ANALOGS OF YUMA TERRAIN IN THE SOUTHWEST UNITED STATES DESERT

TECHNICAL REPORT NO. 3-630

Report 5

Volume I

June 1963

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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Date	Title	Technical Report No.
Feb. 1958 (Under Revision)	Analogs of Yuma Terrain in the Northeast African Desert	3-630
Feb. 1958 (Revised June 1962)	Analogs of Yuma Terrain in the Northeast African Desert	3-630 Report 1
Mar. 1959 (Revised Aug 1962)	Analogs of Yuma Terrain in the South Central Asian Desert	3-630 Report 2
Apr. 1959	Analogs of Yuma Terrain in the Mexican Desert	3-630 Report 3
May 1959	Handbook, A Technique for Preparing Desert Terrain Analogs	3-506
May 1960	Analogs of Yuma Terrain in the Middle Eastern Desert	3-630 Report 4

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ARMY-MRC VICKSBURG, MISS.

PREFACE

This study is part of Research and Development Project No. 1-T-O-25001-A-131 entitled "Military Evaluation of Geographic Areas," which was originally assigned to the U. S. Army Engineer Waterways Experiment Station (WES) by the Office, Chief of Engineers, and is being performed under the sponsorship of the R&D Directorate, U. S. Army Materiel Command. The project is directed by the Area Evaluation Section of the Soils Division, WES.

This report was prepared almost entirely from published reports, maps, and photographs utilizing mapping techniques developed by the Geology Branch, WES. The literature survey and preparation of most of the preliminary maps, with the exception of the analog maps, were done under contract by the Department of Geology, University of Southern California. The work at the University of Southern California was accomplished by Dr. Thomas Clements, Dr. Richard O. Stone, Mr. S. Sterling Neblett, Mr. Detlef A. Warnke, Mr. Rudolph C. Pesci, Mr. Joseph P. Willis, Mr. Robert A. Dicken, and Mr. Michael A. Clary. The preliminary maps were reviewed and final maps were prepared by Mr. John H. Shamburger (assisted in the initial stages by Dr. Stone) under the immediate supervision of Drs. Charles R. Kolb and Jack R. Van Lopik, both formerly with the Geology Branch, Soils Division, WES. The text was written by Drs. Van Lopik and Kolb. Technical assistance in various phases of the work was provided by Mr. W. K. Dornbusch, Jr., and Mr. Harry K. Woods, Geology Branch, WES; Mr. Warren E. Grabau, Chief, Area Evaluation Section; and Mr. Joseph R. Compton, Chief, Embankment and Foundation Branch, WES. The project was under the general supervision of Messrs. W. J. Turnbull and W. G. Shockley, Chief and Assistant Chief, respectively, of the Soils Division, WES.

Directors of the WES during this study and preparation of this report were Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

	Page
PREFACE	iii
SUMMARY	vii
PART I: INTRODUCTION	1
Background	1
Study Area	1
Purpose and Scope of Study	1
Purpose and Scope of This Report	2
PART II: GENERAL COMPARISON OF YUMA AND THE SWUS	4
Factors Used in the Comparison	4
Analogy	4
PART III: TERRAIN FACTORS AND MAPPING METHODS	7
Bases for Selection of Factors	7
Geometry or Form Factors	7
Ground and Vegetation Factors	10
Examples of Designations of Yuma Terrain	11
Summary of Mapping Methods	14
PART IV: DEVELOPMENT OF ANALOGS	19
Method	19
Analysis of General Applicability of Analog Technique	23
Problems and Recommendations for Solution	24
PART V: SOURCES OF INFORMATION	28
TABLES 1-4	
PLATES 1-19	
APPENDIX A: THE PROBLEM OF TERRAIN COMPARISON	A1
Quantitative Versus Qualitative Approach	A1
Terrain Factors Versus Terrain Effects	A2
Scales and Problems of Generalization	A4

SUMMARY

To evaluate the adequacy and suitability of the Yuma Test Station (including the Sand Hills) as a test site representative of world desert conditions it is necessary to determine the extent of occurrence of Yuma terrain types in the Southwest United States (SWUS) desert and in other world desert areas. In order that valid comparisons may be made, a uniform system of describing, mapping, and comparing desert terrain must be employed.

In this report both the Yuma Test Station and the SWUS desert are mapped in terms of general or aggregate terrain, geometry, ground, and vegetation factors. General terrain factors selected for use include physiography, hypsometry, and landform-surface conditions. Geometry and ground factors selected for evaluation are characteristic plan-profile, occurrence of slopes greater than 50 percent, characteristic slope, characteristic relief, soil type, soil consistency, and type of surface rock. Terrain-factor data are synthesized to establish the degree of analogy of a particular SWUS area with selected portions of the Yuma Test Station. This synthesis includes compilation of geometry, ground, and vegetation analog maps--through combinations of their component terrain-factor maps. If a geometry type (identified by an array of four numbers, each representing a particular range of value of the geometry factors) found at Yuma also occurs in another desert area, the tracts are considered as highly analogous. A tract exhibiting three numbers out of four that occur in combination at Yuma is considered to be moderately analogous, and so on. Ground and vegetation analog maps were prepared in similar fashion through utilization of their respective terrain-factor maps.

A terrain-type analog map is prepared by superimposing the geometry, ground, and vegetation analog maps and stratifying the resulting combinations. Highly analogous SWUS 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 such combinations decreases.

The techniques used in preparation of these maps permit comparison of terrain in areas mapped at different scales as well as in areas mapped at similar scales, enabling for the first time comparison of all the deserts of the Northern Hemisphere.

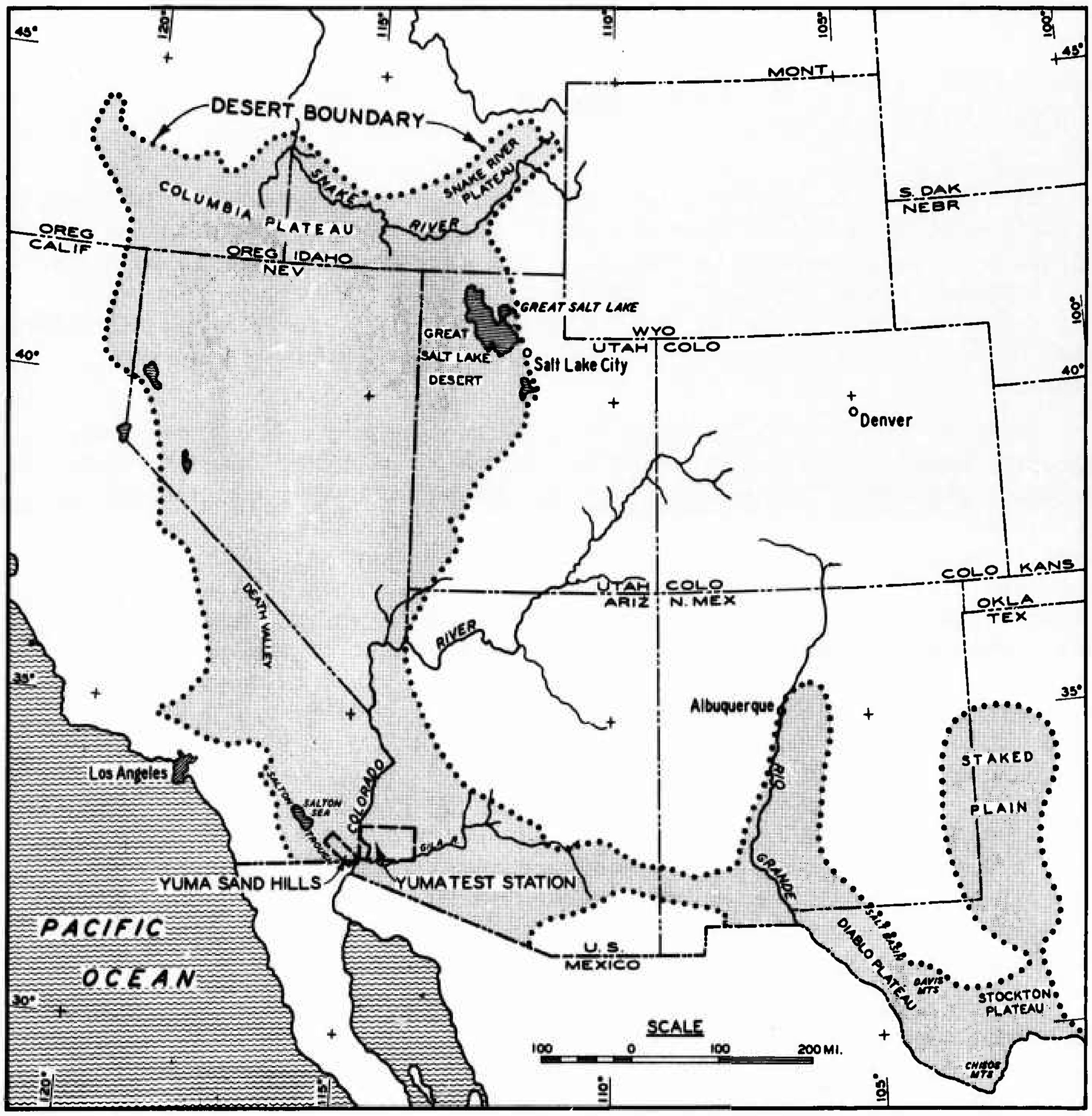

Fig. 1. Southwest United States desert

ANALOGS OF YUMA TERRAIN IN THE SOUTHWEST UNITED STATES DESERT

PART I: INTRODUCTION

Background

1. This report is one of a series comparing the terrain of the U. S. Army Yuma Test Station at Yuma, Arizona, with other world desert areas. The earlier reports in the series,* which compare the Yuma terrain with the deserts of North Africa, South Central Asia, Mexico, and the Middle East, were prepared in very limited numbers. However, copies are on file at the Waterways Experiment Station (WES) and in the Environmental Sciences Branch, Research Division, Research and Development Directorate, Army Materiel Command. A larger edition of this report has been published because of the greater current interest in the Southwest United States desert (SWUS) area.

Study Area

2. The location and limits of the study area and its geographic subdivisions are shown in fig. 1. Desert boundaries were based on homoclimatic maps compiled by Dr. Perevil Meigs.** However, since Meigs' boundary determinations were agriculturally oriented, with temperature and rainfall the most important factors considered, modifications have been made on the basis of geomorphic, soil, and vegetation data collected in the present study.

Purpose and Scope of Study

3. The primary aim of a major phase of the overall project is to evaluate the Yuma Test Station area (including the Sand Hills) as a test site representing world desert terrain conditions. Obviously, Yuma's suitability and adequacy as such a test site are related to (a) the extent to which Yuma terrain types or conditions occur in other world desert areas,

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* See list on inside of front cover of this report.

** Review of Research on Arid Zone Hydrology, UNESCO, 1952.

and (b) whether significant desert terrain types occurring elsewhere are lacking at Yuma. To make these determinations, a uniform system of describing, mapping, and comparing desert terrain had to be established. A system which satisfies most of these requirements has been developed and tested through its application to Yuma and several other world desert areas. In addition, comparisons of the climate of the Yuma Test Station with that of other world desert areas have been made for WES by the Environmental Protection Research Division, Quartermaster Research and Development Center (now the Natick R & E Center).* The climatic and terrain studies together should provide an evaluation of the suitability of the Yuma area as a testing ground for military operations and materiel under conditions representative of those prevailing in desert areas in other parts of the world. The worldwide distribution of desert terrain types and their relative importance can be determined by examining the other reports of this series (see paragraph 1).

