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<td>Analogs of Yuma Terrain in the Northeast African Desert</td>
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<td>Apr. 1959</td>
<td>Analogs of Yuma Terrain in the Mexican Desert</td>
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A technique is described whereby desert areas selected for terrain comparison are mapped in terms of general terrain factors, geometry factors, ground factors, and vegetation. Terrain-factor data are synthesized to establish varying degrees of analogy of particular desert areas with portions of any selected base area. This synthesis includes compilation of geometry, ground, and vegetation analog maps—through combination of their component terrain-factor maps. A composite analog map is prepared by superimposing geometry, ground, and vegetation analog maps and stratifying the resulting combinations. Highly analogous desert tracts exhibit, or closely approximate, combinations of terrain-factor mapping units found in the base area, and the degree of analogy decreases directly as the similarity to such combinations decreases. Small areas mapped at large scales can be compared with areally similar tracts or with larger regions mapped at smaller scales.
A technique is described whereby desert areas selected for terrain comparison are mapped in terms of general terrain factors, geometry factors, ground factors, and vegetation. Terrain-factor data are synthesized to establish varying degrees of analogy of particular desert areas with portions of any selected base area. This synthesis includes compilation of geometry, ground, and vegetation analog maps—through combination of their component terrain-factor maps. A composite analog map is prepared by superimposing geometry, ground, and vegetation analog maps and stratifying the resulting combinations. Highly analogous desert tracts exhibit, or closely approximate, combinations of terrain-factor mapping units found in the base area, and the degree of analogy decreases directly as the similarity to such combinations decreases. Small areas mapped at large scales can be compared with areally similar tracts or with larger regions mapped at smaller scales.
This study is part of Research and Development Subproject No. 8-70-09-400 entitled "Military Evaluation of Geographic Areas" assigned to the U. S. Army Engineer Waterways Experiment Station by the Office, Chief of Engineers, for the requesting agency, Office, Chief of Research and Development, Department of the Army. The Subproject is directed by the Area Evaluation Section, Embankment and Foundation Branch, Soils Division of the Waterways Experiment Station. The mapping techniques described in this handbook were developed by the Geology Branch of the Waterways Experiment Station after tentatively mapping approximately half the desert areas in the Northern Hemisphere. Four folio-reports consisting largely of hand-colored maps at a scale of 1:5,000,000 have been completed using essentially the same techniques as outlined in this handbook. The titles of these reports are printed on the inside of the front cover of this volume.

The text for this handbook was written by Dr. Jack R. Van Lopik and Mr. Charles R. Kolb. The accompanying plates were prepared by Messrs. John H. Shamburger, William K. Dornbusch, and Harry K. Woods, Geology Branch, Waterways Experiment Station. Mr. Warren E. Grabau, Area Evaluation Section, Waterways Experiment Station, prepared Appendix A which deals with the quantification of the plan-profile factor. Special thanks are due Col. J. B. P. Angwin, Mapping and Charting Research Laboratory, the Ohio State University, and Messrs. Nels J. Nyman and Richard T. Whatley, Reproduction and Reports Branch, Waterways Experiment Station, for their work on the special drafting and reproduction techniques utilized in plate preparation. Col. Angwin and Mr. Nyman prepared Appendix B. The guidance and constructive criticism of the following are gratefully acknowledged: Dr. Joseph A. Russell, Dr. Arthur N. Strahler, Dr. Harold G. Wilm, and
Prof. K. B. Woods, consultants; and Messrs. Joseph R. Compton and Warren E. Grabau, Area Evaluation Section, Waterways Experiment Station. All phases of the study were under the direct supervision of Mr. Kolb and the general supervision of Messrs. W. J. Turnbull and W. G. Shockley, Soils Division, Waterways Experiment Station.

Directors of the Waterways Experiment Station during the conduct of this study and preparation of this report were Col. A. P. Rollins, Jr., CE, and Col. Edmund H. Lang, CE. Mr. J. B. Tiffany was Technical Director.
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APPENDIX A: DERIVATION OF A NUMERICAL DESCRIPTION OF
THE CHARACTERISTIC PLAN-PROFILE

APPENDIX B: A SYSTEM FOR SYMBOLIZING THE
GENERALIZED LANDSCAPE MAP

Introduction
Specific Work Requirements
General Cartographic Methods
Characteristic Plan-profile
Characteristic Slope
Characteristic Slope Occurrence
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Complexes
Summary
SUMMARY

A technique is described whereby desert areas selected for terrain comparison are mapped in terms of general terrain factors, geometry factors, ground factors, and vegetation. General terrain factors include physiography, hypsometry, and landforms. Geometry and ground factors considered are characteristic slope, characteristic relief, occurrence of slopes greater than 50 per cent, characteristic plan-profile, soil type, soil consistency, and surface rock. Terrain-factor data are synthesized to establish varying degrees of analogy of particular desert areas with portions of a selected base area. (The Yuma Test Station served as the base area for the present study.) This synthesis includes compilation of geometry, ground, and vegetation analog maps—through combination of their component terrain-factor maps. If a geometry type (identified by four numbers—each representing a particular range of values of the geometry terrain factors) found within the base area also occurs in another desert area, the tracts are considered highly analogous. A tract exhibiting three numbers out of four that occur in combination within the base area is considered to be moderately analogous, and so on. Ground and vegetation analog maps are prepared in a similar fashion through utilization of their respective terrain-factor maps.

A composite analog map is prepared by superimposing geometry, ground, and vegetation analog maps and stratifying the resulting combinations. Highly analogous desert tracts exhibit, or closely approximate, combinations of terrain-factor mapping units found in the base area, and the degree of analogy decreases directly as the similarity to such combinations decreases.

Small areas mapped at large scales can be compared with areally similar tracts or with larger regions mapped at smaller scales.
1. This handbook describes a technique or method utilized in compiling a series of folio-reports comparing the terrain features of the Research and Development Test Station at Yuma, Arizona, with those of various desert areas throughout the world. Each folio-report is concerned primarily with (a) mapping various terrain factors in a particular desert area by means of a standard scheme of classification applicable within all world desert areas; and (b) synthesizing these data so that degrees of analogy between that world desert and Yuma can be determined. As the purpose of the handbook is to describe employed techniques, no attempt has been made to illustrate or fully describe all possible combinations of terrain factors. Climatic comparisons of the Yuma Test Station with the world desert areas have been made for the Waterways Experiment Station by the Environmental Protection Research Division, Quartermaster Research and Development Center. Together the climatic and terrain studies should provide an evaluation of the suitability of the Yuma Test Station for testing men and materiel for military operations in desert areas in other parts of the world.

2. The deserts of the Northern Hemisphere were chosen for mapping and comparison with the Yuma area. Nine folio-reports are planned covering desert regions in Northwest Africa, Northeast Africa, Mexico, the United States, East Central Africa, the Middle East, South Central Asia, Soviet Middle Asia, and Chinese Inner Asia (fig. 1 shows the desert areas of North Africa and Asia). The first four of these folio-reports have been completed. Each completed report consists primarily of a series of maps (at a scale of approximately 1:5,000,000), including one for each of eleven major terrain factors selected for comparison. Written material is confined almost solely to clarification of illustrations of landforms and physiographic types.

* Raised numbers refer to similarly numbered entries in the list of selected references at the end of this report.
3. The Yuma area, similarly mapped but at a scale of 1:400,000, is shown in the same plate for ready comparison. Each terrain-factor map is, therefore, essentially an analog map. An area at Yuma, for example, shown on the slope map as having steep slopes is analogous to a similarly mapped area within the particular world desert area with which the folio deals. The remaining maps in a given folio-report are prepared by superimposing terrain-factor maps, both individually and in groups, in such a way that degrees of analogy, based on consideration of all terrain factors, can be determined. To illustrate the mapping methods used in each folio-report, the Yuma Test Station has been compared with a portion of the Northeast African Desert in plates 1-19 of this handbook. Scales, legends, and mapping symbols used in the folios are, in general, the same as those shown in these plates.
This handbook has been organized to present: (a) the general outline of the approach to the problem of terrain mapping and analog development; (b) the determinants involved in the selection of the terrain factors and the detail with which each is mapped; (c) definitions of the terrain factors and their mapping units—for the sake of clarity, many of the problems associated with mapping procedure, classification, and analog development are also discussed; and (d) the methods of compiling, and the significance of, analog maps.
PART II: APPROACH TO THE PROBLEM

5. The establishment of a technique for developing desert terrain analogs is a prerequisite for evaluating the Yuma area as a desert terrain site for Army tests. Yuma's suitability and adequacy are obviously related to the extent of occurrence of Yuma terrain types or conditions in other desert areas, and to whether significant desert terrain types occurring elsewhere are present or absent at Yuma. In order for these determinations to be made, a uniform system of describing, classifying, mapping, and comparing desert terrain factors had to be established.

Definition of Terms

6. To avoid confusion over terminology, certain frequently recurring words or terms are defined in this paragraph. Other terms are defined where they are discussed. For the purposes of this study, terrain is considered to be the sum of the various physical attributes of the land that describe an area. A terrain factor is an attribute of terrain described in either qualitative or quantitative terms. A composite terrain factor consists of several quantitative terrain factors; in this study the composite terrain factor is expressed qualitatively by either a single symbol or a group of symbols. The term landscape is used in a restrictive sense in that it is defined in terms of only that group of terrain factors which describes surface configuration or geometry. The term terrain type is also restrictive in that it is defined in terms of only that group of terrain factors employed in the analog technique described in this handbook. Because each terrain factor incorporates all possible variations of that attribute in nature, it becomes necessary to stratify each terrain factor in such a way that meaningful differences in the terrain can be delineated. Accordingly, each terrain factor must be subdivided into classes of values. Thus, a mapping unit is a specific class of values or a definable subdivision of a terrain factor. As an example, slope is a terrain factor and $6-14^\circ$ of slope is a mapping unit.
Terrain Factors vs Terrain Effects

7. Two possible approaches to the problem of terrain analogs were considered early in the study. One was to map and compare the ranges of selected terrain factors, such as slope, relief, soils, etc., found in the areas being compared. The other was to describe and map areas in terms of the critical values of such factors at which adverse effects are produced on such military considerations as cross-country movement, fire power, earth construction, radio communication, and cover and concealment. In short, the decision had to be made whether terrain factors or terrain effects should be mapped and compared.

8. It is recognized that the final objective of the project under which this work is being done is to develop techniques of comparing the environmental impacts of different areas on military activities. It might appear from this statement that the better approach would be that of mapping, or otherwise comparing factor values critical to military operations. However, preliminary studies have convincingly shown that areas must first be mapped and compared in terms of their ranges of terrain factors.

9. Several considerations that militate against the scheme of classifying and comparing areas in terms of terrain effects (i.e., critical factor values) are:

   a. Single terrain factors do not necessarily have independent critical values (e.g., the critical slope value for a given vehicle varies directly with the soil strength of the slope surface).

   b. Critical values of a given terrain factor may vary greatly with various military activities (e.g., the density of vegetation when considered in relation to foot movement as against signal communication). In addition, variations may occur within a general class of materiel (e.g., critical slope values are different for different vehicles).

   c. Critical values are not presently known for many activities and items of materiel.

   d. Critical values are not constant, but change with technological advances and obsolescence.

10. Because terrain effects can only be interpreted in terms of both terrain factors and military activity (or item of materiel), it was logically concluded that the first step in the program should be the development
of a system of classifying terrain factors so that areas could be mapped and compared in common terms. A good parallel is the previously mentioned work by the Quartermaster Corps for the WES on analogs of Yuma climate in world deserts. In these studies various climatic factors such as temperature, rainfall, wind velocities, etc., were mapped and served as the bases for comparison. The effects of these climatic factors on food preservation, personnel disability, chemical warfare, etc., were not considered. Indeed, it is a function of the Test Station to test the effects of the various climatic factors on men and materiel. Similarly, the immediate purpose of the terrain analog study is to furnish responsible agencies involved in testing with factual evidence as to whether the individual terrain conditions against which the tests are being conducted are widespread or limited in extent throughout world deserts and whether significant terrain conditions found in other world deserts are nonexistent in the test areas. Mapping and comparing terrain effects are beyond the scope of the study phase covered by this report, and can be done only after the determination of the effects of various terrain types on diverse military activities.

Scales and Problems of Generalization

11. Once the implications of the terrain classification and analog system presented in this handbook are understood, the system can be used in the comparison of any two desert areas of either similar or different sizes. It is hoped that the system can also be made applicable in the comparison of any areas of the world by integrating other terrain factors such as snow cover and hydrologic characteristics, and by expanding or revising the vegetation classification. In contrast with comparisons for test site evaluation, strategic and tactical comparisons of geographic areas will require consideration of a number of additional environmental elements such as transportation routes, population centers, water supply, etc.

12. Analogs of Yuma terrain in world deserts, as defined in this study, are distinctive from homologs. Areas may be homologous from the standpoint of one or more terrain factors such as slope, relief, vegetation, etc. However, true homology can occur only when areas have been
mapped at the same scale and contour interval, utilizing the same sampling
techniques, degree of generalization, and comparable data. The difference
in the degree of mapping generalization, resulting primarily from differ-
ences in map scales and in available data between Yuma and the world desert
areas, dictates that areas mapped the same both at Yuma and in world desert
areas can be considered analogous only, not homologous. This degree of
generalization is necessarily reflected on the maps contained in the folio-
reports. At a scale of 1:5,000,000, the entire Yuma area would be mapped,
from the standpoint of slope, as a complex of "gentle" and "declivitous";
whereas, at the scale utilized in the reports (1:400,000), areas of "flat," "gentle," "moderate," "declivitous," and "steep" characteristic slopes are
found. Yuma, at a scale of 1:5,000,000, would be mapped as having sparse,
scrubby and thorny vegetation; actually, it contains a wide variety of
vegetative types that can be mapped separately at a larger scale. In
short, the generalization involved in mapping has been an areal genera-
lation. The existence and necessity for such generalization in mapping are
well known. For example, when examining a soils map of the United States,
one expects to see the soils of New Jersey mapped as predominantly sandy.
On a map of New Jersey, one expects a number of major soils divisions.
Within a New Jersey county, many more soils units are delineated. The
area to be occupied by a potential airfield within the county could be ex-
pected to be mapped in even more detail.

13. Generalization of the Yuma and world desert maps incorporated
in the folio-reports primarily reflects a variation in the spatial dis-
tribution or density pattern of established areal units* which have been
defined in terms of narrow ranges of specific properties. For example,
areas mapped as silty soil at Yuma and in world deserts are characterized
by an areal predominance of silty soils, but the percentage of surface
covered by silty soil within the area so mapped at Yuma is typically
greater than that of the area so mapped in world deserts. The important
point is that silty soil in areas so mapped is areally predominant. At
Yuma this predominance might be on the order of 95 per cent; in world
deserts, only 70 per cent.

* The size and establishment of such units are discussed in Part IV.
14. In other words, the degree of generalization employed in mapping Yuma is considerably less than that used in mapping world deserts. An area in North Africa, for example, mapped as having the same mapping unit of a particular terrain factor as a section of Yuma will exhibit this unit only as a modal or characteristic range, whereas at Yuma a high percentage of measured values for the particular terrain factor may fall within this range. Statistically speaking, the "peakedness" or kurtosis of the frequency-distribution curve for the Yuma area would typically be of a higher degree than that of the world desert area. A bimodal distribution, when considered significant, is mapped as a complex. The amount of kurtic deviation allowed from the frequency-distribution curve in the Yuma or control area would determine the "tolerance" of the analogy. The amount of kurtic deviation allowed was based on judgment rather than on arbitrarily selected limits. Studies of large-scale detailed maps may make it possible to assign definite limits to the kurtosis value of a given terrain factor which will decide not only whether or not areas are analogous from the standpoint of a particular terrain factor, but the relative degree of analogy as well.

15. In this connection, it should be repeated that one of the immediate objectives is to determine the suitability of Yuma as a Test Station, or to develop "testing" analogs. This requires far less generalization for the Yuma area than for the world desert with which it is being compared. It is important to know that Yuma possesses a fairly complete range of slopes, vegetative types, etc., even if these ranges of terrain factors cover only very limited areas. Conversely, it is desirable that terrain-factor mapping in the world deserts be areally generalized, thus indicating the most characteristic or modal conditions existing within the area mapped. Consequently, a vehicle tested at Yuma on a certain soil type of a certain consistency on a certain slope is being tested against a similar combination of terrain factors that is characteristic or areally predominant in a region so mapped in a particular world desert area.

16. Although this mapping approach and concept of generalization are admirably suited to the development of terrain-testing or terrain-factor analogs, they are obviously less suited to the development of terrain-effect analogs. Although very rough terrain-effect analogs can be
developed through utilization of the folio-report maps, such analog development requires, among other things, a much lower degree of mapping generalization. At the present time, it appears that terrain-effect analogs (actually near-homologs) could be developed most reliably in relatively small, homogeneous areas for which large-scale map coverage and detailed topographic, soils, and vegetative data are available. The development of valid small-scale maps showing analogs of terrain effects will depend on thorough knowledge of the results of generalization or of variations in scales and contour intervals on terrain-factor mapping, as well as upon knowledge of the relative importance of these factors in a specific military consideration. An attempt is now being made, in a separate study, to establish relations between terrain envelopes and degrees of generalization resulting from use of maps of various scales and contour intervals.

Quantitative vs Qualitative Approach

17. Terrain studies and classifications may be either qualitative or quantitative. The qualitative or classical approach to geomorphology consists primarily of written descriptions of terrain and landforms dealing extensively with the genetics of the various landforms and surfaces. The approach depends almost entirely on the skill of the analyst, both as an analyst and as a master of descriptive prose. It has been applied to both large and small areas, but its subjective and qualitative nature lessens its suitability for comparison purposes.

18. On the other hand, a quantitative terrain description is simply one that uses numerical values or ranges of numerical values rather than words to define terrain. The obvious advantages of such an approach are its objectivity and the fact that mapping units can be rigorously defined. A more subtle, but considerably greater advantage is that quantitative factors offer the possibility of being manipulated mathematically so that the effects of individual terrain factors or of factors acting in concert can be determined. Drainage densities, for example, can be expressed in terms of the ratio of the sum of channel lengths to the drainage basin area. The product of drainage density and relief, in turn, is a proposed measure of basin ruggedness. In most instances such quantitative factors
have evolved from studies aimed at determining terrain effects in specific fields such as hydrology and agriculture. As a result, quantitatively expressed factors useful in presenting an aggregate or entire picture of terrain have not been explored to any great extent. Usually the process of quantitative analysis results in a multiplicity of quantitative measurements to express a simple descriptive qualitative term. Thus, the quantitative system gains in precision, but loses in simplicity. Although the quantitative approach is certainly desirable, it may still be wise to utilize semiquantitative or qualitative techniques in many cases. The quantitative approach is no magic cure-all and should never be employed unless its contribution outweighs the complexities it introduces.

19. In the present study a middle course was chosen between the qualitative and quantitative approaches. In the first place, it was recognized that a quantitative approach is ideally suited for terrain analog or comparison purposes, and every attempt was made to quantify. Where attempts at quantifying terrain concepts resulted in overcomplexity, however, a qualitative mapping system was used. Soils, for example, are expressed in standard qualitative terms, i.e., silt, clay, sand, etc., rather than resorting to a quantitative representation such as median grain diameter, cohesive strength, etc. In the second place, the quantitative approach heretofore has been applied primarily to small homogeneous areas for which large amounts of terrain data were available. The scarcity of data in the vast areas mapped in the desert analog study dictated against introducing complex quantitative parameters for which landform-soils-physiographic ties and associations were very difficult or uncertain.

Summary

20. In summary, four important points are emphasized concerning the approach utilized in this study for developing analogs of Yuma terrain in world deserts.

a. Analogs of terrain factors, not terrain effects, have been established. Such analogs imply that terrain conditions are similar regardless of their effect on a wide variety of military considerations.
b. The system permits comparison of terrain in areas mapped at different scales as well as in areas mapped at similar scales.

c. An attempt has been made to keep the mapping units and the system of analogy as quantitative as possible.

d. The system has been kept as simple and mapping methods as objective as possible, while still fulfilling project aims.
PART III: TERRAIN FACTORS AND THEIR MAPPING UNITS

21. As shown in table 1, the twelve terrain factors considered in the present study have been grouped under five major headings: (a) aggregate or general terrain factors, (b) geometry or form factors, (c) ground factors, (d) vegetation, and (e) surface roughness or microrelief. The factors (items numbered 1-10, vegetation, and surface roughness) are briefly described in the following paragraphs and, with the exception of surface roughness, which has not been mapped, the techniques utilized in their mapping are discussed in Part IV. It is not intended that table 1 be considered a complete factorial analysis of terrain. In a more detailed study, with sufficient data, several factors could be added. Nevertheless, proper utilization of the prepared terrain-factor maps should result in a fairly definitive terrain picture of any desert area.

