233) since a proposition could include more than one predication, as explained above, and since predications in the "associated implications" category were often counted in other categories as well, depending upon their referents.

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insert Table 3 about here

TABLE 3

A categorization of the predications in Hoffman's (1983) terrain analysis data base. The table separates propositions which included adjective descriptors from those which did not (i.e., predications that simply assert the presence or absence of a form or feature). Entries consist of the number and percentage of predications of each type. Since each proposition could contain more than one predication, the total number of predications given here (the sum of the two totals columns below, or 1,525) is greater than the total number of propositions (1,233). Furthermore, predications in the "associated implications" category were also counted in other categories, depending on the nature of what was implicated (e.g., an implication about soils, tones, etc.).

CATEGORY	PREDICATIONS FROM PROPOSITIONS WITH ADJECTIVES	PREDICATIONS FROM PROPOSITIONS WITHOUT ADJECTIVES
(1) DRAINAGE	292 = 22.2%	39 = 18.31%
(2) TONES	136 = 10.37%	2 = 0.94%
(3) VEGETATION/ LAND USE	181 =13.79%	17 = 7.98%
(4) RELIEF	401 = 30.56%	59 = 27.69%
(5) SOILS	136 = 10.37%	8 = 3.76%
(6) FORMATION PROCESSES	7 = 0.53%	14 = 6.57%
(7) ASSOCIATED IMPLICATIONS	309 = 23.55%	58 = 27.23%
(8) LOCATIONS	31 = 2.36%	16 = 7.5%
TOTAL	1312	213

Since there were 1,525 predications, the average number of predications per proposition was 1.24 (1525/1233). Of the 1,233 propositions, 77 or 6.2% contained no adjectives at all and 1156 or 93.76% contained at least one adjective. If we compare the total number of adjectives to the total number of propositions which contained adjectives, we find that each predication-containing proposition had an average of 1.46 adjectives.

A final aspect of the results of the analysis of the data base is the finding that a number of the generic terms and descriptors are used in both adjectival and noun form. A listing of all those terms which also occur in adjectival form is included here in Table 4.

---

insert Table 4 about here

TABLE 4

Terrain analysis terms that appear in both noun and adjectival form, from Hoffman's (1984) terrain analysis data base.

NOUN FORM	ADJECTIVAL FORM
bands	banded
beds	bedded
clusters	clustered
contours	contoured
displacements	displaced
dome	dome-like
elevations	elevated
erosion	eroded
fan	fan-shaped
faults	faulted
flats	flat
folds	folded
forests	forested
fringe	fringed
hill	hilly
intersections	intersecting
joints	jointed
meander	meandering
mountain	mountainous
peak	peaked
slope	sloped
stairsteps	stairstep
streaks	streaks
surface	surficial
terrace	terraced

KES PROGRAMS

The KES programs were analyzed in a fashion similar to that used for the data base, i.e., adjectives and their frequencies were counted and categorized.

Table 5 presents the results of the frequency analysis for the KES programs and Table 6 presents a categorization of the predications. Unlike the data base, for the KES programs the total number of propositions is equal to the total number of predications, since the propositions in the KES programs were expressed as simple predications in the questions which the KES programs presented to the user. Hence, the totals row in Table 6 has the same entries as the column in Table 5 labeled "total number of predicates." Only a few propositions in the KES programs contained no adjectives.

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insert Tables 5 and 6 about here

TABLE 5

Analysis of the frequency of predicates (adjectives) in KES terrain analysis files. Each KES file, when executed, asks the user a series of between seven and nine questions and from the answers determines the type of landform that is being analyzed. Thus, the number of categories in a KES file equals one (landform type) plus the number of questions.

SOURCE FILE	NUMBER OF CATEGORIES	TOTAL NUMBER OF PREDICATES	RANGE OF PREDICATES PER CATEGORY	AVERAGE NUMBER OF PREDICATES PER CATEGORY
(1) GLACIAL FORMS	8	29	0 - 8	3.63
(2) DUNES	7	26	2 - 9	3.71
(3) GULLYS	8	26	2 - 5	3.25
(4) DRAINAGE PATTERNS	7	39	3 - 8	5.57
(5) METAMORPHIC ROCK	10	49	0 - 9	4.90
(6) SEDIMENTARY ROCK	10	56	2 - 10	5.60
(7) IGNEOUS ROCK	10	74	1 - 18	7.40
(8) FLUVIAL FORMS	10	67	3 - 13	6.70
OVERALL AVERAGES	8.75	45.75	1.6 - 10	5.09

TABLE 6

Analysis of the frequency of predications (adjectives) in KES terrain analysis files as a function of the category of the predications. Entries consist of the frequency and percentage of predications of each of eight categories. Empty-cells are those with a frequency of zero. The total frequencies at the bottom of the table correspond with the entries in the second column of Table 5.

CATEGORY	SOURCE KES FILE							
	GLAC. FORMS	DUNES	GULLYS	DRAIN. PATT.	META. ROCK	SED. ROCK	IGN. ROCK	FLUVIAL FORMS
DRAIN.	6 20.7%				23 46.9%	14 25%	21 31.1%	22 32.8%
TONES	9 30%		1 3.9%		8 16.3%	7 12.5%	9 12.1%	[illegible] 11.9%
VEGET.	9 30%				5 10.2%	4 7.1%	3 4.1%	10 14.9%
RELIEF	5 17.2%	25 96.1%	20 76.9%	39 100%	13 26.5%	29 51.8%	33 45.6%	21 31.3%
SOILS			3 11.5%					1 1.49%
FORM. PROC.			1 3.9%					
ASSOC. IMPLI.						2 3.6%	6 8.1%	5 7.5%
LOCA.		1 3.9%	1 3.9%					
TOTALS	29	26	26	39	49	56	74	67

One slight departure had to be made from the method of analysis used for the data base. A number of the KES programs included questions about "special features," and a number of them did not. Some but not all of them had propositions of the type I refer to as "associated implications." In order to allow comparison of the KES programs and the data base in terms of their reliance on associated implications, propositions that the KES author(s) included as "special features" were counted here as references to relief, tones, or whatever, depending on their referents (e.g., listing "round hills" as a special feature of sedimentary rocks was counted here as a reference to relief). Only propositions that referred to climatological variations or to the simple presence or absence of associated forms were included here in the category of "associated implications." For example, the statement that "buffalo wallows" occur in fluvial forms and the statement that various fluvial forms occur in a humid climate were counted here as associated implications.

DISCUSSION OF THE RESULTS

TERRAIN ANALYSIS DATA BASE

Analysis of the data base yielded a large corpus of generic terms and descriptors, including a listing of which descriptors get applied to which terms, and how often. The listings presented in Appendix 1 and Appendix 2 are more than just representative of the literature on terrain analysis and photointerpretation. . . .they are no doubt close to an exhaustive listing of the generic terms and descriptors. Thus, the Appendixes provide a good starting point for any attempt to define the generic terms and descriptors (as I shall do in a later section of this report).

By far, most of the propositions and predications in the data base rely on adjectival descriptors, thus verifying the hypothesis that generic desciptors are relied on heavily in terrain analysis. Of the 1,525 predications, 1,312 relied on adjectives. Of the 1,233 propositions, only 6.2 percent included no adjectives at all. These adjective-free propositions tended to be references to relief (e.g., hills have relief less than 300 meters; an outwash plain can be a terrace), to drainage (e.g., in a till plain, drainage patterns are controlled by the underlying rock), and to associated implications that simply assert the presence of a form or feature (e.g., ponds are present in outwash plains).

Comparing the percentages of predications of each type across the propositions that contained adjectives and those that did not, one can see some overall agreement. Since it is hard to refer to tones without using adjectives, the number of adjective-free predications that refer to tones is very small. Conversely, it is easy to refer to formation processes without using adjectives, so the percentage of predications in this category is greater for the adjective-free predications. With regard to the other six categories of predications, there appears to be some overall concordance in the percentage of predications of each type across the two types of propositions, as inspection of Table 3 reveals (for example, 30% of the relief-related predications with adjectives and about 28% of the relief related predications without adjectives).

The propositions in the data base range from being very dense (i.e., containing a number of predications and adjectives) to being very simple (i.e., simply asserting the presence of a form). On the average, each proposition contains 1 to 2 predications and 1 to 2 adjectives. Each different adjective can be applied to many different terms and each term can get predicated by many different adjectives. For example, the adjective "flat" gets applied to 12 different forms (deltas, plains, ridges, etc.) in Appendix 1. The term "hill" gets described by 37 different adjectives (conical, long, rugged, etc.) in Appendix 2. On the average, each different adjective is applied to 17 terms and each term is described using 2.5 different adjectives. Any proposed definition for a term must work when the term is modified by each of the applicable descriptors. Conversely, any proposed definition for a descriptor must work when applied to any applicable term. Thus, the definition for "hill" must work even when the hills in question are blocky, bold, jointed, knobby, etc. The definition of "flat" must work when it is applied to ridges, plains, etc. Coming up with definitions that satisfy these mutual constraints will no doubt be difficult. The effort can be lessened somewhat (but not much) by avoiding the use of words that appear as both adjectives (descriptors) and terms (nouns) (i.e., the terms shown in Table 4).

Ambiguity arises not only when a term appears both in adjectival and noun form, but also when a term is used with more than one meaning. The best example of this is the uses in the data base (and in terrain analysis in general) of the term "relief." It is used to refer to a general description of a region (as in the phrases "gentle relief"), that is, it is used interchangably with the terms "land," "topography," and "terrain." The other meaning of relief is a specific reference to the relief metric, that is, the difference in elevation between the lowest and highest points of a terrain form. Certainly any attempt to systematically define and use generic topographic terms and descriptors will have to avoid such ambiguities by using various terms in a consistent fashion.

The categorization of the predications in the data base reveals something interesting about the traditional pattern element called "special features." In the present analysis, propositions that are ordinarily referred to as special features were counted as associated implications and were also counted in the other categories, depending on the nature of their referents. The fact that the percentage of such propositions (309 or 23%) was higher than any other category except for relief indicates that the "catch-all" category of special features as traditionally may not afford much power in discriminating aspects of terrain. Rather, it is the specific meaning content of various "special features" that is what is important. Certainly, each landform or terrain type will have certain "special" features associated with it. However, these special features are special not just because they are associated with certain forms, but because they refer to such things as relief, tones, etc., and thereby refer to perceptible qualities.

The one category of predications that was relatively low in frequency was the category of "formation processes." This is to be expected since it was not the purpose of the data base to explain the formation of landforms. This task is part of the "explanation" component of an expert system rather than its data base. Clearly, a great deal of information will have to be included in the explanation component of an aerial photo interpretation expert system and the information about formation processes that is included in the data base only scratches the surface.

THE KES PROGRAMS

The analysis of the KES programs also reveals something interesting a the traditional categories of "pattern elements." A number of the cells in Table 5 are blank, indicating that none of the propositions in a given KES program fell into those categories. This is interesting because Way (1978), the source for the information used to build the programs, places great emphasis on analysis of each pattern element for every landform.

Indeed, the present results suggest that different pattern elements are more or less important in the analysis of a given type of landform and they should not be given equal weight, as is traditionally the case. Perhaps more analyses like the present one could be used to derive and assign such weights for various landforms and terrain types. Such weights would assert that for a given landform or terrain type, one or another pattern element should be given more or less weight than other elements.

The eight KES programs were developed by different researchers, and yet each programmer found it necessary to ask the user 7 or 8 questions in order to determine the classification of the forms being analyzed. Even though my attempts to use the KES programs with various aerial photos encountered problems when the features in the photos did not precisely match the features listed in the KES-provided questions, this common reliance on only seven or eight questions suggests that this number of questions is sufficient for classification purposes. Here, the results of the present analysis fit with the traditional practices of terrain analysis, that is, the use of the seven "pattern elements." Although for any given KES program the questions do not necessarily refer to exactly the seven traditional pattern elements, the KES programs do tend to ask seven or so questions. This suggests that seven may be a lower limit on the number of questions needed to categorize landforms.

COMPARISON OF THE DATA BASE AND THE KES PROGRAMS

The KES programs involved a total of 119 different adjectives. of these, 103 appeared in the data base. Thus, the KES programs included 16 adjectives that were not included in the data base. In most cases, equivalent terms could be found, however. For example, the KES term "black tones" corresponded with the data base term, "dark tones." The

KES term, "soft hills" corresponded with the data base descriptor, "gentle relief." Of the 366 adjectives in the KES programs, only a handful had absolutely no corresponding adjective in the data base (i.e., "mixed tones," "abandoned gullys," "coalescing fans" and "complex shapes"). One can safely conclude that the two different sources, the data base and the KES files, relied on essentially the same set of generic terms and descriptors. This is to be expected since they came from the same sources. Development of the KES programs relied almost exclusively on the text by Way (1978) which was also a major source of information for the data base.

GENERIC TOPOGRAPHIC TERMS AND THEIR MEANINGS

The discussion up to this point has set the stage for an attempt to specify some of the meanings of generic terms and descriptors. I began with the hypothesis that generic terminology was relied upon heavily in the literature on terrain analysis, and this hypothesis was borne out by the analysis of the data base and the KES programs. That analysis yielded a cataloging of various generic terms and descriptors, a cataloging that can be the starting point for an attempt to define the terms.