Purpose and Scope of This Report

4. This report is primarily concerned with utilizing the established techniques to (a) map the various terrain factors in the SWUS, (b) determine the distribution of terrain types found at Yuma within the SWUS, (c) determine degrees of analogy between the terrain types of the SWUS and those of the Yuma area, and (d) contribute to an overall evaluation of the suitability of the Yuma Test Station for testing men and materiel for military operations in desert areas of the world.

5. The report comprises two volumes--the text (vol I) and a folio of plates (vol II). Except for two sets of plates (15 and 15A, and 19

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* Headquarters, Quartermaster Research and Development Command, Quartermaster Research and Development Center, U. S. Army, Analogs of Yuma Climate in the Middle East, Report No. 1 (1954); Analogs of Yuma Climate in Northeast Africa, Report No. 2 (1954); Analogs of Yuma Climate in Northwest Africa, Report No. 3 (1955); Analogs of Yuma Climate in South Central Asia, Report No. 4 (1955); Analogs of Yuma Climate in Soviet Middle Asia, Report No. 5 (1955); Analogs of Yuma Climate in Chinese Inner Asia, Report No. 6 (1955); Analogs of Yuma Climate in East Central Africa, Report No. 7 (1956); Analogs of Yuma Climate in North America, Report No. 8 (1957). Environmental Protection Research Division (Natick, Mass).

through 19C) which present tabular descriptions and photographs of the physiography and landform-surface conditions of the Yuma terrain, the folio consists of drawings most of which show a map of the SWUS and a map of the Yuma Test Station to facilitate comparison. Detailed explanations of the mapping procedures used in preparation of the plates are given in WES Technical Report 3-506.* In general, the legends on the plates are self-explanatory; however, additional explanations of each legend may be found in TR 3-506.

6. The remainder of this volume (vol I) consists of Parts II through V, four tables, and an appendix. Part II briefly summarizes the general analogy of the Yuma terrain to that of the rest of the SWUS. Part III describes the terrain factors used to develop the analogy and the methods used in mapping them. Part IV discusses the methods of analog development, and analyzes the mapping technique from the standpoints of its general applicability and deficiencies. Part V gives in very general terms the sources from which the information used in this study was drawn. Tables 1-3 summarize data on the distribution of Yuma terrain factors within the SWUS, while table 4 summarizes data pertaining to distribution of landscape types in Yuma and the SWUS, and in other world desert areas as given in earlier reports of this series. Appendix A discusses the philosophy of and problems associated with terrain analysis and comparison in general.

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* J. R. Van Lopik and C. R. Kolb, Handbook; A Technique for Preparing Desert Terrain Analogs, Waterways Experiment Station (Vicksburg, Miss., May 1959).

PART II: GENERAL COMPARISON OF YUMA AND THE SWUS

Factors Used in the Comparison

7. Terrain may be considered to be the aggregate of the physical attributes that characterize an area. Terrain can thus be analyzed and described in terms of numerous component factors. Eight factors, considered to be basic elements of terrain, have been utilized in comparing the terrain at Yuma with that of the SWUS and other world desert areas. These factors fall into three groups: geometry factors, i.e. plan-profile, slope occurrence, slope, and relief; ground factors, i.e. soil type, soil consistency, and surface rock; and vegetation factors. Plates 1-9 indicate the areal distribution of various ranges of these factors at Yuma and within the SWUS. Plates 14-19 present general or aggregate terrain factors such as physiography, hypsometry, and landform-surface conditions. The last three factors were not utilized directly in preparing the analog maps (plates 14, 16, and 18). Rather these three factors were mapped primarily to (a) provide a familiar geomorphic sphere of reference or gross terrain picture, and (b) present landscape-terrain factor associations that aided in the mapping, in terms of the eight terrain factors, of regions where little information beyond landform identification is available.

8. Each of the terrain-factor maps is, in essence, an analog map. Similarly mapped areas at Yuma and within the SWUS indicate high degrees of analogy from the standpoint of the particular terrain factor under consideration (see plates 1-9). A synthesis of terrain-factor data and maps, resulting in the establishment of varying degrees of analogy of particular SWUS areas with portions of the Yuma Test Station and Sand Hills, has been attempted in plates 10-13. Plates 10-12 show the degree of analogy of geometry, ground, and vegetation factors, respectively, with Yuma, and plate 13 shows degrees of analogy based on all factors considered. Degrees of analogy are expressed as being highly analogous, moderately analogous, slightly analogous, inappreciably analogous, and not analogous.

Analogy

9. As might be expected, the terrain of the SWUS is essentially

similar to that found at Yuma Test Station (plate 13). Approximately 72 percent of the SWUS study area is highly analogous, 12 percent moderately analogous, and 15 percent is slightly analogous with respect to terrain types found at Yuma. Only two small areas in Texas and one in New Mexico, occupying approximately 1 percent of the study area, fall within the inappreciably analogous category. No SWUS area has been classified as not analogous.

10. Highly analogous areas are found within all the major physiographic units of the SWUS (plates 13 and 14). The basin-and-range region proved to be highly analogous with only scattered areas of lower analogy. Sand dunes occurring in each state of the study area were found to be highly analogous with respect to the Yuma Sand Hills, and the Chisos and Davis Mountains of Texas (see fig. 1 for location) also had highly analogous Yuma counterparts. With the exception of a single depression plain in the northwest part of the study area, all such plains (e.g. Salton Trough and Death Valley, California, and Salt Basin, Texas) fall within the highly analogous category. Only the central and southwestern part of the Staked Plain proved to be highly analogous. Somewhat surprisingly, the volcanics in Idaho and most of the Snake River Plateau rated highly analogous when compared with certain Yuma terrain types.

11. Relatively small moderately analogous areas occur throughout the SWUS. The largest regions of the type occur in the Great Salt Lake Desert, the plateau in northern New Mexico, and as irregular bands on the Staked Plains. Playas and elongate basins in the basin-and-range region, as well as parts of the basin ranges in Nevada, proved to be moderately analogous. Parallel and random hills and single-ridge mountains in Texas are also included in the moderately analogous category.

12. Slightly analogous areas occur almost exclusively in the northern and eastern part of the study area. Areas of this type include the dissected part of the Columbia Plateau, the Diablo Plateau, and the Stockton Plateau. The northern part of the Staked Plain, the volcanics, and a depression plain in the extreme northwestern part of the study area were also found to be slightly analogous.

13. Of the approximately 140 different landscape types which have been found in other desert areas mapped (see table 4), only 18, or

approximately 13 percent, occur at Yuma. The landscape types that do not occur at Yuma are typically found in undissected plateaus, moderately and maturely dissected plateaus, vast sand dune regions, sand sheet regions, areas of cinder cones and lava flows, and extensive desert plain regions of world deserts. There is no test site within the SWUS where all or even 75 percent of the desert landscape types occur. However, if the Yuma test site were supplemented with two or three other test areas within the SWUS, adequate representation of dominant world desert conditions should be achieved.

PART III: TERRAIN FACTORS AND MAPPING METHODS

Bases for Selection of Factors

14. Mapping terrain factors involves the selection of a series of component factors that can be precisely defined, mapped, and compared. Any region can be subdivided into areas identifiable by an array of designations or numbers, each representing a value or value range of a specific terrain factor. The complexity of such a system, of course, depends primarily on the number of terrain factors employed. For example, if 20 terrain factors were considered, each area would be identified by an array of 20 symbols, each designating a particular terrain-factor value or range of values. Although this method is plausible, cartographic problems multiply rapidly if it is necessary to map areas exhibiting the same combination of factors and at the same time identify the component terrain-factor values or ranges. Consequently, in the development of the mapping system used herein considerable effort was spent in limiting the number of terrain factors and at the same time making sure that factors which were important in terrain descriptions were not disregarded. Much effort was also devoted to selecting terrain factors that, when considered in concert, are readily visualized and depicted with a minimum of cartographic complexity. The terrain factors mapped were chosen chiefly because of (a) the importance of each as a basic element of terrain, (b) their ability, when viewed together, to provide a reasonably complete picture of a given terrain, and (c) their military significance.

15. The selection of mapping units, or the 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, whenever possible, quantitative definition.

Geometry or Form Factors

Background

16. Landscape, as used in this terrain study, is defined as the surface form or configuration (geometry) of an area. Historically, the

representation of landscapes or surface geometry in plan progressed from simple pictorial symbols on early maps, to hachuring, to the first contour maps in the middle 1880's. The importance of this last step in quantifying cartography cannot be overemphasized; for the first time commensurable vertical as well as horizontal data were included on maps. Advances since that time seem to have been largely concentrated on shading and improved methods of hachuring or pictorial representation. These methods permit a more readily assimilated bird's-eye view of the terrain, but comparison of one such view with another is largely a matter of individual interpretation. Classification and direct measurement of the component parts of such views are necessary before the problems of objective terrain comparison and a host of similar problems can be resolved.

<u>Geometry factors selected</u>

17. Considerable thought has been given to the selection of factors to be included in landscape description. An attempt was made to keep the number of factors at a minimum while still providing, when considered in concert, a reasonably complete picture of the terrain. Preference was given those factors which could be quantitatively expressed and precisely or rigidly defined and mapped with the data available. Four surface geometry factors (plates 1-4) were finally selected: slope, relief, dissection or spacing of steep slopes, and a composite factor called plan-profile. Using these factors, a region can be described as having hills with slopes ranging between 10 and 20 degrees, spaced from 700 to 1000 ft apart, rising to heights between 50 and 100 ft. A less tangible, but equally important property necessary to complete this description is the spatial distribution of these three geometry factors; this distribution is termed plan-profile.

18. The need for the plan-profile factor is readily visualized by considering a hypothetical gently sloping plain dissected by numerous deep, narrow drainageways. Such an area would be mapped as having certain ranges of slopes, relief, and slope spacing. Another gently sloping plain with a series of narrow dikes or ridges crossing it would be mapped with the same ranges of slope, relief, and slope spacing, but the disposition of features composing the landscape in each instance would be different. Profiles of the two landscapes would appear as  in the first instance and as  in the second. In addition, it is desirable to know whether the

ridges or drainageways are parallel or intersecting, continuous or discontinuous, i.e. a plan view of the area is needed. Thus the characteristic plan-profile is a necessary part of landscape definition.

19. The dimensions of the landscape typified by the plan-profile are indicated by relief and slope-occurrence measurements. For example, alluvial aprons scored by steep-sided, shallow washes are mapped with the same plan-profile as extensive, high-standing, dissected plateaus, although the relief and slope-occurrence value ranges are decidedly different. This is considered not only permissible but desirable because, with unrestricted dimensions, the plan-profile allows a convenient mental image of the landscape to be formed. To such an image, known values of slope, relief, and slope occurrence can be assigned and easily assimilated. In the present study, factor values associated with features exhibiting less than 10 ft of relief were considered as microrelief (paragraph 53) and were not included in the landscape descriptions. Consequently, the landscape description is a generalization of the actual ground surface.