Table 1
Terrain Factors

<table>
<thead>
<tr>
<th>A. Aggregate or General Terrain Factors</th>
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<tbody>
<tr>
<td>(Not directly utilized in preparing the analog maps)</td>
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<tr>
<td>1. Physiography</td>
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<tr>
<td>2. Hypsometry</td>
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<tr>
<td>3. Landform-surface condition</td>
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<th>B. Geometry or Form Factors</th>
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<tbody>
<tr>
<td>(Employed in preparing the geometry analog and composite analog maps)</td>
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<tr>
<td>4. Characteristic slope</td>
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<tr>
<td>5. Characteristic relief</td>
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<tr>
<td>6. Occurrence of slopes greater than 50 per cent</td>
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<tr>
<td>7. Characteristic plan-profile</td>
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<tr>
<th>C. Ground Factors</th>
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<tr>
<td>(Employed in preparing the ground analog and composite analog maps)</td>
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<tr>
<td>8. Soil type</td>
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<tr>
<td>9. Soil consistency</td>
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<tr>
<td>10. Surface rock</td>
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<tr>
<th>D. Vegetation</th>
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<tr>
<td>(Employed in preparing the vegetation analog and composite analog maps)</td>
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<tr>
<th>E. Surface Roughness or Microrelief</th>
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<tr>
<td>(Incomplete--classification system not finalized)</td>
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22. The various terrain factors and their mapping units are indicated and defined in the legends of plates 1-19. These legends should be carefully studied by those interested in the details of what is being mapped and the qualitative or quantitative limitations of the terminology employed. The discussion that follows concerns (a) the determinants involved in selecting each of the terrain factors, (b) the terrain factors themselves, and (c) the reasons for, and implications of, the less obvious mapping units and definitions accompanying each legend.

Criteria for Selection

Terrain factors

23. Any region can be subdivided into areas identifiable by a string of designations or numbers, each representing a mapping unit of a series of terrain factors. The complexity of such a system would depend primarily on the number of terrain factors employed. For example, if twenty terrain factors were considered each area would be identified by a string of twenty digits, each designating a particular mapping unit. Although this method is plausible, cartographic problems multiply rapidly if it is considered necessary to map areas of landscape type, for example, and at the same time identify the component terrain-factor classes or mapping units. Consequently, considerable effort was spent in limiting the number of terrain factors while making sure that factors truly important in terrain description were not disregarded; and also in selecting and grouping terrain factors that, when considered in concert, are readily visualized and result in a minimum of cartographic complexity. Terrain factors mapped in this study were chosen chiefly because of (a) their military significance, (b) their suitability in developing "testing" analogs, (c) the importance of each as a basic element of terrain, and (d) their capacity, when viewed in concert, to provide a reasonably complete picture of a given terrain.

24. Individual military considerations are often concerned with different sets of terrain factors and with each factor to an entirely different degree. The military problem of fields of fire, for example, is concerned not at all with soil consistencies; however, this factor is of vital importance in studies of cross-country movement. Military construction
might be vitally concerned with soil type, whereas survival might be only indirectly concerned with this factor. It is difficult to conceive of many terrain factors that would be of no importance from a military standpoint; however, to keep the number of factors within reasonable limits and to prevent the method of analog development from becoming too cumbersome, only the factors considered most important from a military standpoint were chosen for mapping.

25. One method of reducing the number of terrain factors selected for mapping was to eliminate those not pertinent in the development of "testing" analogs. Obviously, certain terrain factors can be simulated or disregarded in testing programs. Road networks, population densities, or availability of water are examples of terrain factors that might easily be simulated or entirely disregarded in specific tests at the Yuma Station. For example, although the road network at Yuma is many times denser than in even some of the more advanced desert regions in other parts of the world, it is still not so dense that it would hinder or significantly affect individual tests at Yuma-as long as these tests do not cover unduly large areas.

26. An important criterion in selecting the terrain factors mapped is that each factor selected be a basic element of terrain in desert regions. Absent from the list of factors chosen, for example, are hydrologic factors, i.e. stream densities, channel depths, stream velocities, etc. Although these terrain factors are considered of utmost importance in temperate or humid areas, it is possible to eliminate them from the analog system developed for arid regions. The final and most important criterion is that those factors selected for mapping must present as complete a definition of the terrain as possible when considered in concert.

Mapping units

27. The selection of mapping units or terrain-factor stratification was based on such considerations as (a) naturalistic breaks, (b) availability of data, (c) military significance, and (d) adaptability of the unit to precise, and wherever possible to quantitative definition.

28. When determinable, naturally occurring groupings or ranges of terrain factors played an important role in establishing the various mapping units. For example, detailed reports dealing with alluvial fans
conclude that the slope of a fan is always less than $10^\circ$, and in the vast majority of cases, less than $6^\circ$. Studies of barchan dunes indicate that windward slopes range from $5^\circ$ to $14^\circ$. These, and additional data, indicated that valid boundaries between slope-mapping units could be set at approximately $6^\circ$ and $14^\circ$. Use of such naturalistic breaks permitted maximum use of landform-terrain factor ties or associations in mapping areas where little quantitative or detailed information was available.

29. Availability of data was another determinant in establishing mapping units. The same units of breakdown had to be utilized in mapping all the world desert areas. Unless this system was adhered to in the entire mapping program, the mapping of one area would have no relation to that of another, and no comparisons could be made. It soon became obvious that although one group of units could be mapped with a great deal of confidence in one area, data were too limited in other areas to permit mapping of the same units. Units finally selected were based in part on a trial-and-error method involving preliminary mapping of the desert areas of Northeast and Northwest Africa, the Middle East, and South Central Asia. It should be emphasized here, however, that availability of data was not permitted to unduly restrict the number of units with which each terrain factor was mapped. Since, for example, dissection (slope occurrence) is an important component of terrain, reasonable ranges of dissection density were assigned for mapping even though very little data might be available in many of the desert areas. Individual terrain factors, therefore, were subdivided into units sufficiently detailed and restrictive to reasonably define a given terrain from both a military and a geomorphic standpoint. Where these ranges could not be mapped from available data, inference or judgment based on soils, landform, or other associations was relied on. This will be discussed further in Part IV.

30. Another criterion for the selection of an individual mapping unit was its susceptibility to precise definition. Wherever possible this definition was made quantitative. Where this was not possible, an attempt was made to select mapping units that synthesized certain quantitative aspects of a particular terrain factor into a qualitative expression or composite terrain factor. Vegetation units (plate 15), for example, rather than being based on taxonomic or climatic groupings, permit estimates of
such quantitative vegetation parameters as densities, spacing, trunk diameters, crown diameters, etc. (see supplemental tabulation on the back of plate 15). As stated in paragraph 18, what is gained in precision by quantification is often lost in simplicity. Unless fairly simple quantitative units can be developed for describing vegetation—and present studies indicate that this is by no means impossible—the vegetation factor becomes extremely cumbersome to integrate into the analog system.

31. In summary, an attempt has been made to establish the most descriptive, useful, and simple system of developing terrain analogs consistent with the paucity of data on the vast areas being mapped. An effort has also been made to steer a middle-of-the-road course between (a) qualitative and quantitative approaches to terrain description, (b) natural and military significance, and (c) availability of data and a reasonably complete definition of terrain. It is felt that this course is the only practical one in view of our present knowledge of the relative significance and suitable stratification of terrain factors in diverse military considerations. It is believed that as this knowledge expands the developed analog system will be flexible enough to accommodate the new data.

Aggregate or General Terrain Factors

32. Aggregate or general terrain factors (table 1) are not utilized directly in preparing the analog maps. In areas where enough data are available, the preparation of aggregate or general terrain-factor maps probably serves no useful purpose. However, terrain data for most of the world desert areas are so sparse that the maps of these factors become all-important sources in the systematic and consistent mapping of the other terrain factors. Judgment based on knowledge of the physiography and associated landforms becomes increasingly important in the mapping of the geometry and ground factors as terrain data become more scarce. Consequently, considerable effort was spent in standardizing and systematically mapping the general terrain factors and in developing geometry- and ground-factor ties or associations that could be applied with equal weight throughout all the desert areas mapped.
Physiography

33. An appreciation of the major surface features of the land (physiographic units) can be of considerable strategic, and to a lesser extent, tactical significance. Mention of a particular physiographic unit should, for example, convey a picture of the general terrain. Concepts of landform spacing, compartmentation, frequency of barriers, etc., are often implied. Certainly to anyone with even a slight knowledge of geomorphology the term "basin and range" suggests a definite pattern of mountains, plains, drainageways, soil types, and other elements of the terrain.

34. In the present study an attempt has been made to progress beyond the qualitative-implication stage of physiographic type. Tabulations have been prepared indicating characteristic landforms, slope, relief, etc., of the pertinent physiographic units in an attempt to depict more clearly the terrain implied. Obviously, as a result of the tremendous range in terrain-factor values included within many physiographic units, this attempt can be only partially successful. Nevertheless, physiography is in effect a generalization of the various features comprising the terrain and consequently forms a valuable, although admittedly rough or qualitative, part of terrain evaluation.

35. An obvious and logical basis for a physiographic breakdown is surface form or geometry. This concept was adhered to in establishing the major physiographic units (mountains, plain-and-mountain complexes, hill lands, plateaus, plains, as illustrated in plate 1); however, it became clear early in the study that exceptions would have to be made in the subdivision of these units. Certain plains and hill lands, for example, exhibited important distinguishing characteristics not adequately defined in terms of form or geometry. In view of this fact, origin or genesis was chosen as a secondary basis of breakdown. However, a maximum of form or geometric criteria are included in all unit definitions.

Hypsometry

36. The gross form or geometry of a region can be determined through an examination of the physiographic and hypsometric maps. Mapping units utilized for the hypsometric map (plate 3) are obviously much too broad to indicate anything but the most general or gross terrain envelope. Detailed treatment of form or geometry is restricted to the geometry-factor maps
It is realized that the military significance of elevation, per se, is relatively slight; however, large differences in elevation within a region should suggest that the climatic and weather conditions of the region should be investigated. In addition, it is known that the efficiency of internal combustion engines progressively diminishes with altitude. Current practice divides the efficiency curve into three classes with the class divisions at 5000 and 9000 ft. These two elevations have been accepted as two of the hypsometric unit boundaries.

Landform and surface conditions

37. The term landform is defined in this report as any topographic expression of the land surface definable in terms of slope, shape, and relief, provided the relief is greater than 10 ft. This definition includes major physiographic features such as mountains, plateaus, etc.; however, in practice these features are usually referred to as first-order forms, and the term landform is applied only to features of lesser magnitude. Landforms generally reflect the origin of sediments and rocks and the past and present processes of weathering and erosion acting upon them. Often they also reflect the structural attitude and composition of the underlying materials. Landforms, therefore, are not merely topographic features; they commonly express definite geological associations.

38. The term surface condition refers to topographic expressions of the land surface exhibiting less than 10 ft of relief and to unusual states or conditions of the ground not definable in terms of relief, slope, or form resulting from a natural process or situation. Solution, cementation, mechanical or chemical disintegration, and evaporation are a few of the many processes that may, under certain conditions, produce exceptional surficial properties. Surface conditions, as well as landforms, often imply definite compositional, genetic, or geologic associations.

39. In much the same manner that the physiographic unit paints a general picture of a region, the landform or surface condition provides a more detailed image of the terrain. The amount of detail provided, of course, depends upon the preciseness of the definition of the landform or surface condition. Consequently, these features have been defined as precisely as possible in terms of slope, relief, soil consistency, and other basic terrain factors.
40. The classification or grouping of landforms and surface conditions in a terrain study presents a problem. The ideal system would be based on magnitude of the fundamental terrain factors, i.e. relief, slope, etc.; however, the ranges of these factors within many features are too great to permit a valid classification or breakdown. For example, barchan dunes range from tens to hundreds of feet in height. Similarly, ranges and combinations of slopes often exist within many features, making classification on this basis very indefinite and arbitrary. Consequently, the widely utilized genetic basis of landform classification has been followed (plates 5 and 6) supplemented by magnitudinal tabulations. Major groups are entitled depositional, erosional, and miscellaneous. Every attempt has been made to include as many features as possible in the first two categories, and to restrict the miscellaneous group to features of tectonic, cultural, or indefinite origin. It should be remembered that the landforms listed in the legend in plate 5 are only those found in the Egyptian and Yuma areas and that the landform associations tabulated in plate 6 represent only a portion of a similar tabulation that will accompany each folio-report. Although the folio-report legends and landform-association tabulations are more extensive, they are still tentative. As folio-reports for additional world desert areas are completed, further additions and revisions will be made. It is hoped that with completion of the folio-reports for the nine world desert areas under consideration, more refined definitions and classifications, and particularly landform associations, will evolve.

**Geometry or Form Factors**

41. A landscape or segment of landscape can be defined in terms of slope, relief, and dissection or slope spacing. Thus, describing an area as having gently sloping, moderately spaced hills rising to considerable heights above the surrounding plain gives a reasonable picture of the landscape. When a region is described as having hills with slopes ranging between 10 and 20 degrees, spaced about 1000 ft apart, and rising to heights of 50 ft, a more quantitative and clearer picture of the landscape is provided. Therefore, assigning a reasonable numerical range to these three factors and cataloging various combinations of ranges of these
three factors is a logical step in landscape definition. A less tangible but equally important property necessary to complete this definition is the spatial distribution of these three geometry factors, called in this study the characteristic plan-profile. To illustrate, let us consider a gently sloping plain dissected by a number of deep, narrow drainageways. This would be mapped as an area of a given range of slopes, relief, and slope spacing. Consider another gently sloping plain with a series of narrow dikes or ridges crossing it. This would be mapped with exactly the same ranges of slope, relief, and slope spacing, yet the disposition of features composing the landscape in each instance would be different. A profile of the two landscapes would appear as \[ \sqrt{\sqrt{\sqrt{\sqrt{}}}} \] in the first instance, and as \[ \sqrt{\sqrt{\sqrt{\sqrt{}}}} \] in the second. In addition, it is desirable to know whether the ridges or drainageways are parallel or intersecting, continuous or discontinuous; in other words, a plan view of the area is needed. The characteristic plan-profile thus is a necessary part of landscape definition. It is concluded that, for purposes of this study, landscape can best be described in terms of these form factors (slope, relief, slope occurrence or spacing, and characteristic plan-profile), each of which will be briefly described in the succeeding paragraphs.

**Characteristic slope**

42. A slope may be defined as a surface identified or designated in terms of its deviation from the horizontal. The amount of deviation is commonly expressed as a rate of vertical rise per horizontal interval, as a percentage, or in degrees. Any change in deviation of this surface from the horizontal would result in a different slope. Slopes in nature are characterized by an infinite number of such deviations from the horizontal, and in mapping these changes in slope some standard of generalization must be adopted. Characteristic slope, therefore, is defined in terms of a set standard of generalization. Primarily, this standard is the contour interval found on available map coverage, the contour interval that determines the resulting topographic picture or "envelope."

43. For example, a map with a contour interval of 200 ft gives a much more generalized topographic picture of a region than a map of the same area utilizing a contour interval of 25 ft. The map with the smaller contour interval will indicate many more slopes than its 200-ft counterpart
and, therefore, the characteristic or most frequently encountered slope would differ. Consequently, the characteristic slope must be defined in terms of a particular contour interval.

Fig. 2 illustrates the variation in slope resulting from mapping the surface shown in profile at contour intervals of 10, 20, and 50 ft. The slope envelope in each instance is decidedly different and, except for the 10-ft contour condition, decidedly misleading. It follows that up to a point, the smaller the contour interval the truer the resulting picture of the surface. It is impractical, however, to consider slope breaks apparent only on maps with 1-, 2-, or 3-ft contour intervals. Besides the almost insurmountable problems inherent in mapping surfaces in such minute detail, this detail often obscures slopes of major importance generated by larger contour intervals. For the purpose of this study, it was found
convenient to arbitrarily set the limiting scale of generalization as that defining landscapes and associated slopes generated by a 10-ft contour interval. Irregularities apparent only on maps with contour intervals less than 10 ft are considered as surface roughness and, as such, mapped separately as a distinctive terrain factor (see discussion in paragraphs 67-77).

45. It is emphasized that the concept of the topographic envelope based on the 10-ft contour interval pertains with equal force to the other three geometry factors: relief, slope occurrence, and plan-profile. The effect of the limiting 10-ft contour is that: (a) relief is not considered unless its magnitude is more than 10 ft; (b) unless slopes generate relief of more than 10 ft they are not considered in calculating slope occurrence; and (c) the spatial distribution of highs and lows in the plan-profile is considered only when these highs are 10 ft or more above the lows.

46. Characteristic slope is defined as the narrow range of slopes which predominates or is most common within a region (possessing a distinctive spacing, arrangement, or pattern of contour lines) mapped with a 10-ft contour interval. The utilized stratification of characteristic slope is shown in plate 9. The breaks or boundaries are primarily "naturalistic" in that they help to define certain commonly recurring desert surfaces. Unit 1a (0 to 0.5°) is typically associated with abnormally flat surfaces such as playas; unit 1b (0.5 to 2°) often identifies the very gently "tilted" valleyward peripheries of alluvial fans or alluvial flats so common in desert regions; unit 2 (2 to 6°) brackets the slopes typically formed by alluvial fans; unit 3 (6 to 14°) represents the normal range of slopes forming the windward sides of sand dunes and consequently forms the characteristic slope of most dune fields; unit 4 (14 to 26.5°) characterizes many hill regions and the upper break approximates the limit of many subdued "angle of repose" deposits such as talus. The 45° break between units 5 and 6 is quite arbitrary; however, the characteristic slope of mountainous regions rarely exceeds this value. Such associations are a definite aid in mapping little-known regions and also provide a more meaningful or more easily comprehended description of desert terrain.
Characteristic relief

47. Relief may be defined as the maximum difference in elevation per unit area. Although this definition is adequate in areas of fairly high characteristic slope, it is inadequate in regions exhibiting low characteristic slope or poorly developed drainage. If, for example, we define relief as the maximum difference in elevation per square mile, the surface of an alluvial fan with a slope of approximately $5^\circ$ could exhibit "relief" of over 500 ft. In such cases it is the depth of incision of the drainage ways that is the important relief consideration rather than difference in elevation per unit area. Similarly, in sand dune areas the important relief consideration, the height of the dune above the interdune troughs, might be missed when relief is expressed as elevation differential per small unit area. Consequently, if certain important considerations are to be properly emphasized, a flexible definition of relief is needed.

48. In the present study a tripartite definition of relief has been formulated, based principally on the characteristic slope of a region and the degree of drainage integration.

I. If the characteristic slope is less than $6^\circ$ (characteristic slope units 1a, 1b, and 2): Relief is defined as the vertical distance from interfluve crest to the nearest adjacent flow line—with no horizontal distance connotation or restriction. (Utilized on surfaces such as alluvial fans where the depth of incision of washes is the important relief consideration.)

II. (a) If the characteristic slope is greater than $6^\circ$ (characteristic slope units 3, 4, 5, and 6) and the drainage lines are reasonably well developed: Relief is defined as the vertical distance from the highest point to the lowest point in a typical square-mile area. (Utilized primarily in hill and mountain regions.)

(b) If the characteristic slope is greater than $6^\circ$ (characteristic slope units 3, 4, 5, and 6) and drainage lines are poorly developed or lacking: Relief is defined as the vertical distance from the peak or crest of an individual prominence to the floor of the nearest adjacent low or hollow. (Utilized in areas of smooth-sided prominences, e.g. dunes and cinder cones, where the height of the feature is the important relief consideration.)

49. Characteristic relief (plate 10) may be either restrictive or gross. Restrictive relief is (depending upon which relief definition must be employed) the modal class of stream depth, elevation differential per unit area, or prominence height which characterizes a tract that lies within or is coincident with an area defined by one of the seven
characteristic slope units. **Gross relief** concerns the height or depth of major topographic features and is defined in paragraph 99.

Occurrence of slopes greater than 50 per cent

50. Slope occurrence gives some measure of dissection or what might be termed "landscape compartmentation." For example, let us consider a wash-scored surface of an alluvial fan. The characteristic slope of the fan approximates $4^\circ$ and the characteristic relief (modal depth of the washes) is 15 ft. As is usually the case, the wash-bank slopes are all steeper than 50 per cent or $26.5^\circ$. In this case the landscape compartmentation consists of a series of flat-topped interfluves separated by pairs of steep slopes descending into narrow shallow washes. Another type of compartmentation is exhibited in a field of complexly overlapping barchan dunes. The characteristic slope of the field falls between 6 and $14^\circ$, viz., the windward slope of the dunes, and the modal height or characteristic relief of the dunes is less than 50 ft. Here the landscape is "compartmented" by the steep (greater than $26.5^\circ$) slip-face slopes of the dunes. In contrast to the wash-scored alluvial fan surface, the steep slopes of the dune field do not occur in pairs. This situation makes it desirable that a simple quantitative expression of the compartmentation factor be formulated in terms of the frequency of occurrence of "compartmenting" slopes per unit of length rather than in terms of average spacing of such slopes. However, some concept of the spacing involved is indicated in the subsequently discussed plan-profile.

51. A compartmenting slope is considered to be any slope steeper than 50 per cent. Here again the limit or boundary was established on the basis of naturalistic and military considerations. In desert regions most stream or wash banks and the surfaces of "angle of repose" deposits exceed 50 per cent. This slope thus divides the landscape into compartments along such naturalistic breaks as stream banks, terrace escarpments, mountain slopes, dune slip faces, etc. Furthermore, except when wet, slopes less than 50 per cent are of minor consequence from the standpoint of many military considerations.

52. Slope occurrence (plate 8) may be either restrictive or gross. **Restrictive occurrence** is the modal range of slopes greater than 50 per
cent in an area found along traverses containing the maximum number of such slopes. Relief of less than 10 ft is not considered. **Gross occurrence** concerns the spacing of major topographic features and is defined in paragraph 95.