The method I used for analyzing the data base and the KES programs can work as a general method for deriving definitions of generic topographic terms and descriptors. In order to derive a definition for a given descriptor (adjective) or a given topic (term), one needs to pair each adjective with each of its topics (in Appendix 1) to see if the candidate definition works across topics. Also, one needs to pair each term with all of the adjectives that are applied to it (in Appendix 2) to see if the candidate definition for the term works across adjectives.

This was the approach I took. What follows is a set of definitions and some commentary on them. I begin at the most general level, with terms and metrics that describe relief. These basic concepts are then used in the definitions of generic terms and descriptors that appear in Appendix 1 and Appendix 2. Each definition relies on definitions that came before.

SOME ASSUMPTIONS ABOUT PERCEPTION

It is assumed in the following discussion, as it is in the literature on terrain analysis and geomorphology, that only a few "slices" of a terrain form are sufficient to capture the important features of the form. This assumption may or may not be an obvious one. Nonetheless, some justification for it should be sought. Otherwise, we might proceed to define generic topographic terms using such diagrams as those shown in Figure 1, when such "slices" may not be sufficient.

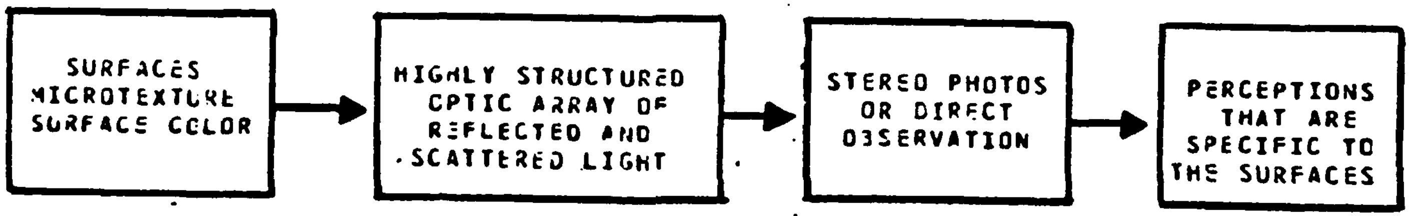
A justification for this assumption can be found in an analysis of perception. In the Introduction I made the claim that definitions of generic terms and descriptors can be derived since generic terminology is used consistently by various terrain analysts. Their perceptions must be similar, and hence, there must be sufficient information in the optic array (and therefore in stereo aerial photos as well) to specify those perceptions.

Surfaces, their orientations, their microtexture, and their surface colors all add structure to the ambient light (Gibson, 1979). The light thus contains information that is specific to the terrain. The information that is available in the optic array that allows for the perception of such aspects as "blockiness" and "plateauness" pervades the landforms. The information that is available is specific to surfaces, not to individual points or "rays" of light. Perception is of surface properties, occluding edges, and variations in surface properties. The dependencies as I have outlined them are illustrated in Figure 2.

insert Figure 2 about here

Figure 2

An overall description of the process of perception of aerial photos according to the theory of Gibson (1979), which emphasizes the constraints between surface properties, the optic array, and perceptual processes.



One implication of this reasoning about "ecological optics" by psychologist James Gibson is that the perception of such aspects as "blockiness" is not layers of inference deep in the cognitive process. Indeed, by this line of reasoning, perception is direct and requires no levels of inference or computation. The labeling process of saying that a terrain form looks blocky requires matching or the recognition of concepts. However, the perceptual act itself of seeing the terrain is direct in that the information available in the optic array directly specifies the terrain.

It is easy to perceive blockiness or ruggedness. So too, it is easy for terrain analysts to consistently decide when descriptors such as "blocky" or "rugged" apply. Therefore, it might not be as difficult as one might suppose to come up with descriptions of surfaces in sufficient detail to give a topographic specification of the meanings of generic descriptors.

In contrast with this line of reasoning, one might begin with the fact that hills and other terrain forms are very complex three-dimensional things. Shouldn't it be necessary to use highly complex topological equations, or even fractals, so that we can build a complete model of terrain and thereby define such features as blockiness? There are two sides to this question. One is, Is a partial description of terrain forms sufficient? The other is, Sufficient for what purposes?

Certainly terrain forms can range from the geometrically simple (e.g., a drumlin as a truncated inclined cylinder) to the geometrically complex (e.g., a highly dissected mountain range where one mountain's slopes blend imperceptibly into the next mountain's slopes). However, Gibson's theory of perception suggests that it is not necessary to generate a complete topological description of terrain forms in order to define generic descriptors. The information that is available in the optic array "pervades" the landforms. Only a few "slices" of a terrain form are needed to describe the surfaces of a terrain form in sufficient detail to determine whether such concepts as hills, plateaus, blocky, or rugged apply. Since the surfaces in the terrain serve to structure the ambient optic array, the surface information that allows for perception of such properties as blockiness is the same information that allows topographers to describe terrain sufficiently in terms of a few "slices" of the surfaces. To determine that a hill is rugged and highly dissected, one need not compute the total three-dimensional shape.

I am now in a position to begin a presentation of some definitions of generic topographic terms and descriptors, and start off at the most general level, that of relief. As the presentation proceeds, the Reader will see that later definitions rely on the earlier ones. The Reader will also see that some of the definitions presented here are "standard" in the literature on terrain analysis and topography (e.g., the definition of degrees of slope). In all cases, the definitions were derived by first seeing whether definitions were offered in reference works on terrain analysis (i.e., those cited in the Introduction to this Report). In some cases, the literature afforded partial definitions, and these were refined and expanded upon here.

BASIC RELIEF TERMINOLOGY

The first terms to define are those that fall at the most basic level of description:

SURFACE: The planar interface of the terrain and the air. The surface can be divided into surfaces.

COVERAGE: The set of all surfaces represented in a particular map or photo.

AREA: Any subset of adjacent surfaces in a coverage.

ELEVATION: The height of a point on a surface relative to the lowest point on the surface, or in the coverage or in an area.

RELIEF: Relative elevation, or the difference between the highest and lowest points on a surface, or in the coverage or in the area.

SLOPE: The angle of a surface relative to the horizontal plane, or the change in extent between two points on the surface divided by the change in elevation across the two same points.

The next set of terms to define are those that deal with the observer's perspective on the surfaces:

ANGLE OF REGARD: The perspective from which a surface is viewed.

AERIAL ANGLE OF REGARD: Viewing a surface from the aerial perspective, that is, gaze direction is downward in the vertical plane.

TERRESTRIAL ANGLE OF REGARD: Viewing a surface from the perspective of someone who is on the surface and directing their gaze horizontally.

Having defined these most basic terms, I can now define the "slices" that will be used to describe terrain surfaces:

CONTOUR: The outline formed by the intersection of a horizontal plane and the areal surface, where the plane is perpendicular to an aerial angle of regard and parallel to a terrestrial angle of regard.

CROSS-SECTION: The outline formed by the intersection of a vertical plane and the areal surface, where the plane is parallel to a terrestrial angle of regard.

PROFILE: The outline formed by the intersection of a vertical plane of and the areal surface, where the plane is perpendicular to a terrestrial angle of regard.

The three terms, contour, cross-section, and profile, are fairly standard in terrain analysis and topography. Together, they define a "normal" perspective on terrain forms. Note, however, that they are relative to the observer's angle of regard or perspective on the surface being intersected. This is illustrated graphically in Figure 3. This Figure is an aerial perspective topographical map of the Menan Butte in Idaho. Each of the contour lines in the map represents a contour as defined above. Hence, all the points on the surface that fall on the outline are of equal relief (relative elevation). In order to identify a cross-section and profile, a particular terrestrial angle of regard is established by locating the observer (large open circles) at a particular position on the terrain. In the top portion of Figure 3, an arbitrary location is selected. Relative to this location, the line labeled 1 would define the plane on which a profile would be drawn, and the line labeled 2 would define the plane on which a cross-section would be drawn. In the lower portion of Figure 3, the observer is shifted so that the line 1 which runs across the butte is longer than any other line that could be drawn across it. Line 2 is then drawn perpendicular to line 1.

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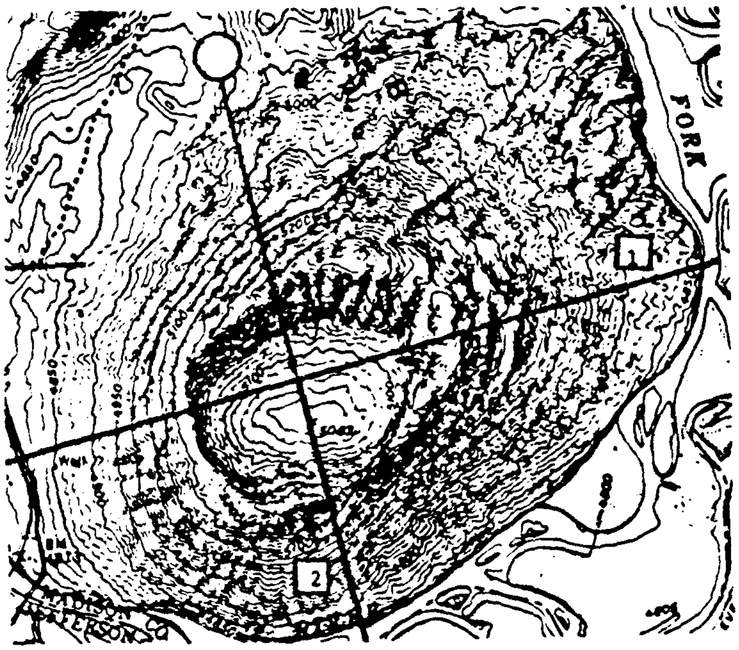
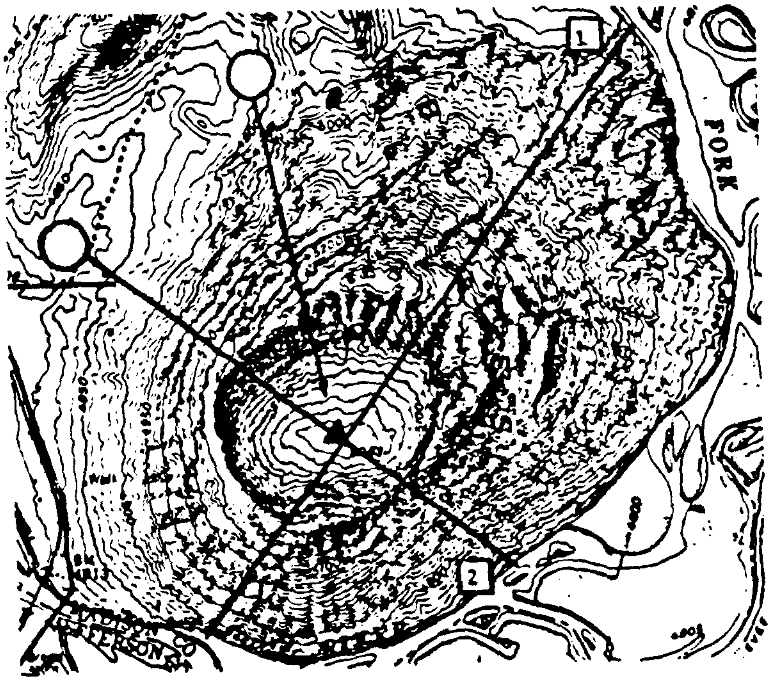
insert Figure 3 about here

FIGURE 3

An illustration of how the positioning of the planes for cross-sections and profiles is relative to the angle of regard taken by the observer. These excerpts from a topographical map show a butte, an example of a form whose boundaries are fairly distinct. In the top portion, an arbitrary position for the observer is selected. In the lower portion, the location of the observer is shifted such that the profile plane (defined by line 1) is maximized in length. The cross-section plane is defined by line 2 and is perpendicular to line 1.





Positioning the observer and the lines of intersection such that the plane of the profile is maximized in length represents the "normal" perspective. Establishing this perspective requires that the boundaries between forms are definable, and this sometimes is a difficult prerequisite to meet. In practice, this may not matter much since, as indicated above, just about any handfull of slices should be sufficient to allow a description of a given form. Indeed, the more complex the form, and the less discernable its boundaries, the less it should matter how the observer is oriented. This is illustrated in Figure 4, which is of a contour map of highly dissected plateaus in Arizona. The forms in this region blend almost imperceptibly into one another. Even so, it seems to be possible to orient the observer in such a way as to establish a "normal" perspective for profiles and cross-sections.