Designations of geometry factors

20. Combining the four basic geometry factors provides a convenient method of mapping terrain or landscape in a fairly quantitative fashion. The method is certainly one of the simplest possible. It permits any landscape to be described 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, defines a plain having characteristic slopes of 1 to 3-1/2 percent and scored by roughly parallel, steep-sided washes from 10 to 50 ft deep which are spaced from 1000 to 5000 ft apart. The landscape type could be sketched as shown in fig. 2.

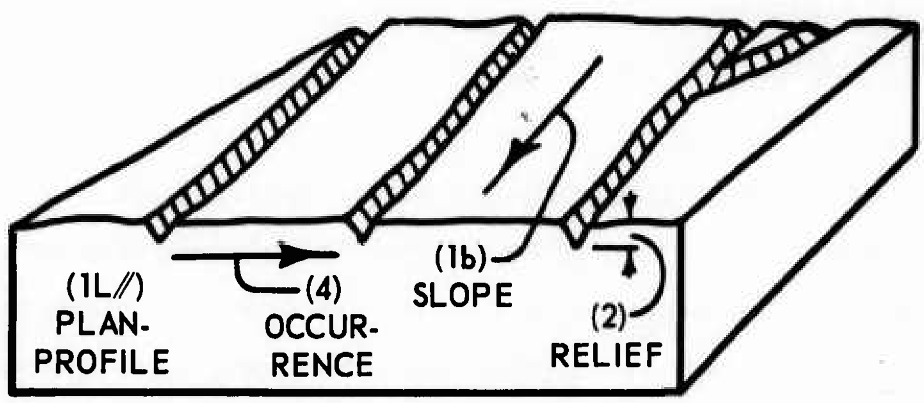

Fig. 2. Landscape representation showing use of number and number-letter symbols to describe surface geometry factors

21. 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 could be substituted for the directly measurable components of the plan-profile. (Methods of quantifying the plan-profile are presented in Appendix A of the Handbook cited in paragraph 5.) Although this procedure makes the landscape designation more truly quantitative, there seemed to be little advantage in its utilization in the present study.

Ground and Vegetation Factors

22. Although the legends on plates 6-9 are self-explanatory, a point concerning the aggregate nature of the ground and vegetation factors should be mentioned. Each factor is actually composed of several quantitative factors or properties that could be defined, stratified, and mapped. 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 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 (plate 9) presents some quantitative values for the mapping units, and the surface-rock tabulation (plate 8) presents property ranges of a more qualitative nature. Although the mapping of ground and vegetation factors used herein is considered adequate for the aims of the present study, it is not considered a final effort in quantitative ground-factor mapping. A more quantitative system is certainly needed in actual terrain-effect testing programs.

Examples of Designations of Yuma Terrain

23. Although the terrain-type designation provides a precise and fairly quantitative description of a region, it is admittedly difficult to visualize an area by reading a group of number or number-letter symbols until the classification system and symbology are thoroughly understood. This capability must, of course, be developed through continued use and familiarization with the terrain-factor ranges designated by the various number and number-letter symbols comprising the terrain types. A few of the landscape and terrain types found at Yuma are briefly described in the following paragraphs in an attempt to initiate familiarity with the system in a relatively well-known desert region. The types are also described within the framework of the well-known and widely utilized genetic system of landform classification (plate 18) to provide an even more familiar base.

Mountainous regions

24. Mountainous regions, i.e. basin ranges, occupy slightly more than 18 percent of the combined Yuma Test Station-Sand Hills area (plates 18 and 5). Landscape types 4,6,5,7; 4,6,5,6; and 4,5,5,5, are found within the basin ranges. These numbers identify mapping units or value ranges of plan-profile, slope occurrence, characteristic slope, and characteristic relief, respectively. Plan-profile unit 4 indicates that topographic highs (a) occupy more than 60 percent of the area, (b) are crested or peaked, (c) are nonlinear, i.e. length is less than 5 times width, and (d) are randomly arranged (see plate 1). Slope occurrence unit 5 (see plate 2) identifies areas where the number of such slopes is 100 to 200 per 10 miles. Characteristic slope unit 5 (plate 3) indicates that the most commonly occurring or characteristic slope is between 26.5 and 45 degrees (approximately 50 to 100 percent). Characteristic relief of 100 to 400, 400 to 1000, and more than 1000 ft is indicated by relief units 5, 6, and 7, respectively (plate 4). <u>All</u> of the basin ranges (plates 6, 11, and 18) are characterized by soil-rock association unit 1 which identifies a mosaic of bare rock and stony soils with a few scattered patches of coarse- and fine-grained soils. Bare rock and stony soils cover more than 50 percent of the area mapped. The small 4,5,5,5 area immediately south of the White Tank Mountains (plate 5) is characterized by surface rock unit 3a, i.e. true

extrusive rocks formed by solidification of molten material that poured out on the surface of the earth, e.g. basalt, dacite, etc. (plate 8). Surface rock unit 4, metamorphic rock, predominates in the 4,5,5,6 areas of the Muggins Mountains; however, areas of true extrusive rock (unit 3a) are also found. In the 4,6,5,7 type mountains south of Growler, Arizona, areas of undifferentiated sedimentary (unit 5) and metamorphic (unit 4) rock are found. This landscape (4,6,5,7) is also found in the Palomas Mountains in association with surface rock unit 2 (intrusive igneous rock). The 4,6,5,6 landscape type is the most widespread of the mountain types at Yuma. In the Trigo and Chocolate Mountains the 4,6,5,6 landscape type is found in areas of metamorphic rock (unit 4) and surface rock complexes of true extrusive rock (unit 3a) and volcanic ejecta (unit 3b). In the portions of the Middle and White Tank Mountains, the landscape type is associated with true extrusive rocks (unit 3a). In the Castle Dome Mountains the 4,6,5,6 landscape type is found in association with the 3a-3b extrusive rock complex, undifferentiated sedimentary rock (unit 5), and metamorphic rock (unit 4). <u>All</u> of the basin ranges are characterized by vegetation unit 2 (plates 18 and 9) which indicates a ground coverage of 1 to 5 percent consisting primarily of widely spaced thorny shrubs, bushes, and low trees. It seems rather obvious, then, that once the classification and symbology of the employed method is understood, a designation such as terrain type 4,6,5,6,1,3a,2 can immediately convey a considerable amount of semiquantitative data regarding the area. In contrast, the classical methods of geomorphic or terrain description would require several paragraphs or pages to convey the same information, and an area described by one person might be unrecognizable as the same area when described by another.

<u>Alluvial fans and aprons</u>

25. Alluvial fans and aprons occupy slightly more than 44 percent of the combined Yuma Test Station-Sand Hills area (plates 18 and 5). Landscape types 1L,4,1b,2; 1L,4,2,2; and 7,1,1b,1 characterize the fan and apron regions. Plan-profile unit 1L indicates that topographic highs (a) occupy more than 60 percent of the area, (b) are flat-topped, (c) are linear, and (d) are randomly arranged or nonparallel. Slope occurrence unit 4 identifies areas where the number of slopes steeper than 50 percent ranges from 20 to 100 per 10 miles. Slope units 1b and 2 indicate that the

characteristic slope is between 0.5 and 2 degrees and 2 and 6 degrees, respectively. Characteristic relief of 10 to 50 ft is indicated by relief unit 2. The 7,1,1b,1 landscape describes an area exhibiting (a) no pronounced topographic highs or lows, (b) no slopes steeper than 50 percent, (c) a characteristic slope of between 0.5 and 2 degrees, and (d) characteristic relief of less than 10 ft. The 1L,4,1b,2 landscape is the most widespread and is usually associated with soil type unit 6, i.e. sand and gravel mixed with minor amounts of finer material, and soil consistency unit 10, i.e. noncohesive surface layer less than 12 in. thick underlain by a dense layer. The most common vegetation found with this combination of factors is a complex of units 3 and 4 (moderately spaced thorny shrubs, bushes, low scrubby trees, herbs or clumps and open stands of coarse grass with scattered denser stands of shrubs and scrubby trees). Areas of soil type unit 4 (gravel) with soil consistency unit 9 (crusted surface of noncohesive pebbles or gravels overlying noncohesive materials), and soil type unit 8 (silt) with soil consistency unit 10 (noncohesive surface layer underlain within 12 in. by dense layer) are also found within this landscape type. Vegetation again is usually a 3-4 unit complex. In general, the same ground and vegetation factor combinations are associated with the 1L,4,2,2 landscape type. The 7,1,1b,1 landscape type is characterized by soil type unit 6 (sand and gravel), soil consistency unit 10 (noncohesive surface layer underlain within 12 in. by a dense layer), and vegetation unit 3. Areas of soil type unit 8 (silt) and soil consistency unit 4 (firm) are also found in association with landscape type 7,1,1b,1 and vegetation unit 3.

Other landforms

26. Examination of plates 18, 5, 9, and 11 easily provides similar descriptions for the remaining landforms--which comprise approximately 38 percent of the area--found at Yuma. Consolidated and unconsolidated hills, floodplains and terraces, and dunes occupy most of the area not composed of basin ranges or fans and aprons. If the terrain types composing these various landforms are determined from the maps, it will be obvious that, even within a region as small as the Yuma Test Station, classical landforms are not homogeneous from the standpoint of terrain types, and the same terrain types can be found within "different" landforms. These

are important points that should be borne in mind if any attempts are made to compare regions on the basis of classical geomorphology.

Summary of Mapping Methods

General concepts

27. The mapping methods are reviewed in more detail in the Handbook cited in paragraph 5; therefore, only a general discussion is presented here. Basically, 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 quantitativeness 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.

28. Furthermore, it has been found that great differences in mapping scale exert relatively little influence on subjective procedures, but often produce complications when precise and objective mapping techniques are utilized. This is especially true in 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 this generalization is difficult to 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 scale. Although some comparative data have been accumulated, in most cases it is currently only possible to estimate scalar effects. In areas such as the SWUS where map coverage at various scales is fairly good, some mapping and scalar correlations or relations can be observed. For example, if objective mapping techniques and 1:25,000 maps with a 10-ft contour interval are employed, many ranges associated with the basin-and-range region of the SWUS will include patches of slope units 3, 4, and 5, with unit 4 being areally

predominant. If the same techniques and 1:250,000 maps with 100-ft contour intervals are employed, these ranges would be mapped as slope unit 3. Obviously, if large and small regions are 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 to ensure that true areally dominant classes will be shown at small scales.

29. 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 some established objective mapping technique is utilized, is unit 3. Based on empirical data, where a range of slopes occurs it can be predicted with some assurance that at a contour interval of 10 ft the areally predominant slope unit will be 4. Consequently, since the 10-ft interval is employed as a base, a mountain mapped at a scale of 1:250,000 is represented as slope unit 4. When good map coverage at different scales is available for a region, this procedure is fairly simple although 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, since ranges of values are used in the mapping scheme employed in this report, subjective estimates can be made with considerable confidence in some areas. 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) and contour-interval (10 ft) mapping of relatively unknown areas. Many of these associations are indicated in plates 19, 19A, B, and C.