53. The stratification employed for the slope-occurrence factor (plate 8) is somewhat arbitrary; however, the maximum value (for unit 6, more than 200 compartmenting slopes per 10 miles) was established after intensive examination of large-scale aerial photographs of selected areas in the southwest portion of the United States. Less extensive surveys of other surfaces in the same region influenced the establishment of the remaining units.

**Characteristic plan-profile**

54. The three terrain factors discussed in preceding paragraphs are adequate measures of specific properties, but even taken in sum they fail to convey an impression of the geometry of the surface as a whole. It is possible, using any given combination of mapping units of these factors, to visualize a large number of quite different geometric configurations. Because over-all configuration is vital to many military activities, it is necessary to provide a descriptive fabric wherein the magnitude of slope, relief, and slope occurrence can be visualized.

55. Upon examination, it was determined that a minimum of four terrain factors was required to provide an adequate descriptive fabric. These four factors concern the spatial distribution and configuration in both plan and profile of the topographic highs and lows. The four factors selected are measures of: (a) the "peakedness" of the topographic highs; (b) the areal occupancy of the highs; (c) the degree of elongation or planar shape of the highs; and (d) the orientation or degree of alignment exhibited by the highs. The process of measuring these four factors is discussed in detail in Appendix A.

56. It follows that for complete quantification of surface geometry the descriptive system should include four additional maps, each showing the distribution of one of the terrain factors mentioned above. However, the mental integration of these four factors into a visualization of the landscape is so difficult that they have been combined for the purposes of this study into a single composite terrain factor called characteristic
plan-profile. This has been done by classifying each of the four factors (peakedness of highs, areal occupance of highs, planar shape of highs, and orientation of highs) in such a way that, combined in the manner shown in the legend of plate 7, they identify 24 basic variations of landscape configuration. Each of these 24 types, plus one other anomalous type, has been assigned a symbol (1, 1L, 2, etc.) and these types have been mapped as units.

57. It should be kept firmly in mind that each mapping unit of the characteristic plan-profile actually represents a specific combination of values of four terrain factors and is thus unlike the previously discussed geometry factors (slope, relief, and slope occurrence). Plan-profile is a composite terrain factor, and each component factor making up the composite is susceptible to quantitative treatment. Plan-profile, as mapped in this study, however, can be considered only qualitative or, at best, semi-quantitative, since only the component factor of areal occupance is expressed in the legend in quantitative terms whereas the peakedness, planar shape, and orientation of highs are expressed in qualitative terms.

58. To establish the classes used to differentiate types of plan and profile, two arbitrary assumptions were necessary: (a) a topographic high is peaked or crested when the characteristic slope is in excess of $6^\circ$, and is flat-topped when the characteristic slope of the summit area is less than $6^\circ$ and the side slopes exceed $14^\circ$; and (b) topographic highs are areally predominant when they occupy more than 60 per cent of the total area, neutral when they occupy between 40 and 60 per cent of the total area, and subordinate when they occupy less than 40 per cent of the total area.

59. The dimensions of the landscape typified by the plan-profile are dependent upon the magnitude of relief and slope occurrence. For example, alluvial fans scored by steep-sided, shallow washes are mapped with the same plan-profile as extensive, high-standing, dissected plateaus. This is considered not only permissible but desirable because, with unrestricted dimensions, the plan-profile offers a convenient framework within which a knowledge of the values of slope, relief, and slope occurrence permits a readily assimilated mental image of the landscape.

60. The characteristic plan-profile (plate 7) is the most commonly
found plan-profile within a region. It may be either restrictive or gross. The **restrictive plan-profile** is based on random sampling with circles 1 mile in diameter. Local relief of less than 10 ft is not considered. The **gross plan-profile** is based on random sampling with circles 35 miles in diameter. Relief of less than 100 ft is not considered. The prominences within the gross plan-profile are termed component highs; the intervening lowlands, component lows.

**Generalized landscape - a synthesis**

61. The generalized landscape is defined as the synthesis of mapping units of all geometry factors applicable to a particular area. The generalized landscape map (plate 11) has therefore been prepared by combining the characteristic plan-profile, slope occurrence, slope, and relief factors. Through superposition of the various maps, combinations of these factors evolve, each representing a distinctive landscape type. Cartographic problems related to this work are discussed in Appendix B. As the number of possible combinations of the stratifications of the four factors is rather appalling, it was considered impractical during the early stages of the study to try to develop any logical scheme for delineating individual landscape types. Multiplying the number of mapping units for each factor (25 x 6 x 7 x 7) results in 7350 mathematically possible combinations. Fortunately, nature has been far more selective and superposition of the maps resulted in only 18 combinations occurring at Yuma and only 78 in the entire Northeast African Desert. Comparable figures are available for three other world desert areas and it is anticipated, based on the present system of classification and mapping, that approximately 100 variations of landscape type will be found.

62. Combining the four basic geometry factors thus provides a convenient method of mapping terrain or landscape in a fairly quantitative fashion. The method is certainly one of the simplest possible. Any landscape can be designated by a combination of four numbers or number-letter symbols, each representing a particular range of values of plan-profile, slope occurrence, slope, and relief. The combination (1L//, 4, 1b, 2), for example, would define a plain with a slope of 1/2 to 3-1/2 per cent, scored by roughly parallel steep-sided washes from 10 to 50 ft deep and spaced from 1000 to 5000 ft apart. The landscape type could be sketched as follows:
63. It might be pointed out that the median value or some function (square root, sine, cube root) of the median value of the slope occurrence, slope, and relief units could be substituted for the unit number or number-letter symbol if a more quantitative or direct landscape designation is desired. Similarly, actual values of the four factors comprising each plan-profile unit could be employed. Although this procedure makes the landscape designation more truly quantitative, there seemed to be little advantage in its utilization in the present study. Perhaps the most advantageous use of such quantitative landscape values would be in determining the impact of individual landscapes on specific military considerations. After a period of testing landscape-impact relations, it may be possible to manipulate such values and develop effect analogs.

Ground and Vegetation Factors

Soil type

64. Soil type has been divided into two categories on the basis of percentage of area covered by bare rock and stony soils (plate 12). If more than 20 per cent of a region is covered by bare rock and stony soils, a soil-rock association is mapped; if less than 20 per cent is covered, a soil association is mapped. Generally speaking, areas of soil-rock associations exhibit soil thicknesses of less than 5 or 10 ft, whereas in areas of soil associations soil thicknesses exceed these figures. However, the scale of mapping precludes delineation, especially in mountainous regions, of many alluvial basins in which the thickness of soil cover may be greater than 10 ft; conversely, portions of many sand-sheet areas in which soil
cover is probably less than 5 or 10 ft have been mapped as soil associations since data permitting more accurate delineation were lacking. Stratification of the soil-rock category is quite arbitrary and is based on the percentage of area covered by bare rock and stony soils. Stratification of the soil category is based on grain sizes* of random samples and, it is hoped, is somewhat naturalistic in that the units define commonly occurring soil types of desert regions.

Soil consistency and surface rock

65. The soil-consistency and surface-rock factors (plates 13 and 14) complement soil type. Soil consistency is mapped in soil-association regions and surface rock in soil-rock areas. The primary stratification of soil consistency is based on homogeneity or lack of homogeneity in the upper 12 in. of soil; surface rock is stratified on the basis of the widely utilized genetic classification. Because a genetic classification has been used in mapping surface rock, ratings of some of the more important engineering properties of each rock type have been tabulated on the back of plate 14.

Vegetation

66. The vegetation factor (plate 15) is subdivided on the basis of naturally occurring desert assemblages and their structure or physiognomy. Physiognomic aspects considered in the classification are ground cover, canopy cover, spacing, height, trunk diameter, and crown diameter. Quantitative ranges of each of these vegetative subdivisions have been tabulated on the back of plate 15. A preliminary study aimed at the development of a quantitative classification of vegetation with world-wide application has been completed. It is expected that the final vegetative classification will be applicable to the analog system described herein.

Surface Roughness or Microrelief

67. Surface roughness or microrelief is an integral part of terrain

* In view of the sparse data available for soils mapping, limiting boundaries between various size ranges cannot be taken too seriously. However, using part of the U. S. Army Engineer Unified Soil Classification System as a base, the following size ranges were established as mapping guides: gravel, 76.2 to 4.76 mm; sand, 4.76 to 0.074 mm; silt, 0.074 to 0.0039 mm; and clay, less than 0.0039 mm.
geometry which has not yet been integrated into the description of terrain presented in this report. As previously stated, a landscape is defined in terms of the plan-profile, slope occurrence, slope, and relief generated by the 10-ft contour interval, i.e. having relief of more than 10 ft. Surface roughness or microrelief, then, is concerned with those features of terrain geometry having relief of less than 10 ft. It is clearly recognized that microrelief is often militarily important, and that to such military considerations as cross-country movement it may be of paramount importance. For example, such difficult terrain as boulder-strewn plains, fans cut by steep-sided washes, and many badland areas often exhibit relief too small to be considered in the mapping system outlined in this handbook.

68. There are excellent reasons for disregarding these minor features in mapping terrain factors previously discussed. In the first place, a reasonable lower limit had to be placed on the scale of generalization. Consideration of these minor features would have hopelessly complicated the system. In the second place, although travelers' accounts, available maps, landform ties and associations, and a liberal infusion of judgment permit reasonably consistent delineation of the terrain as generated by the 10-ft contour interval, delineation of microrelief within the vast, uncharted areas dealt with in this study would result in excessive subjectivity.

Classification

69. Preliminary attempts have been made to devise a method of classifying and mapping surface roughness in a fairly quantitative fashion. Roughness can be thought of as microgeometry and handled in much the same manner as the larger terrain envelope. Thus, relief might be divided into increments between 1/4 ft and 10 ft (it is necessary in such a scheme that a lower limit be established), and slope occurrence might consider the spacing of steep slopes where such slopes generate relief as low as 1/4 ft. Slopes generated by the 10-ft contour interval, and mapped as part of the generalized landscape, partially define terrain even at the microrelief scale; consequently, mapping of slopes defined by a smaller contour interval may not be necessary. This is particularly true since microrelief slopes greater than 50 per cent would be mapped as part of microslope
occurrence. Plan-profile, being independent of scale, may be applied intact to the microrelief envelope. Tentative mapping in several areas, however, indicates that a quantitative delineation of the four basic factors of plan-profile (Appendix A) or slight variations thereof may be feasible.

70. Many problems are unresolved in this scheme of classification. The cumbersome complexities introduced into the system by both positive and negative departures from a plane of reference are difficult to handle. Consider the difficulty of classifying, for example, a bouldery surface scored by a number of shallow washes.

71. Another weak point, which can only be resolved by testing materiel-surface roughness relations, is the arbitrary nature of the factor stratification. Unlike the mapping units utilized in the geometry factors, the roughness stratifications are not terrain-related or naturalistic. It seems probable that the best basis for stratification will be related to the effects or impacts of roughness on materiel. It is nevertheless true that if naturalistic groupings can be established that correspond closely with a determined roughness effect or impact they would be of great assistance in mapping relatively unknown desert regions. In any event, considerably more data must be accumulated concerning the impact on military activities and naturalistic groupings of surface roughness before an entirely suitable classification can be evolved.

72. A third consideration that remains unresolved is whether certain of the ground factors--or the vegetation factor--may be disregarded when dealing with microrelief. Should the fact, for example, that a given surface geometric pattern is made up of boulders, unconsolidated protuberances, or bedrock knobs be considered in the classification? Does the scale of generalization used in mapping the ground and vegetation factors apply when mapping microrelief, or must these factors be reconsidered at the lower scale of generalization used in microrelief?

Mapping

73. These questions are even more pertinent when an attempt is made to map microrelief and to integrate it into the system of analogy. Areas of homogeneous microrelief (areas throughout which a single microrelief feature prevails) are normally of small areal extent, and thus cannot be
shown at the scales of one to several millions used in the mapping system simply because of mechanical limitations. It is also true that a systematic and fairly objective approach to mapping these minor terrain features must be found if any confidence is to be placed in the resulting maps. Several methods have been proposed, none of which have been found satisfactory.

74. The simplest method has been to correlate microrelief with the landform-surface condition map illustrated in plate 5. Landforms, it may be recalled, are arbitrarily defined as topographic expressions having relief of 10 ft or more. Topography with relief of less than 10 ft is designated as a surface condition. Since microrelief has a similar 10-ft limitation, a simple translation of the surface conditions shown in plate 5 into microrelief units is possible. It is recognized that this method leaves much to be desired. The surface conditions shown in plate 5 are those to which formal names have been given and represent only a few of the pertinent ranges of microrelief that should be considered in mapping. Often, surface conditions such as the wavy bedrock surfaces called kharafish are described in the literature because of their uniqueness. Less striking, but no less important minor topographic variations are often disregarded. However, such a method does result in a map, which when compared with a similarly prepared map of Yuma, will permit a very rough comparison of the microrelief features of the two areas. No practical way has been found to integrate a microrelief map prepared in this manner into the composite analog map (plate 19, method described in Part V) in order to show degrees of analogy between Yuma and other world desert areas.

75. Another method, somewhat related to the first, is based on the assumption that given similar gross topographic features, rock types, and climatic conditions, similar groupings of microrelief units can be expected. For example, given an alluvial fan scored by washes draining from mountains composed of andesitic rock, it would be possible to make at least a rational guess as to the nature of the surface of both the fan and the washes incised in it. In effect, this method would use for its basic mapping units the major physiographic divisions used in mapping plate 1. In this method typical terrain "transects" are constructed showing, for example, the group of microrelief features typically associated with a
basin-and-range area, or with various natural subdivisions within a basin-
and-range area. When a scale of 1:5,000,000 is used in mapping, this
method results in arbitrary and subjective boundaries between units, and
as in the case of the first method, the groups of microrelief units chosen
as typical of each mapping unit are based on a depressing paucity of sound
data. Like the first method, this method would be extremely difficult to
fit into the composite analogy.

76. It will be noted that the major difficulties in integrating
microrelief into terrain description lie not in its classification but
rather in developing a reasonably objective approach to mapping this factor
and in fitting it into the scheme of over-all terrain analogy. A possible
solution to the dilemma is to accept the fact that our present knowledge
of the variations in microrelief is too limited for reasonably accurate
mapping of this factor, and to search for a method of improving estimates
of microrelief conditions in unmapped areas. At present, such estimates
must be based on landform-lithologic-soils associations. Why not use the
much less qualitative terrain-mapping scheme represented by the geometry,
ground, and vegetation factors outlined in this report as a basis for de-
tailed study of microrelief features? Thus, a 5L///, 2, 4, 6 type landscape
with a unit 2 soil-rock and unit 6 surface-rock association, and unit 3
vegetative cover might be studied where detailed, large-scale maps are
available. That distinctive groups of microrelief features are associated
with such distinctive terrain-factor units seems almost inevitable. Cer-
tainly such a method affords an orderly and objective approach to the
problem.

77. A map of microrelief prepared in such fashion would, in effect,
be a composite of the geometry, ground, and vegetation factors, with var-
ious combinations of these factors delineated as map units (essentially
the method by which the composite analog map, plate 19, was prepared).
Groups of microrelief units would be cataloged as characteristic of each
of these map units and used as a basis for analogy and degree of analogy.
Determination of these groups of microrelief units would, of course, in-
volve a detailed and long-range mapping program. Short of this, the
existence or nonexistence of terrain types (specific combinations of geom-
etry, ground, and vegetation factors) and, by inference, their associated
microrelief groups, is the best indication of the degree to which Yuma does or does not compare with other world deserts from the standpoint of microrelief. Conveniently, the degree of analogy as determined in the composite analog map (plate 19) automatically considers this relation. For these reasons this report does not attempt either to map microrelief separately or to determine its effect on the composite analog map. Synthesis of the ground, geometry, and vegetation factors, it is believed, determines the effect of microrelief on over-all terrain analogy as well as it can presently be determined.
78. This study does not purport to add to or even exhaustively summarize present terrain intelligence on the various desert areas mapped. Every attempt has been made, within the time limits allowed for the study, to utilize available unclassified data. However, the major emphasis has been on developing a valid scheme for determining terrain-factor similarities between various world desert areas and between these areas and the Yuma Test Station, and on synthesizing these data into maps showing varying degrees of analogy. As indicated in Part III, choice of terrain factors and refinement of mapping units depended to a large extent on their value in presenting a reasonably complete definition of terrain and on the detail necessary to establish valid "testing" analogs. Where data commensurate with the detail used in the mapping scheme were not available--and this was the normal situation in the relatively unmapped world areas dealt with--mapping was done subjectively, based on associations. It is thought that the considerable effort and time necessary to include the most recent data and refine the outlines of the mapping units should be expended only after the mapping techniques outlined in this report have been proved valid and useful.

79. Although the paucity of data required subjective mapping in many instances, it is emphasized that every effort has been made to prevent the inconsistencies inherent in such mapping. This was done by (a) a systematic sequence of mapping, (b) the establishment of as many physiographic, landform, and lithologic associations as possible in determining soil and soil-consistency units, and (c) setting up associations of both the general and ground factors to determine geometry factors. A time-consuming but rewarding method of establishing landform-physiographic associations for mapping the geometry factors was a limited study of aerial photographs and large-scale contour maps of arid portions of the United States. Where the required topographic data were available, such studies were instrumental in establishing entirely objective procedures for mapping the various terrain factors in the units chosen for this study. They further served to discipline subjective judgments made in the world-wide, small-scale mapping program.
Sequence of Map Preparation

As work progressed in the compilation of draft folio-reports for the North African and Middle Eastern deserts, it soon became apparent that certain terrain-factor maps aided or were essential in the preparation of others. The sequence outlined in table 2 evolved as the most effective in mapping the terrain factors established in the present study and in compiling the analog maps. Assembling existing data and maps is, of course,

Table 2
Outline for Map Preparation

I. Preparation of terrain-factor maps
   A. Assemble existing maps and textual-photographic data
   B. Prepare concurrently:
      1. Physiographic map, descriptions, and photographic tabulation (plates 1-2)
      2. Hypsometric map (plate 3)
   C. Prepare concurrently:
      1. Soil-type map (plate 12)
      2. Soil-consistency map (plate 13)
      3. Surface-rock map (plate 14)
      4. Vegetation map (plate 15)
   D. Prepare concurrently, by evaluation of the above:
      1. Landform-surface condition map, descriptions, and photographic tabulation (plates 5-6)
      2. Characteristic plan-profile map (plate 7)
   E. Prepare in the following order, by evaluation of the above plus analysis of textual descriptions and photographs:
      1. Slope-occurrence map (plate 8)
      2. Characteristic slope map (plate 9)
      3. Characteristic relief map (plate 10)
      4. Generalized landscape map (plate 11, then revise physiographic map, plate 1)

II. Preparation of analog maps (plates 16-19)
   A. Prepare geometry analog map
   B. Prepare ground analog map
   C. Prepare vegetation analog map
   D. Prepare composite analog map
the obvious first step. When this formidable task is nearly completed and a firm concept of the general terrain of the region has been obtained, preparation of the physiographic map can begin. Concomitant preparation of the hypsometric map is also advisable since the study of available contour maps often aids in the delineation of physiographic regions. With the completion of these two maps the investigator has strengthened his concept of the general terrain and, as a result of the extensive literature-map survey required, has garnered considerable data concerning vegetation, surface rock, soil type, and soil consistency. Subsequent mapping of these interdependent ground and vegetation factors brings a lower-order terrain envelope into focus. Thus, after mapping physiography, hypsometry, and the ground and vegetation factors, numerous landforms and surface conditions have been brought to the researcher's attention and the mapping of these features and their geometric expression (plan-profile) follows logically. Additional geometric aspects of the plan-profile, i.e. slope occurrence, characteristic slope, and characteristic relief, are then mapped in sequence. At this point it is advisable to revise the physiographic map, utilizing the more definitive boundaries established in geometry-factor mapping. Compilation of the generalized landscape and various analog maps from data presented in the previously prepared maps completes the terrain cartography for a particular desert area.

Aggregate or General Terrain Factors

81. Once the existing textual data and maps for a particular desert region have been assembled and surveyed, concomitant mapping of physiography and hypsometry presents very few problems. The contour interval utilized on the 1:1,000,000 World Aeronautical Charts provides the necessary data for completion of the hypsometric map (plate 3). More detailed maps and information taken from the literature usually provide ample material for the compilation of the definitive, but fairly qualitative, physiographic map and accompanying photographic tabulation. An example of this type of map, the Egyptian section of the Northeast African Desert, is found in plate 1.