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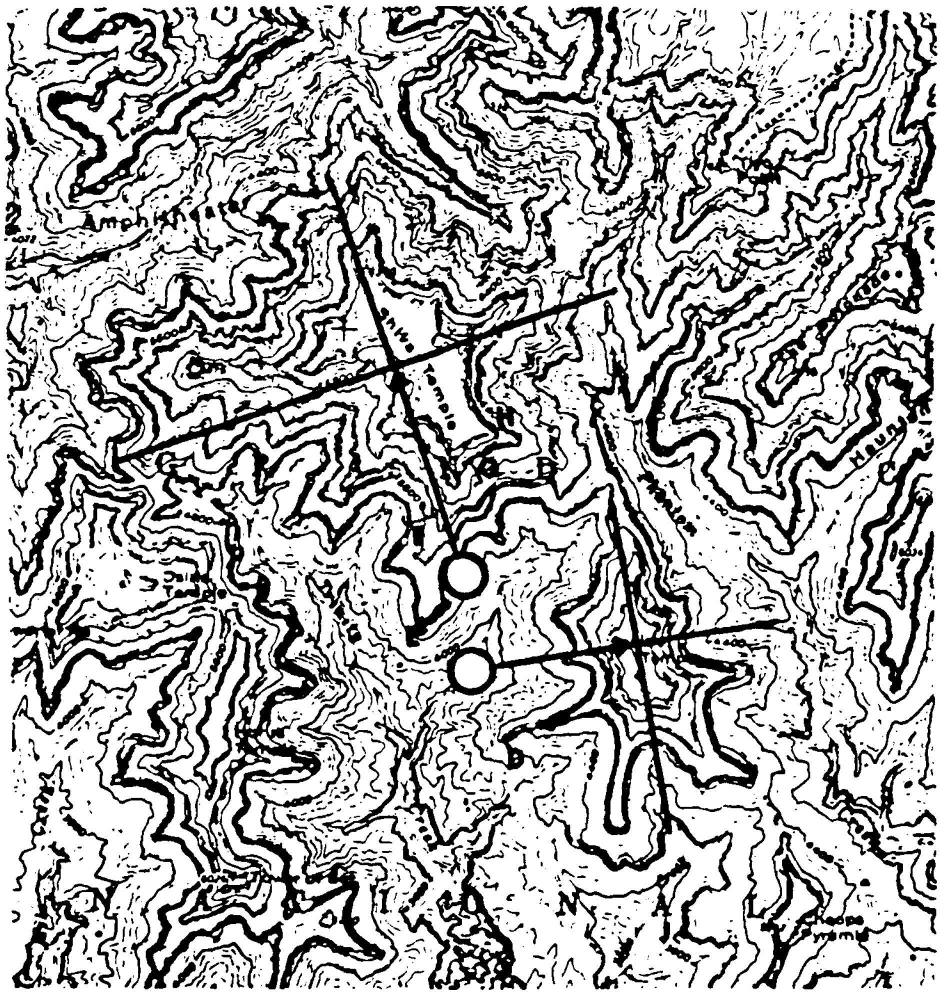
insert Figure 4 about here

FIGURE 4

An illustration of the "normal" perspective for a form whose boundaries are indistinct. This exerpt is from a topographic map showing highly dissected plateaus. Note that the normal perspective for the two plateaus requires a different location for the observer, since the major axes of the two plateaus are in different orientations.



Having defined these three "slices," I can now define other concepts that are used to describe terrain surfaces.

CONVEX: A sloped surface for which a profile or cross-section contains an increase of relief toward the center of the plane of intersection and a decrease of relief toward at least one of the the margins of the plane of intersection, when the plane is centered on the elevation maximum.

CONCAVE: A sloped surface for which a profile or cross-section contains a decrease of relief toward the center of the plane of intersection and an increase of relief toward at least one of the the margins of the plane of intersection, when the plane is centered on the elevation minimum.

Having defined these basic terms to be used in describing terrain surfaces, I can now move on to defining terms and concepts that involve the "scaling" of differences in surfaces.

RELIEF SCALAR

GENTLE RELIEF: Difference of between zero and 100 meters in the relief of points within an area.

MODERATE RELIEF: Difference of between 100 and 300 meters in the relief of points within an area.

STRONG RELIEF: Difference of greater than 300 meters in the relief of points within an area.

SLOPE SCALAR

HORIZONTAL SLOPE: Slope of approximately zero percent.

VERY GENTLE SLOPE: Slope of between zero and five percent.

GENTLE SLOPE: Slope of between 5 and 15 percent.

MODERATE SLOPE: Slope of between 15 and 40 percent.

STEEP SLOPE: Slope of between 40 and 60 percent.

VERY STEEP SLOPE: Slope of between 60 percent up to vertical.

The above two scalars are a traditional part of terrain analysis and topography. However, they appear to be insufficient for providing a full picture of the appearance of terrain, and hence insufficient for the definition of generic topographic terms. For this reason, I found it necessary to look beyond these available scalars.

What is needed is a means for describing the variability of slopes both within a particular form and across various forms within an area. I could find in the literature only one such scalar, which goes by various names and which I refer to as the Slope Change Index, or SCI. To determine the SCI one counts the number of slopes with a positive sign (i.e., the slopes are going up as one moves across the terrain) and the number of slopes with a negative sign (i.e., the slopes are going down as one moves across the terrain). The sum of these two gives the SCI, and is an index of the number of deflections in slope as one moves across forms. This is illustrated in Figure 5.

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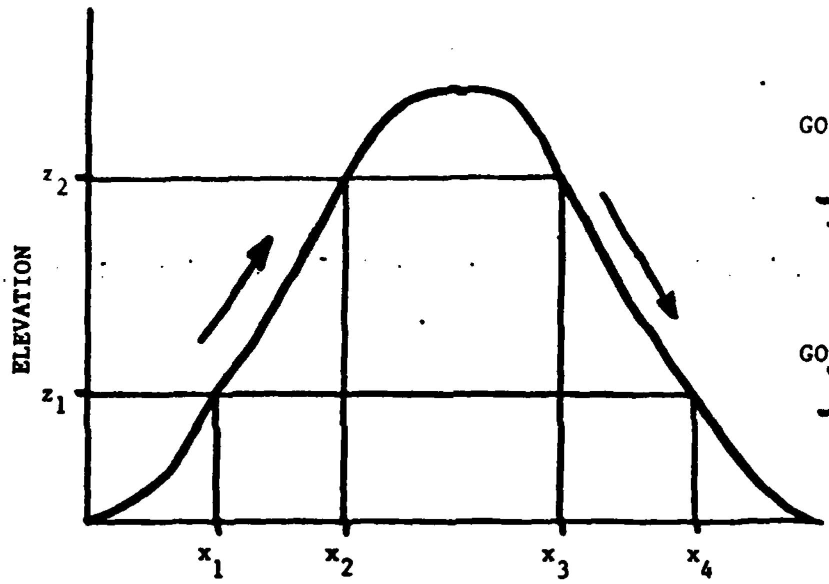
insert Figure 5 about here

FIGURE 5

Illustration of the Slope Change Index, or the number of times the slope changes sign from positive to negative. Capital N represents the counting function. The diagram could be a cross-section or a profile.



$$\frac{X_2 - X_1}{Z_2 - Z_1} = +1 \qquad \frac{X_4 - X_3}{Z_1 - Z_2} = -1$$

$$SCI = \left[1 - \left(N\left(\frac{x_j - x_i}{z_j - z_i} > 0 \right) + N\left(\frac{x_j - x_i}{z_j - z_i} \right) < 0 \right) \right]$$

The major problem with this scalar is that it yields a value of zero for slopes that vary and yet that have no deflection points. Thus, a mountain with very steep slopes and a hill with smooth slopes would have the same SCI even though the slopes on the hill might be more variable (e.g., a steep crest region, a less steep side, and a flared base). This is illustrated in Figure 6. The SCI is able to discriminate between the two "tough cases" but is unabe to discriminate between the clear cases and their corresponding tough cases.

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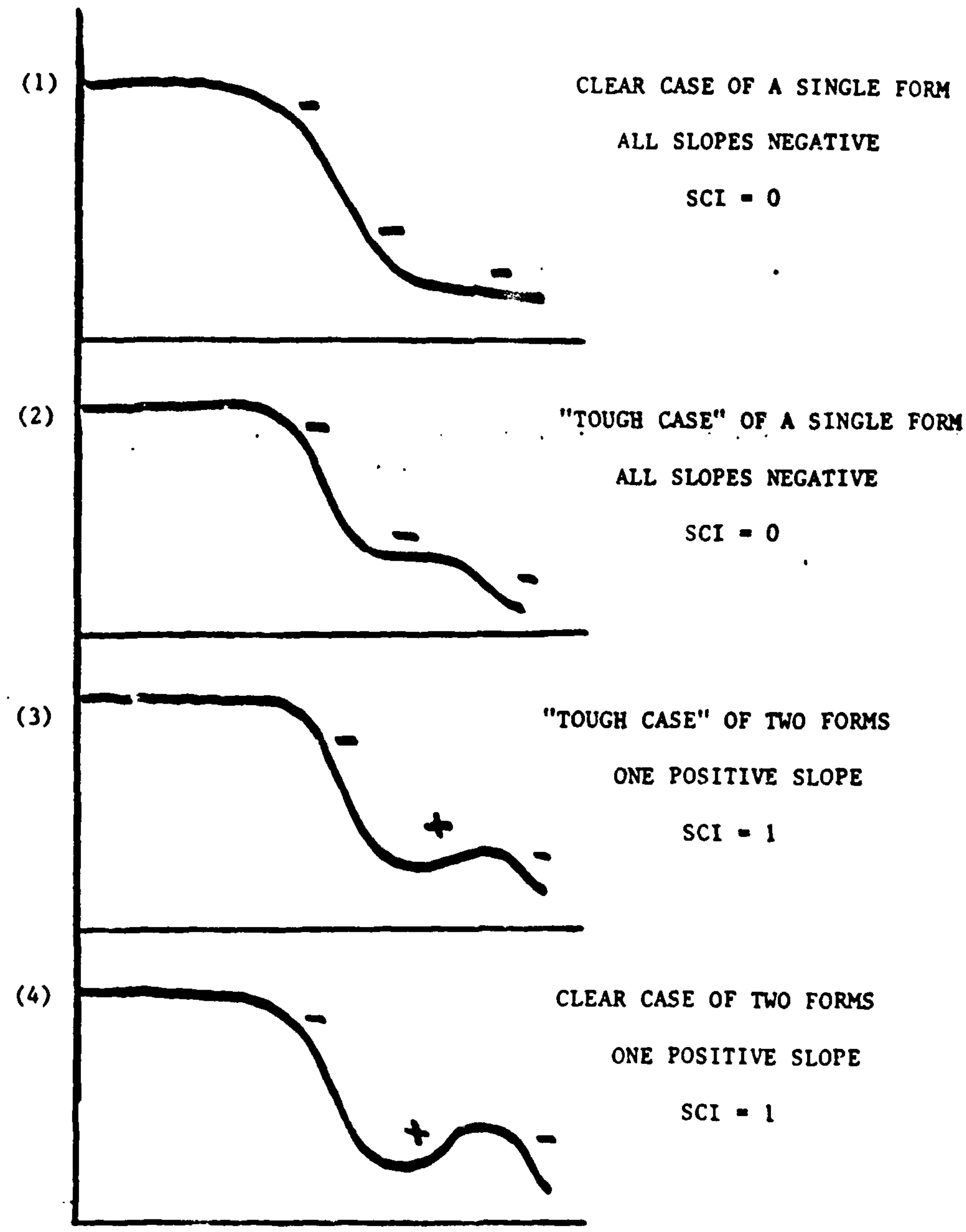
insert Figure 6 about nere

FIGURE 6

An illustration of the Slope Change Index of slope variability. Note that the SCI can discriminate between the two "tough cases," but cannot discriminate each tough case from its corresponding clear case.



Since the SCI is unable to discriminate between the clear cases and their corresponding tough cases, I went in search of additional scalars that might be of use in describing the variability of relief in such a way as to make further discriminations. The metric called relief involves comparing surfaces only in terms of the elevations of two points, the highest and the lowest. What if new metrics are defined which involve more fine-grained analysis and which involve various transformations of the raw elevations other than a single difference?

One possibility that comes to mind immediately is the concept of a slope, the angle of a surface. This angle is computed as the ratio of the differences in values on the two coordinates of a slice (cross-section or profile). What if the slopes at various points along a surface were calculated and these values compared? For most forms, they would differ. For many areas, the values would differ across forms. Can some metric be devised to capture this variability?

That very word, variability, is the key. The statistical concept of the "variance" is a very useful tool in descriptive and inferential statistics. The variance is a measure of the degree to which a set of numbers deviates from its own average value. First one computes the average. Then each of the numbers in the set is subtracted from the average and the resulting value is squared (the arithmatical mean is like a "balance point" and if one does not square the differences, they would sum to zero, for any set of numbers). The squared values are next summed and the result is divided by the number of numbers involved. The result, the variance, is a kind of average, the average degree to which a set of numbers "scatter" or differ from their own average. Calculation and use of the variance is a basic part of statistics and is illustrated in all statistics texts (e.g., Mood, et al., 1974).

One could compute the variance of the slopes, that is, the average of the squares of the deviations of the slopes about their mean slope. This is illustrated in Figure 7. The Slope Variance could take on any positive value from zero (for a flat plane) onward, expressing the degree of variability of the slopes.