30. The preceding general concepts are considered in establishing procedures for general mapping of geometry, ground, and vegetation factors. Probably the most important point is that the mapping bases utilized for the various factors, with the exception of physiography and hypsometry, are "large scale" in nature. Therefore they are closely allied with the Yuma area. Through the areal generalization process just described, the same mapping base was employed in the small-scale mapping of world desert areas. In geometry-factor mapping, a scale of 1:25,000, contour interval of 10 ft,

and a 1-mile-diameter sampling circle were employed as the datum, and fairly objective techniques for mapping Yuma and world deserts were established. Areas of geometry factors mapped in this manner are considered to be characterized by a restrictive geometry-factor type. Although the limits of the ground- and vegetation-factor mapping classes were established with all possible precision, fairly qualitative data and subjective techniques were employed in actual mapping of these factors. Existing soils, geologic, agricultural, and vegetation maps, written descriptions, and newly established landform-ground factor associations were necessarily the primary bases for mapping. The objective sampling and mapping techniques required for ground-factor mapping in actual field investigations have been explored, but could not be employed in the present study.

Mapping complexes

31. One of the more important concepts in the method employed in terrain-factor mapping is 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 symbolizations illustrated in plates 1-9. Complexes may be either areal or gross-component.

32. Areal complexes indicate the existence of two codominant mapping units within a given area. These complexes are mapped in regions, for example where two major, areally restricted soil types occur but cannot be separately delineated because of the smallness of the mapping scale or lack of detailed information. It follows that areal complexes become less important as scales become larger and as the amount of mapping information increases. Terrain-factor complexes represent mosaics of factor classes or mapping units; i.e., they indicate distinct, areally restricted tracts of specific, dominant mapping units rather than mixtures of these units. The legends of plates 1-9 explain the significance of the symbolization utilized in mapping areal complexes. It should be mentioned that for cartographic reasons, areal complexes of geometry factors are mapped only where the plan-profile factor is mapped as an areal complex.

33. The gross-component or gross-restrictive complex is used solely in geometry-factor mapping. 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 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 some cases, however, such as the situation illustrated in fig. 3, this landscape forms a component part of a larger or gross landscape and must be mapped to obtain an adequate portrayal of the area. Note that in fig. 3 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 (restrictive) landscape. Two scales of generalization are used in this portrayal. Using the plan-profile factor as an example, the restrictive, or component, plan-profile is determined by utilizing a sampling circle 1 mile in diameter, a contour

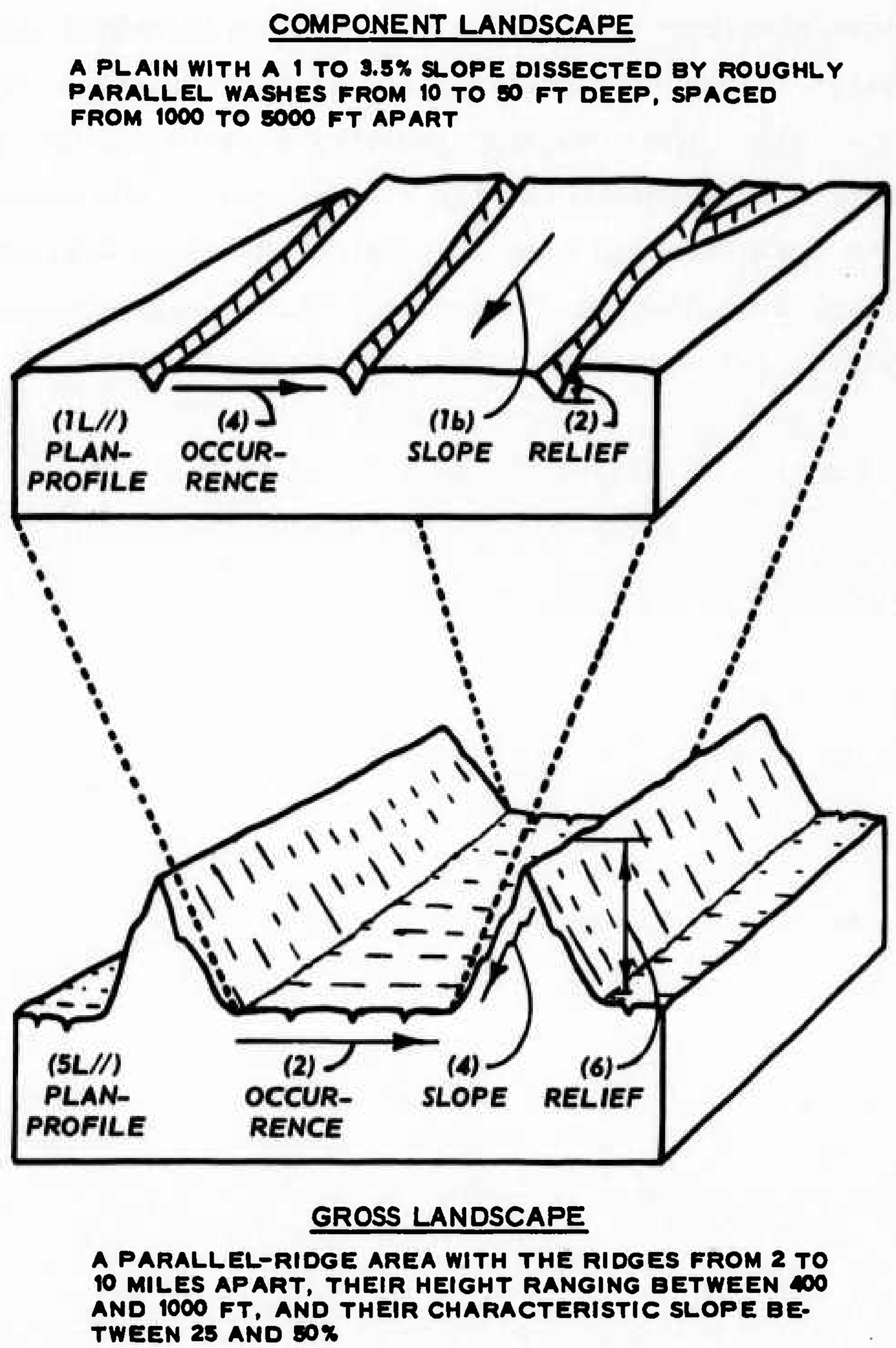

Fig. 3. Schematic relation between gross and component landscapes

interval of 10 ft, and a map scale of 1:25,000. At least two characteristic plan-profile types will be found: one for the plains and one for the ridges. The gross plan-profile is determined utilizing a 35-mile-diameter sampling circle and 1:250,000 maps with 100-ft contour intervals. Obviously, then, a gross plan-profile can be divided into a minimum of two restrictive, component types, either of which can be mapped with the gross plan-profile. Each restrictive plan-profile must exhibit relief of a lower order than the gross plan-profile if a gross type is to be mapped. This qualification explains why many areas are shown on maps with only restrictive plan-profiles; i.e., characteristic relief within a 1-mile circle falls in the same relief class as that within a 35-mile circle.

34. The remaining geometry factors simply provide additional quantitative data concerning the plan-profile. The meaning or significance of the symbolization used in mapping the gross-component complex varies somewhat, depending on the geometry factor mapped; however, the legends on plates 1-4 should provide adequate explanation.

PART IV: DEVELOPMENT OF ANALOGS

Method

35. As previously mentioned, each of the terrain-factor maps is actually an analog map. Similarly mapped areas at Yuma and within the SWUS exhibit high degrees of analogy from the standpoint of the particular terrain factor under consideration (see plates 1-9). Table 1 indicates the terrain-factor value ranges, or mapping units, that are found (a) both at Yuma and within the remainder of the SWUS, (b) at Yuma only, and (c) within the SWUS only.

36. A synthesis of terrain-factor data and maps, resulting in the establishment of varying degrees of analogy of particular SWUS areas with portions of the Yuma Test Station and Sand Hills, has been attempted in plates 10-13. This synthesis involved the preparation of (a) a geometry or form analog map, (b) a ground analog map, (c) a vegetation analog map, and (d) a terrain-type analog map.

37. The geometry analog map (plate 10) is merely a modification of the generalized landscape map (plate 5) 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 number 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 the SWUS, the area so mapped is considered to be highly analogous to the region exhibiting this landscape type at Yuma. An area in the SWUS, or any other world desert area, 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. The analog determinations are indicated in table 2. Note that gross landscapes (mapped utilizing a 35-mile-diameter sampling cell and 100-ft contours) are distinguished from component or restrictive types (mapped utilizing a 1-mile-diameter sampling cell and 10-ft contours). Gross landscapes in one area are compared only with gross landscapes in another, as is also the case with restrictive types.

38. The ground analog map (plate 11) was prepared in a manner very similar to that used in the preparation of the geometry analog map, i.e. by

superimposing the soil-type, soil-consistency, and surface-rock maps. In the Yuma area and the rest of the SWUS soil-rock units (soil units 1-3) are always found in combination with surface-rock types, and soil units 4-10 are always found in combination with soil-consistency types. Hence, ground analogs are designated by only 2 digits (or 4 digits where a complex is mapped); their determination is outlined in table 3. The vegetation analog map (plate 12) is a slight modification of the vegetation map. SWUS desert areas mapped with vegetation units found at Yuma are considered to be highly analogous to their Yuma counterparts.

39. Note 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 area 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.

40. The terrain-type analog map (plate 13) was compiled by superpositioning the factor maps and identifying individual terrain types by a series of seven numbers or number-letter symbols, each representing a value range or class of the four geometry factors (plan-profile, slope occurrence, slope, and relief), two ground factors (soil type-soil consistency, and soil type-surface rock), and vegetation. The terrain-type arrays in the SWUS were compared with the most similar terrain-type arrays at Yuma, and the mapping units or components of geometry, ground, and vegetation were assigned values ranging from 0 to 4, based upon the number of mapping units in common with Yuma. In other words, areas delineated on the terrain-type analog map were designated by three digits. The numbers indicate, in sequence, the number of identical geometry, ground, and vegetation-factor value ranges occurring in the SWUS terrain type that are also found in combination at Yuma. For example, the series 4,2,1 found in SWUS indicates that all seven terrain-factor classes characterizing an area in SWUS are found in combination at Yuma. The series 2,1,1 mapped in SWUS indicates that two of the four geometry-factor classes, one of the two ground-factor classes, and the vegetation class are found at Yuma. Totaling each series of numbers results in a value ranging from 0 to 7. This range was then

divided into five groups by degree of analogy, and the areas exhibiting these value groupings were outlined on the map. Regions where terrain-type analog values resulted in totals 6-7 were mapped as highly analogous; 4-5.5, moderately analogous; 2-3.5, slightly analogous; 0.5-1.5, inappreciably analogous; 0, not analogous (see plate 13). 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 easily through examination of the other analog maps.

41. It should be mentioned that all terrain factors were given equal importance in the analog determinations. No serious effort was made to establish a more suitable "weighting" system because of the difficulty inherent in any attempt to determine the relative importance 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 <u>within</u> specific terrain factors. For example, Yuma landscape type 4,<u>4</u>,3,5 is more analogous to landscape 4,<u>5</u>,3,5 than to 4,<u>6</u>,3,5, but in the method employed each of the world desert areas characterized by these landscapes would be given a value of 3, i.e. considered to be moderately analogous. "Weighting" systems for entire terrain factors or terrain-factor mapping units can be devised for many <u>specific</u> considerations and employed when desired.