82. The mapping of landforms and surface conditions is far more
complicated. In spite of the usual lack of detailed information on most desert regions, the researcher is still aware of a multitude of landforms and surface conditions comprising the terrain of the area under consideration. Although the small-scale mapping utilized for the world desert areas prohibits actual delineation of most landforms and surface conditions, the list of features and their mapping should be as complete and precise as possible. Consequently, actual landform borders are often shown on the fairly large-scale maps of the Yuma area whereas the same map pattern in Northeast Africa, for example, indicates only that the particular landform predominates or is very common within the patterned area (plate 5). Where the underlined designation (e.g. EW-kh) for a particular landform or surface condition appears in Northeast Africa, it indicates that this feature is widespread or common throughout the physiographic unit (plate 1) within which the designation lies. Where a designation is not underlined, it indicates that the feature is common within a region surrounding the designation, the limits of which are shown by a dashed line when known. In deciding whether a particular landform or surface condition should be mapped, the military importance of the feature, its "mappability" at the scale of mapping used, its distribution or frequency of occurrence and/or areal extent, its adaptability to precise definition, and many other factors were considered. It is thus obvious that two independent researchers would not compile the same list of landforms and surface conditions for a particular world desert area; however, it is hoped that upon completion of the folio-reports for the nine world deserts under consideration a fairly complete listing of landforms and surface conditions common to desert areas the world over will be possible. Landform-surface condition classification presented in plate 6 includes in its "world-wide range" ranges of geometry-factor mapping units for Yuma, the Egyptian section of Northeast Africa, and the four world desert areas that have been mapped to date. Plate 6 is tentative and lists only a few of the landforms and surface conditions found in Egypt. It is intended merely to show (a) the format utilized in classifying these features, and (b) the landform-geometry factor associations that are being developed. Note that no ranges of geometry-factor mapping units have been listed for "rippled surfaces," since these are classified as surface conditions characterized by less than 10 ft of relief.
83. Another problem connected with landform mapping concerns the fact that significant spatial groupings of distinct landforms, which cannot justifiably be considered as definitive physiographic units, often occur. Within the Sand Dune physiographic unit, for example, many different types of dune fields are found. Many such fields may be classified on the basis of spatial arrangement of a particular dune form or combination of forms. In addition, the fields or colonies themselves often exhibit a definite outline and spatial distribution. Unfortunately, most research concerning sand forms has been concentrated on individual dune types rather than associations or over-all field characteristics. Consequently, many militarily important landform groupings or associations cannot be mapped or defined per se. In a similar vein, most landforms or surface conditions that attract study and description are exotic, extraordinary, often localized features, and wide expanses of desert become "nonlandform" areas as a result of vastness or lack of data. Nevertheless, generalized terrain differences in landform groupings and nonlandform areas can often be determined by examining the generalized landscape map.

**Geometry or Form Factors**

**General**

84. Before the mapping of specific geometry or form factors is discussed, a few comments concerning maps and mapping techniques are in order. First of all, the primary function of any map is to show the plan distribution of classes of things. These "things" may represent ranges of elevation—as on contour maps—vegetation types, countries, or innumerable other classes or groupings. For accurate mapping, the precision of the methods and techniques employed varies directly as the quantitiveness of these classes. For example, fairly qualitative classes such as physiographic units can be mapped with qualitative data and fairly subjective procedures, whereas the accurate mapping of hypsometric, slope, and relief classes requires quantitative data as well as precise and objective mapping techniques. Furthermore, great differences in mapping scale exert relatively minor influence on subjective procedures, but often produce complications when precise and objective mapping techniques are utilized.
This is especially true when going from large-scale to small-scale mapping and indicates that scalar-determined generalization can be easily handled in mapping qualitative classes with subjective techniques, but is difficult to explain or describe when precise and objective mapping techniques are utilized. In fact, the scalar generalization resulting when such techniques are employed can only be determined through collection of empirical data in actual mapping at small and large scales. Some data have been accumulated; however, in most cases at the present time, it is only possible to estimate scalar effects. In areas such as the southwest United States where mapping coverage at varying scales is fairly good, some mapping and scalar correlations or relations can be observed. For example, when employing objective mapping techniques and 1:25,000 maps with a 10-ft contour interval, many ranges associated with the basin-and-range region of the southwest United States include patches of slope units 3, 4, and 5, unit 4 being areally predominant. Employing the same techniques and 1:250,000 maps with 100-ft contour intervals, these ranges would be mapped as slope unit 3. Obviously, if large and small regions are going to be compared in terms of terrain factors such as slope, these differences cannot be allowed. Thus, all terrain-factor mapping must utilize as a base the same contour interval, sampling area, and scale in order to insure that true areally dominant classes will be shown at small scales. Referring again to the U. S. basin-and-range region, let us assume that only 1:250,000 maps with 20-ft contour intervals are available for certain lithologically similar ranges and the resulting slope, when utilizing the established objective mapping techniques, is unit 3. Based on empirical data we can predict with some assurance that at a contour interval of 10 ft the areally predominant slope unit would be 4. Consequently, since we employ the 10-ft interval as a base, the mountain at a scale of 1:250,000 is mapped as slope unit 4. When good map coverage at varying scales is available for a region, this procedure is fairly simple but tedious to follow. In other relatively "unmapped" desert areas, subjective estimates must suffice until enough maps and empirical mapping data are available to allow objective determination of scalar effects. Nevertheless, as ranges of values are used in the present mapping scheme, subjective estimates can be made with considerable confidence. Spot-mapping of world desert tracts,
for which both large- and small-scale maps are available, has also provided numerous landform-terrain factor associations that aid in base-scale (1:25,000) mapping in relatively unknown areas. A few of these associations are presented in plate 6.

85. The preceding comments apply in varying degrees to the mapping procedures described in the following paragraphs. Probably the most important point is that the mapping bases utilized, with the exception of physiography and hypsometry, are "large-scale" in nature. In other words, they are closely allied with the Yuma area. Through areal generalization, described above, the same bases were employed in the small-scale mapping of world desert areas. This technique provides a means for comparison and analog development in areas of the same or different sizes, mapped at the same or different scales.

**Mapping complexes**

86. One of the more important concepts in the mapping method has been the use of complexes to illustrate dual classifications. Mapping is accomplished within the pertinent area by simply showing the two classifications (mapping units) on either side of horizontal, vertical, or diagonal lines. This results in the fractional or banded color and/or symbol patterns illustrated in plates 7-15. Complexes may be either areal or gross-component.

87. Areal complexes simply indicate the existence of two codominant mapping units within a given area. They are mapped in regions, for example, where two major, areally restricted, soil types occur but because of the smallness of the mapping scale or lack of detailed information these types cannot be separately delineated. It follows that areal complexes become less important as scales become larger and as the amount of mapping information increases. Fig. 4 shows the standard plan for symbolizing areal complexes. A diagonal line slanting upward to the right is used for areal complexes in mapping the ground and vegetation factors. The line may slant either to the right or to the left in the geometry-factor maps. The line may slant to the right or to the left in the geometry-factor maps. In any case the numerator always designates the areally predominant of two mapping units. When the line slants upward to the left in the geometry-factor maps, the denominator designates the areally subordinate mapping unit within the "lows." When the line slants upward to the right, the denominator
GROUND AND VEGETATION FACTORS (PLATES 11, 12, 13, AND 14)

GROUND AND VEGETATION COMPLEXES ARE MAPPED WHERE NO AREALLY PREDOMINANT (70 PER CENT OR MORE) SOIL OR VEGETATION TYPE OCCURS. IN SUCH INSTANCES THE TWO MOST COMMONLY OCCURRING TYPES ARE MAPPED USING FRACTIONAL PATTERN ILLUSTRATED BELOW.

![Fractional Pattern](image)

GEOMETRY FACTORS (PLATES 7, 8, 9, 10)

AREAL COMPLEXES ARE MAPPED ONLY WHEN THE PLAN-PROFILE IS MAPPED AS AN AREAL COMPLEX.

PLAN VIEWS SHOWING DISTRIBUTION OF HIGHS AND LOWS IN TYPICAL AREAL COMPLEXES

![Plan Views](image)

THE NUMERATOR INDICATES THE MAPPING UNIT OF AREALLY PREDOMINANT HIGHS. THE DENOMINATOR INDICATES THE MAPPING UNIT OF AREALLY SUBORDINATE LOWS. (CASE a).

THE NUMERATOR INDICATES THE MAPPING UNIT OF AREALLY PREDOMINANT LOWS. THE DENOMINATOR INDICATES THE MAPPING UNIT OF AREALLY SUBORDINATE HIGHS (CASE b).

Fig. 4. Areal complexes designate the areally subordinate mapping unit within the "highs." It should be noted that for cartographic reasons, areal complexes of geometry factors are mapped only where the plan-profile is mapped as an areal complex. Ground and vegetation areal complexes can be mapped regardless of the geometry of the region. In most cases plan-profile areal complexes can be limited to combinations of units 4, 4L, 4//, or 4L//, with units 1, 1L, 1//, 1L//, or 7. In every case unit 4 and its associated geometry-factor units refer to "highs" and the unit 1 or 7 association to intervening "lows."
The gross-component complex is used solely in mapping the geometry factors. The need for such a complex is obvious. As defined in this study, landscapes are semiquantitative descriptions of terrain geometry designated by four-number or number-letter symbols, each corresponding to mapping units of the four geometry factors. Each such landscape, however, is composed of smaller landscapes and is, in turn, part of a larger or next-order landscape. The lower limit of such landscapes has been set by definition as those exhibiting relief of at least 10 ft, i.e., those generated by a 10-ft contour interval. In most instances this landscape adequately depicts terrain geometry. In other cases, however, such as the situation illustrated in fig. 5, this landscape forms a component part of a larger or gross landscape which must be mapped to obtain an adequate portrayal of the area. Note that in fig. 5, a parallel ridge area with ridges from 2 to 10 miles apart comprises the gross landscape, whereas the plain between these ridges is a component landscape. Two scales of generalization, depending on the plan-profile, are used in this portrayal and
will be described more fully in the following section. Since the significance of the symbolization used in mapping the gross-component complex varies somewhat depending on the geometry factor mapped, this too will be discussed under the appropriate headings in the following paragraphs.

Characteristic plan-profile

89. As previously pointed out, mapping for comparison or analog purposes requires that a common sampling unit, contour interval, scale, and mapping technique be employed for all areas regardless of size. Any scalar generalization is then of an areal nature (which can be evaluated through the collection of empirical data) and mapped units represent true modal (most commonly occurring) classes. A dual method has been employed in plan-profile mapping. First a sample circle 1 mile in diameter, contour interval of 10 ft, and a map scale of 1:25,000 are utilized in the determination of restrictive plan-profiles. In other words, random sampling with circles 1 mile in diameter, using 1:25,000 maps with 10-ft contour intervals, is used to determine the restrictive plan-profile. Therefore, some scalar generalization is incorporated in the 1:400,000 map of the Yuma area, and even more in the 1:5,000,000 map of Egypt shown in plate 7. Regardless of scale, the most common plan-profile found within any region is always mapped; consequently, a restrictive type is either at Yuma or in Egypt.

90. The gross plan-profile is determined utilizing a 35-mile-diameter sampling circle and 1:250,000 maps with 100-ft contour intervals. A gross plan-profile can be divided into a minimum of two restrictive component plan-profiles, each exhibiting relief of a lower order than the gross plan-profile. This qualification explains why many areas are shown on the maps with only restrictive plan-profiles, i.e., characteristic relief within a 1-mile circle falls within the same relief class as that within a 35-mile circle.

91. In addition, since one of the component or restrictive plan-profiles of the gross is always shown, the gross plan-profile is never mapped singly. This procedure results in the mapping of what is termed a gross-component complex. For example, if a 6L//= gross plan-profile of a particular region consists of 4 and 1 restrictive plan-profiles (within the highs and lows, respectively), a gross-component complex of 6L//=l or
THIS LANDSCAPE COULD BE MAPPED AS:

1. TWO RESTRICTIVE PLAN-PROFILES, i.e., 1 AND 4.
2. AN AREAL COMPLEX 1/4.
3. A GROSS-COMPONENT COMPLEX 6L// 1.

MAPPING IS DETERMINED BY CONSIDERING:

1. WHETHER THE RESTRICTIVE PLAN-PROFILES (1 AND 4) ARE DELINEABLE — A FUNCTION OF MAPPING SCALE AND AVAILABLE DATA. (IF DELINEABLE, TWO SEPARATE PLAN-PROFILES ARE MAPPED; IF NOT DELINEABLE, AN AREAL COMPLEX IS MAPPED 1/4.)
2. IF THERE IS A NEED TO KNOW THE SHAPE AND PLAN DISTRIBUTION OF HIGHS AND CONDITIONS WITHIN LOWS, A 6L// 1 GROSS-COMPONENT COMPLEX IS MAPPED.
3. IF THERE IS A NEED TO KNOW THE SHAPE AND PLAN DISTRIBUTION OF HIGHS AND CONDITIONS WITHIN HIGHS, A 6L// | 4 GROSS-COMPONENT COMPLEX IS MAPPED.

Fig. 6. Mapping complexes—plan-profile

6L// 4 could be mapped (fig. 6). The choice here is based on military importance from the trafficability or movement standpoint; since it is more important to know the distribution of the highs and the conditions within the lows, a 6L// 1 complex would be mapped. In the case of a slightly dissected plateau exhibiting a gross plan-profile of 1, the most important consideration would be the condition of the highs or plateau tops. Consequently, a 1-7 gross-component complex would be mapped. As shown in plate 7, the vertical or horizontal position of the fraction line in the mapped complex pattern indicates the presence of a gross-component complex and whether the component plan-profile typifies the highs or lows.

92. Areal complexes are sometimes employed in mapping plan-profile. For example, a plains region dotted with hills might be mapped as a 1-4 areal complex. Theoretically, these hill tracts should be more than 18 or 20 miles apart to avoid classification of the region in a gross
plan-profile; however, as it is sometimes desirable to show conditions within both highs and lows rather than distribution of highs and conditions within either highs or lows, this spacing requirement may be relaxed if or when desired.

Occurrence of slopes greater than 50 per cent

93. The occurrence, slope, and relief factors assign value ranges to the plan-profile. Consequently, a dual system of mapping is necessary to handle both restrictive and gross plan-profile types.

94. Within the restrictive plan-profile area, random points and four lines at specific bearings (N-S, E-W, NE-SW, and NW-SE) passing through these points are located. Slopes greater than 50 per cent, generating relief of more than 10 ft, are counted along these lines until the requirements of one of the occurrence classes are met. The maximum occurrence class found in the line count is recorded at the central point. A sufficient number of random points within the restrictive plan-profile are so treated to determine a modal maximum occurrence class—or several classes if widely divergent point values necessitate areal stratification. Ideally, occurrence values are obtained utilizing 1:25,000 maps with 10-ft contour intervals and strictly objective mapping techniques. At present, however, mapping units must usually be approximated by means of empirically derived scalar correlations and landform-terrain factor associations—as is also the case in slope and relief mapping. In any event, a mapped restrictive-occurrence unit indicates the modal range of slopes greater than 50 per cent found along traverses—containing the maximum number of such slopes—within the area.

95. Areal complexes indicate that two major, areally restricted, occurrence types are found in the region, but because of the smallness of the mapping scale or lack of detailed information these types cannot be delineated. Occurrence units mapped in areas of gross-component plan-profile complexes indicate (a) the gross occurrence of the component highs or lows of the gross plan-profile, and (b) the restrictive occurrence of slopes greater than 50 per cent within a component of the gross plan-profile. The gross occurrence is a modal class determined within the gross plan-profile by sampling traverses aligned to cross the maximum number of
component highs or lows.* Maps at a scale of 1:250,000 with contour intervals of 100 ft are used as a base in these determinations. The restrictive occurrence of the component is obtained using the methods outlined in the preceding paragraph. As shown in plate 8, the vertical or horizontal position of the fraction line in the mapped complex pattern indicates (a) the presence of a gross-component complex and (b) whether the indicated restrictive occurrence of the component typifies the highs or lows.

**Characteristic slope**

96. Slope in a restrictive sense is mapped on the basis of the spacing of 10-ft contour lines, the closer the spacing the greater the slope. Spacing is always determined along a line perpendicular to the trend of the contour lines and the slope value computed directly. Utilizing a base at a scale of 1:25,000 or 1:50,000, areas containing 95 per cent of the type of slope mapped can readily be delineated. Greater precision can be attained by more careful mapping. As scales become smaller, contour intervals increase, and data become scarce, the percentage of actual slopes corresponding to the mapped slopes decreases. However, even in the most remote areas, landform, physiographic, and lithologic associations permit reasonably valid mapping within the definition of characteristic slope, viz., a narrow range of slopes that predominates or is most common within a region (see legend, plate 9).

97. Unlike slope occurrence, which considers the gross spacing between highs or lows on the gross plan-profile, gross slopes are never mapped. Justification for this methodology is found, for example, in considering a gross-component complex of plan-profile units 5L// and 7 (fig. 7a). Such a complex could represent a portion of basin-and-range topography, in which case the true gross slope (from range top to basin floor) usually falls between 1 and 3°. It is felt, however, that slope conditions within the range (component high) are of greater interest—and can be

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* For utilization with gross occurrence, the words "component highs (lows)" should replace "slopes steeper than 50 per cent" in the mapping-unit descriptions (plate 8). For example, in gross occurrence, unit 2 should read "The number of component highs (lows) ranges from 1 to 5 per 10 miles" rather than "The number of slopes steeper than 50 per cent ranges from 1 to 5 per 10 miles."
GROSS COMPONENT COMPLEX OF PLAN-PROFILE $\frac{5L}{7}$
GROSS COMPONENT COMPLEX OF SLOPE $\frac{4}{1b}$

a. Basin-and-range topography

GROSS COMPONENT COMPLEX OF PLAN-PROFILE $\frac{3L}{7}$
GROSS COMPONENT COMPLEX OF SLOPE $\frac{3}{1b}$

b. Longitudinal dune field

Fig. 7. Mapping complexes--characteristic slope
determined utilizing the large-scale mapping techniques. On the other hand, if the $5L/-7$ complex represented a longitudinal dune field or other area of smooth-sided prominences, the same mapping technique would result in an approximation of the gross slope--the important consideration in this instance (fig. 7b). As shown in plate 9, the angle of the fraction line in the mapped complex pattern indicates the presence of areal or gross-component slope complexes as well as their intra-area relations.

Characteristic relief

98. Relief in a restrictive sense is based on delineation of
restrictive slope units. Slopes mapped on a 1:25,000 base, for example, are divided into areas of less than 6° slope (units 1 and 2), and slopes greater than 6° (units 3 through 6). In the areas mapped with 3 through 6 slope units relief, by definition, is (a) the vertical distance from the highest point to the lowest point in randomly selected one-mile-diameter circles in which drainage lines are reasonably well developed; and (b) the vertical distance from peak or crest of an individual prominence to the floor of the nearest adjacent low where drainage lines are undeveloped, e.g. dunes and cinder cones. Where restrictive slopes are less than 6° (units 1 and 2), relief measurements are based on aligned indentations in contour lines, i.e. computation of wash or gully depth. With a 10-ft contour interval, areas with less than 10 ft of dissection (relief unit I-1, plate 10) are easily delineated and the mapping of subdivisions within Type I is relatively simple. As contour intervals increase, such a procedure becomes less objective. Where contour intervals are more than 50 ft, truly objective determinations are impossible. As in the case of the other geometry factors, determinations of relief when mapping at a scale of 1:5,000,000 must be based on lithologic and landform associations.

99. Gross relief is the modal height of component highs or the modal depth of component lows in areas of gross-component plan-profile complexes. Maps at a scale of 1:250,000 with 100-ft contour intervals are employed in making this determination; consequently, only relief units 5 (50 to 400 ft), 6 (400 to 1000 ft), and 7 (greater than 1000 ft) are used in mapping gross relief.

Generalized landscape

100. Mapping the generalized landscape is no problem. Plate 11, which shows the various landscapes that occur at Yuma and compares them with those occurring in Egypt, is made by simply overprinting plates 7, 8, 9, and 10. Theoretically, more than 7000 different landscape symbolizations could be shown by overprinting the various combinations of units of the four geometry factors. Areal and gross-component complexes of the generalized landscape are also automatically mapped by overprinting.

101. The landscape map synthesizes the four geometry factors of terrain and is used in the preparation of the geometry and composite analog maps (Part V). The preparation of the analog maps requires that a
distinction be made between gross and component or restrictive landscapes. For this reason notations have been added beneath the map of the Yuma Test Station and Sand Hills indicating the two gross landscapes occurring there, i.e., the landscapes determined utilizing a 35-mile-diameter sampling circle with 100-ft contour intervals.

Ground and Vegetation Factors

102. Although the limits of the mapping classes have been established with all possible precision, fairly qualitative data and subjective mapping techniques must usually be employed in actual ground- and vegetation-factor mapping. Existing soils, geologic, and vegetation maps, written descriptions, and established landform-ground factor associations are the primary bases for mapping. Objective sampling and mapping techniques required for ground-factor mapping when actual field investigations are possible have been explored, but were not applied in the present study. In an ideal situation, soils would be sampled a standard number of times within a sample area of a stipulated size. Soils would then be mapped depending upon the modal class of soil type.

103. The complexes in the ground and vegetation mapping are of an areal nature and represent mosaics of factor classes or mapping units. Complexes thus indicate distinct areally restricted tracts of specific mapping units rather than mixtures of these units. These areally restricted tracts cannot be delineated because of the small mapping scale utilized or because of the lack of detailed information. Complexes are mapped where no areally predominant (70 per cent or more) mapping unit occurs and only the two most common mapping units are shown; the predominant is shown as the numerator, the subordinate as the denominator in the fraction mapping pattern (plates 12, 13, 14, and 15).

