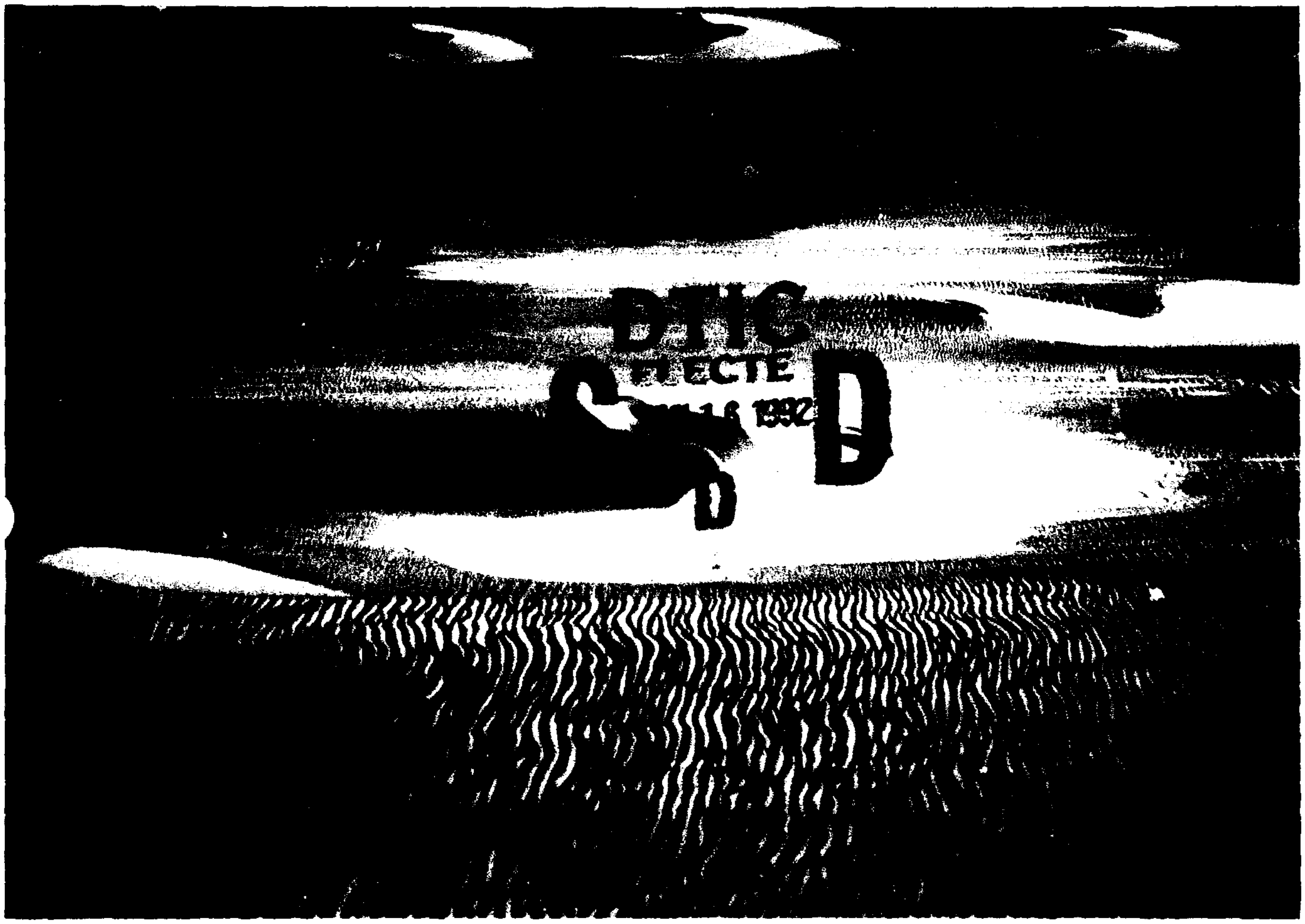
ETL-0588 SEPTEMBER 1991

REMOTE SENSING FIELD GUIDE

DESERT



Prepared by

THE DESERT PROCESSES WORKING GROUP

USAETL **USGS/FLAGSTAFF**

ETL-0588

Remote Sensing Field Guide - Desert

Desert Processes Working Group

September 1991

U.S. Geological Survey
Flagstaff, AZ 86001

U.S. Army Corps of Engineers
Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060-5546