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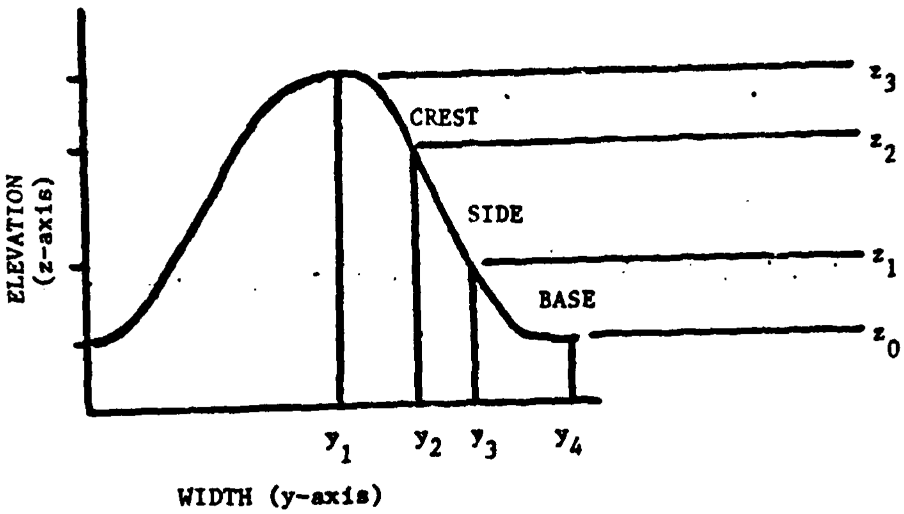
insert Figure 7 about here

FIGURE 7

Illustration of the computation of the Slope Variance. The diagram represents a cross-section. Slopes would be computed for the right and left halves of the cross-section, similar to the formulas shown here for the right half. Six slopes would also be computed for a profile. The letter c stands for components (right and left halves, crest, side and base). S-sub y represents a slope on the y-axis (width or cross-section) and S-sub x represents a slope on the x-axis (length or profile). The mean slope for a form would be the sum of all 12 component slopes divided by 12. The Slope Variance is the average of the squares of the deviations of each of the 12 slopes from their mean.



CROSS-SECTION RIGHT CREST SLOPE $= \frac{\Delta z}{\Delta y} = \frac{|z_3 - z_2|}{|y_1 - y_2|} = S_y$

CROSS-SECTION RIGHT SIDE SLOPE $= \frac{\Delta z}{\Delta y} = \frac{|z_2 - z_1|}{|y_2 - y_3|} = S_y$

CROSS-SECTION RIGHT BASE SLOPE $= \frac{\Delta z}{\Delta y} = \frac{|z_1 - z_0|}{|y_3 - y_4|} = S_y$

MEAN SLOPE $= \overline{X}_s = \frac{\sum_{c=1}^{6} (S_y + S_x)}{12}$

SLOPE VARIANCE $= \frac{\sum_{n=1}^{12} (S_i - \overline{X}_s)^2}{12}$

Together, the Slope Variance and the SCI augment our ability to describe terrain surfaces since they make up for each other's deficiencies. Both the SCI and the Slope Variance would yield a value of zero when a single, unvarying surface is described. For such surfaces, the concepts of surface and slope would be sufficient for descriptive purposes. The Slope Variance has an advantage over the SCI in that the Slope Variance will discriminate cases that the SCI will not. The SCI gives a value of zero for any slope that varies without changing sign. For such slopes, the Slope Variance would yield numbers whose magnitude is in proportion to the degree of variability. Referring back to Figure 6, the Slope Variance would discriminate each tough case from its corresponding clear case. For case (1) the Slope Variance would be less than for case (2), for case (3) the Slope Variance would be less than for case (4). The Slope Variance is sensitive to the magnitude of change across three negative slopes, or across one positive and two negative slopes.

In contrast, the SCI has an advantage over the Slope Variance. Consider a "sawtooth" form in which there are repeating crests with equal slopes between them. As the number of such crests being counted increases, the SCI would keep on increasing. However, since the alternating ascending and descending slopes are all equal, the Slope Variance would remain constant. The SCI does not apply to individual forms that have no slope changes, such as a "rolling" plain. Unlike the Slope Change Index, the Slope variance would apply to all individual forms as well as to areas. Thus, the SCI and Slope Variance augment each other's descriptive powers.

This line of reasoning about the utility of variability metrics can be taken yet another step further. The raw elevation data can also be entered into a calculation of the skew and kurtosis of a profile or cross-section.

These concepts are also basic to descriptive staticstics, as the concept of a variance is. Skew (symmetry) and kurtosis (flatness) are computed in a way very similar to the variance. Both are averages of sums of deviations of a set of numbers from their average. In the case of Slope Variance, the numbers that entered into the calculations were slopes, a derivative of "raw" elevation data (a ratio of differences). For skew and kurtosis, one returns to the raw elevation data. Each elevation point is subtracted from the average elevation. Rather than squaring the differances, if one cubes them the result is informative about skew. If one raises them to the fourth power, the result is informative about kurtosis. Simple. And elegant.

The full formula for Elevation Skew would be:

$$\frac{\sum (e-\bar{e})^3}{\sigma_e^3}$$

and the full formula for Elevation Kurtosis would be:

$$\frac{\sum (e-\bar{e})^4}{\sigma_e^4}$$

where e represents an elevation and $\bar{e}$ represents the average elevation. Unlike for the simple variance, the sums are not divided by N, but by a power of the variance (here, variance of the elevations, not the Slope Variance). This "normalizes" the metrics. Skew can take on values between -1.00 and +1.00, with the extremes representing skew in opposing directions. Kurtosis can take on values that center around 3, with numbers less than 3.00 a sign of flatness ("platykurtic") and numbers greater than 3.00 a sign of peakedness ("leptokurtic").

The full set of metrics, the Slope Variance, Elevation Skew, and Elevation Kurtosis, should in theory be sufficient to describe any distributio of elevations exactly (since the three basic "moments" or deviations about the average are sufficient to describe any distribution of numbers [Mood, et al., 1974]). They are illustrated in Figure 8.

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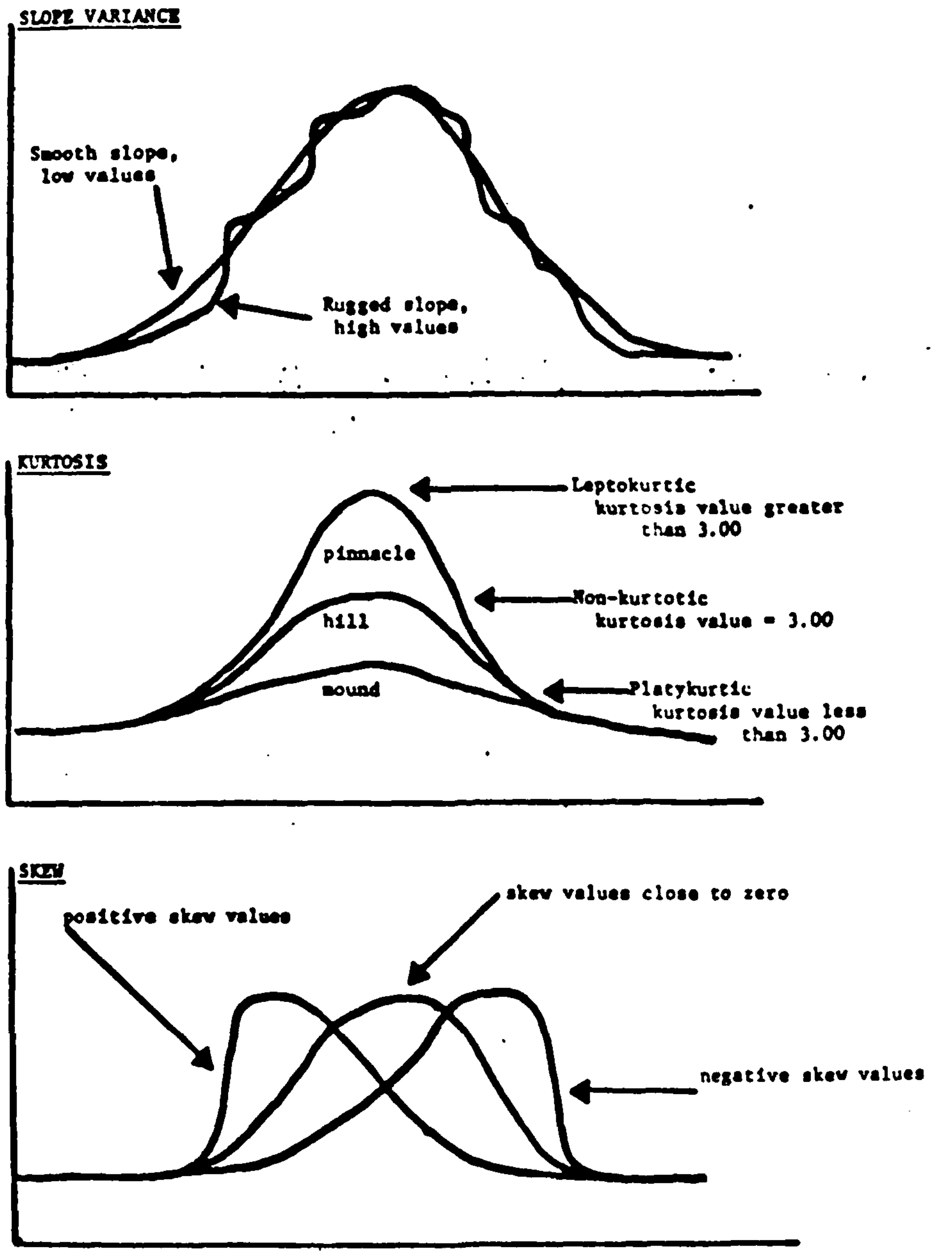
insert Figure 8 about here

FIGURE 8

An illustration of slope variance, kurtosis, and skew.



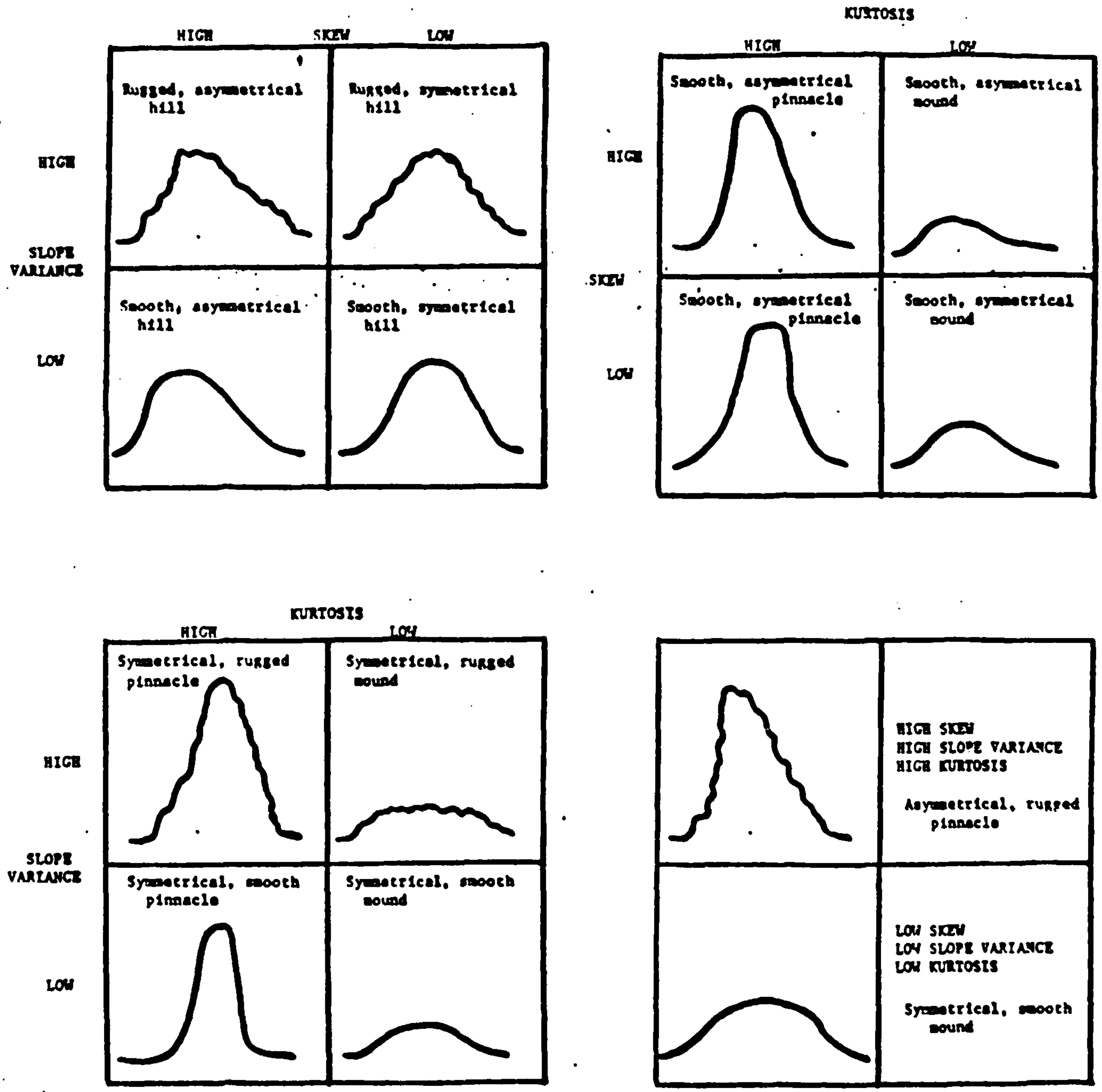
(I should point out parenthetically that the traditional distinction between a hill and a mountain as a difference in relief confounds increasing relief with increasing volume [mass]. Hills are of lower elevation, but one can increase elevation without getting a mountain: If the volume is constant one would get a pinnacle.)