104. A point concerning the aggregate nature of the ground factors should be mentioned. In much the same fashion as the plan-profile factor is composed of several quantitative factors or properties, each of the ground factors could be similarly divided. Surface rock, for example, could be stratified in quantitative values of compressive strength, abrasion resistance, sphericity of fragments, proportion of free silica, and
many other considerations. As the ranges of these considerations, for the most part, overlap any stratification based on the widely utilized genetic classification of rock, tabulation of these properties within a genetic or descriptive classification is quite difficult. The alternative of preparing a separate map for each property is, in the light of present knowledge, a formidable if not impossible task. Nevertheless, some method of separate mapping or—preferably—synthesizing through meaningful tabulations must be developed for quantitative ground-factor data before a truly quantitative method of terrain mapping can be devised. In this report, the vegetation tabulation (back of plate 15) presents some quantitative values for the mapping units and the surface-rock tabulation (back of plate 14) presents property ranges of a more qualitative nature. Although the mapping of ground and vegetation factors is considered adequate to satisfy the aims of the present study, it certainly should not be considered a final effort in quantitative ground-factor mapping.
PART V: COMPILATION AND INTERPRETATION OF ANALOG MAPS

105. As previously pointed out, each of the terrain-factor maps is, in reality, an analog map. Similarly mapped areas exhibit high degrees of analogy from the standpoint of the particular terrain factor under consideration. However, a synthesis of terrain-factor data and maps, resulting in the establishment of varying degrees of analogy of particular world desert areas with portions of the Yuma Test Station, has been attempted in the final plates of the folio-reports. This synthesis can be divided into steps involving the compilation of the following four maps: (a) geometry or form analog map, (b) ground analog map, (c) vegetation analog map, and (d) composite analog map.

106. The geometry analog map is merely a modification of the generalized landscape map which was prepared through superposition of the slope, relief, slope occurrence, and plan-profile maps. If a landscape type (designated by a combination of four numbers or number-letter symbols, each representing a specific mapping unit of characteristic plan-profile, slope occurrence, slope, and relief) found at Yuma also occurs in Northeast Africa, for example, the area so mapped in Northeast Africa is considered to be highly analogous to the region exhibiting this landscape type at Yuma. An area in Egypt exhibiting three numbers or number-letter symbols out of four found in a combination at Yuma is considered to be moderately analogous, and so on (table 3). Plate 16 more fully illustrates the geometry analog legend and presents a portion of a typical map. Note that all gross landscapes are distinguished from component or restrictive types. This is done so that gross landscapes in one area will be compared only with the gross landscapes at another area. The two gross landscapes found at Yuma have been indicated below the maps.

107. The ground analog map is prepared in a manner very similar to that used in preparation of the geometry analog map, by superimposing the soil-type, soil-consistency, and surface-rock maps. Soil-rock units (soil units 1 through 3) are always found in combination with surface-rock types, and soil units 4 through 10 are always found in combination with soil-consistency types. Hence, ground analogs are designated by only two digits (or 4 digits where a complex is mapped). The vegetation analog map is a
Table 3: Landscapes Found at Yuma and in Egypt: Analogy Determinations

I. Restrictive or Component Landscapes

<table>
<thead>
<tr>
<th>Egyptian Landscape Array*</th>
<th>compared with</th>
<th>Yuma Landscape Array</th>
<th>Degree of Analogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 4 lb 2</td>
<td>1L 4 lb 2</td>
<td></td>
<td>Moderately</td>
</tr>
<tr>
<td>LL 2 lb 2</td>
<td>1L 4 2 2</td>
<td></td>
<td>Moderately</td>
</tr>
<tr>
<td>1 4 2 2</td>
<td>1L 4 2 2</td>
<td></td>
<td>Slightly</td>
</tr>
<tr>
<td>LL 3 2 2</td>
<td>4L 4 3 5</td>
<td></td>
<td>Highly</td>
</tr>
<tr>
<td>1 4 3 5**</td>
<td>4 5 3 4</td>
<td></td>
<td>Highly</td>
</tr>
<tr>
<td>4 5 4 5</td>
<td>4 5 4 5</td>
<td></td>
<td>Moderately</td>
</tr>
<tr>
<td>4 6 4 5</td>
<td>4 6 4 5</td>
<td></td>
<td>Highly</td>
</tr>
<tr>
<td>4 6 5 6</td>
<td>4 6 5 7</td>
<td></td>
<td>Highly</td>
</tr>
<tr>
<td>7 1 la 1</td>
<td>7 1 lb 1</td>
<td></td>
<td>Highly</td>
</tr>
<tr>
<td>7 1 la 2</td>
<td>7 1 lb 2**</td>
<td></td>
<td>Slightly</td>
</tr>
<tr>
<td>7 1 2 2**</td>
<td>7 1 lb 1</td>
<td></td>
<td>Moderately</td>
</tr>
<tr>
<td>7 1 2 1</td>
<td>7 1 lb 1</td>
<td></td>
<td>Moderately</td>
</tr>
</tbody>
</table>

II. Gross Landscapes

<table>
<thead>
<tr>
<th>Egyptian Landscape Array*</th>
<th>compared with</th>
<th>Yuma Landscape Array</th>
<th>Degree of Analogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 5 5**</td>
<td>1 5 7 7</td>
<td></td>
<td>Slightly</td>
</tr>
<tr>
<td>1 3 5 5**</td>
<td>3 5 5 7</td>
<td></td>
<td>Slightly</td>
</tr>
<tr>
<td>1 3 6 7</td>
<td>5L 1 5 7</td>
<td></td>
<td>Slightly</td>
</tr>
<tr>
<td>1 4 5 5**</td>
<td>2 5 5 7</td>
<td></td>
<td>Slightly</td>
</tr>
<tr>
<td>3 2 5 5**</td>
<td>6L 1 3 5</td>
<td></td>
<td>Slightly</td>
</tr>
<tr>
<td>1 2 6 5</td>
<td>4 3 5</td>
<td></td>
<td>Slightly</td>
</tr>
<tr>
<td>5L 4 3 5</td>
<td></td>
<td></td>
<td>Not</td>
</tr>
</tbody>
</table>

* Units in lightface type indicate the maximum number of units found in the closest-corresponding array at Yuma. Units shown in boldface type are not found at Yuma in combination with the remaining units of the array.

** In a particular array it may be possible to choose different sets of light- or boldface units to indicate the maximum degree of analogy. In such instances units are compared in the order given in the array. For example, the Egyptian array 4,4,3,5 was compared with the Yuma array 4,5,3,5 rather than 4L//,4,3,5.
slight modification of the vegetation map. World desert areas mapped with vegetational units found at Yuma are considered to be highly analogous to their Yuma counterparts. Additional information concerning the ground and vegetation analog legends and maps is presented in plates 17 and 18.

108. It should be noted that the identity of the various terrain-factor mapping units has been retained, through utilization of their number or number-letter symbols, on the three analog maps. Thus, for example, when a tract within a world desert exhibits two out of four geometry-factor mapping units found in combination at Yuma, it is possible to identify the units common to both areas. In other words, the units that determine the degree of analogy can be identified.

109. The composite analog map (plate 19) is compiled through superposition of the geometry, ground, and vegetation analog maps. The mapping units or components of the geometry, ground, and vegetation analog maps were first assigned values ranging from 0 to 4, based on the number of mapping units in common with Yuma. For example, the moderately analogous unit of the geometry analog legend is mapped in areas possessing three out of four terrain-factor symbols found in a combination at Yuma; consequently, a value of three was assigned this unit. When the three maps are superimposed, and the unit or component values totaled for each area, the totals range from 0 to 7. This range was then divided into five groups and the areas exhibiting these value groupings were outlined on the map. Regions where superposition of the geometry, ground, and vegetation analog values resulted in totals of 6 through 7 were mapped as highly analogous; 4 through 5-1/2, moderately analogous; 2 through 3-1/2, slightly analogous; 1/2 through 1-1/2, inappreciably analogous; 0, not analogous (plate 19). In general, highly analogous world desert tracts exhibit, or closely approximate, combinations of terrain-factor mapping units found at Yuma and the degree of analogy decreases directly as the similarity to a combination of mapping units found at Yuma decreases. Although the identity of the individual terrain-factor mapping units has not been retained on the composite analog map, identification can be made quite simply through examination of the other analog maps.

110. It should be mentioned that all terrain factors, regardless of whether the factor is simple or composite, were given equal weight in the
analog determination. No serious effort was made to establish a more suitable "weighting" system because of the difficulty inherent in any attempt to determine the relative worth of any terrain factor from the standpoint of (a) geomorphic considerations, or (b) general or universal military application. Furthermore, for reasons of simplicity and universality, no attempt has been made to differentiate between degrees of analogy within specific terrain factors. For example, Yuma landscape type 4,4,3,5 is more analogous to Egyptian type 4,5,3,5 than to Egyptian type 4,6,3,5, but in the method employed in this handbook each of the Egyptian types would be given a value of 3, i.e. moderately analogous. Weighting systems for entire terrain factors and/or terrain-factor mapping units can be easily devised for many specific considerations and employed when desired.

111. It should also be noted that analog determinations in areas of complexes are based on the entire area and not on independent consideration of specific areal or gross and component types. For example, a region mapped as an areal complex consisting of two landscape types--one highly analogous with a type at Yuma, the other, slightly analogous--would be mapped the same as an areal complex of two moderately analogous landscape types. Thus, in the present system, the analogy in regions of areal or gross-component complexes is based on a consideration of the entire area. Obviously, different methods could be utilized if it is deemed desirable to recognize the analogy of the types comprising the area.

112. A detailed examination of the composite analog map and areas exhibiting varying degrees of analogy can be of great help in understanding the technique described in this handbook. The composite analog map delineates areas possessing combinations of geometry, ground, and vegetation factors that--when compared with the most similar combination at Yuma--exhibit the same degree of analogy. Such combinations, consisting of a string of seven numbers or number-letter symbols, each identifying a terrain-factor mapping unit, are termed terrain types. Any area on the composite analog map exhibiting a particular degree of analogy (highly, moderately, etc.) may consist of either a single characteristic terrain type or of several terrain types--each type, however, must exhibit the same degree of analogy when compared with the most similar type found at Yuma. For example, most of the Qattara Depression consists of a single
terrain type shown as moderately analogous in plate 19. In contrast, the Nile Delta, located roughly within the triangular area described by Cairo, Alexandria, and Port Said, and shown as highly analogous, consists of several terrain types, each of which is highly analogous.

113. Using the Qattara Depression as an example, the area is shown in plate 19 as moderately analogous because the summation of the area's geometry, ground, and vegetation analog values (4, 0, and 1, respectively) falls in the moderately analogous range, i.e. 4 through 5.5. From the geometry analog map (plate 16) it can be seen that the landscape or geometry-factor array or group for the area is 7,1,1a,1--indicating respectively the associated mapping units of plan-profile, slope occurrence, slope, and relief. The 7 plan-profile unit indicates that the characteristic plan-profile exhibits no pronounced highs or lows. The 1 slope-occurrence unit indicates that the number of slopes steeper than 50 per cent is less than 1 per 10 miles. A characteristic slope between 0 and 1 per cent is denoted by the 1 slope unit. Finally, the characteristic relief of less than 10 ft is indicated by relief unit 1. The fact that all of these unit designations are shown in lightface type on the geometry analog map--and the area, consequently, shown as highly analogous--indicates that this geometry-factor group or landscape type is found at Yuma.

114. From the ground analog map (plate 17) it can be seen that the Qattara region possesses a ground-factor group or combination of 10,6--indicating respectively the associated units of soil type and soil consistency. The 10 soil-type unit denotes a saline clay or silt. A hard surface crust overlying (within 12 in. of the surface) soft materials--commonly muck, ooze, or saturated silts--is indicated by soil-consistency unit 6. The fact that these unit designations are shown in boldface type on the ground analog map--and the area, consequently, shown as not analogous--indicates that this ground-factor combination is not found at Yuma.

115. From the vegetation analog map (plate 18) it can be observed that the Qattara region is mapped with vegetation unit 2--sparse shrub and grass. The fact that this unit designation is shown in lightface type on the vegetation analog map--and the area, consequently, shown as highly analogous--indicates that this vegetation unit is found at Yuma.
116. Thus, the Qattara area is characterized by a geometry-factor group or landscape type, viz., 7,1,la,1, that is found at Yuma; by a ground combination, viz., 10,6, that is not found at Yuma; and by a vegetation unit, viz., 2, that is found at Yuma. In other words the area is highly analogous from the standpoint of geometry factors (analog value of 4); not analogous from the standpoint of ground factors (analog value of 0); and highly analogous from the standpoint of vegetation (analog value of 1). Thus, the composite or terrain-type analogy of the area is moderate (analog value of 5). By checking the geometry, ground, and vegetation analog maps, the terrain type at Yuma that most closely approximates the characteristic terrain type of the Qattara area can be found--by locating tracts mapped with a 7,1,la,1 landscape type and vegetation unit 2. The largest tract of this nature found at Yuma surrounds the R & D area. The terrain type of this tract is 7,1,la,1,5,1,2 and most closely approximates the 7,1,la,1,10,6,2 of the Qattara. It is obvious that the dissimilarities in soil type and soil consistency relegate the Qattara area to its moderately analogous position. Testing programs concerned with military activities affected solely by geometry and vegetation factors could be conducted in this tract at Yuma and similar terrain impacts* on the same activities could be expected in most of the Qattara area. However, if the activities are affected by soil type and soil consistency, the Yuma tract would be wholly inadequate for testing and subsequent prediction of effects in the Qattara area.

117. Two very significant points can be derived from the preceding examination of the Qattara region and its closest counterpart at Yuma. First of all, it is interesting to note the relatively high degree of analogy (moderate) between a playa in Egypt and a river terrace, its closest counterpart, at Yuma.** If the classical or qualitative geomorphic descriptions of these areas had been utilized this similarity would, for the most part, be ignored. Conversely, it is also common to find many different terrain types within a single physiographic "unit,"

* Disregarding microrelief considerations.
** This is, of course, from the standpoint of developing testing programs in relatively small areas--the concept of size or vastness is not incorporated.
such as volcanics or dunes, established on the basis of qualitative methods. In the light of these observations alone the quantitative or semiquantitative factorial approach to terrain classification is certainly warranted.

118. Secondly, the examination of the Qattara hints at the almost infinite number of special consideration or purpose maps which can be prepared utilizing the terrain-factor and analog maps. For example, by combining certain terrain-factor maps, e.g. slope, relief, and soil type, special maps showing resulting combinations and their distribution in Egypt and at Yuma are possible. Analog maps for these special combinations can be prepared. Only slight modifications of existing maps are necessary to provide maps showing the distribution, in Egypt, of Yuma terrain types, landscape types, or any desired terrain-factor combinations. Conversely, maps showing the distribution, at Yuma, of Egyptian terrain types, landscape types, etc., are easily prepared. Mapping units found at Yuma and in Egypt are listed in table 4.

Table 4: Distribution of Mapping Units

<table>
<thead>
<tr>
<th>Units Occurring in</th>
<th>Geometry Factor Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope</td>
</tr>
<tr>
<td>Plan-profile</td>
<td>Occurrence</td>
</tr>
<tr>
<td>Both Areas</td>
<td>1L, 4, 4L, 7</td>
</tr>
<tr>
<td>Yuma Only</td>
<td>4L</td>
</tr>
<tr>
<td>Egypt Only</td>
<td>1, 4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Restrictive or Gross Units</th>
<th>Ground Factor Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Units</td>
<td>Soil Type</td>
</tr>
<tr>
<td>Both Areas</td>
<td>1, 4, 5, 6, 8</td>
</tr>
<tr>
<td>Yuma Only</td>
<td>-----</td>
</tr>
<tr>
<td>Egypt Only</td>
<td>2, 3, 10</td>
</tr>
</tbody>
</table>
PART VI: SIGNIFICANCE OF ANALOG TECHNIQUES

General Review

119. A primary objective of this study has been the development of a technique for describing and classifying desert terrain in a manner that is fairly objective and quantitative. Researchers attempting to compare two areas are continually plagued by the qualitativeness and subjectivity of terrain description. Considering the complexities of quantitative terrain description, it is understandable why this has been true for such a long time. However, it is felt that advances in various fields concerned with terrain, and particularly with the effects of terrain on military considerations, will be seriously hampered until there is a reasonably sound and accepted system of terrain classification, one that permits individuals of varied backgrounds to classify the same terrain in the same terms given the same basic information.

120. This defect in terrain description is particularly troublesome in considering terrain geometry or surface configuration, and it is in this field that the present study has made some headway. As described earlier, the system permits the classification of terrain geometry or landscape in terms of four terrain factors, three of which are quantitative while the other is a qualitative framework actually made up of four additional quantitative factors. Among the desirable attributes of the landscape classification are: (a) a great variety of natural landscapes are objectively identifiable and classifiable in the same terms—given similar basic information; (b) refinement of the various ranges of factors represented by the mapping units is possible without altering the fundamentals of the landscape classification in any way; and (c) the system may permit mathematical manipulation of geometry factors in such a way that the effects of individual factors or factors acting jointly on a particular military activity can be determined.

121. One of the major limitations of the method is that the degree of detail necessary to map terrain objectively in the units suggested is available for only the better-mapped areas of the world. The world desert areas mapped in this study are almost entirely lacking in such detail. As
a result, although the system is objectively oriented where data are available, subjective methods were necessarily resorted to in mapping most of the world deserts. It should be recognized, however, that subjective methods of mapping must be used in these poorly mapped world deserts regardless of whether the mapping units are expressed in qualitative or quantitative terms. Moreover, the few detailed qualitative maps of desert areas which indicate the more important aspects of terrain are often expressed in entirely different terms. Consequently, comparison of these areas is difficult or impossible. The present study will at least result in the mapping of world desert terrain in common units so that direct comparison is possible--this being a primary purpose of the project. In addition, it may be accepted as, or at least stimulate the development of, a universal, quantitative, and objectively oriented system of terrain classification--a classification that can be applied with equal validity to small- as well as large-scale maps.

**Yuma Terrain Analogs**

122. As previously mentioned, an immediate aim of the present study has been to compare the terrain at Yuma with that of world deserts, and also to develop a technique for (a) determining the suitability of a small area as a representative testing site for world desert conditions, and (b) comparing two desert areas of similar or differing sizes. Obviously, the value of tests conducted at a site such as Yuma depends on the extensive distribution in world desert areas of the specific terrain-factor combinations found at Yuma. Utilizing the technique and resulting maps described herein, the distribution and extensiveness of individual or combinations of terrain-factor ranges can be determined, and the suitability of the area as a test station for specific or combined terrain factors effectively established.

123. After the method has been applied to the nine world desert areas under consideration, it may be found that the Yuma Test Station lacks certain ranges or combinations of terrain-factor ranges found in other desert areas. Application of the analog technique to the western United States, however, will permit a quick evaluation of areas within the United
States that may be more analogous to aggregate world desert conditions than the Yuma area, or which, when considered with Yuma, will cover a much more representative range of desert terrain. Such areas could well be utilized as supplementary testing sites. In any event, the system dictates that if an area at Yuma exhibits a certain combination of geometry, ground, and vegetation factors, more than 50 per cent of a similarly mapped tract in any world desert will offer similar detriments or advantages to any given military activity affected by these factors.

124. Once the implications of the terrain classification and analog technique presented in this handbook are understood, the technique can be used in the comparison of any two desert areas of either similar or differing sizes. Areas of analogy in various world deserts can thus be readily determined.

Long-range Significance

125. The development of a technique for preparing desert terrain analogs was the first, and a very important, step toward the goal of predicting quantitative impacts of terrain on military activities in world deserts. Steps necessary for the attainment of this goal are indicated in fig. 8. An attempt at the development of a technique for describing terrain and preparing desert terrain analogs (Step I) is described in this handbook. The more tangible portion of Step II, evaluation of the effects of terrain on military activities based on a survey of the records, has been partially accomplished by a group at George Washington University.1

126. The less tangible portion of Step II, the integration of the experience of military personnel into the mass of terrain-impact data, cannot be adequately reviewed or evaluated. In fact, it is probable that such knowledge can be properly correlated and its significance assessed only when military personnel are armed with a workable, quantitative, objective system of terrain classification along the lines attempted in this handbook.

127. Data provided in Steps I and II should permit fairly good qualitative estimates of military activity-terrain factor relations. Examination of the terrain-factor maps prepared for any world desert area (by personnel familiar with the technique of terrain description, the analog
Fig. 8. Steps in development of desert terrain-effect analogs

development, and a particular military activity) should aid considerably in compiling general (strategic level) terrain-effect maps. For example, zones most suitable for mass movement, from the standpoint of terrain, could be delineated and strategic route maps compiled. Although a worthy contribution in itself, this qualitative strategic adaptation is not part of the program designed to attain the goal of quantitative impact-terrain relations.
128. Perhaps Step III's position and significance can be best explained as the necessary thinking process that must be pursued prior to undertaking Step IV--quantitative determination of the impact of terrain factors on military activities through actual testing programs. Individual military considerations are each concerned with different terrain factors and with varying degrees of refinement of the mapping units within each factor. Desert road construction, for example, might be concerned with only six of the eight factors, survival with three, cross-country movement with all eight. Reasonably sound decisions can be made concerning the pertinence of various terrain factors, thus permitting some of them to be disregarded in the testing program. In addition, judgment may often prove a valid basis for grouping certain of the mapping units within each selected factor or for limiting the testing to a particular range of units. For example, in planning tests for the M4 tank the programmer may have firm grounds for concluding that desert vegetation can be disregarded and that merely the presence or absence of surface rock need be considered. He may conclude that some of the characteristic slope mapping units can be combined to establish slope ranges more in keeping with the performance abilities of the tank. His knowledge and experience may also indicate that tank movement is obviously impossible in areas exhibiting certain ranges of relief, thus making testing in such areas unnecessary. Thus, after the various terrain factors have been modified to meet the needs of the particular problem, tests can be conducted in areas characterized by distinctive combinations of the devised mapping units. The important point is that the same system of characterizing the testing environment be used in all areas so that tests in one area can be related specifically to tests in another.