42. It should also be noted that analog determinations in areas of complexes are based on independent consideration of specific areal or gross-component types. For example, a region mapped as an areal complex consisting of two landscape types, one highly analogous with a type at Yuma and the other slightly analogous, would be mapped as an areal complex showing each degree of analogy. Thus, in the present system, the analogy in regions of areal or gross-component complexes is based on each landscape or terrain type. Obviously, different methods could be utilized if it were desirable to recognize the analogy of the entire area.

12

43. The terrain-type analog map thus 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. Any area on the terrain-type analog map exhibiting a particular degree of analogy (high, moderate, etc.) may consist of either a single characteristic terrain type or a mosaic of several characteristic terrain types; however, each type must exhibit the same degree of analogy when compared with the most similar type or types found at Yuma. Utilizing areas in the SWUS as examples, the south central portion of the Staked Plain has been mapped as a single terrain type and the entire area is shown as highly analogous on the terrain-type analog map (plate 13). In contrast, the southeastern portion of the Staked Plain, which is mapped as moderately analogous, consists of several terrain types, each of which is moderately analogous.

44. Careful examination of the terrain-type analog map and various terrain-factor maps emphasizes some interesting points. First, areas composed of different genetically-described landforms often exhibit relatively high degrees of analogy. For example, playas and river-terrace surfaces are moderately analogous. If the classical, qualitative, and genetically-based geomorphic descriptions of such areas were employed, 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," such as volcanics or dunes, established on the basis of qualitative methods. Second, such examination 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 such as slope, relief, and soil type. Special maps showing resulting combinations and their distribution can be easily prepared. Analog maps for these special combinations can also be compiled. Only slight modification of existing maps is necessary to show the distribution on other world desert areas of Yuma terrain types, landscape types, or any desired terrain-factor combinations. Conversely, maps showing the distribution at Yuma of terrain types, landscape types, etc., common in other world desert areas can be easily prepared.

45. Table 4 and plates 10-12 provide a wealth of data that can be

utilized in (a) evaluating Yuma as a test station for specific activities or overall suitability as a testing site, and (b) locating areas within the SWUS that may be more analogous to aggregate world desert conditions than Yuma, or which, when considered with Yuma, will cover a much more representative range of desert terrain. Although table 4 deals solely with landscape types, examination of it in conjunction with plates 6-13 will indicate (a) landscape and terrain types found in other world deserts which do not occur at Yuma, (b) other areas of the SWUS that can supply the types missing at Yuma, (c) the subareas at Yuma that are representative of conditions found in other world desert areas, and (d) the subareas at Yuma that are anomalous from the standpoint of world desert conditions. It is, of course, also possible to compare the various world desert areas in terms of their landscape and terrain types, and their distribution or relative importance.

Analysis of General Applicability of Analog Technique

46. The following is a brief analysis of the techniques which have been employed in preparing analogs for this series of reports:

a. The geometry, ground, and vegetation factors selected for mapping define terrain in simple, yet reasonably complete terms.

b. In the system of mapping used, terrain factors in all world desert areas are mapped utilizing the same units. Hence, the completion of all reports in this series will afford, for the first time, a ready comparison of the terrain of all the deserts of the Northern Hemisphere.

c. Terrain factors at the Yuma Test Station have been mapped using the same units used for other world desert areas, thus permitting ready comparison of Yuma with world deserts.

d. Mapping generalizations have been areal, and the degree of refinement has varied with the scale. This implies that an area at Yuma delineated as having steep slopes, for example, may consist of 95 percent or more steep slopes, whereas in some other world desert area, steep slopes may occupy only 50 percent of the region so mapped. This is considered ideal in establishing "testing" analogs since tests within restrictively mapped units at Yuma would be representative of 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. In mapping gross geometry the 100-ft contour interval has been utilized.

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 occurrence, slope, and relief. This provides 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 geometry, ground, and vegetation factors are synthesized by superposition into a terrain-type analog map which indicates degrees of analogy or similarity of the mapped world desert areas to the Yuma Test Station. Each terrain factor has been given equal weight in this synthesis. "Weighting" systems can be devised for specific considerations.

h. It is believed that the analog techniques, with modifications and additions, will be applicable in environments other than the desert.

Problems and Recommendations for Solution

47. Three of the most serious problems in connection with the system of classification and mapping employed in this report concern: (a) the qualitativeness of the ground and vegetation factors, (b) the overly subjective methods that must be used in mapping areas for which little data are available, and (c) the difficulties involved in integrating microrelief into the present system. The following paragraphs discuss these problems and offer recommendations for steps toward their solution.

Quantitative classification of ground and vegetation factors

48. 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. A tentative system for classifying and mapping vegetation in a quantitative manner has been developed and is presently being evaluated.

49. A 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 which is 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 reemphasized that although the quantitative approach is desirable, it may still be wise to utilize semiquantitative or qualitative techniques in some cases.

Mapping techniques

50. 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; however, these instructions need refining and simplifying. Rigorous techniques should also be developed for mapping the ground and vegetation factors if a suitable quantitative classification system can be devised.

51. 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 utilized in this report. The effects of climate, lithology, and elevation on soil type; the effects of soil type and landform association on relief; and the consequences 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 were made preparatory to mapping the world deserts in the various reports of this series. An example of this work is the chart of landform-geometry factor associations in plate 19. However, much additional work is needed on methods of disciplining subjective mapping.

52. 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 pertinent 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 should be conducted to compare and graph the various quantitative geometry factors in areas covered by maps employing 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, which may be dependent upon lithology and climate.

Surface roughness (microrelief)

53. Surface roughness, or microrelief, is an important aspect of terrain geometry which was not integrated per se with the description of terrain presented in this report because it is concerned with those features of terrain geometry having relief of less than 10 ft. It is recognized that microrelief is extremely important; however, there are excellent reasons for disregarding these minor features in mapping the terrain factors previously discussed. In the first place, a reasonable lower limit had to be placed on the scale of generalization. Consideration of very minor features would have hopelessly complicated the system. Secondly, 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 of some of the world deserts considered would result in excessive subjectivity. Furthermore, areas of homogeneous microrelief, i.e. areas throughout which a single microrelief feature prevails, are normally of small extent, and thus could not be shown at the scales of one to several million used in portions of this study.

54. Major difficulties in microrelief consideration lie not only in its classification, but also in developing a reasonably objective approach to mapping this factor and in fitting it into the scheme of overall terrain analogy. A possible solution is to accept the fact that our present knowledge of the variations in microrelief is too limited for reasonably

accurate classification and mapping of this factor, and to search for a method of improving estimates of microrelief considerations in unmapped areas. At present, such estimates must be based on landform-lithologic-soils associations. The much less qualitative terrain-classification scheme represented by the geometry, ground, and vegetation factors utilized in this study consequently provides a more adequate base for detailed studies of microrelief. For example, a 1L,4,1b,2 landscape type with a unit 6 soil type, unit 10 soil consistency, and a 2-4 vegetation complex can be examined either in the field or on detailed, large-scale maps if available. It seems almost inevitable that distinctive groups of microrelief features will be associated with such distinctive terrain-factor combinations. Groups of microrelief types could be cataloged as characteristic of various terrain-factor combinations and used as a basis of analogy. Determination of these associated microrelief types would, of course, involve a detailed and long-range mapping program. Short of this, the existence or lack of terrain types (specific combinations of geometry, 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 terrain-type analog map (plate 13) automatically considers this relation. For these reasons no attempt was made in the present study either to map microrelief or to determine its effect on the terrain-type analog map. It is believed that synthesis of the ground, geometry, and vegetation factors determines the effect of microrelief on overall terrain analogy as well as it can presently be determined.

55. While the above-mentioned terrain type-microrelief association seems adequate to indicate the presence, lack, and distribution of microrelief types at Yuma and in world deserts, it is certainly not adequate for determining the effect of microrelief on various military activities or materiel in tests at Yuma. A quantitative system of classifying, mapping, and comparing microrelief is needed in this case, and studies are presently (1963) being conducted in this vein.

PART V: SOURCES OF INFORMATION

56. An annotated bibliography of approximately 500 references pertinent to the SWUS was compiled during this study. The references varied from general reviews concerning the entire study area to detailed descriptions of specific localities. The references also varied as to their adaptability to the type of mapping employed in this report. In many instances, detailed information on specific areas had to be generalized for compatibility with the employed mapping scale and techniques. Although no field work was conducted, mapping was done by personnel having field experience in many parts of the study area.

57. Almost complete coverage of the area was available from the Army Map Service's V502 series maps at a scale of 1:250,000. When these maps were not available, U. S. Air Force Section Aeronautical Charts at a scale of 1:500,000 were substituted. These maps were used as a base in preparing the terrain-factor maps. Maps published by the U. S. Department of Agriculture were extremely useful in determining the basic soil types and soil consistencies. These maps included the Soils Map of the United States compiled by the Soil Survey, and detailed reconnaissance soil surveys of counties or regions compiled by the Soil Conservation Service in cooperation with various state agricultural experiment stations. Geologic maps of specific areas, state geological maps, and the Geological Map of the United States published by the U. S. Geological Survey were utilized in mapping rock types. The vegetation map was compiled from reports and maps published by several agencies. The hypsometric map of Yuma was adapted from U. S. Strategic Charts at a scale of 1:500,000, and USAF World Aeronautical Charts at a scale of 1:1,000,000 were used in preparing the map of the SWUS. Most of the physiographic photographs were obtained from the Photo Library of the U. S. Geological Survey, Denver, Colorado.

58. The principal sources of information concerning the Yuma Test Station were: a report, <u>Terrain Study of the Yuma Test Station Area, Arizona,</u> prepared for WES by a group from Purdue University in March, 1955; <u>Handbook of Yuma Environment,</u> published by Office, Quartermaster General, in February 1953 (Report No. 200); and <u>A Study of Desert Surface</u>

<u>Conditions,</u> by Thomas Clements and others, published by Quartermaster Research and Development Command in April 1957 (Technical Report EP-53).

Table 1

Distribution of Terrain Factor Mapping Units

Geometry-Factor Units	Restrictive or Component Units Occurring in: SWUS Only	Yuma Only	Both Areas	Gross Units Occurring in: SWUS Only	Yuma Only	Both Areas
Plan-profile	1,2,3,6	---	1L,4,4L,7	1,2,3,5,6	5L//,6L	---
Slope occurrence	2,3	---	1,4,5,6	2,3	---	1
Slope	---	---	1a,1b,2,3,4,5	4,6	3	5
Relief	3	---	1,2,4,5,6,7	6	7	5

Ground-Factor Units	Restrictive Units Occurring in: SWUS Only	Yuma Only	Both Areas
Soil type	2,3,7,9,10	---	1,4,5,6,8
Soil consistency	5,6,8,11	---	1,3,4,9,10
Surface rock	1*,3*,6*,7*,8*,9	---	2,3a,3b,4,5*
Vegetation	1,4a,6,7	---	2,3,4,5,5a,5b,9,10

* At Yuma surface rock unit 5 (sedimentaries undifferentiated) includes units 6,7,8 (sandstone, limestone, and shale, respectively), and in the SWUS unit 1 (igneous undifferentiated) includes units 2,3a,3b (intrusives, true extrusives, and rocks formed by secondary cementation of loose deposits of volcanic ejecta, respectively).