Just and the SCI and the Slope Variance complement each other, so too do the Slope Variance, Elevation Skew and Elevation Kurtosis metrics complement each other. Various combinations of levels of each of these three metrics are illustrated in Figure 9.

----
insert Figure 9 about here

FIGURE 9

The various combinations of levels of slope variance, skew, and kurtosis. For the matrix comparing slope variance and skew, kurtosis was set at at a non-kurtotic value, making the forms hills rather than pinnacles or mounds. For the matrix comparing skew and kurtosis, slope variance was set at a low level, making all the forms smooth. For the matrix comparing slope variance and kurtosis, skew was set at zero, making all the forms symmetrical. The fourth matrix illustrates forms that fall at the extremes of slope variance, skew and kurtosis.



Note that for all of the forms illustrated in Figure 8 and all those illustrated in Figure 9, the SCI would yield the same value (i.e., 1). This is not to say that the three variability metrics replace the SCI. The Elevation Skew and Kurtosis metrics apply to individual forms and the SCI and Slope Variance apply to regions as well as to individual forms. Each of the metrics, the SCI, the Slope Variance, Elevation Skew, and Elevation Kurtosis, discriminates some aspect of the variability of relief. Together, they offer a powerful set of tools since each one makes up for one or another deficiency in the others. This is illustrated in Table 7.

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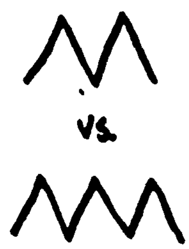
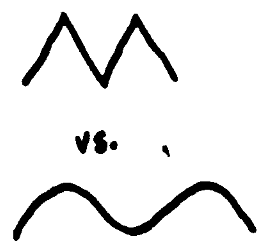
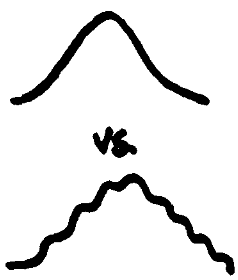
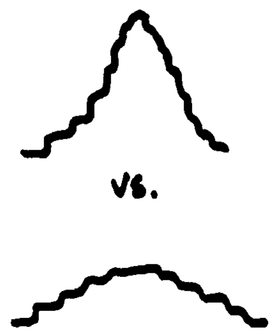
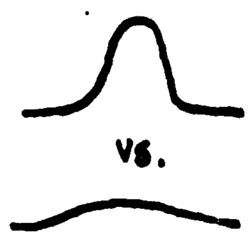
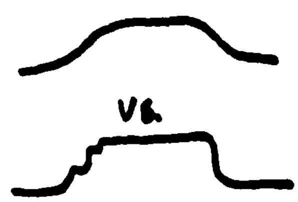
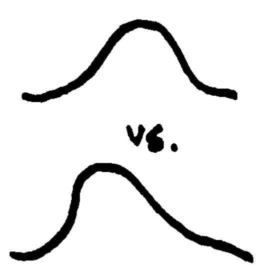
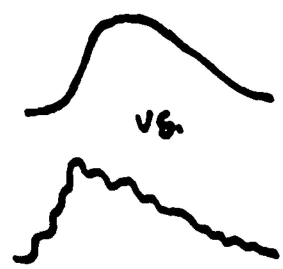
insert Table 7 about here

TABLE 7

A comparison of the slope change index, slope variance, kurtosis, and skew metrics.

METRIC	MEANING	EXAMPLE FORMS IT DISTINGUISHES	EXAMPLE FORMS IT DOES NOT DISTINGUISH
SLOPE CHANGE INDEX	Amount of change in the signs of the slopes, whether or not they are kurtotic or skewed. Assumes non-zero slope variance.		
SLOPE VARIANCE	Variability of the slopes, whether or not they are kurtotic or skewed.		
KURTOSIS	Flatness of the slopes, whether or not they are skewed. Assumes non-zero slope variance.		
SKEW	Asymmetry of the slopes, whether or not they are kurtotic. Assumes non-zero slope variance.		

It should be pointed out that these relief metrics apply to inverted forms, such as canyons or gullys, as well as to elevated forms like hills and plateaus. For example, hanging valleys are skewed in that one slope rises into mountains and another slope declines into a larger valley below. Box-shaped gullys would be defined metrically in the same way as plateaus: The base of the gully is flat and the crest of the plateau is flat. Both have steep slopes and both are leptokurtic with low Slope Variance.

So far in the presentation, I have introduced and defined basic concepts about surfaces (slope, orientation, elevation) and about surface variations (relief scalar, slope scalar, and variability metrics). My study of the use of generic descriptors in the terrain analysis data base showed that we need metrics of surfaces that will enable us to define such things as roughness and knobiness. In Figures 8 and 9 I could hint at this by labeling forms as smooth, rugged, and asymmetrical. Having so far defined basic relief terminology and metrics, I am now ready to get back to task and will use the basic terminology to define generic topographical concepts, with each step closing the gap between topography and perception.

I can now define an important generic concept, "form," much more precisely than by saying that a form is "any perceptually discriminable area" or "any area of homogeneous relief":

FORM: Any subset of surfaces (any area) described in terms of its relief, slopes, Slope Change Index, Slope Variance, Elevation Skew, and Elevation Kurtosis.

What one perceiver sees as a separate "form" may not be what another perceiver sees, nor need it correspond to what terrain analysts call "landforms." The definitions to be provided in the remainder of this Dicsussion will provide further constraints on what a "form" is.

ELEVATED FORM: A form which has non-zero relief and that has elevations that lie above a horizontal plane that is tangential to the lowest elevation in the coverage.

INVERTED FORM: A form which has non-zero relief and has its highest point at an elevation that is coincident with the lowest elevation of the adjacent areas.

In Figure 7 I illustrated the Slope Variance bhy by showing the slope at the crest, side and base of an elevated form. Before going further I need to define these three terms more explicitly.

CREST (apex): The upper quartile of the relief of an elevated form.

SIDE: The middle two quartiles of the relief of an elevated form.

BASE: The lower quartile of the relief of an elevated form.

These three terms will be very useful in what follows. They apply to both elevated and inverted forms. The term "side" was chosen over the common term "slope" so as to avoid ambiguity (see Table 4). Here, "slope" refers only to the angle of a surface.

With the introduction of the concept of a form and its two basic types and three basic components, I can now commence a rather long list of of definitions of generic descriptors, definitions that rely on the terminology of relief to describe the different characters of forms.

FLAT: An area or surface with gentle, non-varying slope that is highly platykurtic but not necessarily horizontal.

SMOOTH: A surface or area with no slope variance.

LEVEL: A surface or areathat is flat or flat and horizontal.

GRADUAL (slope): A surface or area with gentle slope and low Slope Variance.

SUBDUED: A surface with horizontal or very gentle slope, gentle relief, low Slope Variance, and a Slope Change Index value of zero.

ROLLING: A surface without elevated or inverted forms, with platykurtic slope a Slope Change Index value of zero and low Slope Variance.

SYMMETRICAL: When the forms within an area have similar Slope Variances and Elevation Skews and Kurtoses in their profiles or cross-sections as the plane of intersection is rotated about a vertical axis or translated from one form to another.

HOMOGENEOUS RELIEF: When subsets of adjacent surfaces (areas) have profiles and cross-sections with similar relief, SCIs, Slope Variance, and Elevation Skews and Kurtoses. There are no elevated or inverted forms that fall outside the ranges of relief, SCIs, Slope Variance, and Elevation Skews and Kurtoses of a majority of the forms in the coverage.

The concepts of non-symmetricality and non-homogeneity would be defined as the complements of the above definitions.

PREDOMINANT: A form that is the most frequently occurring form within an an area or coverage.

PROMINENT: A form that falls outside the range of relief or slope change or Slope Variance or Elevation Skew or Elevation Kurtosis of the form that is predominant.

LARGE: When the profile, contour, or cross-section of a form is greater than the range of same for a majority of forms of the same characterwithin the area or coverage.

SMALL: When the profile, contour, or cross-section of a form is less than the range of same for a majority of forms of the same character within the area or coverage.

BROAD (wide): When the cross-section of a form is larger than the range of cross-sections for a majority of the forms of the same type within the area or coverage. If all the forms of that type are of homogeneous cross-section, broad is when the largest cross-section of the form is wider than its relief is high. Ths distance from the profile plane to the largest contour on both sides of the profile plane will be greater than the range of same for forms of the same type within the area or coverage. If all the forms in the area are homogeneous in this regard, broad will be when the greatest distance between its profile plane and the largest contour is greater than the form's relief.

NARROW (thin): When the cross-section of a form is less than the range of cross-sections for a majority of the forms of the same type within that area or coverage. If all the forms of that type are of homogeneoous cross-section, narrow is when the largest cross-section of the form is less wide that its relief is high. The distance from the profile plane to the largest contour on both sides of the profile plane will be less than the range of same for a majority of the forms of the same type in the coverage. If all the forms are homogensous in this regard, narrow is when the greatest distance between the profile plane and the largest contour is less the form's relief.

LONG: When the profile of a form is greater than the range of profiles for a majority of the forms of the same tyoe within the area or coverage. If all the forms of that type are of homogeneous profile, long is when the largest profile of the form is greater than its relief is high.

SHORT: When the profile of a form is smaller than the range of profiles for a majority of the form of the same type within the area or coverage. If all the forms of that type are of homogeneous profile, short is when the largest profile of the form is less than its relief is high.

DEEP: When the relief of an inverted form is greater than the range of relief in the adjacent areas.

SHALLOW: When the relief of an invertad form is less tha the range of relief of the adjacent areas.

EXTENSIVE: A large, broad, or wide form. Its largest profile plane will have an area that is larger than that of a majority of the forms of the same type within the area or coverage. coverage.

MASSIVE: An extensive form with moderate to strong relief.

SPACED (spacing): The horizontal separation between forms in an area or coverage.

ISOLATED: A form that is the only form of its character within an area or coverage, or a form that is spaced from other forms of the same character within the same area or coverage by a distance that is equal to or greater than the largest axis in the contour plane of the form that is predominant.

DISTINCT: A form that is isolated or prominent, or which has an SCI=1 or high Slope Variance between it and the adjacent surfaces or forms, or which has a flat base or an inverted form between it and the adjacent surfaces or forms.

CONTINUOUS (interconnected): When the forms within an area are not spaced and each form shares part of its side, crest or base with an adjacent form.

DISCONTINUOUS: When the forms within an area are spaced and the area has slope changes in profile or cross-section.

REPEATED: When there is more than one form of the same character in an area or coverage.

LINEAR: Repeated forms that have profiles or cross-sections that are parallel and colinear as the axis plane is translated from form to form.

PARALLEL: Repeated forms that have profiles or cross-sections that are parallel as the axis plane is translated from form to form.

CLUSTERED: When a form is repeated within an area with little spacing between the forms and when the area is isolated relative to the adjacent areas.

WINDING (curvilinear): When a form or a linear cluster of forms has curvature along its profile plane.

SCATTERED: Repeated isolated forms within a coverage.

COMPOUND: When repeated forms are continuous.

BRANCHING: When a form furcates into two or more forms along its profile, or when a set of continuous repeated linear forms furcates into two or more sets of continuous forms with parallel profiles.

DISSECTED: A form with inverted forms within it.

FLARED: A base with a cross-section or profile which is of moderate to very steep slope and moderate to low Slope Variance at its higher elevations, and which is concave or convex at its base.

CIRCULAR: A form with round contours.

ELLIPTICAL: A form with elliptical contours.

FAN-SHAPED: A form with convex contours.

DISH-SHAPED: An inverted form with concave sides and base.

OVAL: A form with elliptical contours.

CIGAR-SHAPED: A long oval form.

CONICAL: A circular elevated form with very steep to moderately steep sloped convex sides, low to moderate Slope Variance, leptokurtic, and non-skewed.

ANGULAR: Repeated ascending and descending sides that are flat or of moderate to very steep slope, moderate to strong relief, and low Slope Variance.

RUGGED (rough): An elevated or inverted form or repeated forms with moderate to strong relief, steep to very steep sloped sides, and moderate to high Slope Variance.

COLUMNAR: Elevated forms with very steep slope sides, small, and flat or slightly convex crests, and bases that are narrow.

At this point, I need to define a "ridge" in order to define the descriptors that apply to ridges.

RIDGE: A crest that is long and narrow.

JAGGED: A crest or ridge that is rugged or angular.

SCALLOPED: A ridge or base with repeated concave sides with parallel cross-sections or profiles that maximize the concavity of each side.

SAWTOOTHED: An angular ridge of compound repeated crests of equal spacing and homogeneous relief.

SADDLED: A ridge that is convex in profile and concave in cross-section.

FINGER: A long, elevated form with a ridge.

SHARP: A crest or ridge with steep or very steep sloped sides.