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1991

3. REPORT TYPE AND DATES COVERED
Technical Report 1985 - 1991

4. TITLE AND SUBTITLE
Remote Sensing Field Guide - Desert

5. FUNDING NUMBERS
2112040 08-8002
P611102.52C S44213
QG152COC10

6. AUTHOR(S) The Desert Processes Working Group, whose members are:
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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Flagstaff, AZ 86001

8. PERFORMING ORGANIZATION REPORT NUMBER
ETL-0588

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES By the conclusion of Operation Desert Storm, the U.S. Marine Corps had printed and distributed over 27,000 copies of this manual in an unedited draft form. Effective 1 October 1991, the 1U.S. Army Engineer Topographic Laboratories (ETL) became U.S. Army Topographic Engineering Center (TEC).

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

In support of military operations, Army terrain analysts are frequently required to provide terrain information about an area, and to do so quickly. Examples of needed information include: location of engineering materials, potential ground water drilling sites, influence of the terrain on cross-country movement, potential for dust generation, potential for cover and concealment, and sites suitable for ambush and defilade. The task is not easy because of the lack of sources for detailed and reliable information. Such information is not yet available in data bases, nor in existing maps, and neither can it be obtained by computer analysis of digital imagery. It can, however, be derived by the manual, or "eyeball," evaluation of image patterns. Although airborne or satellite imagery is now available for most of the world, the translation of these image patterns into forms usable by the terrain analysts has not been done. To bridge this gap, for at least one climatic zone, the Desert Processes Working Group has developed this Remote Sensing Field Guide directed towards desert operations. Although developed for military uses, this guide can serve all who travel and work in desert regions.

14. SUBJECT TERMS
Image Analysis, Desert Operations, Terrain Utilization, Remote Sensing, Cross-country Movement, Desert Landforms, Desert Geology

15. NUMBER OF PAGES
568

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

CONTENTS

PREFACE

This report was prepared under DA Project 4A161102B52C, Task OC, Work Unit 010, "Indicators of Terrain Conditions."

This report was prepared during the period 1985-1991 under the supervision of Dr. Jack N. Rinker, Chief, Remote Sensing Division; and Mr. John V.E. Hansen, Director, Research Institute.

The Desert Processes Working Group members are: Dr. Jack N. Rinker and Ms. Phyllis A. Corl of USAETL, and Ms. Carol S. Breed and Dr. John F. McCauley (Emeritus) of USGS.

The Desert Processes Working Group would like to thank Ms. Doris Weir, USGS, Flagstaff, AZ, for extensive editing and rewriting of portions of the Guide, and to the USAETL editorial staff for their assistance during preparation of the final copy for printing.

When Operation Desert Shield started, demand for this manual instantly emerged, even though it was in an unedited draft form. By the end of Operation Desert Storm, the U.S. Marine Corps had printed and distributed over 27,000 copies of the manual.

As of 1 October 1991, the U.S. Army Engineer Topographic Laboratories will change its name to the U.S. Army Topographic Engineering Center.

Colonel David F. Maune, EN, was Commander and Director, and Mr. Walter E. Boge was Technical Director of the U.S. Army Engineer Topographic Laboratories during final preparation of the report.

INTRODUCTION

In support of military operations, Army terrain analysts are frequently required to provide terrain information about some area, and to do so quickly--sometimes in hours. The task is not easy because of the lack of, or inadequacy of, information resources for much of the world. Detailed and reliable terrain information required by the analysts is not yet available in the Defense Mapping Agency (DMA) data bases, nor in existing maps, and neither can it be obtained by computer analysis of digital imagery. It can, however, be derived by the manual, or "eyeball" evaluation of image patterns. Airborne and satellite remote sensor imagery, in one form or another, is now available for most of the world. The translation of these image patterns into forms usable by terrain analysts, however, has not been done. To bridge this gap for at least one climatic region, the Desert Processes Working Group† has developed this Remote Sensing Field Guide. Members of this Group have extensive field experience and a large repository of aerial photography and satellite imagery of the world's deserts. The U.S. Geological Survey (USGS) members, particularly, have an extensive collection of ground photographs, notes, and samples from foreign deserts. The guide is based on the Air Photo Indicator Sheets developed at the U.S. Army Engineer Topographic Laboratories (USAETL),[1] the results of the USAETL/USGS Workshop on Desert Processes,[2] the cooperative research on desert processes by USGS and USAETL, and meetings with terrain analysts of the U.S. Army.