Table 2

Landscapes Found at Yuma and in Southwest United States Desert

Analogy Determination

SWUS Landscape Array*	Yuma Landscape Array	Degree of Analogy
Restrictive or Component Landscapes		
1,3,1b,2		Slightly
1L,3,1b,2		Moderately
1,3,1b,3		Slightly
1,4,1b,2		Moderately
1L,4,1b,2	1L,4,1b,2	Highly
2,2,1b,3		Slightly
3,2,1b,3		Slightly
6,2,1b,2		Slightly
1,2,2,3		Slightly
1,3,2,2		Slightly
1,3,2,3	1L,4,2,2	Slightly
1,4,2,2		Moderately
1L,4,2,2		Highly
1,5,2,2		Slightly
4L//,4,3,5	4L//,4,3,5	Highly
4,5,3,4	4,5,3,4	Highly
4,4,3,4		Moderately
4,5,3,5	4,5,3,5	Highly
4,4,4,5**	4,5,4,5	Moderately
4L//,5,4,5		Moderately
4L,5,4,5		Moderately
4,5,5,5	4,5,5,5	Highly
4,5,5,6		Highly
4L,5,5,6	4,5,5,6	Moderately
4,3,5,6**		Moderately
4,6,3,5	4,6,3,5	Highly
4,6,4,5	4,6,4,5	Highly

SWUS Landscape Array*	Yuma Landscape Array	Degree of Analogy
Restrictive or Component Landscapes (Cont'd)		
4,6,5,5	4,6,5,5	Highly
4,6,5,6		Highly
4L//,6,5,6	4,6,5,6	Moderately
4,6,5,7	4,6,5,7	Highly
4L,6,5,7	4L,6,5,7	Highly
7,1,1a,1		Highly
7,1,2,1**	7,1,1a,1	Moderately
7,2,1a,2		Slightly
7,1,1b,1		Highly
7,2,1b,1	7,1,1b,1	Moderately
7,2,1b,2**		Slightly
Gross Landscapes		
1,2,5,5**		Slightly
1,3,5,5**		Slightly
1,3,5,6	5L//,1,5,7	Slightly
1,3,6,6		Not
2,2,5,6		Slightly
2,2,5,5		Slightly
2,2,4,5		Slightly
3,1,5,5**		Slightly
3,2,5,5**	6L,1,3,5	Slightly
5,2,4,5		Slightly
5,2,5,5**		Slightly
6,2,4,5		Slightly
6,2,4,6		Not

* Lightface type indicates the 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 lightface or boldface units to indicate the maximum degree of analogy. In such instances units are compared in the order given in the array, e.g. the SWUS array 4,3,5,6 was compared with the Yuma array 4,5,5,6 rather than 4,6,5,6.

Table 3

Ground-Factor Arrays* Found at Yuma and in Southwest United States Desert

Analogy Determinations

SWUS Ground-Factor Arrays**	Yuma Ground-Factor Arrays	Degree of Analogy
1,1†		Highly
1,2		Highly
2,1†	1,2	Partially
2,2		Partially
3,2		Partially
1,3†		Highly
1,3a		Highly
2,3	1,3a	Partially
2,3a		Partially
3,3		Partially
3,3a		Partially
1,3b		Highly
2,3b	1,3b	Partially
3,3b		Partially
1,4	1,4	Highly
2,4		Partially
1,5		Highly
1,6†		Highly
1,7†		Highly
1,8†		Highly
2,5		Partially
2,6		Partially
2,7		Partially
2,8	1,5	Partially
3,5		Partially
3,6		Partially
3,7		Partially
3,8		Partially
3,9		Not

SWUS Ground-Factor Arrays**	Yuma Ground-Factor Arrays	Degree of Analogy
4,1		Highly
4,2		Partially
4,10††	4,1	Partially
4,11		Partially
4,9	4,9	Highly
5,1		Highly
5,8	5,1	Partially
5,10		Partially
6,10		Highly
6,11	6,10	Partially
7,10		Partially
7,11		Not
8,3		Highly
9,3	8,3	Partially
10,3		Partially
7,4		Partially
8,4		Highly
8,5	8,4	Partially
9,5		Not
10,5		Not
10,6		Not
8,10	8,10	Highly

* Ground-factor arrays are two symbols indicating mapping units. Soil-rock units (soil units 1,2,3) are always found in combination with surface-rock types, and soil units 4,5,6,7,8,9,10 are always found in combination with soil-consistency types.

** Lightface type indicates the 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.

† At Yuma surface rock unit 5 (sedimentaries undifferentiated) includes units 6,7,8 (sandstone, limestone, and shale, respectively), and in the SWUS unit 1 (igneous undifferentiated) includes units 2,3a,3b (intrusives, true extrusives, and rocks formed by secondary cementation of loose deposits of volcanic ejecta, respectively); therefore, where these units are mapped in SWUS, they are designated by lightface symbols.

†† In a particular array it may be possible to choose different sets of lightface or boldface units to indicate the maximum degree of analogy. In such instances units are compared in the order given in the array; e.g. the SWUS array 4,10 was compared with the Yuma array 4,1 rather than 6,10.

Table 4

Distribution of Landscape Types Within World Desert Areas

Landscape Description — Areal Importance: Percent and Actual Area Occupied by Landscape Type or Array

Plan-Profile (See Plate 1)	Slope Occurrence (See Plate 2) Per 10 miles						Characteristic Slope (See Plate 3) deg							Characteristic Relief (See Plate 4) Type I ft			Characteristic Relief (See Plate 4) Type II ft				Array	Yuma Area 2,080 sq mi		Southwest United States Area 360,000 sq mi		Middle East Area 1,390,000 sq mi		Mexico Area 144,500 sq mi		Northeast Africa Area 1,916,600 sq mi		Northwest Africa Area 2,013,000 sq mi		South Central Asia Area 784,000 sq mi		% Mapped World Desert Area Area 6,608,100 sq mi
	< 1	1 to 5	5 to 20	20 to 100	100 to 200	> 200	0 to 1/2	1/2 to 2	2 to 6	6 to 14	14 to 26-1/2	26-1/2 to 45	> 45	0 to 10	10 to 50	> 50	0 to 100	100 to 400	400 to 1000	> 1000		%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	
Topographic Highs are Flat-Topped; Occupy > 60% of Area; Nonlinear and Random	x											x						x			1,1,5,5*											0.28	5,636			0.085
		x						x							x						1,2,1b,2											0.07	1,409			0.021
		x						x								x					1,2,1b,3											0.11	2,214			0.034
		x							x							x					1,2,2,3			0.05	180											0.003
		x										x						x			1,2,5,5*			1.24	4,464					3.67	70,317	6.27	126,215			3.040
		x										x							x		1,2,5,6*							0.76	1,098							0.017
		x											x					x			1,2,6,5*									0.10	1,916	0.32	6,442			0.127
			x				x								x						1,3,1a,2											0.28	5,636			0.084
			x					x							x						1,3,1b,2			4.06	16,552	4.07	56,573			0.46	8,614	8.64	173,923	16.64	130,529	5.850
			x					x								x					1,3,1b,3			0.14	504							0.03	604	0.35	2,747	0.058
			x						x						x						1,3,2,2			1.03	3,708	5.29	73,531			3.07	58,821	2.09	42,072	3.43	3,375	2.745
			x						x							x					1,3,2,3			0.06	216									0.95	7,457	0.116
			x									x						x			1,3,5,5*			0.54	1,944	1.74	24,186			0.54	10,346	3.16	63,611			1.510
			x									x						x			1,3,6,5*			0.03	108							4.43	89,176			1.344
			x										x						x		1,3,6,6*			0.04	144							1.17	23,552			0.359
			x										x							x	1,3,6,7*									0.03	575					0.009
				x									x		x						1,4,1b,2			8.68	31,248	0.60	8,340			0.06	1,150	0.40	8,052	0.16	1,256	0.756
				x				x							x						1,4,2,2			1.58	5,688	1.06	14,734	0.85	1,228	2.97	56,905	0.09	1,812	0.46	3,611	1.270
				x					x							x					1,4,2,3									0.10	1,916					0.029
				x					x									x			1,4,5,5*									5.35	102,506	2.09	42,072			2.180
				x								x							x		1,4,5,6*											2.10	42,273			0.640
				x								x						x			1,4,6,5*									3.02	57,863	1.59	32,007			1.360
				x									x						x		1,4,6,6*					0.14	1,946			0.35	6,706					0.131
					x								x		x						1,5,2,2			0.26	936											0.014
Linear and Random		x						x							x						1L,2,1b,2							14.25	20,591							0.311
		x										x						x			1L,2,5,5*					1.20	16,680									0.252
			x					x							x						1L,3,1b,2			0.18	648	3.95	54,905	3.94	5,693	0.41	7,856	1.30	26,169	0.16	1,256	1.460
			x						x						x						1L,3,2,2					1.07	14,873	0.14	202			0.12	2,416	0.09	706	0.275
			x						x							x					1L,3,2,3							3.98	5,751							0.087
			x									x						x			1L,3,5,5*									0.05	958					0.015
				x				x							x						1L,4,1b,2	29.3	609	2.09	7,524	1.04	14,483	19.1	27,600	0.12	2,299	0.23	4,630	0.93	7,300	0.960
				x					x						x						1L,4,2,2	3.1	64	27.60	99,360	1.73	24,047			1.22	23,375	0.17	3,422	11.40	89,400	3.630
				x					x							x					1L,4,2,3					0.57	7,923									0.120
				x								x						x			1L,4,5,5*					2.84	39,476									0.598
				x								x							x		1L,4,5,6*									0.32	6,131					0.093
				x									x					x			1L,4,6,5*									0.55	10,538	1.35	27,176			0.570
				x									x						x		1L,4,6,6*					5.39	74,921									1.134

(Continued)

* Gross.