HOGBACKED: A jagged ridge with repeated ascending and descending sides with equal spacing and homogeneous relief and orientation.

KNIFE-EDGED (peaked): A crest or ridge with steep to very steep slope and low Slope Variance

KNOBBY: When a form or cluster of forms has a narrow, convex crest, and convex profiles and contours with moderate to steep sloped sides with moderate to low Slope Variance.

BLOCKY: A non-skewed leptokurtic elevated form or cluster of continuous elevated forms with low Slope Variance, steep or very steeply sloped sides, and a flat sloped crest.

LOBATE: Compound elevated forms with high Slope Variance and high Slope Change Index values. The component forms are continuous, highly skewed, moderately kurtotic, and have convex crests.

LUMPY: Compound elevated forms with high Slope Variance and high Slope Change Index values. The component forms are continuous, moderately kurtotic, with have convex crests and profile and contour planes of similar extent.

POCKMARKED (pitted): A surface that has within its contour repeated, small, circular or elliptical platykurtic convex inverted forms with varying relief, gentle to moderate slope sides, and a flat or convexs base.

STAIRSTEPPED: Crests, sides or bases whose contours or cross-sections have surfaces that alternate between low relief with very gentle to horizontal slope, and moderate to very strong relief with moderate to very steep slope.

V-SHAPED: An inverted form with steep to very steep sides with low Slope Variance, and a narrow base.

U-SHAPED: An inverted form with steep concave sides and a concave base.

BOX-SHAPED: A non-skewed leptokurtic elevated form with a flat crest and very steep slope sides with low Slope Variance, or a leptokurtic inverted form with a flat base and very steep slope sides with low Slope Variance.

TRAPEZOID-SHAPED: A leptokurtic inverted form with a flat base and steep to moderately steep slope sides with low Slope Variance.

So far, I have focused on generic descriptors, although along the way

I have had to define a few generic terms (such as "ridge"). With the definitions of the descriptors in hand, I can now proceed to define some generic terms. My discussion of generic descriptors was step-wise in that later definitions relied heavily on earlier ones. For generic terms, I can go through them and their definitions in alphabetical order (even though there are a few sequential dependencies, e.g., a horn is a type of mountain crest). I begin with elevated forms, followed by inverted forms.

ELEVATED FORMS

ARCH: The crest of an elevated form.

BLUFF: A steep, high, broad slope valley side.

BUTTE: Small, isolated hill with steep slope sides and a flat or horizontal crest.

CLIFF: Vertical or overhanging side of moderate to strong relief, with slopes greater than 50 degrees to to 90 degrees, and beyond 90 degrees for overhanging cliffs.

DOME: A hill or mountain with concave cross-sections and profiles and elliptical or oval contours. Can be small or large and broad.

ESCARPMENT: Steep or very steep sloped side of a ridge that separates two gently sloped or flat areas.

HILL: Elevated form with relief less than 700 meters.

LOW HILL: Hills with moderate to steep sloped sides, relief between 160 and 320 meters, and slopes between 30 and 40 degrees.

HIGH HILL: Hills with steep slopes, gentle relief, and convex crests. Relief of between 320 and 600 meters and slopes generally greater than 40 degrees. Spaced by steep sloped valleys with narrow floors.

HORN: Mountain crest with four distinct, very steep sloped sides.

LOWLAND: An extensive, broad, or large area of homogeneous relief that is at lower relative elevation than adjacent areas in the coverage.

MESA: Broad, isolated mountain or hill with a horizontal or flat crest. Extends from an escarpment or cliff on at least one side and is of greater relief than the adjacent forms or surfaces on all sides.

MOUND: An elevated form of low Slope Variance and less than 100 meters in relief.

MOUNTAIN: Elevated form with moderate to very steep slope sides, and rising to a peak or a ridge with small area in contour. More than 700 meters in relief.

MOUNTAIN BELT: A cluster of closely spaced or continuous mountains that is compounded of more than one parallel or linear cluster of mountains.

MOUNTAIN RANGE: A linear cluster or cluster of parallel, closely spaced or continuous mountains

NEEDLE: A small pinnacle that is adjacent to or continuous with the base of an elevated form of greater relief.

PEAK: A mountain crest with small area in contour, moderate to very steep sloped sides, and low Slope Variance.

PINNACLE: Narrow, isolated, leptokurtic form with very steep to vertical slope sides, a base that is flared, and a peak or flat crest.

PLAIN: A broad, continuous surface of gentle relief, horizontal, flat or gentle slope, and having only small, isolated variations in relief. There are no prominent elevated or inverted forms within its contour.

LOW PLAINS: Plains with gentle relief of between 20 and 60 meters, slope commonly less than 3 degrees.

HIGH PLAINS: Plains with gentle to moderate relief of between 60 to 160 meters, with slope ranging from horizontal to 15 degrees.

PLATEAU: High, broad plain with horizontal or flat slope and with an escarpment or cliff on at least one side. Uusuzlly of more than 150 to 300 meters relief.

TERRACE: A long, flat, narrow, horizontal or gently sloped surface lying along the contour of a valley side or other inverted form, and thus lying between a floor or plain and an upland or steeper ascending side.

UPLAND: An extensive, broad, or large area of homogeneous relief that is at higher elevation than adjacent areas in the coverage.

INVERTED FORMS

BASIN: An isolated depression enclosed by uplands. Can range from small vzlleys to large, mountain-rimmed depressions.

CANYON: A deep, narrow, long, very steep sloped passage between elevzted forms or cut into an inverted form. Usually the floor is occupied by a river or stream.

CRATER: A depression that is circular in contour and has a knife-edged ridge, a concave crest, and broad, concave, conical outer sides.

DEPRESSION: An inverted form with a concave profile and cross-section.

GORGE: A deep, very steep sloped, very narrow passage between closely spaced elevated forms or cut into an inverted form. Usually the floor is occupied by a river or stream.

VALLEY: A broad depression or lowland with horizontal to gentle slope with gentle to moderate relief and low Slope Variance, and that is bordered on at least two sides by uplands. Usually the floor is occupied by a river.

This concludes my presentation of definitions. With all these definitions behind us, it may not be clear how the later ones rely on the earlier ones. An example might proove instructive. A horn is defined as a kind of mountain peak, a peak is a kind of crest, a crest is a kind of elevated form, an elevated form is a kind of sloped surface. My point here is that all the various descriptors and terms should be consistent and coherent with one another. For instance, a rugged plain would be defined as:

> A broad, continuous and possibly flat surface of gentle relief, horizontal to gentle slope, with small isolated variations in elevation (the "plain" part) and that has within its contours repeated inverted forms with moderate to strong relief, steep to very steep sloped sides, and moderate to high Slope Variance (the "rugged" part).

As another example, a knobby ridge would be defined as:

> A crest that is long and narrow (the "ridge" part) and is compounded of forms with narrow, convex crests with moderate to steep slope sides with moderate to low Slope Variance (the "knobby" part).

The above list of descriptors, terms, and their definitions allow for many combinations and permutations, all of which should be consistent and coherent.

FURTHER WORK TO BE DONE

There are, no doubt, a number of "glitches" in the definitions that have been offered here, both in terms of the individual definitions and in terms of their combinations. These will have to be identified and corrected.

A number of relief-related descriptors appear in Appendix 1 and have not been defined here. Time did not permit me to define them, yet I believe that definitions can be derived. Some terms in need of definition are: bay, desert, dune, and prarie. Descriptors in need of definition are: beaded, blended, bold, closed, concentric, crescent-shaped (dunes), hook-shaped, hummocky, intersecting, scrabbled, snake-like, star-shaped (dunes), and wave-shaped.

In this discussion I have focused on generic terms and descriptors that refer to relief. Further work will be needed to define those generics that refer to tones (e.g., fringed, dark, banded), soils (e.g., soil creep), drainage patterns (e.g., arcuate), vegetation (e.g., forested), and rock types (e.g., stratified, bedded, faults [faulted], folds [folded], fissures, joints [jointed], lineaments, troughs, displaced, exfoliated, tilted, uplifted). Here too, Appendix 1 and Appendix 2 would be the starting point.

Throughout this discussion I have been describing terrain and terrain forms without reference to formation process or geological dynamics. In other words, I have been describing forms, not landforms. The definitions offered here should be sufficient to describe landforms in such a way as to allow for precise description of their features. For example, here are a few candidate definitions for some landforms:

CINDER CONE: A conical elevated form with concave sides and either a concave crest or a crater.

CIRQUE: Small, steep slope basin which is circular in contour and concave in profile and cross-section and exists as an inverted form in a mountain side, usually at the end of a valley. Usually less than 300 meters in contour diameter. The side that is adjacent to or continuous with the upland has very steep slope down to a slope change at the base. The base gradually falls into the lowland or vallay base.

COASTAL PLAIN: Broad plain of gentle relief bordering the sea on one side upland on the other. Rises with gentle slope from the sea, often in a series of terraces of gentle to moderate relief, and leads up to hills of 100 to 300 meters relief. Usually contains at least one major stream.

DRUMLIN: A long elevated form with a skewed profile, elliptical contours, moderately steep slope sides, and a convex crest. Usually less than 1.6 kiulometers long and usually located within a rolling plain. Usually clustered, sometimes compound.

SINKHOLE: A cicrular or elliptical, leptokurtic, convex inverted form with steep to very steep slope sides with low Slope Variance, and a flat or convex base. Usually located within a plain or subdued or rolling plain.

Further work will be needed to generate definitions for other landforms.

Time did not permit me to apply the concepts of Slope Variance, Elevation Skew, and Elevation Kurtosis to actual elevation data to compare values for actual forms and regions. However, the use of the variance and its derivatives is a straight-forward process. Elevation Skew and Kurtosis are directly computable from elevation data and the Slope Variance is a simple derivative of the elevation data (i.e., a ratio of differences). It has not escaped my attention that these concepts imply an entire program of basic topographical research, perhaps involving both field measurements as well as theoretical calculations.

It has also not esacaped my attention that the definitions offered here can be used in terrain descriptions for military purposes. For example, the concept of a "back slope" could be defined as: "An ascending slope behind the Observer as the Observer descends along a profile or contour toward or beyond a change in the slope." Further work will be needed to apply the above definitions of descriptors and terms to other concepts that are used by the military in their descriptions of terrain.

The nex big "piece of the puzzle" of how to generate artifical intelligence systems for aerial photo interpretation is the question of how to use these definitions of generic descriptors and terms in symbolic communications with the human operator of the expert system.

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APPENDIX 1

An alphabetical listing of the adjectives used in Hoffman's (1984) terrain analysis data base. Frequency data refer to how often a descriptor was applied to a given topic. The terms in parentheses following some of the descriptors appeared in the data base as modifiers or variants of the descriptors or topics.

PREDICATE OR DESCRIPTOR	TOPIC TO WHICH THE PREDICATE IS APPLIED	FREQUENCY OF USE
(1) abundant	soil (sand)	1
(2) active	dunes	6
(3) aeolian	deposits	2
(4) anastamotic	drainage pattern	2
(5) alluvial	deposits	1
	deserts	1
	fans	6
	landforms	1
	plains	2
	soils	2
(6) angular (acute, angled, right-angled, sharp)	drainage pattern	4
	field patterns	1
	gullys (streams, tributaries, intersections)	16
	ridges	1
(7) annular (ring)	drainage patterns	4
(8) apex	fan	1
	horn	1
(9) arcuate	deltas	1
	streaks	1
(10) artificial	drainage patterns	3
(11) banded	hills	1
	tones	15
	vegetation	1
(12) barbed	drainage pattern	1
(13) barchan	dunes	1

(14) bare	rock	2
	soils	2
(15) barren	dunes	7
	land	12
(16) beach	dunes	1
	ridges	3
(17) beaded	eskers	1
	ponds	1
(18) beds (bedded)	rock	4
(19) birdsfoot	deltas	1
(20) blended	relief	1
(21) blocked	drainage pattern	3
(22) blocky	hills	5
	profile	1
	ridges	1
(23) bold	domes	1
	hills	1
(24) boulder	deposits	3
(25) box-shaped	gullys	6
(26) braided	drainage patterns	7
	gullys (streams)	1
	scars	1
(27) branching	hills	1
	ridges	2
(28) broad	base	2
	dome	1
	gullys (meanders)	2
	horns	1
	meanders	1
	plains	7
	ridges	1
	slope	2
	valleys	1
(29) centrifugal	drainage pattern	1
(30) centripetal	drainage pattern	1
(31) channel (stream, sand)	scars (streaks)	4
(32) cigar-shaped	hills	1