129. Subsequent testing (Step IV) of various areas exhibiting different terrain-factor combinations at Yuma should result in conclusions regarding the impact of factor combinations and individual factors on tank movement. It may be possible to establish a system of weighting the various terrain factors in relation to their impact or effect on tank movement. For example, soil consistency may be found to be three times more important in tank movement than steep slope occurrence. A weighting system within each terrain factor might also be formulated. Possibly a combination of
two factors may be the decisive parameters in tank movement in more than 80 per cent of the trials. Many data such as these should result from impact testing in the test site area. Impact testing of various terrain factors and combinations of factors will thus permit the mapping of terrainwise analogous areas in world desert areas in terms of impact. Furthermore, interpretation and extrapolation of testing data should permit impact mapping of world desert areas which do not exhibit the exact combinations of terrain-factor units found within portions of the Yuma area. When this becomes possible in a refined quantitative manner, a primary objective of the over-all project will have been realized (Step V). To reach this objective, testing-mapping programs similar to the one roughly outlined above must be carried out for all military activities (e.g., construction, communications, cover and concealment, survival, fields of fire) wherein terrain is significant.

130. In summary, although the technique developed in this study is presently tentative and far from a geomorphic panacea, it is felt that it can be developed into an objectively oriented analytic tool for describing, mapping, and adequately comparing terrain of areas exhibiting great differences in size, homogeneity, and available data. It is also believed that quantitative testing programs will demonstrate the usefulness of the technique in impact-terrain correlations in a wide variety of military considerations.
PART VII: ANALYSIS AND RECOMMENDATIONS

Analysis

131. The following is a brief analysis of the analog techniques described in this handbook:

a. The factors chosen permit defining terrain in simple, yet reasonably complete terms.

b. Terrain factors in all world desert areas are mapped utilizing the same units. Hence, the folio-reports prepared in accordance with the mapping techniques described in this handbook afford, for the first time, a ready comparison of terrain in all the deserts of the Northern Hemisphere.

c. Terrain factors at the Yuma Test Station have been mapped in the same units, permitting ready comparison of Yuma with world deserts.

d. Mapping generalizations have been areal, the degree of refinement varying with the scale. This implies that an area at Yuma delineated as having steep slopes, for example, may consist of 95 per cent or more steep slopes. In North Africa, steep slopes may occupy only 50 per cent of the area so mapped. This is considered ideal in establishing "testing" analogs since tests within restrictively mapped units at Yuma would be representative of the typical situations within a similarly mapped but more generalized world desert area.

e. Terrain geometry has been mapped at a standard topographic envelope—the 10-ft contour interval—regardless of scale. This solves the troublesome problem posed by terrain envelopes and permits comparison of terrain geometry regardless of scale.

f. Terrain geometry has been reduced to four major factors. One, the plan-profile, is a qualitative framework, the dimensions of which are indicated by three quantitative factors: slope, relief, and slope occurrence. This permits a readily assimilated mental image and a semiquantitative classification of the landscape. The system permits mapping of more than 7000 mathematically possible landscapes, but natural selectivity seems to have limited landscape types in most desert areas to about 100.

g. All terrain factors are synthesized by superposition into a composite analog map which indicates degrees of analogy or similarity of the mapped world desert areas to the Yuma Test Station. Each terrain factor, regardless of whether it is simple or composite, has been given equal weight in this synthesis.
h. It is believed that the analog techniques, with modifications and additions, will be applicable in environments other than the desert.

Recommendations for Future Studies

132. Three of the most serious deficiencies of the system of classification and the mapping techniques presented herein concern: (a) the difficulties involved in integrating microrelief into the system; (b) the qualitativeness of the ground and vegetation factors; and (c) the overly subjective methods necessary in mapping areas for which little data are available.

Microrelief studies

133. Of considerable importance is the development of a method of classifying and mapping microrelief and integrating the mapped results into the system of analogs. Classifying microrelief in a fairly quantitative manner will probably be the least difficult task. Finding a method for adequately mapping this composite factor and of generalizing it for mapping at a scale of, say, 1:5,000,000 will probably be very difficult. Once this problem of mapping generalization is resolved, the integration of the microrelief concept into the analog system should not be too difficult. Studies along the lines suggested in paragraphs 74-75 might go far toward resolving this difficult problem of microrelief. At least these methods will permit an orderly approach to a study that might otherwise bog down in a morass of detail.

Quantitative classifications of ground and vegetation factors

134. It is generally agreed that quantitative classifications of the ground and vegetation factors would be most desirable, and that studies to quantify these aspects of terrain should be intensified. At the present time considerable headway is being made in developing a quantitative classification of vegetation that will be universally applicable. Problems concerned with employing this vegetation classification system in mapping have not been fully resolved, and problems concerned with generalizing the resulting maps so that the data can be shown at various scales are far from resolved.
135. A truly troublesome aspect of the various attempts that have been made thus far to quantify the ground and vegetation factors is that such quantification invariably necessitates consideration of a multitude of quantitative factors to express a single composite factor now expressed qualitatively. Although this multiplication of factors should be expected if the benefits of quantification are to be realized, the number must be kept within reasonable and practical limits if the classification is to be integrated into a usable system that fully describes terrain. Otherwise the researcher is soon buried under a plethora of symbols, and his maps are so complex that they become useless. It is re-emphasized that, although the quantitative approach is certainly desirable, it may still be wise to utilize semiquantitative or qualitative techniques in some cases.

Mapping techniques

136. **Objective mapping.** Considerable progress has been made in preparing a set of rules or instructions for truly objective mapping of the geometry factors in areas mapped with 10- or 20-ft contours. Additional effort must be spent in refining and simplifying these instructions. Rigorous techniques should also be developed for mapping the ground and vegetation factors if a suitable quantitative classification system can be devised.

137. **Guides for subjective mapping.** A regrettable but necessary corollary of mapping poorly known regions is that subjective techniques become increasingly important as data decrease. The need for guides to aid the analyst in subjective mapping has long been recognized and considerable valuable information exists in the literature which, when properly assembled, could be used to translate raw descriptive data into the classification system presented in this handbook. The effects of climate, lithology, and elevation on soil type; the effect of soil type and landform association on relief; and the consequence of lithology and vegetative cover on terrain geometry in general are examples of the types of studies that serve as excellent guides to mapping in poorly known areas and permit a somewhat objective approach. Preliminary studies along these lines have been made preparatory to mapping the world deserts in the folio-reports. An example of this work is the chart of landform-geometry factor
associations in plate 6. However, much additional work is needed on methods of disciplining subjective mapping.

138. Another approach to establishing guides, particularly for mapping the geometry of poorly known regions, is through detailed study of a hierarchy of terrain envelopes. Preliminary studies indicate that valid and worth-while inferences can be made of the geometry of a particular region from maps with scales as small as 1:1,000,000 and a 500-ft contour interval. Reasonably valid relations can be established, for example, between slopes measured directly from such a map, slopes measured from 1:250,000 maps with a 100-ft contour interval, and those measured from a 1:25,000 map with a 10-ft contour interval. Detailed studies could compare and graph the various quantitative geometry factors in areas covered by maps at these scales. Relations between the hierarchy of envelopes could then be compared in all the areas mapped and hypotheses developed and tested concerning significant variations in these relations.
SELECTED REFERENCES


12. Purdue University Engineering Experiment Station, Terrain Study of the Yuma Test Station. Joint Highway Research Project, Airphoto Interpretation Laboratory, Lafayette, Ind., March 1955.


A Technique for Preparing Desert Terrain Analogs

PHYSIOGRAPHY
PHYSIOGRAPHY

MOUNTAINS: Masses of land, in which summit areas are small in proportion to their total dimensions, rising more than 1000 feet above the surrounding terrains. The characteristic slopes in declivitous or steep.*

Massive Mountains: Extensive multiple-peaked mountain masses characterized by either a high centrally located core or an elongate crest which rises more than 5000 feet above the surrounding terrains.

Range: Elongate hills of massive mountains.

Massif: Roughly circular aggregation of massive mountains.

Ridge Mountains: Continuous ridges of elongated crested peaks typically rising less than 5000 feet above the surrounding terrains.

Single Ridge: Single, isolated mountain ridge.

Parallel Ridges: A series of roughly parallel ridges; some peaks may rise more than 5000 feet above surface, interesting relief.

Heterogeneous Mountains: Mountain masses, commonly separated by regions of other terrain types, cover substantially more than 50 per cent of the total area. Any area so mapped is not characterized by either a high centrally located core or an elongate crest.

Peaks and Groups of Peaks: The mountain masses consist predominantly of peaks and groups of peaks.

Random Ridge: The mountain masses consist predominantly of discontinuous, randomly oriented ridges.

PLAIN AND MOUNTAIN COMPLEX: Mountains, separated by plains with occasional hills, cover less than 50 per cent of the total area.

Isolated Peaks and Ridges: The mountain masses consist predominantly of peaks and randomly oriented discontinuous ridges.

Batholith: The mountain masses consist predominantly of roughly parallel ridges.

HILL LANDS: Areas characterized by prominence of small summit area, with characteristic slopes gentle to steep, rising less than 1000 feet above the surrounding terrains. Place regions between hills may range as high as 75 per cent of the total area.

Parallel Hills: Prominences consist predominantly of persistent elongate hills with characteristic slopes moderate to steep.

Rampant Hills: Prominences consist predominantly of randomly distributed hills with characteristic slopes moderate to steep.

Valleys: Prominences consist predominantly of randomly distributed crestal and irregularly shaped hill forms. Inter-hill areas characterized by rough surface of angular to jagged cobbles and boulders. Shapes may range from gentle to precipitous. In some instances characterized by sharply defined and complex surface drainage patterns.

Sediment Dunes: Prominences, consisting chiefly of sand, sandy, or sandstone, not interpreted by change shape and position rapidly. Areas characterized by a broad lack of organized drainage forms and by movement to steep slopes.

PLATEAUS: Elevated masses of land characterized by eucalyptus, more or less flat-lying eucalyptus areas bounded on one or more sides by escarp, dissected plateaus are indicated by a (low escarpment) where less than 45 per cent of the original surface remains.

Plains: Extensive tracts of land with characteristic shapes flat to gentle. Less than 15 per cent of the surface is occupied by hills, and least relief within the plains seldom exceeds 25 feet. (Because of the transitional nature of most plains types, boundary lines are often difficult to establish and in many cases are quite arbitrary.)

Alluvial Plains: Floodplains, terraces, and subterminal fans of major streams.

Coastal Plains: Plains bordering the sea and extending inland to the nearest elevated land, or to a gradual horizon with another plains type.

Depressional Plains: Low-lying plains of interior drainage bounded on two or more sides by escarpments or deep mountain ranges, and commonly characterized by a centrally located broad low area. Generally flat but locally undulating.

Desert Plains: Interior plains not easily classifiable as alluvial or depression plains. These plains are often formed of or significantly modified by sand deposition or movement.

* Slope classification: flat = 0 to 2 degrees, gentle = 2 to 6 degrees, moderate = 6 to 14 degrees, precipitous = 14 to 26.5 degrees, very precipitous = greater than 26.5 degrees.

† A escarp is defined as a more or less continuous precipitous slope exhibiting more than 100 feet of relief. Important escarpments are indicated in plates 9 and 18.

SOUTHWESTERN UNITED STATES

PLATE 1
A Technique for Preparing Desert Terrain Analogs

PHYSIOGRAPHY: DESCRIPTIONS AND PHOTOGRAPHS

Each folio of maps prepared for a specific world desert area contains several plates, titled as above, with photographs grouped by physiographic units. Photographs are located by latitude and longitude or directly on the physiographic map of the subject area. Photographs of landforms, surface conditions, or vegetative patterns typically associated with each physiographic unit are also presented. Descriptive material includes terrain-factor ranges typical of each of the physiographic units.
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HYPSOMETRY
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT
A Technique for Preparing Desert Terrain Analogs

RAISZ’S LANDFORM MAPS
RAISZ'S LANDFORM MAP

SOUTHWESTERN UNITED STATES

Base Map Reproduced from Map of the Landforms of the United States by Permission of Erwin Raisz (Ref. 4) and Ginn & Co.
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SELECTED LANDFORMS AND SURFACE CONDITIONS
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE

100 0 100 200 Mi.
SELECTED LANDFORMS AND SURFACE CONDITIONS

I. DEPOSITIONAL

SEDIMENT

Joint surface (undiff.).........DE-jn
Peak and tail............................DE-pn
Terraces.................................DE-tc
Longitudinal sheets..........................DE-ls
Accumulations over dunes..........................DE-am
cannel sheets...........................DE-cs
Sheet dunes..............................DE-se
Large convolutions..........................DE-lv
Footing with rivers..........................DE-fr
Sand sheet...............................DE-sd
Pleistocene..............................DE-pl
Lateral dunes............................DE-la
canal dunes..............................DE-cn
Savannas.................................DE-sn
Shrubland...............................DE-sh
Sand sheets..............................DE-sd
Sand blowers.............................DE-bc

colluvial

Alluvial

Alluvial apron..........................DA-ap
Flood plains..............................DA-fp
Gold......................................DA-gd
Alluvial channel..........................DA-ac
Alluvial fan.............................DA-fn
Alluvial terrace..........................DA-at
 levee.................................DA-lv
Levee flat...............................DA-lf
Terraces.................................DA-tc

colluvial

Gross

Structure..................................DC-str
Talus......................................DC-ta
Natural levees............................DC-ne
Marsh.....................................DC-ma
Beaches....................................DC-be
Talus......................................DC-ta
Marsh.....................................DC-ma
Salt marsh...............................DC-sm
Beaches....................................DC-be
Talus......................................DC-ta
Marsh.....................................DC-ma

III. MISCELLANEOUS

SURFACE WATER (Continued)

Surface water (undiff.)..............ES-sw
Dry valleys...............................ES-dv
RESIDUAL

Fluvial.................................FR-fl
WIND

Desert pavement (undiff.).............EW-p
Fossil dunes..............................EW-fd
Hamadas.................................EW-ha
Climbing sand drifts.................DE-ac-sm-cd
Sand drifts................................DE-ac-sm-sm
Sand dams..............................DE-ac-sm-sm
Salt.................................DE-ac-sm-sa
Billows...............................DE-ac-sm-bw
Large extensive obstacles..............DE-sd
Shifting sand drifts.................DE-ac-sm-sh
Sand sheet..............................DE-sd
Flanking sand sheet....................DE-ac-sm-fs
Sinks......................................EG-si
Scarps.....................................ES-sc

YUMA TEST STATION

YUMA SAND HILLS

PLATE 5
A Technique for Preparing Desert Terrain Analogs

LANDFORMS-SURFACE CONDITION
Descriptions and Photographs
### Landforms-Surface Conditions: Descriptions and Photographs (Sample Tabulation)

**Descriptive Tabulation**

<table>
<thead>
<tr>
<th>Landform Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eolian</strong></td>
<td>Mobile heaps of wind-blown sand independent of fixed objects or underlying topography.</td>
</tr>
<tr>
<td>Barchans</td>
<td>Crescentic ground plan with the convex side facing the wind and horns extending leeward.</td>
</tr>
<tr>
<td>Peak and Fulji</td>
<td>Occur where the tips or horns of a fast-moving barchan join or intersect the windward side of another barchan, forming a circular or horseshoe-shaped hollow known as a fulji.</td>
</tr>
<tr>
<td>Transverse</td>
<td>Asymmetric ridges extending transverse to the direction of dominant sand-moving winds.</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>A single continuous ridge which swells and rises at regular intervals to form a chain of summits connected by a continuous wavy crest.</td>
</tr>
<tr>
<td>Complex</td>
<td>Irregular masses of sand not readily classifiable into types.</td>
</tr>
<tr>
<td>Falling sand drifts</td>
<td>Massive accumulations of wind-blown sand which form as lee-ward of obstacles such as plateaus, scarps, hills, and mountains.</td>
</tr>
<tr>
<td>Sand sheets</td>
<td>Extensive essentially flat areas of wind-blown sand; surfaces may be smooth, slightly hilly, or rippled.</td>
</tr>
<tr>
<td>Rippled surfaces</td>
<td>Washboard-like surfaces caused by the heaping up of sand by wind action.</td>
</tr>
</tbody>
</table>

**TYPICAL GEOMETRY FACTOR RANGES (Plates 7, 8, 9, and 10)**

<table>
<thead>
<tr>
<th>Plan-Profile Units</th>
<th>Range at Yuma</th>
<th>Range in Northeast Africa</th>
<th>Relief Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slope Occurrence Units</strong></td>
<td>Number of slopes greater than 50% per 10 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Degrees</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Feet</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>30</td>
<td>50</td>
</tr>
</tbody>
</table>

**PLATE 6**

This phenomenon is classed as a surface condition and mapped in terms of surface roughness or microrelief rather than geometry-factor ranges. Rippled surface heights range from one to two inches to three feet and are spaced at intervals of several inches to four or five feet.
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CHARACTERISTIC PLAN-PROFILE
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE

100  0  100  200 MI.
The characteristic plan-profile is the most commonly found plan-profile within a region. It may be either restrictive or gross. The restrictive plan-profile is based on random sampling with circles 1 mile in diameter. Local relief of less than 10 ft is not considered. The gross plan-profile is based on random sampling with circles 35 miles in diameter. Relief of less than 100 ft is not considered. The prominences in such a plan-profile are termed component highs, the intervening lowlands component lows.

**LEGEND**

<table>
<thead>
<tr>
<th>Highs</th>
<th>Occupies:</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;40% of area</td>
<td>3L//</td>
</tr>
<tr>
<td>40-60% of area</td>
<td>3L/</td>
</tr>
<tr>
<td>&gt;60% of area</td>
<td>3L</td>
</tr>
<tr>
<td>No pronounced highs or lows</td>
<td>1L //</td>
</tr>
</tbody>
</table>

**PLAN-PROFILE COMPLEXES:**

**Areal Complexes:** Confined to areas where two major, areally restricted plan-profiles, both of the restrictive type, are mapped.
- Plan-profile of the areally predominant lows.
- Plan-profile of the areally subordinate highs.
- Plan-profile of the areally predominant highs.
- Plan-profile of the areally subordinate lows.

**Gross-component Complexes:** Confined to areas where a gross and a restrictive plan-profile of either a component high or a component low are mapped.
- Gross plan-profile of the areally predominant highs.
- Restrictive plan-profile of component lows.
- Gross plan-profile of component lows.
- Restrictive plan-profile of component highs.

* Highs are considered to be (1) peaked or crested prominences which exhibit characteristic slopes greater than 6 degrees or (2) fairly flat-topped prominences or high-level areas bounded by slopes in excess of 12 degrees.

**/** Indicates linearity of highs. A high is considered to be linear when its length is greater than 3 times its width.

***//** Indicates roughly parallel arrangement of highs or aligned highs.
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OCCURRENCE OF SLOPES GREATER THAN 50 PER CENT
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT
OCCURRENCE OF SLOPES GREATER THAN 50 PER CENT

Occurrence may be either restrictive or gross. A restrictive occurrence class indicates a modal range of slopes greater than 50 per cent found along traverses containing the maximum number of such slopes. Relief of less than 10 ft is not considered. A gross occurrence indicates the modal distance between component highs or component lows. Relief of less than 100 ft is not considered.

1. The number of slopes steeper than 50 per cent is less than 1 per 10 miles in areas less than 10 miles in maximum dimension, where such slopes are lacking.
2. The number of slopes steeper than 50 per cent ranges from 1 to 5 per 10 miles.
3. The number of slopes steeper than 50 per cent ranges from 5 to 20 per 10 miles.
4. The number of slopes steeper than 50 per cent ranges from 20 to 100 per 10 miles.
5. The number of slopes steeper than 50 per cent ranges from 100 to 200 per 10 miles.
6. The number of slopes steeper than 50 per cent exceeds 200 per 10 miles.

OCCURRENCE COMPLEXES: (Mapped only where plan-profile complexes are mapped.)

Areal Complexes: Confined to areas where two major, areally restricted occurrence units, both of the restrictive type, are mapped.

2. Slope occurrence of areally subordinate highs.

Gross-component Complexes: Mapped only where gross-component plan-profile complexes are mapped.


Restrictive occurrence within component lows.

Restrictive occurrence within component highs.
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CHARACTERISTIC SLOPE
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT
Characteristic slope is defined as a narrow range of slopes which predominates or is most common within a region (possessing a distinctive spacing, arrangement, or pattern of contour lines) mapped with a 10-ft contour interval.

Flat: Characteristic slope between 0 and 2 degrees (approx. 0 - 3.5%)

Gentle: Characteristic slope between 0 and 1/2 degree (approx. 0 - 1%)

Between 1/2 and 2 degrees (approx. 1 - 3.5%)

Between 2 and 6 degrees (approx. 3.5 - 10%)

Moderate: Characteristic slope between 6 and 14 degrees (approx. 6 - 25%)

Gross-component Complexes: Mapped only where gross-component plan-profile complexes are mapped. The symbols in the complex are arranged vertically or horizontally depending on the plan-profile.

Steep: Characteristic slope between 14 and 26.5 degrees (approx. 25 - 50%)

Declivitous: Characteristic slope between 26.5 and 45 degrees (approx. 50 - 100%)

Precipitous: Characteristic slope greater than 45 degrees (greater than 100%)

Important Scarps: An important scarp is defined as a more or less continuous precipitous slope exhibiting more than 100 feet of relief. Only the better known scarps which extend for considerable distances have been mapped. Scarp height is indicated where known.