(1 of 6 sheets)

Table 4 (Continued)

Landscape Description																								Areal Importance: Percent and Actual Area Occupied by Landscape Type or Array															
Plan-Profile (See Plate 1)			Slope Occurrence (See Plate 2) Per 10 miles						Characteristic Slope (See Plate 3) deg							Characteristic Relief (See Plate 4) Type I ft			Characteristic Relief (See Plate 4) Type II ft				Array	Yuma Area 2,080 sq mi		Southwest United States Area 360,000 sq mi		Middle East Area 1,390,000 sq mi		Mexico Area 144,500 sq mi		Northeast Africa Area 1,916,600 sq mi		Northwest Africa Area 2,013,000 sq mi		South Central Asia Area 784,000 sq mi		% Mapped World Desert Area Area 6,608,100 sq mi
			< 1	1 to 5	5 to 20	20 to 100	100 to 200	> 200	0 to 1/2	1/2 to 2	2 to 6	6 to 14	14 to 26-1/2	26-1/2 to 45	> 45	0 to 10	10 to 50	> 50	0 to 100	100 to 400	400 to 1000	> 1000		%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	
Topographic Highs Are Flat-Topped	Occupy 40 to 60% of Area	Nonlinear and Random		x						x								x					2,2,1b,3			0.01	36											0.001
				x									x							x			2,2,4,5*			0.04	142	0.24	3,336									0.053
				x										x						x			2,2,5,5*			0.04	142	0.14	1,946					0.54	10,870			0.196
				x										x							x		2,2,5,6*			0.05	180											0.003
					x								x							x			2,3,4,5*					1.43	19,877									0.300
					x									x						x			2,3,5,5*					0.08	1,112			2.85	54,606	0.18	3,623			0.896
		Linear and Parallel			x								x							x			2L//,3,4,5*					0.32	4,448									0.067
	Occupy < 40% of Area	Nonlinear and Random	x											x						x			3,1,5,5*			0.39	1,404			3.11	4,495							0.089
				x						x								x					3,2,1b,3			0.01	36											0.001
				x									x							x			3,2,4,5*					1.18	16,402									0.248
				x										x						x			3,2,5,5*			1.40	5,040					0.11	2,108	1.24	24,961			0.482
				x											x					x			3,2,6,5*											0.18	3,623			0.055
					x						x							x					3,3,2,3					0.11	1,529									0.023
		Linear and Random		x										x							x		3L,2,5,6*											0.05	1,007			0.015

(Continued)

* Gross.

(2 of 6 sheets)

Table 4 (Continued)

Landscape Description

Plan-Profile (See Plate 1)			Slope Occurrence (See Plate 2) Per 10 miles: < 1	1 to 5	5 to 20	20 to 100	100 to 200	> 200	Characteristic Slope (See Plate 3) deg: 0 to 1/2	1/2 to 2	2 to 6	6 to 14	14 to 26-1/2	26-1/2 to 45	> 45	Characteristic Relief (See Plate 4) Type I ft: 0 to 10	10 to 50	> 50	Type II ft: 0 to 100	100 to 400	400 to 1000	> 1000	Array
Topographic Highs are Peaked or Crested	Occupy > 60% of Area	Nonlinear and Random			x							x							x				4,3,3,4
					x							x								x			4,3,3,5
					x								x						x				4,3,4,4
					x								x							x			4,3,4,5
					x								x								x		4,3,4,6
					x									x							x		4,3,5,6
						x						x							x				4,4,3,4
						x						x								x			4,4,3,5
						x							x							x			4,4,4,5
						x								x						x			4,4,5,5
							x					x							x				4,5,3,4
							x					x								x			4,5,3,5
							x						x							x			4,5,4,5
							x							x						x			4,5,5,5
							x							x							x		4,5,5,6
								x				x								x			4,6,3,5
								x					x							x			4,6,4,5
								x						x						x			4,6,5,5
								x						x							x		4,6,5,6
								x						x								x	4,6,5,7
		Linear and Random			x							x							x				4L,3,3,4
					x							x								x			4L,3,3,5
						x						x							x				4L,4,3,4
						x						x								x			4L,4,3,5
						x							x							x			4L,4,4,5
						x								x					x				4L,4,5,4
							x						x							x			4L,5,4,5
							x						x								x		4L,5,4,6
							x							x						x			4L,5,5,5
							x							x							x		4L,5,5,6
								x						x						x			4L,6,5,5
								x						x							x		4L,6,5,6
								x						x								x	4L,6,5,7

Areal Importance: Percent and Actual Area Occupied by Landscape Type or Array

Array	Yuma Area 2,080 sq mi %	Yuma Actual	Southwest United States Area 360,000 sq mi %	Southwest United States Actual	Middle East Area 1,390,000 sq mi %	Middle East Actual	Mexico Area 144,500 sq mi %	Mexico Actual	Northeast Africa Area 1,916,600 sq mi %	Northeast Africa Actual	Northwest Africa Area 2,013,000 sq mi %	Northwest Africa Actual	South Central Asia Area 784,000 sq mi %	South Central Asia Actual	% Mapped World Desert Area Area 6,608,100 sq mi
4,3,3,4											0.10	2,013			0.030
4,3,3,5									0.09	1,724	1.39	27,981			0.450
4,3,4,4											0.01	201			0.003
4,3,4,5											0.07	1,409			0.021
4,3,4,6							0.03	43							0.001
4,3,5,6			0.01	36											0.001
4,4,3,4			0.35	1,260	0.92	12,788			0.01	192	0.11	2,214			0.249
4,4,3,5					2.77	38,503			0.96	18,394	1.35	27,176	0.31	2,433	1.310
4,4,4,5			0.01	36	0.13	1,807	3.64	5,260	0.85	16,286	0.05	1,007			0.369
4,4,5,5									0.03	575					0.009
4,5,3,4	3.41	71	0.10	360	0.39	5,421	0.01	14	0.02	383	0.02	403			0.101
4,5,3,5	11.10	230	0.45	1,620	0.63	8,757			0.24	4,598	0.29	5,838			0.032
4,5,4,5	2.70	56	2.85	10,260	1.69	23,491	0.77	1,113	4.36	83,538	1.30	26,169	2.38	18,681	2.470
4,5,5,5	0.02	.4	0.78	2,808	1.17	16,263	6.45	9,320	0.15	2,874	0.07	1,409	0.92	7,221	0.604
4,5,5,6	0.9	20	0.58	2,088			15.80	22,831	0.02	383	0.60	12,078	0.20	1,568	0.059
4,6,3,5	0.7	15	0.04	142											0.002
4,6,4,5	8.1	168	0.63	2,268	0.02	278			0.18	3,449	0.53	10,669	0.57	4,474	0.322
4,6,5,5	0.09	2	3.30	11,880	1.39	19,321			0.06	1,150	0.77	15,500	5.19	40,736	1.340
4,6,5,6	17.4	362	11.80	42,400	1.78	24,742	10.00	14,450	1.86	35,638	2.58	51,935	9.93	77,862	3.740
4,6,5,7	0.14	3	0.25	900	6.33	87,987	0.18	260	1.76	33,722	0.61	12,279	3.27	25,666	2.440
4L,3,3,4											0.41	8,253			0.125
4L,3,3,5											2.90	58,377			0.884
4L,4,3,4					0.05	695									0.011
4L,4,3,5									0.28	5,365	0.31	6,240			0.176
4L,4,4,5					0.02	278									0.004
4L,4,5,4											0.58	11,675			0.176
4L,5,4,5			0.02	72	1.08	15,012			0.04	767					0.240
4L,5,4,6					0.02	278									0.004
4L,5,5,5					0.35	4,865					0.06	1,208	0.29	2,276	0.126
4L,5,5,6			0.09	324	0.91	12,649					0.05	1,007			0.212
4L,6,5,5											0.05	1,007			0.015
4L,6,5,6											0.11	2,214			0.033
4L,6,5,7	0.09	2	0.03	108			1.20	1,734	0.27	5,173					0.106

(Continued)

Table 4 (Continued)

Plan-Profile (See Plate 1)			Landscape Description: Slope Occurrence (See Plate 2) Per 10 miles						Characteristic Slope (See Plate 3) deg							Characteristic Relief (See Plate 4) Type I ft			Type II ft				Array	Areal Importance: Percent and Actual Area Occupied by Landscape Type or Array — Yuma Area 2,080 sq mi		Southwest United States Area 360,000 sq mi		Middle East Area 1,390,000 sq mi		Mexico Area 144,500 sq mi		Northeast Africa Area 1,916,600 sq mi		Northwest Africa Area 2,013,000 sq mi		South Central Asia Area 784,000 sq mi		% Mapped World Desert Area Area 6,608,100 sq mi
			< 1	1 to 5	5 to 20	20 to 100	100 to 200	> 200	0 to 1/2	1/2 to 2	2 to 6	6 to 14	14 to 26-1/2	26-1/2 to 45	> 45	0 to 10	10 to 50	> 50	0 to 100	100 to 400	400 to 1000	> 1000		%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%	Actual	
Topographic Highs are Peaked or Crested	Occupy 40 to 60% of Area	Linear and Parallel	x											x								x	5L//,1,5,7*	93.12	1937													
					x							x								x			5L//,3,3,5*									6.17	118,217	3.82	76,897			2.954
						x						x								x			5L//,4,3,5*					2.67	37,113			8.56	164,010	0.06	1,208	4.25	33,358	3.560
						x							x							x			5L//,4,5,5													0.17	1,334	0.020
	Occupy < 40% of Area	Nonlinear and Random	x									x								x			6,1,3,5*											0.21	4,227			0.064
				x						x							x						6,2,1b,2			0.01	36							1.07	21,539			0.327
				x								x							x				6,2,3,4*							2.11	3049					1.18	9,261	0.186
				x								x								x			6,2,3,5*							2.14	3092	1.83	35,063	0.74	14,896			0.803
				x									x							x			6,2,4,5*			8.70	31,320							1.60	32,208			0.961
				x									x								x		6,2,4,6*			0.36	1,296							0.07	1,409			0.041
					x						x							x					6,3,2,3					0.03	417									0.006
					x							x							x				6,3,3,4													0.66	5,180	0.079
					x							x								x			6,3,3,5*					0.11	1,529			0.74	14,178	0.64	12,883			0.443
					x									x						x			6,3,5,5*					3.75	52,125									0.789
						x					x						x						6,4,2,2					0.02	278									0.004
		Linear and Random	x									x								x			6L,1,3,5*	6.87	143													0.002
				x								x								x			6L,2,3,5*											3.29	66,228			1.002
					x						x						x						6L,3,2,2			0.27	973											0.015
					x						x							x					6L,3,2,3			0.05	2,085											0.032
					x							x								x			6L,3,3,5*			0.28	10,147					0.66	12,646	0.09	1,812	4.11	32,259	0.860

* Gross.

(Continued)

Table 4 (Continued)

Plan-Profile (See Plate 1)	Slope Occurrence (See Plate 2) Per 10 miles: < 1	1 to 5	5 to 20	20 to 100	100 to 200	> 200	Characteristic Slope (See Plate 3) deg: 0 to 1/2	1/2 to 2	2 to 6	6 to 14	14 to 26-1/2	26-1/2 to 45	> 45	Characteristic Relief (See Plate 4) Type I ft: 0 to 10	10 to 50	> 50	Type II ft: 0 to 100	100 to 400	400 to 1000	> 1000	Array	Yuma Area 2,080 sq mi: %	Actual	Southwest United States Area 360,000 sq mi: %	Actual	Middle East Area 1,390,000 sq mi: %	Actual	Mexico Area 144,500 sq mi: %	Actual	Northeast Africa Area 1,916,600 sq mi: %	Actual	Northwest Africa Area 2,013,000 sq mi: %	Actual	South Central Asia Area 784,000 sq mi: %	Actual	% Mapped World Desert Area Area 6,608,100 sq mi
Topographic Highs are Peaked or Crested; Occupy > 60% of Area; Parallel					x					x								x			4//,5,3,4					0.07	973									0.015
					x						x							x			4//,5,4,5									0.02	383					0.006
Linear and Parallel			x							x								x			4L//,3,3,5											0.09	1,812			0.027
				x						x								x			4L//,4,3,5	3.51	73	0.05	180							0.64	12,883			0.198
				x						x								x			4L//,4,3,5*									0.06	1,150					0.017
				x							x							x			4L//,4,4,5											0.03	604			0.009
					x					x							x				4L//,5,3,4					0.06	834									0.013
					x						x							x			4L//,5,4,5			0.03	108							0.17	3,422			0.054
					x							x							x		4L//,5,5,6							2.00	2890							0.044
						x						x							x		4L//,6,5,6			0.02	72									8.52	66,874	1.010
						x						x								x	4L//,6,5,7					0.17	2363							0.77	6,044	0.127
Occupy 40 to 60% of Area; Nonlinear and Random		x									x							x			5,2,4,5*			0.04	142											0.002
		x										x						x			5,2,5,5*			1.48	5,328											0.081
			x							x							x				5,3,3,4					0.09	1251									0.019
			x							x								x			5,3,3,5*									0.14	2,682					0.039
			x									x						x			5,3,5,5*									0.05	958					0.015
				x					x							x					5,4,2,3					0.58	8062									0.122
				x						x								x			5,4,3,5*					0.07	973			0.26	4,982					0.090
				x								x						x			5,4,5,5*									0.71	13,604					0.206
Linear and Random				x						x								x			5L,4,3,5*					0.39	5421									0.082

* Gross.