Because three-dimensional shape is the most direct link to terrain properties in terms of form, composition, and condition, the critical need is for stereoscopic imagery. Although information can be derived from small-scale monoscopic imagery, such as Landsat Thematic Mapper (TM) scenes, the results are restricted in quality and quantity--excellent for portraying regional characteristics and relations, but not adequate for tactical applications. As needed, however, such information can be converted into reliable tactical data bases by the analysis of larger scale stereoscopic images, or by air and ground reconnaissance. Each pattern element in an image is indicative of some characteristic in the landscape, and a careful evaluation and interpretation of these patterns can yield the types of terrain information shown in Table 1. Tactical information is goal oriented, and requirements vary in relation to the military operation envisioned. Examples of tactical information that can be derived from the terrain data of Table 1 are shown in Table 2.

Although developed for military uses, this guide can serve all who travel and work in desert regions.

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† The Desert Processes Working Group is a joint endeavor between USAETL's Remote Sensing Division of the Research Institute, and USGS's Desert Studies Group at Flagstaff, Arizona.

ARRANGEMENT AND FORMAT OF THE GUIDE

Most entries in the loose-leaf guide have a single-sheet format, which will allow the user to arrange the information according to need. This format also enables easy update and additions in the form of periodic supplements. The present guide has the following sections:

- Classification of Desert Patterns
- Summary Sheets
- Pattern Indicator Sheets
- Image File Sheets
- Operational Comments
- Application Examples

Classification of Desert Patterns. The first task was to produce a classification of patterns found in deserts in a form suitable for image analysis (Table 4). Because future field studies and research will require changes in the guide, the classification system is compartmented so that it can be easily added to, subtracted from, or otherwise altered without destroying the basic structure.

Summary Sheets. Each item in the classification (Table 4) will have a single sheet entry that gives the following information, where pertinent:

- Name of the feature or pattern
- Description
    - Shape, orientation, distribution, characteristics
- Origin or Regime (wind, water, or other)
- Engineering and Military Uses
    - Soil texture, if known, and the indicative value of the pattern in terms of support for foot or vehicular traffic, limits on speed and direction of movement, support for fixed- and rotary-wing aircraft operations, potential for dust generation, cover and concealment, sources and types of engineering materials, potential water sources, navigation points, and sites for ambush, defilade, observation, bivouac, rest and repair.
- Foreign Names and Synonyms
- References

Pattern Indicator Sheets. Each Summary Sheet is illustrated by Pattern Indicator Sheets that show the feature in various types of monoscopic and stereoscopic imagery, such as ground and aerial photography (vertical and oblique), radar, or Landsat. After the basic document is published, additional sheets will be distributed periodically. These sheets contain the following information:

Name of the feature or pattern
Location
Country, specific area therein, and latitude/longitude where known
Climate (based on Trewartha)[3,4]
Image Credits
Type of image, source, identifying information, image characteristics, date, scale
One or more illustrations
Comments
A brief description of the imaged feature or pattern
Engineering and Military Uses
Soil texture, if known, and the indicative value of the pattern in terms of support for foot or vehicular traffic, limits on speed and direction of movement, support for fixed- and rotary-wing aircraft operations, potential for dust generation, cover and concealment, sources and types of engineering materials, potential water sources, navigation points, and sites for ambush, defilade, observation, bivouac, rest and repair.
Reference(s) where applicable

Image File Sheets. These are single-sheet presentations of images listed according to feature or pattern type, without text. They serve to illustrate varieties of features or patterns. Additional sheets will be distributed periodically. They contain the following information:

Name of the feature or pattern
Image type
Location
Climate
Image credits
Comments (if needed)

Operational Comments. Entries about a feature, condition, or activity, such as dust, navigation, and cross-country movement.

Appendices. This provides a place for future inclusion of topics such as a glossary, distribution of desert patterns, etc.

Application Examples. This provides a place for future inclusion of completed image analyses.