* In cases where the gross plan-profile is flat-topped or flat-bottomed the characteristic slope is considered to be the modal slope of the bounding inclines.
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CHARACTERISTIC RELIEF
CHARACTERISTIC RELIEF

Characteristic relief may be either restrictive or gross. Restrictive relief is based on modal classes of stream depth, elevation differential per unit area, or prominence height. This is further defined under type I and type II relief.

Gross relief indicates the modal height of component highs or the modal depth of component lows.

I. RELIEF IN AREAS WHERE THE CHARACTERISTIC SLOPE IS LESS THAN 6 DEGREES (APPROX. 10 PER CENT)

Relief is defined as the modal vertical distance from interfluve crest to the immediately adjacent flow line.

1. Characteristic relief between 0 and 10 feet.

2. Characteristic relief between 10 and 50 feet.

3. Characteristic relief between 50 and 100 feet.

II. RELIEF IN AREAS WHERE THE CHARACTERISTIC SLOPE IS GREATER THAN 6 DEGREES (APPROX. 10 PER CENT)

Relief is defined as the modal maximum difference in elevation per square mile, or in areas where drainage lines are poorly developed or lacking, from summit to adjacent low.

* Usually restricted to sand dune areas—maximum height of dunes indicated where known.

RELief COMPLEXES: (Mapped only where plan-profile complexes are mapped.)

Areal Complexes:

- Relief of areally predominant lows.
- Relief of areally subordinate highs.
- Relief of areally predominant highs.
- Relief of areally subordinate lows.

Gross-component Complexes: (Mapped only where gross-component plan-profile complexes are mapped.)

- Gross relief of component highs
- Gross relief of component lows

* Important scarps: A scarp is defined as a more or less continuous precipitous type exhibiting more than 100 feet of relief. Only the better known scarps which extend for considerable distances have been mapped. Scarp height is indicated where known.
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GENERALIZED LANDSCAPE

PLATE 11
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE

100 0 100 200 MI.
The generalized landscape map is prepared by superposing the plan-profile, slope occurrence, slope, and relief maps. Gross and restrictive landscapes and areal and gross-component complexes are thus automatically delineated and defined in terms of the four geometry factors.

YUMA TEST STATION
(GROSS LANDSCAPE: 5L/I/5, 7)

YUMA SAND HILLS
(GROSS LANDSCAPE: 6L/I, 3, 5)

LANDSCAPE COMPLEXES
Areal Complexes: Areas where two major, areally restricted landscape types, both of the restrictive type, occur.

Gross-component Complexes: Confined to areas where a gross and a restrictive landscape of either a component high or a component low are mapped.

Each landscape type in the legend is identified by a series or an array of four symbols indicating mapping units of plan-profile (PP), slope occurrence (SO), characteristic slope (CS), and characteristic relief (CR), always designated in that order.

A circled series of numbers identities a gross landscape type.

Major groupings of generalized landscapes are based on physiography for convenience only. It should be realized that surface geometry is often entirely independent of physiographic association.
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SOIL TYPE
**Soil-Soil Associations**

- **Gravel:** More than 10 per cent of a typical sample consists of gravel.
- **Sand:** More than 50 per cent of a typical sample consists of sand.
- **Silt:** More than 15 per cent of a typical sample consists of silt.
- **Clay:** More than 75 per cent of a typical sample consists of clay.

**Soil Complexes:** Soil complexes are mapped where no area predominantly (25 per cent or more) soil type occurs. In such instances, the less predominant occurring soil type is mapped. When several soil types occur, the subordinate as the denominator in the fractional pattern.

---

**Soil Types**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse-grained soils</td>
<td>More than 50 per cent of a typical sample consists of sand.</td>
</tr>
<tr>
<td>Fine-grained soils</td>
<td>More than 25 per cent of a typical sample consists of silt and/or clay.</td>
</tr>
<tr>
<td>Silt and clay with minor amounts of coarse material</td>
<td>More than 50 per cent of a typical sample consists of silt and/or clay.</td>
</tr>
<tr>
<td>Sand and fine gravel</td>
<td>More than 50 per cent of a typical sample consists of sand and/or gravel.</td>
</tr>
<tr>
<td>Coarse-grained soils</td>
<td>More than 50 per cent of a typical sample consists of sand.</td>
</tr>
<tr>
<td>Fine-grained soils</td>
<td>More than 10 per cent of a typical sample consists of silt and/or clay.</td>
</tr>
<tr>
<td>Silt and clay</td>
<td>More than 15 per cent of a typical sample consists of clay.</td>
</tr>
<tr>
<td>Clay</td>
<td>More than 75 per cent of a typical sample consists of clay.</td>
</tr>
<tr>
<td>Silt and sand with minor amounts of coarse material</td>
<td>More than 10 per cent of a typical sample consists of silt and/or sand.</td>
</tr>
<tr>
<td>Silt and clay with minor amounts of coarse material</td>
<td>More than 25 per cent of a typical sample consists of silt and/or clay.</td>
</tr>
</tbody>
</table>

---

**Soil Complexes:** Soil complexes are mapped where no area predominantly (25 per cent or more) soil type occurs. In such instances, the less predominant occurring soil type is mapped. When several soil types occur, the subordinate as the denominator in the fractional pattern.
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SOIL CONSISTENCY
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE

100 0 100 200 MI.
SOIL CONSISTENCY

Soil consistencies are mapped only where soil associations occur. Areas predominantly (95 percent or more) of soil consistencies mapped, consistencies are summarized in Table 6.

I. HOMOGENEOUS CONSISTENCIES: Soils of essentially unmodified consistencies to depths greater than 12 inches.

A. Hard: Grains are closely packed. The ratio of voids to constituent grains in close is less than a naturally occurring maximum. This zone is commonly of sandy gravel overlying noncohesive material (commonly sand or gravel). Surface of closely packed noncohesive pebbles or gravel overlying noncohesive material (commonly sand or gravel). (Most common development in areas of close to a naturally occurring maximum, i.e., the grains are closely packed.)

B. Soft: Grains are loosely packed. The ratio of voids to constituent grains is close to a naturally occurring maximum, i.e., the grains are loosely packed.

II. LAYERED CONSISTENCIES: Soils possessing two or more underly closely packed layers within 12 inches of the surface.

A. Crusted: Hard crust (commonly of cemented materials) consisting of soft materials (commonly muck, ooze, or organic waste). Surface crust (commonly of cemented materials) consisting of noncohesive material (commonly sand or gravel). (Most common development in areas of closely packed, with more or less continuous vegetation cover.)

B. Soft: Grains are loosely packed. The ratio of voids to constituent grains is close to a naturally occurring maximum, i.e., the grains are loosely packed.

In instances, the two most commonly occurring consistencies are mapped (the predominant is shown as the numerator, the subordinate as the denominator in the fractional notation).

PLATE 13
A Technique for Preparing Desert Terrain Analogs

SURFACE ROCK
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE

100 0 100 200 MI.
Surface Rock

Mapped in regions where rock is exposed or at shallow depths (i.e., 0-10 feet) throughout the remainder of the area. In effect this procedure restricts the mapping of surface rock to areas mapped as 1, 2, or 3 under Soil Type.

Areally predominant (70 per cent or more) rock type mapped.

**IGNEOUS (UNDIFFERENTIATED):** Rocks formed by solidification or crystallization of a hot fluid mass.

- Intrusive: Igneous rocks, typically crystalline, which have formed by cooling below the surface of the earth.
  - Granite, syenite, diorite, etc.
- Extrusive (lava-related): Igneous rocks which have formed by cooling at the surface of the earth.
  - Basalt, rhyolite, andesite, etc.
- True extrusive rocks formed by solidification of molten material that poured out on the surface of the earth.
  - Basalt, rhyolite, andesite, etc.

**METAMORPHIC (UNDIFFERENTIATED):** Rocks formed from original igneous or sedimentary rocks through alterations produced by pressure, heat, or the infiltration of other materials at depths below the surface zones of weathering and cementation.

**SEDIMENTARY (UNDIFFERENTIATED):** Rocks formed from material laid down in a more or less finely divided state, as sediment, through the agency of water, wind, or glaciers.

- Sandstone: A sedimentary rock predominantly composed of sand grains cemented together.
- Limestone: A sedimentary rock consisting essentially of calcium carbonate.
- Shale: A sedimentary rock in which the constituent particles are predominantly of clay size.
- Evaporites: A sedimentary rock whose origin is largely due to evaporation and subsequent precipitation of salt from water. (Gypsum, anhydrite, and rock salt are the only evaporites of quantitative importance.)

**ROCK COMPLEXES:** Rock complexes are mapped where no areally predominant (70 per cent or more) rock type occurs. In such instances, the two most commonly occurring rock types are mapped; the predominant is shown as the numerator, the subordinate as the denominator in the fractional pattern.

*It should be realized that the scale of mapping precludes delineation, especially in mountainous regions, of many alluvial basins where the thickness of soil cover is much greater than 10 feet.*

Note: Tabulation of generalized rock properties on reverse side.
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VEGETATION
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE

100  0  100  200 MI.
Vegetation

A really predominant (70 per cent or more) vegetation type mapped.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Barren: Devoid or nearly devoid of vegetation.</td>
</tr>
<tr>
<td>2</td>
<td>Sparse shrub &amp; grass: Widely spaced thorny shrubs, low scrubby trees, herbs, or vines and open stands of coarse grasses. Also includes brush in the U.S.</td>
</tr>
<tr>
<td>3</td>
<td>Scattered shrub &amp; grass: Moderately spacing of forms mentioned under unit 2.</td>
</tr>
<tr>
<td>4</td>
<td>Scattered shrub and/or scrubby trees: This mixture of shrubs and scrubby trees, undergrowth (if present) consists of low shrubs, bushes, and herbs.</td>
</tr>
<tr>
<td>4a</td>
<td>a. With scattered low shrub: Dense shrub and/or scrubby trees undergrowth (if present) consists of low shrubs, bushes, and herbs.</td>
</tr>
<tr>
<td>4b</td>
<td>b. With dense scrubby: Orchard areas with grain-herb cultivation forming the 1st story.</td>
</tr>
<tr>
<td>5</td>
<td>Dense shrub and/or scrubby trees: Dense stands of shrubs and scrubby trees, undergrowth of grasses consists of low shrubs, bushes, and herbs.</td>
</tr>
<tr>
<td>5a</td>
<td>a. With scattered 3rd-story trees: Dense palm groves, 1st-story grain-herb cultivation may or may not be present.</td>
</tr>
<tr>
<td>5b</td>
<td>b. With sparse 3rd-story trees: High continuous grass cover, includes scattered scrubby trees and shrubs. Height of grass averages 3-5 ft.</td>
</tr>
<tr>
<td>6</td>
<td>Palms with or without grain-herb cultivation: Cultivated plots of grains, vegetables, etc.</td>
</tr>
<tr>
<td>7</td>
<td>Steppe: Dense growth of grasses, sedges, etc.</td>
</tr>
<tr>
<td>8</td>
<td>Steppe-savanna: Vegetation complexes are mapped where no areally predominant (70 per cent or more) vegetation type occurs. In each instance, the two most common types are mapped; the predominant is shown as the numerator, the subordinate as the denominator in the fractional pattern.</td>
</tr>
</tbody>
</table>

Note: Tabulation of supplementary data on reverse side.

PLATE 15
A Technique for Preparing Desert Terrain Analogs

GEOMETRY ANALOGS
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE

100 0 100 200 Mi.
YUMA SAND HILLS

(YUMA TEST STATION
(GROSS LANDSCAPE: 6L, 1, 3, 5)
A Technique for Preparing Desert Terrain Analogs

GROUND ANALOGS
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT
Numbers designate mapping units of soil type and surface rock or soil consistency, respectively. If the soil type (first number) is 1, 2, or 3 the second digit designates a surface-rock mapping unit; if the soil type (first number) is 4 or higher, the second number designates a soil-consistency mapping unit. In the example given, e.g., 1,7 the first digit is soil type, the second, surface rock.

Ground factors in Egypt are always compared with Yuma ground factors and not vice versa. If both digits are lightface, the units designated are found in combination at Yuma. If one is light- and the other boldface, a combination exists at Yuma containing the lightface unit. If both digits are boldface, neither unit is found at Yuma.

Indicates area of ground complex. Two definite soil type-surface rock or soil consistency combinations are present but the scale of mapping precludes delineation.

2 Highly Analogous Combination found at Yuma. In areas of complexes, both of the combinations are found at Yuma.

1 Partially Analogous One of the two units is found at Yuma. In areas of complexes, two or three of the possible four units are found in combination at Yuma.

0 None Analogous None of the units are found at Yuma. In areas of complexes, one or none of the possible four units is found at Yuma.

Values assigned in compiling the Composite Analogue Map.

* At Yuma surface rock unit 5 (sedimentary undifferentiated) includes units 6, 7, and 8 (sandstone, limestone, and shale), whereas where these units are mapped in Egypt, they are designated by lightface symbols.
A Technique for Preparing Desert Terrain Analogs

VEGETATION ANALOGS
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE

100  0  100  200 MI.
LEGEND

1. Number designates vegetation mapping unit.
2. Lightface numbers indicate that the unit is found at Yuma.
3. Boldface numbers indicate that the unit is not found at Yuma.
4. Indicates area of vegetation complex. Two definite vegetational types are present but the scale of mapping precludes delineation.
5. Highly Analogous Unit found at Yuma. In areas of complexes, both units are found at Yuma.
6. Partially Analogous In areas of complexes, one of the two units is found at Yuma.
7. Not Analogous None of the units are found at Yuma. In areas of complexes, none of the units are found at Yuma.

Values assigned in compiling the Composite Analog Map.

VEGETATION ANALOGS

YUMA TEST STATION

PLATE 18
A Technique for Preparing Desert Terrain Analogs

COMPOSITE ANALOGS
EGYPTIAN SECTION OF THE NORTHEAST AFRICAN DESERT

SCALE
COMPOSITE ANALOGS

LEGEND

<table>
<thead>
<tr>
<th>Values of geometry, ground, and vegetation analogs, respectively. (See plates 16, 17, and 18.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,1,0</td>
</tr>
<tr>
<td>6.5</td>
</tr>
<tr>
<td>5.5</td>
</tr>
<tr>
<td>4.5</td>
</tr>
<tr>
<td>3.5</td>
</tr>
<tr>
<td>2.5</td>
</tr>
</tbody>
</table>

Values resulting from superposing and totaling the geometry, ground, and vegetation analog mapping components.
APPENDIX A: DERIVATION OF A NUMERICAL DESCRIPTION
OF THE CHARACTERISTIC PLAN-PROFILE

1. A purely quantitative system for describing the characteristic plan-profile is possible. In general, such a system should meet four basic requirements:

   a. It should be compatible with qualitative classification systems so that landscape types already mapped can be easily transformed into the numerical terms of the quantitative system if no quantitative data can be obtained.

   b. It should be purely quantitative, with the descriptive numbers representing measurable attributes of the terrain. Further, they should be continuous mathematical functions.

   c. It should be simple to derive, by techniques both easily understandable and readily applied. It should avoid complex mathematical derivations as much as possible.

   d. It should be independent of all prior knowledge, and should require no form of subjective judgment at any point in the derivation.

2. The characteristic plan-profile legend (hereinafter called CPPL) in the main text depends upon a double set of criteria: the shape of the ground profile, and the plan of arrangement of surface features (see plate 7).

3. The first task thus resolves into a quest for a numerical device to describe the six profile shapes defined in the CPPL. The "hypsometric integral" employed so successfully by Strahler\(^6\) is a most useful device, enabling the analyst to define a number of different erosional types. Its major disadvantage is the extremely laborious derivation required to produce the integral. Upon examination it was found that the essential features of the hypsometric integral could be retained and the process of deriving it enormously simplified. However, the simplified form is no longer an integral in any classical sense, and the name "hypsometric integral" has accordingly been abandoned.

4. To derive the simplified form, which is called the profile area (A) for want of a better term, the following procedure is carried out:

   * Raised numbers refer to similarly numbered entries in the list of references printed at the end of the main report.
Fig. Al. Layout of typical traverse used to determine profile area (A) and peakedness index (S) of the plan-profile

a. A sample point (P in fig. Al) is selected on the landscape by any standard random-sampling technique. The method employed for this study was to place a grid having an arbitrary—but very small—interval between lines, over the area to be examined. The angle at which the grid is set down is determined by selecting by arbitrary means two digits from a table of random numbers, and using these digits to represent the tangent of the angle between the grid and the base of the map being used. The table of random numbers was then used to select a grid intersection. From this point a random-directed line is projected. On this line, the first point
from the origin (the sample point) at which the sign of the slope angle changes (from "down" to "up," or vice versa) is identified. The line is then projected backward (at an azimuth different by 180° from the original line) until the slope angle again changes sign.

b. The difference in elevation between the two extremes of the line just constructed is called the profile relief, and the horizontal distance between the two extreme points, the profile distance. In fig. A2 these parameters are identified as R and D, respectively.

c. The profile so selected is then plotted on any convenient horizontal and vertical scale. Points are located at which the trace of the surface intercepts lines parallel to the D axis at R = 10%, 50%, and 90% of the profile relief. The points so identified on the profile are labeled D_{100}, D_{50}, and D_{90}, respectively.

d. The D and R values shown on the profile of fig. A2a are reduced to decimal fractions of a common distance, and re-plotted as D_0 and R' as shown on the diagram of fig. A2b.

5. The area under the curve of fig. A2b is computed using the formula:

\[ A = 0.05 + 0.25 (d_{10} + d_{90}) + 0.4 d_{50} \]

The term A, called the profile area, is analogous in function to the hypsometric integral.

6. In general, the value of the profile area permits a decision as to whether highs are predominant, roughly equal to, or subordinate to the lows, but does not differentiate between crested and flat-topped highs. A second term must therefore be devised to perform this separation.

7. If a local point of maximum deviation is determined in the manner outlined in paragraph 4a, the determination of whether the topographic high is flat-topped or crested depends on the way in which the surface departs from the horizontal as related to the slopes farther down the topographic high.

8. These relations are reflected in the profile diagram of fig. A2b by the slope of the line from d_{100} to d_{90}. This value, termed the peakedness index (S), is computed by the formula

\[ S = \frac{0.1}{d_3} \].

Thus, in fig. A2b,
a. Profile of traverse shown in fig. A1

b. Profile diagram

c. Test for validity

Fig. A2. Derivation of profile area (A) and peakedness index (S)
the slope of that line segment is 0.45. Note that this is not the slope of the actual ground surface, but a dimensionless number derived from the profile diagram.

9. In theory, these two values, A and S, should permit the differentiation of all six types of profiles defined in the CPPL. Testing this theory involves the reconstruction of the six types with sets of values to determine if the values do indeed result in detectably different geometric forms. For example, for the profile of the traverse in fig. A1, \( A = 0.47 \) and \( S = 0.45 \). The value of \( S \) fixes the position of \( d_{90} \). In order for the value of \( A \) to match the given value (see fig. A2c), the line segment to \( d_0 \) must be concave upward, and must dip "beneath" the diagonal connecting \( d_{100} \) with \( d_0 \). In reconstructing the profile diagram from the derived values \( A \) and \( S \), only the position of the profile at \( d_{10} \) can be determined. The position of \( d_{10} \) is derived by the equation:

\[
d_{10} = 2.2 A - (d_{90} + 0.11)
\]

Using the values of fig. A2b, this gives: \( d_{10} = 0.71 \), which is very close to the original position. It is therefore evident that the landscape is of the same basic profile as type 2 in the CPPL.

10. Properly selected ranges of values, in combination, make it possible to differentiate among the six profile classes. For example, a value of \( A \) between 0.55 and 1.0, and a value of \( S \) between 0.0 and 0.99 indicate profile type 1, as indicated in the CPPL (see fig. A4, page A10).

11. In practice, the values \( A \) and \( S \) should be the mean of a significant number of samples. For this study, 25 samples were taken in each area of a given landscape type. The type had previously been selected on the basis of the characteristic slope, characteristic relief, and slope occurrence, as developed in the main text. Variances between sample populations taken in the same landscape type were large, but it is believed that a large sample number would reduce the variance appreciably.

12. There remains the problem of describing the plan occurrences of the various landscape types. Upon examination, the four distinctions made in the CPPL reduce to two basic characteristics. One of these is the tendency of the "highs" to be either "hills" or "ridges"; the other is the
tendency of these highs to align themselves in relation to each other. Both of these characteristics are qualitatively recognizable by the tendency—or lack thereof—of the strike of the slopes to cluster about some preferred orientation. Accordingly, a procedure to establish the degree of clustering is required.

13. To distinguish between "hills" and "ridges," a single identifiable terrain unit of some type must be isolated. This is accomplished in the following way:

a. In the area being examined, a number of random points are selected. In this study, the same points used for the construction of the profiles were employed.

b. From the selected point, a series of 10 lines radiating in random directions were constructed. (See fig. A3 for an example of this process.)

c. On each of the radiating lines, the point at which the slope changes from "down" to "up" was determined. Note that this fixes the position of topographic depressions, but not topographic crests. That is, changes of slope attitude from "up" to "down" are ignored.

d. These points are connected with each other, thus enclosing an irregular polygon, with the sample point somewhere in the middle. This polygon encloses a terrain unit.