(Continued)

Table 4 (Concluded)

Landscape Description

Plan-Profile (See Plate 1)	Slope Occurrence (See Plate 2) Per 10 miles: < 1	1 to 5	5 to 20	20 to 100	100 to 200	> 200	Characteristic Slope (See Plate 3) deg: 0 to 1/2	1/2 to 2	2 to 6	6 to 14	14 to 26-1/2	26-1/2 to 45	> 45	Characteristic Relief (See Plate 4) Type I ft: 0 to 10	10 to 50	> 50	Type II ft: 0 to 100	100 to 400	400 to 1000	> 1000	Array
Topographic Highs are Peaked or Crested; Occupy < 40% of Area; Linear and Parallel		x								x								x			6L//,2,3,5*
			x							x								x			6L//,3,3,5*
No Pronounced Highs or Lows	x						x							x							7,1,1a,1
	x						x								x						7,1,1a,2
	x							x						x							7,1,1b,1
	x							x							x						7,1,1b,2
	x								x					x							7,1,2,1
	x								x						x						7,1,2,2
		x					x								x						7,2,1a,2
		x						x						x							7,2,1b,1
		x						x							x						7,2,1b,2
		x							x						x						7,2,2,2
			x					x							x						7,3,1b,2
			x						x						x						7,3,2,2

Areal Importance: Percent and Actual Area Occupied by Landscape Type or Array

Array	Yuma Area 2,080 sq mi %	Actual	Southwest United States Area 360,000 sq mi %	Actual	Middle East Area 1,390,000 sq mi %	Actual	Mexico Area 144,500 sq mi %	Actual	Northeast Africa Area 1,916,600 sq mi %	Actual	Northwest Africa Area 2,013,000 sq mi %	Actual	South Central Asia Area 784,000 sq mi %	Actual	% Mapped World Desert Area Area 6,608,100 sq mi
6L//,2,3,5*					0.52	7,228			1.80	34,488	2.63	52,942			1.432
6L//,3,3,5*					12.81	178,059					6.28	126,416	2.13	16,718	4.861
7,1,1a,1	8.1	168	22.98	82,728	7.23	100,497	6.95	10,043	4.85	92,926	11.62	233,911	14.89	116,793	9.626
7,1,1a,2									0.01	192	3.14	63,208			0.960
7,1,1b,1	12.2	254	6.17	22,212	17.07	237,273	9.28	13,410	15.42	295,447	7.13	143,527	13.49	105,805	12.900
7,1,1b,2					1.99	27,661			34.74	665,810	20.00	402,600	0.03	236	15.045
7,1,2,1			0.01	36	2.34	32,526			0.04	766					0.047
7,1,2,2					8.37	116,370			3.05	58,438	0.01	201	0.04	314	2.654
7,2,1a,2			0.13	468											0.007
7,2,1b,1			0.01	36	2.13	29,607									0.448
7,2,1b,2			0.10	360	4.14	57,546			4.64	88,902	16.18	325,703	3.16	24,803	7.530
7,2,2,2					2.97	41,283			5.87	112,469	0.51	10,266			2.480
7,3,1b,2					2.05	28,495			0.77	14,753					0.654
7,3,2,2					1.38	19,182			0.36	6,898					0.395

* Gross.

APPENDIX A: THE PROBLEM OF TERRAIN COMPARISON

1. The following comments on the philosophy, purpose, and problems associated with terrain analysis and comparison are based, to a considerable extent, on material included in Technical Report 3-506.

Quantitative Versus Qualitative Approach

2. Terrain studies and classifications may be either qualitative or quantitative. The qualitative, or classical, approach to geomorphic description consists primarily of written descriptions of terrain and landforms dealing extensively with the genesis of 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. Such terrain description can be vivid and penetrating, conveying to the reader a clear mental image of the landscape. Alternatively, depending on the skills or backgrounds of both the analyst and reader, it can be poor and misleading. In any case, it is patently unsuited for objectively comparing one landscape with another and developing terrain analogs.

3. As previously mentioned, terrain may be considered to be the aggregate of the physical characteristics of the land. A quantitative terrain description is simply one that uses numerical values rather than words to define terrain or its component factors. It is usually less vivid than the qualitative approach, but has obvious advantages in its objectivity and in the fact that terrain factors and their subdivisions can be rigorously defined. A more subtle but even greater advantage is that terrain factors which are stratified in a quantitative manner may be 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 lengtns 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 systems have evolved from studies aimed at determining (a) terrain effects in specific fields such as hydrology and agriculture, and (b) a method for describing a single terrain factor such

as slope or relief. As a result, quantitatively expressed factors useful in presenting an aggregate or entire picture of terrain have not been explored to any great extent. It should also be pointed out that qualitative terms are usually expressions of a group of factors that could be expressed in a more quantitative and precise manner; however, precision is usually gained at the price of simplicity. While the quantitative approach is not propounded as a magic cure-all, and while admittedly it may be wise, or necessary, to utilize qualitative techniques in many cases, quantitative methods must be favored in objective terrain classification and effect investigations.

4. The techniques on which the SWUS desert study was based follow a middle course between the qualitative and quantitative approaches. It was recognized that a quantitative approach was ideally suited for terrain analog or comparison purposes, and every attempt was made to quantify. Where attempts at quantifying terrain factors resulted in overcomplexity, however, a qualitative system was employed. Soils, for example, are expressed in standard qualitative terms, i.e. silt, clay, sand, etc., rather than in quantitative terms such as median grain diameter, cohesive strength, etc. It was also apparent that the quantitative approach had heretofore been applied to small homogeneous areas for which large amounts of terrain data were available or obtainable. The scarcity of such data for larger areas precluded the utilization of strictly quantitative systems for describing and mapping various terrain factors. Consequently, a middle course between the quantitative and qualitative approaches was the only one consistent with the goal of determining, with available data, the suitability of the Yuma area as a desert test site.

Terrain Factors Versus Terrain Effects

5. Terrain factors and terrain effects were considered for utilization as a base in establishing a uniform system of describing, classifying, mapping, and comparing terrain. One system would involve the mapping of ranges of selected terrain factors, such as slope, relief, soils, etc., and comparing areas so mapped. The other system would involve the describing and mapping of areas in terms of the effect of terrain factors on such

military considerations as cross-country movement, firepower, earth construction, radio communications, and cover and concealment.

6. Preliminary studies convincingly showed that comparison of terrain based on its effects on military activities is impractical except for specific usage. Entirely different terrain types, or associations of terrain factors may have the same total impact on a particular military activity. Conversely, the same terrain type will have different effects on different military activities. Thus, before classifying terrain in terms of "go" or "no go" for trafficability considerations, "good," "fair," or "poor" for chances of survival, etc., an orderly classification of basic terrain elements or factors which create these conditions should be made. Analyzing and recombining data incorporated in such effect classifications for actual terrain comparison would be a hopeless task. It follows that tests aimed at determining terrain effects should be conducted in areas where quantitative measurements are available for basic factors comprising the terrain. Empirical determinations of the impact of a qualitatively or subjectively described terrain type on a particular activity do not provide data that can be objectively transferred or utilized in other regions.

7. A somewhat intermediate approach to terrain evaluation would be to map and compare values of terrain factors that are critical to specific military considerations. However, it soon becomes apparent that no system of classification can hope to satisfy the requirements of all military activities. Several considerations that militate against the scheme of classifying and comparing areas in terms of critical values of various terrain factors 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.

8. It was therefore concluded that a system should be developed for classifying basic terrain factors or elements so that areas could be mapped and compared in common terms. Although available data on the military significance of terrain are an important consideration, they have not been unduly emphasized in the system developed for classifying, mapping, and comparing terrain factors. This approach is consistent with the immediate purpose of furnishing responsible agencies involved in testing with factual evidence on whether terrain conditions at the Yuma Test Station are widespread or limited throughout world deserts, and whether significant terrain types found in other world deserts are present or lacking at Yuma.

Scales and Problems of Generalization

9. Cartographic problems, availability of data, and other considerations demand that information on large-scale maps be generalized in order that it can be shown on small-scale maps. The existence and need for such generalization in mapping are well known and universally accepted. Note, for example, the degree of generalization in the map showing characteristic slopes of the SWUS and the Yuma Test Station (plate 3). The former map is at a scale of 1:2,500,000, and the latter at a scale of about 1:400,000. The Castle Dome Mountains mapped at a scale of 1:400,000 contain areas of "gentle," "moderate," "declivitous," and "steep" characteristic slopes with "steep" slopes predominating. At a scale of 1:2,500,000 these mountains can be shown as having only "steep" characteristic slopes.

10. Generalization of the Yuma and world desert maps incorporated in this and other reports primarily reflects a variation in the spatial distribution or density pattern of established area units which have been defined in terms of narrow ranges of specific properties. By definition, the system dictates that if an area at Yuma exhibits a certain combination of terrain factors, more than 50 percent of a similarly mapped tract in a world desert area will also possess this combination of factors. Areas mapped as silty soil at Yuma and in world deserts are characterized by an areal predominance of silty soils, but because of the scale difference 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 90 percent, and in world deserts, only 70 percent. In other words, the degree of generalization employed in mapping Yuma is considerably less than that used in mapping world deserts.

11. In this connection, it should be emphasized that since the objective is to determine the suitability of Yuma as a test station, more detailed mapping of the Yuma area is required than of the world deserts 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, terrain-factor mapping in the world deserts can justifiably be areally generalized, as this will indicate the most characteristic or modal condition existing within the area being mapped. Consequently, a vehicle tested at Yuma on a certain soil of a certain consistency on a certain slope is being tested against a similar combination of terrain factors that is characteristically or areally predominant in a region so mapped in a particular world desert.

12. In summary, an attempt has been made to establish a more descriptive, useful, and simple system of developing terrain analogs which will be consistent with the paucity of data concerning the vast areas being mapped. In this system of terrain comparison, 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 believed 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 also believed that as this knowledge expands the developed analog system will be flexible enough to accommodate additional data.

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