CLIMATE CLASSIFICATION

Brief summaries of the climatic conditions in areas where patterns or features are shown are given in a two-part entry on the Pattern Indicator Sheets and on the Image File Sheets. In the first part of the entry, climate is expressed in commonly used terms such as extremely dry (hyperarid), dry, arid, humid, and subhumid. Though lacking in precision, these terms have a generally understood descriptive connotation. In the second part, climate is expressed in the symbols and terminology of a worldwide classification system (Table 3) developed by Trewartha,[3,4] which is a simplified version of a system developed by Köppen.[5,6] The symbols are combinations of upper- and lower-case letters, with each succeeding letter providing more detailed information. Because this is a general, regional classification, some of the examples shown in this Guide do not seem to belong in the cited category. Such anomalies are to be expected because climatic regions are not homogeneous throughout, and because borders between climatic zones are commonly gradual rather than abrupt. Furthermore, the maps showing climatic zones of the examples are of small scale. Climatic classes and boundaries can also change as regions undergo climatic alteration.

Table 1.

Terrain Information That Can Be Derived From Image Analysis By Direct Observation, or By Inferential Procedures, and Which Can Be Converted Into Data Bases in Support of Military Operations

Drainageways
- Stream channels, lakes, playas, sabkhahs

Geologic structure
- Fractures, faults, bedding

Landforms
- Mountains, hills, plains, valleys, basins, ridges, knobs, plateaus, yardangs, dunes, mounds, escarpments

Obstacles
- Drainageways, escarpments, coppice dunes, rocks, knobs and ridges, vegetation mounds

Surface characteristics
- Hard, soft, firm, loose, sticky, crusted, cemented
- Dry, wet
- Smooth, rough, rolling, dissected

Surface composition
- Rocky and rubbly, sharp rock fragments, duricrust, gravel, sand (sheets, ripples, drifts, streaks), silt, clay, evaporites

Tone/Texture
- Light tones
  - Frequently associated with loose sand, silt, dry playas and sabkhahs, evaporites
- Dark tones
  - Frequently associated with vegetation, varnish, lag, duricrust, moisture, wet playas, sabkhahs, and recent basaltic volcanic rocks

Unstable slopes and conditions

Vegetation types
- Distribution and characteristics

Table 2.

Tactical Information That Can Be Derived From The Data Base Elements In Table 1

Excavation potential

Cover and concealment

Dust generation potential

Engineering construction problems
Unstable slopes, conditions, and materials

Engineering materials (sand, gravel, rock, timber)

Hazards
Sharp rocks (flat tires), thorns, flash floods, quick conditions

Navigation points (visible and common to maps and imagery)

Restrictions on surface movement and speed (foot, vehicle)

Restrictions on aircraft operations (fixed- and rotary-wing)

Sources for water

Sites for observation, ambush, defilade, drop zones, rendezvous, bivouac, rest and repair, and shelter from sun, wind, and blowing sand

Terrain to avoid

Table 3.

Symbols and Meanings Used in The Guide to Denote Climate Characteristics (From Trewartha).[3,4]

1. General categories (upper case letters):

A	Tropical Rainy Climates
B	Dry Climates
BS	Dry climate, steppe
BW	Dry climate, desert, "W" from wüste, the German word for desert
C	Humid Meso-Thermal Climates
D	Humid Micro-Thermal Climates
E	Polar Climates
ET	Polar climate, tundra
EF	Polar climate, icecap
H	Undifferentiated Highlands

2. Descriptors (lower case letters):

a	Warmest month above 22°C
b	Warmest month below 22°C
c	Less than four months over 10°C
f	Same as "c" but coldest month below -38°C
h	Hot and dry. All months above 0°C "h" from heiss, the German word for hot
k	Cold and dry. At least one month below 0°C "k" from kalt, the German word for cold
m	Monsoon rain with short dry season. Total rainfall enough to support a rainforest
n	Frequent fog. "n" from nebel, the German word for fog
n'	Infrequent fog, but with high humidity and low rainfall
s	Dry season in summer
w	Dry season in winter

Table 4.

Classification of Desert Patterns

DEPOSITIONAL PATTERNS AND TRANSPORTED MATERIAL	
WIND	**WATER**
Dunes	Playas
Linear/Seif	Sabkhahs
Crescentic	Alluvial Features
Barchan/Megabarchan and Barchanoid/Megabarchanoid	Fans
Transverse	Bajadas
Reversing	Gravel Plains
Star	
Dome	
Climbing	
Falling	
Lee/Shadow	
Parabolic	
Lunette	
Coppice	
Vegetation Mounds	
Ripples	
Sand	
Truncated	
Pebble/Gravel	
Granule (Megaripples)	
Giant	
Sand Plains/Sand Sheets	
Streaks/Drifts	
Sand Seas/Ergs/Dune Fields	