14. To determine the tendency of slopes within the terrain unit to cluster about some preferred direction, the following procedure is employed:

a. By random-sampling techniques, a statistically valid number of points within the terrain unit polygon is selected, and the strike of the slope at that point measured, i.e., the direction of the contour line measured. In this study, the strike was measured as an azimuth. It should be noted that because the dip of the slopes is not considered, only two quadrants of the azimuth circle are required.

b. The distribution curve of the tabulated azimuths is peaked if the slopes of the terrain unit occur with a preferred orientation, or nonpeaked if there is no preferred orientation. Thus, a strongly peaked distribution implies a strongly linear or elongate terrain unit, and a nonpeaked distribution implies a nonelongate terrain unit. One measure of peakedness (or kurtosis) of the distribution curve is the relation:

\[ E = \frac{N}{N_c F_h} \]
Fig. A3. Layout used to determine the elongation number (E) and parallelism number (P) of the plan-profile

where $N =$ the number of samples, $N_c =$ number of classes, and $F_h =$ the frequency of the classes containing the greatest number of samples. This measure of kurtosis is exceedingly crude, but it is correspondingly simple. The derived value, $E$, is called the elongation number; a low value implies
elongate terrain units, and a high value implies nonelongate terrain units. In practice, the elongation number should be a statistical summation (e.g. mean or mode) of a statistically valid number of values of E for individual terrain units.

15. Accordingly, the following table of values was derived:

<table>
<thead>
<tr>
<th>Elongation Number</th>
<th>CPPL Unit</th>
<th>Elongation Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 to 0.30</td>
<td>All L// units</td>
<td>Pronounced ridges</td>
</tr>
<tr>
<td>0.31 to 0.49</td>
<td>All L and // units</td>
<td>Ridges strongly to weakly developed</td>
</tr>
<tr>
<td>0.50 to 1.0</td>
<td>All others</td>
<td>Hills</td>
</tr>
</tbody>
</table>

For example, the elongation number for the Mannington, West Virginia, quadrangle, 0.34, indicates a rather strong tendency for the terrain units to be ridgelike.

16. The tendency of the terrain units to align themselves in relation to each other is also a function of the strikes of the slopes, but on a much grosser scale. In order to detect any tendency toward alignment, a number of terrain units must be sampled. This raises the issue of the size of the sample area to be used. For example, in the CPPL unit 4L, a sample area that encompassed only one terrain unit would result in an E value of less than 0.3, while a sample that included two or three terrain units might result in a value between 0.31 and 0.49, and finally, a very large area that included a large number of terrain units would presumably result in a nearly random distribution of slopes, and therefore an E value of more than 0.5 would be expected.

17. Because it is the over-all tendency toward randomness that is desired, the sample area used in this study is a homogeneous area as defined by the geometry factors of characteristic slope, characteristic relief, and occurrence of steep slopes. The following procedure is then employed:

a. A statistically valid number of sample points are selected by random methods.

b. The strike of the slopes is measured and manipulated by the same method outlined in paragraph 14. The value obtained in this case is called the parallelism number (P).

18. In a qualitative sense, a value of P ranging from 0.0 to 0.3
indicates strong parallelism. The following tabulation relates the value of P to the CPPL units:

<table>
<thead>
<tr>
<th>Parallelism Number</th>
<th>CPPL Unit</th>
<th>Parallelism Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 to 0.30</td>
<td>All L// units</td>
<td>Strongly parallel</td>
</tr>
<tr>
<td>0.31 to 0.49</td>
<td>All // units</td>
<td>Moderately to weakly parallel</td>
</tr>
<tr>
<td>0.50 to 1.0</td>
<td>All others</td>
<td>Essentially random</td>
</tr>
</tbody>
</table>

In other words, increasing values of P imply increasingly random arrangements of the terrain units. For example, the strongly linear topography of the Pina-Escobal highlands in the Panama Canal Zone has a P value of 0.28, whereas the weakly linear Fort Sherman highlands in the Zone has a P value of 0.46.

19. To test the theory outlined in paragraph 16, three sample sizes were employed in the Mannington, West Virginia, area, with this result:

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>One terrain unit</td>
<td>E</td>
<td>0.34</td>
</tr>
<tr>
<td>Three square miles</td>
<td>-</td>
<td>0.40</td>
</tr>
<tr>
<td>Entire quadrangle</td>
<td>P</td>
<td>0.56</td>
</tr>
</tbody>
</table>

This is precisely the result anticipated from the theoretical considerations outlined in paragraph 16.

20. Therefore, it is now feasible to quantitatively define any of the units shown in the CPPL (plate 7) using a system of four numbers: profile area (A), the peakedness index (S), the elongation number (E), and the parallelism number (P). The relation between the CPPL units and the values derived above can be arranged in tabular form, as shown in fig. A4.

21. The values assigned to differentiate among the various categories of landscape type are assigned on the basis of purely theoretical considerations, leavened slightly by an admittedly inadequate amount of experimental evidence. Furthermore, each experiment was more or less carefully selected to prove a point. The results, and especially the specific ranges of values attached to each CPPL unit, should be considered tentative.
<table>
<thead>
<tr>
<th>Characteristic plan-profile units (see Plate 7)</th>
<th>A (area profile)</th>
<th>S (peakedness index)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 L</td>
<td>0.55 - 1.0</td>
<td>0.0 - 0.99</td>
</tr>
<tr>
<td>2 L</td>
<td>0.45 - 0.54</td>
<td>0.0 - 0.99</td>
</tr>
<tr>
<td>3 L</td>
<td>0.0 - 0.44</td>
<td>0.0 - 0.99</td>
</tr>
<tr>
<td>4 L</td>
<td>0.45 - 0.54</td>
<td>1.0 - ∞</td>
</tr>
<tr>
<td>5 L</td>
<td>0.35 - 0.44</td>
<td>1.0 - ∞</td>
</tr>
<tr>
<td>6 L</td>
<td>0.0 - 0.34</td>
<td>1.0 - ∞</td>
</tr>
</tbody>
</table>

Fig. A4. Values of A, S, E, and P corresponding to plan-profile units
APPENDIX B: A SYSTEM FOR SYMBOLIZING THE GENERALIZED LANDSCAPE MAP

Introduction

1. The sequence for the preparation of analog maps as described in the main report is based on a unique, comprehensive, orderly method of terrain classification which blends quantitative and qualitative systems. The generalized landscape map, particularly, is an innovation in that it combines four basic terrain geometry or form factors into a single map that represents topographic expression or landscape. It provides, moreover, for certain rigid mapping techniques so that when the four geometry-factor maps are superposed, combinations of specific mapping units of each of the four factors evolve.

2. This synthesis could, of course, have been accomplished by going through the following steps: (a) systematically overlaying each geometry-factor map; (b) determining distinctive groupings of specific mapping units of these four terrain factors; and (c) mapping each such distinctive grouping with a specific pattern. However, a more desirable approach was to devise a cartographic system such that simple printing of each map over the other would automatically delineate the several thousand possible combinations of mapping units of the four geometry factors.

Specific Work Requirements

3. The system of symbolization had to provide for an easily interpretable lithographic presentation of the four basic geometry factors of terrain, which, when superposed or successively overprinted, would identify distinctive combinations of mapping units of these four factors. The resulting generalized landscape map was to possess patterns distinctive enough to be identified through use of an accompanying legend. (It was realized by all concerned, however, that each individual geometry-factor pattern making up the landscape pattern need be identifiable only on close examination.) In addition, the symbolization had to provide for distinction of "complexes" and types of "complexes." This will be explained in
subsequent paragraphs. The system planned included the following requisites:

a. Color was to be used as sparingly as possible for reasons of economy.

b. Clashing of patterns, as for example, indiscriminately used dot patterns, was to be avoided.

c. Mnemonic devices were to be used to the fullest possible extent.

d. Notations, letters, numbers, or figures were not to be used unless inescapable.

e. The minimum dimension of mappable salients, enclaves, narrow strips, and the like was to be 1/8 in. on the map.

General Cartographic Methods

4. In each case the four geometry factors had to be shown in from 6 to 25 "simple" mapping units, as well as in "complexes" of these simple units as defined in plates 7, 8, 9, and 10.

5. It is important from the reproduction standpoint to note that, generally speaking, the mapped limits or boundaries of one unit of a particular geometry factor either correspond exactly with, or diverge considerably from, the limits of at least some of the mapping units of the other factors. For this reason it is essential not only that all reproduction material used be extremely stable and mutually registered prior to photographic processing but also that one original drawing or scribing (on stable material) should be prepared at the outset that contains every boundary or limit of all mapped geometry factors--both simple and complex types. Later, any limit not pertaining to a particular factor must be erased or duffed out at an appropriate stage.

6. The etchable "dri-strip" process was found to be the most satisfactory method of preparing the base maps. Lines from original (transparent) drawings of each geometry-factor map are transferred to pre-registered photomechanical, etchable, "dri-strip" sheets for making open-window negatives of area color separation, for laying screens, and for patterns used in mapping. These sheets (transparent and dimensionally stable--usually vinyl) are sprayed with uniform thin coatings of red,
opaque, lacquered base to a strip thickness of approximately 0.0015 in. The strip-coating at this stage is not sensitized and can be applied to the sheets in advance and the sheets stored for future use.

7. Before the image is transferred, the stripping base is sensitized with a deep-etch coating. The sensitized coat is then registered and exposed with the geometry-factor map and developed with etching solution. The images of the lines are etched down to the base (vinyl). Strip-coating in areas to be printed can be removed with a needle or knife. Etched areas not to be printed can be opaqued as on an ordinary negative.

**Characteristic Plan-profile**

8. The 25 units of this geometry factor are defined and schematically illustrated in plate 7. Units can be divided into (a) four groups of characteristic plan forms, within each of which are six profile types, and (b) one anomalous unit lacking pronounced highs and lows.

9. The plan-profile map, as a single entity, has an over-all monochrome (gray) background, with symbolized patterns cleared to paper white. This result is obtained by "knocking out" the background in transparency NEGATIVE form with the symbolized patterns in black line on a clear transparency. The patterns are drawn at a large scale, and are reduced photographically to the required size, i.e., so the pattern is recognizable in the smallest enclave shown on the map (1/8 in. across).

10. The system of symbolization, as shown in plate 7, is based on a pattern of hexagons, squares, broken squares, and lines. Areal occupancy of highs is indicated by three thicknesses of the lines forming these patterns, indicating highs predominating, highs and lows approximately equal, and lows predominating. Flat-topped highs are distinguished from peaked highs in that the latter contain dots within the areas bounded by the line pattern.

11. When used as a geometry-factor element of the generalized landscape map, the background knocked out by the plan-profile patterns is the characteristic slope background described under the next heading instead of the over-all monochrome (gray) background used for the plan-profile map alone.
12. Whole symbol patterns are used in areas having no "complexes." For complexes the patterns are treated fractionally as described in a later paragraph.

**Characteristic Slope**

13. The seven mapping units of characteristic slope, ranging from flat to precipitous, are shown in plate 9. The symbolization devised consists of dark gray flecks on a gray halftone background. The mapping units are distinguished by characteristic differences in: (a) the shapes of the flecks, as well as by increasing numbers of flecks, as the angle of slope increases; (b) the sizes of the flecks; (c) the fleck angle as related to the map horizontal; and (d) the over-all darkness of the fleck-background combination. A dot-screen background is used for mapping units 1a, 1b, and 2, and a line-screen background for mapping units 3 through 6. The seven units of slope are thus divided into two groups which correspond to the divisions of the characteristic relief factor. Originally, it was thought desirable to show a marked distinction between these two groups by having a marked increase in the darkness of the background of the steeper group. Subsequently, however, this plan was abandoned, first, because too marked an increase diminishes the necessary clear color distinction required for another form factor in the combined generalized landscape map, and, second, because a sufficiently marked group distinction in the tone of the combined fleck-background pattern was found to occur fortuitously when the halftone-background value of both groups was about the same, i.e. around 30 per cent. The flecks are obtained by a technique which may be termed a form of controlled moiré pattern.* To obtain a given fleck pattern in positive form, that is, black flecks on a clear background, two line-halftone screen transparencies of different line

---

* Moiré patterns can be obtained by overprinting or superposing two distinctive patterns. Patterns of dots, arranged in offset fashion, for example, on a transparent background, can be placed over dots arranged in horizontal and vertical rows. If the former is gradually rotated above the latter, waves or clusters of dot patterns form, rearrange themselves, and dissipate, forming a subsidiary (moiré) pattern entirely independent of the original dot patterns.
spacings are overlaid at a small angle and exposed together. Particulars of the transparencies used for the flecks chosen are given in Table Bla.

14. To obtain a combination of fleck and halftone background, the required positive fleck transparency is exposed with the appropriate dot or line halftone screens to get the combined characteristic slope negative. In doing this, the fleck lines are oriented at specified angles with the map horizontal and with the pattern of the dot or line screens, as given in Table Blb. The angles with the map horizontal are selected to afford the desired progressive fleck-angle increases (fig. Bl). The angling relative to the dot or line screen was determined empirically in each case to as to avoid random, unwanted moiré patterns which could occur.

Table Bl
Development of Characteristic Slope Patterns

<table>
<thead>
<tr>
<th>Mapping Unit</th>
<th>Combination of Line Screens</th>
<th>Angular Relation Between Screens</th>
</tr>
</thead>
<tbody>
<tr>
<td>la</td>
<td>65%, 60-line + 80%, 120 line</td>
<td>10°</td>
</tr>
<tr>
<td>lb</td>
<td>80%, 33-line + 80%, 120 line</td>
<td>5°</td>
</tr>
<tr>
<td>2</td>
<td>50%, 33-line + 80%, 120 line</td>
<td>5°</td>
</tr>
<tr>
<td>3</td>
<td>50%, 33-line + 65%, 60 line</td>
<td>22-1/2°</td>
</tr>
<tr>
<td>4</td>
<td>20%, 33-line + 65%, 60 line</td>
<td>30°</td>
</tr>
<tr>
<td>5</td>
<td>40%, 33-line + 50%, 60 line</td>
<td>13°</td>
</tr>
<tr>
<td>6</td>
<td>15%, 33-line + 50%, 60 line</td>
<td>15°</td>
</tr>
</tbody>
</table>

b. Combinations of fleck positives with screens to produce characteristic slope patterns (see fig. Bl).

<table>
<thead>
<tr>
<th>Mapping Unit</th>
<th>Orientation Relative to Map Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fleck</td>
</tr>
<tr>
<td>la</td>
<td>Rows 4° up left</td>
</tr>
<tr>
<td>lb</td>
<td>Rows 12° up right</td>
</tr>
<tr>
<td>2</td>
<td>Rows 18° up right</td>
</tr>
<tr>
<td>3</td>
<td>Lines 32° up right</td>
</tr>
<tr>
<td>4</td>
<td>Lines 45° up right</td>
</tr>
<tr>
<td>5</td>
<td>Lines 60° up right</td>
</tr>
<tr>
<td>6</td>
<td>Lines 75° up right</td>
</tr>
</tbody>
</table>
Fig. Bl. Development of characteristic slope patterns: orientation of flecks and screens

in combination with other geometry-factor patterns having intrinsic angled characteristics. For avoidance of random moiré patterns it was found that a dot screen should be used for the background of the gentle group of slopes (about 30 per cent dot value), whereas for the steeper group, a line
screen (about 25 per cent value) was required. Had time permitted further investigations into the question of avoidance of random moiré patterns, it might have been possible to formulate some simple rules that would lessen empirical work.

**Characteristic Slope Occurrence**

15. This geometry factor concerns the occurrence of slopes greater than 50 per cent, or in gross-component complexes, the spacing of component highs or lows. There are six mapping units covering specified ranges of slope occurrence from widely separated to very close together (plate 8).

16. In order to provide a convenient aid for recognizing each category, the basic symbol used consists of fairly heavy parallel rulings at equal spacings of just under 1/8 in. This is used to represent the widest spacings of 50 per cent slopes or component highs and lows (mapping unit 1). For the other five units, distinctively finer lines, 1, 2, 3, 4, and 5 in number, are used between each pair of heavy lines. All lines are angled at 63° to map horizontal, in a direction opposite to that of the characteristic slope flecks, so as to avoid coincidence with any other angled geometry-factor line on the generalized landscape map. The lines are obtained by hand-ruling or scribing at a large scale for reduction by photography. They are printed in magenta.

**Characteristic Relief**

17. The seven mapping units of characteristic relief, falling in two principal groups, are defined in plate 10. These units are identified by seven well-differentiated colors, each color being intense enough to be clearly identifiable over any of the characteristic slope patterns, yet not so dark as to diminish the clarity of the characteristic slope flecks. Colors therefore had to be transparent.

18. For reasons of economy, it was desired that the number of printing inks to be used to obtain the seven colors should be the fewest possible. Adequate color differences were obtained by using only the three process printing colors—red, yellow, and blue. As had been determined in
preparing test color overprints by the Watercote process, unpredictable moiré patterns arise with certain angular relations between characteristic slope patterns and characteristic relief, halftone, color overprints. Through trial positioning of the slope pattern and the color screens such moiré can be avoided. Tests showed that a dot-screen (halftone) color overprint can be used with the final designs of characteristic slope-fleck tone combinations without any disturbing moiré pattern (see preceding discussion of characteristic slope) provided that the dot screen is set thus, to the map horizontal:

```
\[ \text{Map horizontal} \]
```

On the other hand, as expected, it is not possible to overlay two process colors in this normal halftone arrangement without getting random strong moiré patterns purely due to the color combination. For this reason, any color scheme devised must make use of no more than one dot-halftone component in any composite color; the other color component(s) must be a solid color.

19. Certain basic rules were required in the color printing plan to produce the desired results. With the three basic unscreened colors to be used on the press designated Y, B, and R, these rules are:

a. Let Y be any good commercial transparent PROCESS YELLOW reduced in the proportion 1 part ink to 1 part tint base.

b. Let B be any good commercial transparent PROCESS BLUE reduced in the proportion 1 part ink to 2 parts tint base.

c. Let R be any good commercial transparent PROCESS RED reduced in the proportion 1 part ink to 3 parts tint base.

The following color combinations of Y, B, and R at the above-listed basic unscreened strengths were used for printing:
Relief Mapping

<table>
<thead>
<tr>
<th>Unit</th>
<th>Combinations</th>
<th>Resulting Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B unscreened over Y unscreened</td>
<td>BLUE-GREEN</td>
</tr>
<tr>
<td>2</td>
<td>B 50% dot screen over Y unscreened</td>
<td>YELLOW-GREEN</td>
</tr>
<tr>
<td>3</td>
<td>Y unscreened</td>
<td>YELLOW</td>
</tr>
<tr>
<td>4</td>
<td>R 20% screen over Y unscreened</td>
<td>YELLOW-ORANGE</td>
</tr>
<tr>
<td>5</td>
<td>R 50% screen over Y unscreened</td>
<td>ORANGE</td>
</tr>
<tr>
<td>6</td>
<td>R 50% screen over Y unscreened over B unscreened</td>
<td>OLIVE-BROWN</td>
</tr>
<tr>
<td>7</td>
<td>R unscreened</td>
<td>RED</td>
</tr>
</tbody>
</table>

20. The combination colors were chosen so as to have a moderate mnemonic value since they correspond more or less with the rising color arrangement of numerous conventional layered maps or atlases. The absence of RED from relief mapping units 1, 2, and 3 (Type I relief) should also be a mnemonic aid. The reduction of the basic inks with tint base was suggested so as to make the darkest colors sufficiently transparent to enable the characteristic slope fleck patterns to be seen clearly as well as to permit clarity in the slope occurrence overprint.

Complexes

21. Two kinds of complexes may occur on any of the geometry-factor maps. These are areal complexes in which two different mapping units of the same factor are mingled in the same area but cannot be mapped separately, and gross-component complexes in which one mapping unit of the geometry factor is an intrinsic element of another.

22. The system designed for showing both types of complexes is a repetitive fractional arrangement of two narrow bars of the patterns of the two mapping units involved. These bars are obtained by knocking out a phototransparency of each mapping-unit pattern with a transparency carrying a black band ruling of just over 50% of the line spacing (which is just under 1/8 in.), combining the two required unit bars by contact exposure of the two, set together so that the two patterns abut on one edge while a "fraction" line falls between them on the other. Distinction between the two kinds of complexes and in the relation between component and gross elements of the gross-component complex is obtained by orienting the
fraction line in specified ways as shown in the legends of plates 7-11. The orientation is designed to convey immediately the general nature of the complex to the user; careful scrutiny is often necessary to determine the details.

Summary

23. To summarize, plan-profile units are identified by a pattern of hexagons, squares, broken squares, or latticelike lines, with or without dots; slope occurrence units, by parallel magenta lines; characteristic slope units, by lines of flecks; and characteristic relief units by background colors.

24. Plate 11 (generalized landscape) is an example of the superposition of the four geometry-factor mapping-unit patterns described in the preceding paragraphs. On close examination, the specific combination of geometry-factor mapping units for any area can be determined.

Note: It should be emphasized that this plate is of a tentative or experimental nature. It is believed that certain modifications will still allow for easy identification of mapping units of the four terrain factors on individual terrain factor maps (plates 7, 8, 9, and 10) and make them much more legible on the generalized landscape map (plate 11). Such modifications might include the utilization of (1) a slightly darker gray for the plan-profile and characteristic slope background, (2) slightly wider lines for the plan-profile pattern, (3) a less intense magenta for the slope occurrence pattern, and/or (4) more transparent printing inks.