(33) circular	depressions	1
	domes	1
	drainage patterns	1
	hills	1
	sinkholes	2
(34) cirque	valleys	1
(35) close	gullys	1
(36) closed	topography	1
(37) clustered	craters (cinder cones)	1
	dome	1
	drumlins	1
	dunes	1
	gullys	1
	lineaments	1
	mounds	1
	sinkholes	1
(38) coarse	drainage pattern	8
	soils	8
	texture	3
(39) coastal	plains	3
(40) cohesive	soils	3
(41) columnar	escarpments	1
	joints	1
(42) compound	domes	1
	slopes	2
(43) concave	hills	1
	slopes	1
(44) concentric	depressions	1
	drainage pattern	1
	knobs	1
	ridges	1
(45) conical	hills	3
	mounds	1
(46) continental (alluvium)	plains	2
(47) continuous (discontinuous)	drainage pattern	7
	eskers	1
	gullys (streams)	3
(48) contoured	plowing	7
	tone pattern	1

	tree pattern (orchards)	1
(49) convex	delta (edge)	1
	slopes	1
(50) creep	rock	1
(51) crescent-shaped	dunes	1
(52) cultivated	hills	2
	land	5
	plains	4
	slopes	3
	uplands	3
	valleys	4
(53) curvilinear (curved)	beds (sheets, rock beds)	3
	field patterns	3
	gullys	4
	joints	1
	ridges	4
	slopes	1
	tone streaks	4
	valleys	3
(54) dark (very)	tones (tone streaks)	23
(55) deep	gorges	1
	gullys	2
	sinkholes	1
	soils	4
(56) dendritic (tree-like)	drainage pattern	34
(57) dense	forest	3
	vegetation	4
(58) deranged	drainage pattern	4
(59) desert varnish	tone	2
(60) dichotomic	drainage pattern	3
(61) dish-shaped (profile)	crater	1
(62) displaced	rock	1
(63) dissected (highly, undissected)	dome	1
	land	1
	mountains	1
	plains	5
	plateau	1
	ridges	2
	topography	3
(64) distinct (indistinct,	drainage pattern	2

abrupt, sharp, not sharp, even, perfect)	dunes	1
	edges (to sinkholes)	1
	field patterns	3
	gullys	1
	landform boundary	8
	tones	2
	soil moisture	1
(65) dome-like	elevations	1
	hills	2
(66) drained (well, poorly)	soils	2
(67) dry	lakebed	1
	soils	2
(68) dull	tones	2
(69) durable	rock	1
(70) elastic	soils	2
(71) elevated	plain	1
(72) elliptical (ellipsoid)	bays	1
	depressions	1
	dome	1
	sinkholes	1
(73) equal (unequal, differing, varying)	drainage	1
	elevations	12
	shapes	2
	sizes (depressions, ponds)	2
	slopes	2
	tones	3
	topography	1
(74) eroded (erodable, highly)	land	2
	soils	4
(75) even (uneven)	terrain	1
	topography	1
(76) estuarine	delta	1
(77) exfoliated	dome	1
(78) expanding (expandable)	soils	1
(79) extensive	floodplains	1
	plains	1
(80) fan-shaped	deposits	1
	drainage pattern	1
	plain	1

(81) faulted (disrupted)	beds	1
	rock	2
(82) few (occasional, nc)	beds	2
	fans	1
	gullys (meanders)	24
	orchards	1
	ridges	1
	rock outcroppings	1
(83) field tile	drainage pattern	5
(84) fine	drainage density	13
	soils	7
	texture	1
(85) finger	lakes	1
	ridges	2
(86) flared	base	4
	ridges	2
(87) flat (very)	beds	1
	deltas	2
	depression bottoms	1
	drumlins	1
	gully bottoms	3
	hills (tops)	2
	land	3
	plain	8
	ridge	1
	rock	9
	topography	11
	valleys	3
(88) flood	plains	7
(89) fluvial	fans	1
	landforms	1
(90) folded	rock	2
(91) forested (deforested, heavily)	hills	5
	land	7
	lowlands	1
	plain	1
	ridges	2
	slopes	5
	v-lleys	1
(92) fringed	tones	2
(93) gentle	relief	1
	slopes	6
	topography	1

(94) glacial (glaciated)	features (forms)	1
	lakebed	3
	terrain	1
	till (soil)	2
(95) gradual	slope	5
(96) granular	soils	2
(97) grass	land	27
(98) grey	tones	1
(99) hair-like	drainage channels	1
(100) hanging	valleys	1
(101) heavy	forestation	1
	scrub	1
	vegetation	1
(102) hexagonal	drainage pattern	1
(103) high (higher)	arch (to a slope)	1
	elevations	1
	plain	1
	water holding capacity	1
	water table	2
(104) hilly	terrain	1
(105) hogback	ridges	2
(106) homogeneous	rock	1
	soil	1
(107) hook-shaped	mounds	1
(108) horizontal	plain	1
(109) hummocky	dunes	1
(110) inactive	gullys (streams)	1
(111) increasing	slope	1
(112) infiltration	basins	3
(113) inland	ponds	1
	ridges	1
(114) integrated (well)	drainage pattern	1
(115) intense (intensive)	agriculture	3
	cultivation	4

(116) interbedded	rock	12
(117) interconnected	eskers	1
(118) intermittent	drainage pattern	1
(119) internal	drainage pattern	15
(120) intersecting	fractures	1
	gullys	2
	lineaments	1
(121) intrusive	rock	4
(122) irrigation	drainage pattern (ditches)	5
(123) isolated	hills	1
	mounds	1
	trees	1
(124) jagged	needles	1
	pinnacles	1
	profile	1
	ridges	2
(125) jointed	hills	1
(126) knife-edged (knife-sharp)	crater	1
	ridges	1
(127) knobby	hills	5
	mounds	1
	ridges	2
	texture	1
(128) lake	beds	3
(129) large (major)	depression	2
	gullys (stream channels)	5
	plain	4
	sinkholes	2
(130) lattice	field pattern (orchards)	1
(131) level	plains	1
	terrain	1
(132) light (lighter)	tones	61
(133) linear	beach ridges	1
	dome	1
	faults	1
	folds	1
	hills	2
	relief	1

	tone streaks	2
	troughs	1
	valleys	1
	vegetation pattern	2
(134) little (slight, no occasional, some)	agriculture	2
	cultivation	2
	drainage pattern	6
	forestation	1
	hills	1
	meandering (streams)	1
	moisture (soil)	1
	soil	1
	vegetation	4
(135) loaded (heavily)	gullys (streams)	1
(136) lobate	lava flows	2
(137) loess	plains	2
	soils	4
(138) long (elongated, very)	bay	1
	depressions	1
	escarpments	1
	faults	1
	fissures	1
	gullys	2
	hills	2
	mounds	1
	ridges	8
	sinkholes	2
	slopes (gradients)	1
	valleys	3
(139) longitudinal	dunes	1
(140) low (low-lying)	hills	2
	prarie	1
	profile	2
	relief	1
	ridges	1
	water holding capacity	1
(141) lumpy	hills	1
(142) lush	vegetation	2
(143) many	gullys (streams)	7
	hills	1
	inlets	1
	islands	1
	ponds	1
	ridges	1
	swamps	1

	terraces	1
	valleys	1
(144) massive	beds	3
	domes	2
	hills	2
	ridges	1
(145) mature	crops	1
	streams (drainage pattern)	1
(146) meandering (significant)	eskers	1
	gullys (streams, channels)	5
(147) medium	drainage density	2
	tones	24
(148) mineral	deposits	3
(149) minor	terraces	2
(150) mixed	soils	1
(151) moderate	slope	1
(152) moist (wet)	base	1
	land	2
	soils	6
(153) mottled (slightly, occasional, sharp)	tones	14
(154) mountainous	topography	1
	uplands	1
(155) mud	deposits	1
	flats	1
(156) narrow	bays	1
	beds	1
	crests	1
	deltas	1
	floodplains	1
	gullys	2
	horns	1
	joints	1
	ridges	6
	slopes	1
	valleys	2
(157) offset	beds	1
	gullys (streams)	2
(158) old	drainage pattern	1
	plains	7
	till	1

(159) outwash	plains	4
(160) oval	hills	1
(161) oxbow	lakes	1
(162) parallel	axis (dunes)	2
	bays	1
	depressions	1
	drainage pattern	6
	drumlins	2
	dunes	1
	gullys (streams)	7
	hills	1
	joints	2
	lakes	1
	lineaments	1
	ridges	15
	uplands	1
	valleys	4
(163) peaked	crests	1
	ridges	1
(164) perfect	outline (lake)	1
(165) permeable (impermeable, low permeability, less, imprevious)	rock (bedrock)	2
	soils	4
(166) perpendicular	vegetation pattern (by gullys)	1
(167) pinnate (feather-like)	drainage pattern	4
(168) pitted	plain	1
	texture	1
(169) plastic	soils	3
(170) pockmarked	dunes	1
	plains	1
(171) polygonal	drainage pattern	1
	ponds (frost wedges)	1
(172) porous (highly)	rock	1
	soils	3
(173) radial (radiating)	drainage pattern	8
	fractures	1
	gullys (streams)	3
(174) random	drainage pattern	1
(175) range	land	1

(176) raised	dome	1
	rock	1
(177) rapid	erosion	1
(178) rectangular (nonrectangular)	drainage pattern	9
	field pattern	12
	tree array (orchards)	1
(179) regular (irregular)	drainage pattern	1
	field pattern	4
	gullys	1
	hills	3
	plains	1
	topography	2
(180) repeated	hills	1
(181) resistant (more, less)	rock	3
(182) rolling (gently)	plains	7
	prarie	5
	relief	1
	slopes (gradients)	9
	surfaces	1
	terrain	1
	topography	6
	uplands	1
(183) ropey	lava flows	1
	profile	1
(184) rose-shaped	rock (granite)	1
(185) rough	slopes	1
	texture	1
(186) round (rounded)	contours	1
	crests (tops)	4
	depressions	1
	drumlins	1
	hill (tops)	14
	mounds	1
	profile	2
	ridges	7
	sinkholes	1
	slopes	1
	terraces	1
	topography	4
	valleys	1
(187) row	crops	2
(188) rugged (very)	hills	1
	mountains	3

	plains	1
	topography	8
(189) saddle	ridges	2
(190) salt	flats	1
(191) saucer	gullys	11
(192) sawtooth	ridges	5
(193) scalloped	bases	1
	dunes	1
	hills	4
	rocks	1
	slopes	3
(194) scattered	buttes	1
	forests	4
	mesas	1
	orchards	1
	plateaus	1
(195) scrabbled	surface	1
(196) scrub	land	4
(197) shallow	depressions	1
	gullys (channels)	1
(198) sharp	crests	2
	hill	1
	peak	1
	ridges	7
(199) short (shorter)	fans	1
	gullys	7
	joints	1
	ridges	2
	slope	2
(200) shrub	land	10
(201) silky	texture	1
(202) silty	soil	7
(203) slump	soil	1
(204) small (very, minor)	depressions	3
	domes	1
	gullys	3
	hills	1
	islands	1
	knobs	1
	plains	1

	ponds	1
	ridges	3
	valleys	2
(205) smooth	hills	3
	ridges	2
	slopes	5
	terraces	1
	texture	4
	topography	1
(206) snake-like	ridges	1
(207) soil	deposits	4
(208) spaced (widely, closely, evenly)	gullys	2
	joints	1
	ridges	1
(209) sparse	vegetation	2
(210) spurred	drainage pattern	1
(211) stable (stabilized)	dunes	4
	gullys (stream channels)	1
	slope	2
(212) stairstep	slopes	2
(213) star-shaped (many-pointed)	dunes	2
(214) steep (steeper, moderate, very)	bluffs	1
	cliffs	1
	drumlins	1
	escarpments	1
	gullys	6
	hills	4
	mounds	1
	pinnacles	1
	ridges	5
	slopes (gradients, sides)	30
	valleys	1
(215) straight	gullys (tributaries, streams)	2
	ridges	1
	slopes	1
(216) stratified (layered, unstratified)	rock	3
	soils	5
(217) streaked	plain	1
	sand	3
	tones	4
(218) striped	tones	2

(219) strong	relief	2
(220) subdued	topography	1
(221) surface (subsurface)	deposits (minerals, soils)	1
	drainage pattern	4
	erosion scars	1
	ice	1
(222) symmterical (asymmetrical, central-point)	drainage pattern	[illegible]
	hill	1
	mountains	2
	ridges	3
	slopes	7
(223) table	rock	2
(224) tarn	lakes	1
(225) talus (rubble)	deposits	9
(226) teardrop-shaped	hills	1
(227) terraced	canyons	1
	gorges	1
	hills	4
	slopes	4
(228) thermokarst	drainage pattern	2
(229) thick	beds	6
	plain	2
	ridges	1
	soils	1
(230) thin (thinner)	beds	9
	plain	2
	ridges	1
	soils	2
(231) tidal	basin	1
	flats	2
(232) till	plains	5
(233) tilted (not tilted)	beds (rock)	13
	plains	1
(234) transverse	dunes	1
(235) trapezoid	gullys	5
(236) trellis	drainage pattern	4
(237) undeveloped	drainage pattern	1

(238) undulating (slightly)	hills	2
	lowlands	1
	plains	2
	topography	5
(239) uniform (non-uniform)	angle (gullys)	1
	depressions	1
	erosion	1
	rows (crops)	1
	slopes (gradients)	10
	soils	1
	tones	2
	topography	2
(240) uplifted	beds (rock)	1
(241) U-shaped	dunes (wind-drift)	2
	gullys (profiles)	15
	valleys	1
(242) varying (sizes)	craters (cinder cones)	1
(243) vertical	beds (rock)	1
	bluffs	1
	cliffs	2
	escarpments	2
	fractures	1
	slopes	1
(244) V-shaped	dunes	1
	gullys (profiles)	34
	valleys (profiles)	1
(245) wave-shaped	dunes	1
(246) wide	faults	1
	gully (bottoms)	4
(247) winding	ridges	1
(248) yazoo	drainage pattern	1
(249) young	domes	1
	drainage pattern	1
	plain	6

APPENDIX 2

A listing of the adjectives used in terrain analysis, alphabetically entered according to the topic to which the adjectives are applied. As for Table 1, the source is Hoffman's (1984) terrain analysis data base. Frequency data refer to how often each topic was described with a particular adjective. Terms in parentheses appeared as modifiers or variants of the descriptors or topics.