EROSIONAL PATTERNS AND RESIDUAL MATERIAL	
WIND	**WATER**
Interdune Areas	Badlands
Depressions	Pediments
Deflation Hollows/ Basins/Blowouts	Drainage Courses
Grooved Terrain	Rivers
Yardangs	Wadis
Hoodoos	Washes
	Gullies
	Arroyos
	Ravines/Canyons
	Inverted
	Inselbergs/Hills/Knobs
	Monuments
	Solution Pans/Pits/ Cavities/Hollows

SPECIAL AND MINOR FEATURES
Beach Ridges
Burn Scars
Desert Pavement
Dikes
Duricrusts
Caliche
Gypcrete
Laterite/Ferricrete
Silcrete
Dust
Escarpments
Nafash
Tafoni
Varnish
Ventifacts
Seasonal and Cyclic Changes

CULTURAL FEATURES
Abandoned Structures/Ruins
Agriculture
Fencelines
Industrial
Residential
Transportation
Water Related

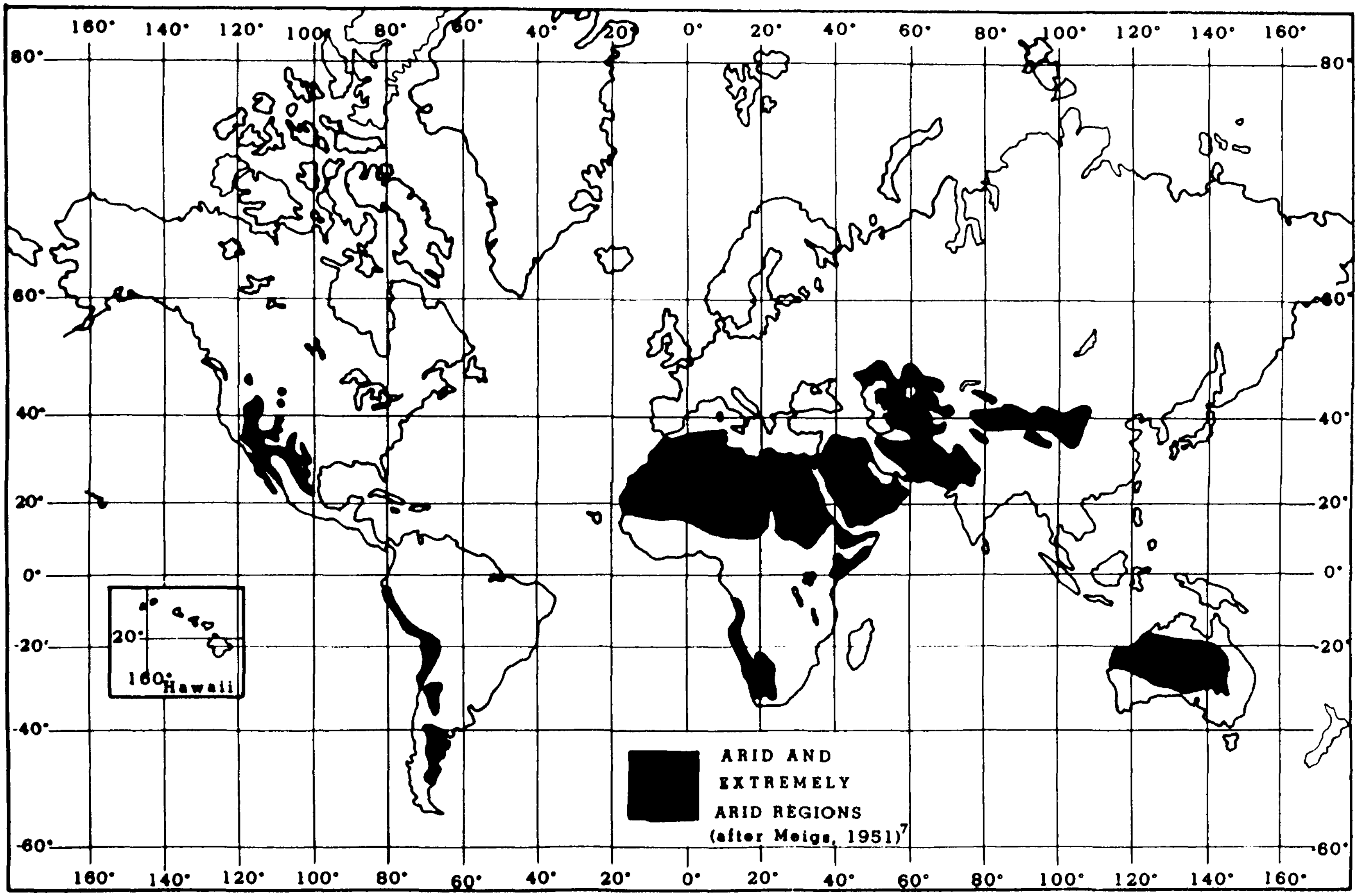

Figure 1. Arid and Extremely Arid Regions of the World.

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[1]Rinker, J.N. and P.A. Corl. 1984. Air Photo Analysis, Photo Interpretation Logic, and Feature Extraction. U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA 22060-5546. ETL-0329. AD-A153 926.

[2]McCauley, J.F. and J.N. Rinker. 1987. A Workshop on Desert Processes, September 24-28, 1984 - Report on the Conference. U.S. Geological Survey Circular 989.

[3]Trewartha, G.T. 1957. Elements of Physical Geography. New York: McGraw-Hill Book Co.

[4]Finch, V.C., G.T. Trewartha, A.H. Robinson, and E.H. Hammond. 1957. Physical Elements of Geography. New York: McGraw-Hill Book Co.

[5]Köppen, W. 1923. Die Klimate der Erde; Gundriss der Klimakunde. Berlin: Walter de Gruyter Co.

[6]Köppen, W. and R. Geiger. 1930 (and later). Handbook der Klimatologie, 5 vols. Berlin: Gebruder Borntraeger.

[7]Meigs, P. 1953. World distribution of arid and semiarid homoclimates. In Review of research on arid zone hydrology, Arid Zone Programme I. Paris: UNESCO, pp. 203-209.

DESCRIPTION: Dunes are accumulations of loose, well-sorted, windblown sand grains (mostly very fine to medium) in wavelike mounds or ridges whose characteristic shapes are maintained by periods of wind-induced, grain-by-grain movement. Dunes occur wherever topographic and climatic conditions permit the deposition of sand-sized, wind-borne material; they are usually found in arid regions where wind erosion is less inhibited by vegetation. Dunes tend to migrate from sources of sand, such as riverbeds, beaches, and playas, to sites of accumulation that are topographically controlled, such as basins and valleys. Individual mounds or ridges are meters to hundreds of meters high. They have one or more gentle upwind slopes of about 10 to 20°, one or more steep lee slopes of about 32° (the angle of repose of loose, dry sand), and may have extending arms of various shapes and sizes. The upwind surfaces are usually hard packed and smooth, locally cut by minor flutes, grooves, and hollows (blowouts). The lee slopes are soft and unstable, and are called slip faces, or avalanche faces. Dunes can occur as solitary features, but are more common in groups called fields. Regionally extensive fields are called sand seas or ergs. Any given dune field, or erg, usually consists of individuals of similar shapes repeated across the center of a field; variations in shape are common along the margins. Within a field or erg, individual dunes are separated by areas of desert floor whose shape and extent are related to the dune type (see Summary Sheet for Interdune Areas). In areas of occasional rainfall, the base of a dune may store enough moisture to nourish grasses in the interdunal flat immediately adjacent, and seepage of moisture may occur around the dune perimeter.

The types of dunes listed below are classified on the basis of the external shape of the dune and the arrangement of its slip faces, if any, relative to its shape in plan view. These characteristics are primarily functions of wind direction and sand supply, although local topography and presence of vegetation are also important factors. All have variant forms called simple, compound, and complex. Simple dune forms are mounds or ridges with a minimum of slip faces, all of which are similar in size or character. Simple dunes tend to be small, i.e., meters to a few hundred meters in width or length and tens of meters high. Compound dunes are mounds or ridges on which smaller dunes of similar type and slip face orientation are superposed; these "two-story" dunes tend to be very large, measured in hundreds to thousands of meters in width or length, and some are as high as 400 m. Complex dunes are combinations of two or more dune types, and may be small, if coalesced, or large, two-story constructs like compound dunes, if superposed.