TOPIC	PREDICATE OR DESCRIPTOR WHICH IS APPLIED TO IT	FREQUENCY OF USE
(1) agriculture	intense	3
	little (sparse)	3
(2) axis (of dunes)	parallel	2
(3) angle (of gully intersections)	uniform	1
(4) arch (to a slope)	high	1
(5) base	broad	2
	flared	4
	moist	1
	scalloped	1
(6) basins	infiltration	3
	tidal	1
(7) bays	elliptical	1
	long	1
	narrow	1
	parallel	1
(8) beach ridges	linear	1
(9) beds (rock sheets)	curvilinear (curved)	3
	faulted	1
	few (none)	2
	flat	1
	lake	3
	massive	3
	narrow	1
	offset	1
	thick	6
	thin	9
	tilted	13
	uplifted	1
	vertical	1
(10) bluffs	steep	1

	vertical	1
(11) buttes	scattered	1
(12) canyons	terraced	1
(13) cliffs	steep	1
	vertical	2
(14) contours	rounded	1
(15) crater (cinder cones)	clustered	1
	dish-shaped (profile)	1
	knife-edged	1
	varying sizes	1
(16) crests	narrow	1
	peaked	1
	rounded	4
	sharp	2
(17) crops	mature	1
	row	1
(18) cultivation	intensive	4
	little	2
(19) deltas	arcuate	1
	birdsfoot	1
	convex (delta edge)	1
	estuarine	1
	flat	2
	narrow	1
(20) deposits	aeolian	2
	alluvial	1
	boulder	3
	fan-shaped	1
	mineral	3
	mud	1
	soil	4
	surface	1
	talus	9
(21) depressions	cicrular	1
	concentric	1
	elliptical	1
	flat (bottoms)	1
	large	2
	long	1
	nonuniform	1
	parallel	1
	round	1
	shallow	1
	small	3
	various sizes	1

(22) deserts	alluvial	1
(23) domes	bold	1
	broad	1
	circular	1
	clustered	1
	compound	1
	dissected	1
	elliptical	1
	exfoliated	1
	linear	1
	massive	2
	raised	1
	small	1
	young	1
(24) drainage pattern	anastamotic	2
	angular	4
	annular	4
	artificial	3
	barbed	1
	blocked	3
	braided	7
	centrifugal	1
	centripetal	1
	circular	1
	coarse (density)	8
	concentric	1
	dendritic (tree-like)	34
	deranged	4
	dichotomic	3
	discontinuous	7
	distinct	2
	fan-shaped	1
	field tile	5
	fine (density)	13
	hair-like (channels)	1
	hexagonal	1
	integrated	1
	intermittent	1
	internal	15
	irregular	1
	irrigation	5
	little (slight)	6
	mature	1
	medium (density)	2
	old	1
	parallel	6
	pinnate	4
	polygonal	1
	radial	8
	rectangular	9
	spurred	1
	surface (subsurface)	4
	symmetrical	1

	thermokarst	2
	trellis	4
	undeveloped	1
	varying	1
	yazoo	1
	young	1
(25) drumlins	clustered	1
	flat (tops)	1
	parallel	2
	round	1
	steep	1
(26) dunes	active	6
	barchan	1
	barren	7
	beach	1
	clustered	1
	distinct	1
	crescent-shaped	1
	hummocky	1
	longitudinal	1
	parallel	1
	pockmarked	1
	scalloped	1
	stabilized	4
	star-shaped	2
	transverse	1
	U-shaped (wind-drift)	2
	V-shaped	1
	wave-shaped	1
(27) edges (to sinkholes)	abrupt (distinct)	1
(28) elevations	equal (unequal, differing)	12
	dome-like	1
	high	1
(29) erosion	rapid	1
	scars	1
	uniform	1
	surface	1
(30) escarpments	columnar	1
	long	1
	steep	1
	vertical	2
(31) eskers	beaded	1
	discontinuous	1
	interconnected	1
	meandering	1
(32) fans	apex	1
	alluvial	6
	few	1

	fluvial	1
	short	1
(33) faults	linear	1
	long	1
	wide	1
(34) features	glacial	2
(35) fissures	long	1
(36) fields (field patterns)	angular	1
	curvilinear (curved)	3
	distinct	3
	irregular	4
	lattice	1
	regular	12
(37) flats	mud	1
	tidal	2
	salt	1
(38) floodplains	extensive	1
	narrow	1
(39) folds	linear	1
(40) forest (forestation, tree array)	contoured (pattern)	1
	dense	3
	heavy	1
	little	1
	rectangular	1
	scattered	4
(41) fractures	intersecting	1
	radial (radiating)	1
	vertical	1
(42) gorges	deep	1
	terraced	1
(43) gullys (streams, tributaries, meanders)	angular (acute)	16
	box-shaped	6
	braided	1
	broad	2
	close	1
	clustered	1
	curvilinear	4
	deep	2
	discontinuous	3
	few	24
	flat (bottoms)	3
	inactive	1
	indistinct	1
	intersecting	2
	irregular	2

	large (channels)	5
	loaded (heavily)	1
	long	2
	many	7
	meandering	5
	narrow	2
	offset	2
	parallel	7
	radial (radiating)	3
	saucer	11
	shallow	1
	short	7
	small	3
	spaced	2
	stable	1
	steep	6
	straight	2
	trapezoid	5
	U-shaped	15
	V-shaped	34
	wide (bottoms)	4
(44) hills	banded	1
	blocky	5
	bold	1
	branching	1
	cigar-shaped	1
	circular	1
	concave	1
	conical	3
	cultivated	2
	dome-like	2
	flat (tops)	2
	forested	5
	irregular	3
	isolated	1
	jointed	1
	knobby	5
	linear	2
	little	1
	long	2
	low-lying	2
	lumpy	1
	many	1
	massive	2
	oval	1
	parallel	1
	repeated	1
	round	14
	rugged	1
	scalloped	4
	sharp	1
	small	1
	smooth	3
	steep	4
	symmetrical	1

	teardrop-shaped	1
	terraced	4
	undulating	2
(45) horns	apex	1
	broad	1
	narrow	1
(46) ice	surface	1
(47) inlets	many	1
(48) islands	many	1
	small	1
(49) joints	columnar	1
	curvilinear	1
	narrow	1
	parallel	2
	short	1
	spaced	1
(50) knobs	concentric	1
	small	1
(51) lakes	finger	1
	oxbow	1
	parallel	1
	perfect (outline)	1
	tarn	1
(52) lakebed	dry	1
	glacial	3
(53) land	barren	12
	cultivated	5
	dissected	1
	eroded (highly)	2
	flat	3
	forested	7
	grass	27
	moist	2
	range	1
	scrub	4
	shrub	10
(54) landforms	abrupt (distinct) boundary	8
	allivial	1
	fluvial	1
	indistinct boundary	1
(55) lava	lobate (flows)	2
	ropey	1
(56) lineaments	clustered	1
	intersecting	1

	parallel	1
(57) lowlands	forested	1
	undulating	1
(58) meanders	broad	1
	little (meandering)	1
(59) mesas	scattered	1
(60) moisture (soil)	distinct	1
	little	1
(61) mounds	clustered	1
	conical	1
	hook-shaped	1
	isolated	1
	knobby	1
	long	1
	round	1
	steep	1
(62) mountains	asymmetrical	2
	dissected	1
	rugged	3
(63) needles	jagged	1
(64) orchards	occasional	1
	scattered	1
(65) outline (lake)	perfect	1
(66) peak	sharp	1
(67) pinnacles	jagged	1
	steep	1
(68) plains	alluvial	2
	broad	7
	coastal	3
	continental	2
	cultivated	4
	dissected	5
	elevated	1
	extensive	1
	fan-shaped	1
	flat	8
	flood	7
	forested	1
	high	1
	horizontal	1
	irregular	1
	large	4
	level	1
	loess	2

	old	7
	outwash	4
	pitted	1
	pockmarked	1
	rolling	7
	rugged	1
	small	1
	streaked	1
	thick	2
	thin	2
	till	5
	tilted	1
	undulating	3
	young	4
(69) plateau	dissected	1
	scattered	1
(70) plowing	contour	7
(71) ponds	beaded	1
	inland	1
	many	1
	polygonal (frost wedges)	1
	small	1
	various sizes	1
(72) prarie	low-lying	1
	rolling	5
(73) profile	blocky	1
	jagged	1
	low	2
	ropey	1
	round	2
(74) relief	blended	1
	gentle	1
	linear	1
	low	1
	rolling	1
	strong	2
(75) ridges	angular	1
	beach	3
	blocky	1
	branching	2
	broad	1
	concentric	1
	curvilinear	4
	dissected	2
	finger	2
	few	1
	flared	2
	flat	1
	forested	2

	hogback	2
	inland	1
	jagged	2
	knife-edged	1
	knobby	2
	linear (beach)	1
	long	8
	low	1
	many	1
	massive	1
	narrow	6
	parallel	15
	peaked	1
	round	7
	saddle	2
	sawtooth	5
	sharp	7
	short	2
	small	3
	smooth	2
	snake-like	1
	spaced	1
	steep	5
	straight	1
	symmatrical	3
	thick	1
	thin	1
	winding	1
(76) rock	bare	2
	bedded	4
	displaced	1
	durable	1
	faulted	2
	few (outcroppings)	1
	flat	9
	folded	2
	homogeneous	1
	interbedded	12
	intrusive	4
	permeable (impermeable)	2
	porous	1
	raised	1
	resistant	3
	rose-shaped (granite)	1
	scalloped	1
	stratified	3
	table	1
(77) rows (crops)	uniform	1
(78) sand	streaked	3
(79) scars (streaks)	arcuate	1
	braided	1
	channel (stream)	4

(80) scrub	heavily (vegetated)	1
(81) shapes	various	1
(82) sinkholes	circular	2
	clustered	1
	deep	1
	elliptical	1
	large	2
	long	2
	round	1
(83) slopes (gradients)	asymmetrical	5
	broad	2
	compound	2
	concave	1
	convex	1
	curvilinear	1
	cultivated	3
	equal (differing)	2
	forested	5
	gentle	8
	gradual	5
	increasing	1
	long	1
	moderate	1
	narrow	1
	rolling	8
	rough	1
	round	1
	scalloped	3
	short	2
	smooth	6
	stable	2
	stairstep	2
	steep	30
	straight	1
	symmetrical	2
	terraced	4
	uniform (nonuniform)	10
	vertical	1
(84) soils	abundant	1
	bare	2
	coarse	8
	cohesive	3
	creep	1
	deep	4
	drained (well)	2
	dry	2
	elastic	2
	eroded (erodable)	4
	expandable	1
	fine	7
	granular	2

	homogeneous	1
	little	1
	mixed	1
	moist	6
	permeable	4
	plastic	3
	porous (highly)	3
	silty	7
	slump	1
	stratified	5
	thick	1
	thin	2
	uniform	1
(85) surfaces	rolling	1
	scrabbled	1
(86) swamps	many	1
(87) terraces	many	1
	minor	2
	round	1
	smooth	1
(88) terrain	glacial	1
	hilly	1
	level	1
	rolling	1
	uneven	1
(89) texture	coarse	3
	fine	1
	knobby	1
	pitted	1
	rough	1
	silky	1
	smooth	4
(90) till	glacial	2
	old	1
	plains	5
(91) tones	banded	15
	contoured	1
	curvilinear (streaks)	4
	dark (very)	23
	desert varnish	2
	distinct	2
	dull	2
	equal (varying)	3
	fringed	2
	grey	1
	light	61
	linear (streaks)	2
	medium	24
	mottled	14

	streaked	4
	striped	2
	uniform (nonuniform)	2
(92) topography	closed	1
	dissected	3
	flat	11
	gentle	1
	irregular	2
	mountainous	1
	rolling	7
	round	4
	rugged	8
	smooth	1
	subdued	1
	uneven	1
	undulating	5
	uniform	1
	varying	1
(93) trees	isolated	1
(94) troughs	linear	1
(95) uplands	cultivated	3
	mountainous	1
	parallel	1
	rolling	1
(96) valleys	broad	1
	cirque	1
	cultivated	4
	curvilinear	3
	flat	3
	hanging	1
	long	3
	linear	1
	many	1
	narrow	2
	parallel	4
	round	1
	small	1
	steep	1
	U-shaped	1
	V-shaped	1
(97) vegetation	banded	1
	dense	4
	heavy	1
	linear (pattern)	2
	little	4
	lush	2
	perpendicular (to gullys)	1
	sparse	2
(98) water-holding capacity	high	1

	low	1
(99) water table	high	2