- Linear/Seif
- Crescentic
  - Barchan/Megabarchan and Barchanoid/Megabarchanoid
  - Transverse
  - Reversing
- Star
- Dome
- Climbing
- Falling
- Lee/Shadow
- Parabolic
- Lunette
- Coppice
- Vegetation Mounds

WIND REGIME: The physiographic variations of dunes result from the interaction of winds of various strengths and directions with collections of various particles whose sizes allow them to be sorted and moved by wind. Consequently, these sand patterns can tell much about the characteristics of both historical and present winds. Details, where known, are given in the appropriate dune sections. The most reliable clue to wind direction is that the slip face is always on the most recent lee (downwind) side of the dune. Horns or arms that extend from the dune can point either upwind or downwind. They normally point downwind unless anchored by vegetation, as in the case of parabolic dunes.

ENGINEERING AND MILITARY USES: Sand grains of all dune forms described in this section (except those of lunettes) are very fine to medium, about 0.06 to 0.5 mm. On dunes with asymmetric slopes, the gentler upwind slope is wind compacted and can usually support foot and light vehicular traffic. The steep lee slope, or slip face, will not support either foot or vehicular traffic without avalanching. Although skillful and experienced drivers can take some kinds of vehicles (dune-buggy, light truck, etc.) down lesser lee slopes, it can be a dangerous procedure and should be avoided. On dunes of any size, these vehicles must travel straight down the 32° slip face to its abrupt junction with the interdune desert floor. A general rule is that vehicles should not be driven down the lee slope of a dune taller than the wheelbase of the vehicle, and such descents down the lee slope should begin slowly from the brink of the dune to avoid becoming airborne and crash-landing at the foot of the slip face, with likelihood of serious injury. A better route for descent can usually be found down the flank of the dune. The interdunal floor is usually relatively flat and compacted, and easy to travel across unless occupied by seasonally wet playas or smaller dunes. The floor may contain patches of loose sand, which should be avoided, and it may be partly or fully enclosed by dunes so that upslope escape is impossible (see Summary Sheet for Interdune Areas). In general, fixed-wing aircraft operations are not appropriate to dune areas because of the uneven topography and blowing sand, but rotary-wing aircraft can operate on the interdune floors in many areas.

GENERAL REFERENCES:

McKee, E.D. (ed.). 1979. A study of global sand seas. U.S. Geological Survey Professional Paper 1052, 429 pp.

Pye, K. and H. Tsoar. 1990. Aeolian sand. Cambridge, MA: Unwin Hyman, 396 pp.

DESCRIPTION: These dunes are straight to irregularly sinuous, elongate, sand ridges of loose, well-sorted, very fine to medium sand. The straight varieties are often called "sand ridges," and the sinuous varieties are often called "seifs." The lengths of individual dunes, which are much greater than the widths, can range from a few meters to many kilometers. Because of the temporal alternation of the slip faces on the ridge from one side to the other, both flanks can be steep, and loose sand will be found on the top of the ridge as well as on both sides near the top. Surfaces on the lower flanks of both sides of the ridge are wind compacted. These temporal alternations, which are caused by changes in wind direction, range in duration from daily to seasonal, depending on the regional wind regime. Linear dunes can occur in simple, compound, and complex forms. Simple dunes are single ridges with slip faces of the same size and location along the dune flanks. Simple forms, commonly fixed by vegetation, are found mostly in semiarid deserts. Compound dunes are usually found in much drier regions. Superposed on the main ridges of the compound dune are smaller, secondary, linear ridges, some of which have coalesced. These large, compound forms, where sinuous, are also known as seifs. Complex dunes are basal linear ridges superposed by other types of dunes (commonly star dunes). Linear dunes cover more desert area than any other type of dune, especially in central Australia, southern Africa, the southwestern Arabian Peninsula, and parts of the Sahara, but they are not as common (in the sense of occurring in almost every desert) as are the crescentic dunes.

WIND REGIME: Linear dunes have formed in areas now characterized by wide ranges of wind speeds and directions. Most are probably "fossil" dunes formed under more vigorous wind regimes during Pleistocene climatic conditions. Since then, wind regimes have apparently become less intense, although wind directions are apparently similar. Thus, where linear dunes are active today, they are commonly being modified into compound or complex features by the addition of secondary dunes. Nonetheless, the long axes of linear dunes are aligned generally within 15° of the prevailing wind or with the resultant drift direction of the local winds. The sinuosity and alternate slip faces develop because crosswinds change direction and alternately shepherd the sand to each side of the dune axes. The wind regimes of linear dunes usually have a wider directional variability than those associated with parabolic dunes or dunes in the crescentic group (barchans and transverse dunes), despite the strong directionality of their ground pattern. On small-scale imagery, such as Landsat, the appearance of fields of narrow, simple-to-compound linear dunes can resemble that of large-scale, barren, bedrock yardangs in grooved terrain (see Summary Sheets for Grooved Terrain and for Yardangs). Other visual clues besides shape are needed to distinguish between them, such as vegetation, slip faces, color, and local geology.

ENGINEERING AND MILITARY USES: The grain size of these loose, well-sorted, very fine to medium sands is about 0.06 to 0.5 mm. Linear dunes can be continuous for many tens and even hundreds of kilometers, and they can form parallel barriers to cross-country movement except down the interdunal passages, which are parallel to the long axes of the dunes. These passages are frequently called corridors or "streets." Their surfaces are usually stabilized and firm, although they might contain coppice dunes, playas, or other obstacles. Two adjacent dunes often join. The resulting Y junction almost always opens into the prevailing wind (and thus closes in the downwind direction). Compound linear dunes typically have many subsidiary oblique ridges whose junctions with the main ridge also open into the wind. Interdunal corridors are sometimes closed by secondary dunes joining the main ridges. In spite of the blind alleys and the interconnected, mazelike nature of these interdunal corridors, they provide the only practical passage through the dune field for foot and vehicular traffic. Areas of loose sand and active dunes cannot be crossed unless the dunes are very small (a meter or so high) or wet, following rain. Where vegetation is visible on the dune surface, vehicles can probably "bull" their way straight up and over the dune and into the next corridor. Travel up the stable flanks may need to follow an oblique path, not perpendicular to the crest, depending on the steepness and surficial characteristics. These judgments can be made at the site. Serious problems for navigation include the restricted field of view from the floor of the interdunal corridor, the similarity of the adjoining, repeated dune ridges, and the limited view from the tops of the dune ridges--all that can be seen are the flanks and tops of the immediately adjacent ridges and the tops of more distant ridges. So far as we are aware, except for parts of northern Africa, southern Africa, and central Australia, maps do not show the necessary surface details to support cross-country navigation. Without air photos or equivalent imagery, passage through such a field will be, at best, a time-consuming trial and error procedure, and perhaps impossible. In such a case, the best procedure is to head upwind to avoid being "boxed in" by two dunes that join. The restrictions on the horizontal field of view within dune fields make possible some level of horizontal and oblique cover and concealment from aircraft. However, there is no cover and concealment from overhead aircraft, or from units within the same interdunal area.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Longitudinal dunes, seifs, sand-ridge dunes, oblique dunes, sigmoidal dunes, slouk, silk, alab, uruq, whalebacks (some).

DESCRIPTION: These dunes are arc-shaped individual mounds or arc-shaped segments of sand ridges consisting of loose, well-sorted, very fine to medium sand. The upwind slope, which is usually less than 15°, is wind packed, and firm; the slip face, or lee slope, is composed of unstable, loose sand at its customary angle of repose of about 32°. Two arms, also called horns, extend from the main body of the dune mound or from each segment of a dune ridge; they point downwind. Sizes of individual simple barchans range from a meter or so to perhaps a hundred meters from horn to horn. Compound barchans are large basal mounds with a single proportionately large slip face and an upwind slope covered with many smaller barchans or barchanoid ridges with proportionately smaller slip faces, all oriented in the same direction as the main dune. Such dunes have a "two-story" aspect and commonly grow to sizes of 1 or 2 km from horn to horn, with heights of 30 m or more. These large compound dunes are often called "megabarchans." Individual barchans or megabarchans commonly occur in elongate chains or trains that merge with coalesced dunes in fields or ergs. Barchans and megabarchans are highly migratory: small barchans typically move several meters to tens of meters per year, at speeds inversely proportional to their size. Megabarchans move more slowly and commonly "shed" smaller barchans off their horns, as at Pur-Pur Dune north of Trujillo in coastal Peru (Simons).[1]

Barchans and megabarchans frequently occur in coalesced form as highly curved segments in continuous dune ridges more or less perpendicular to the wind direction. Although this coalescence tends to obliterate the pattern of the arms, the main characteristics of barchans--arcuate slip faces and more gentle upwind slopes--persist. Because these characteristics have been retained, such dunes are called barchanoid or megabarchanoid ridges. These wavy, barchanoid forms contrast with the straight or slightly curved segments of transverse ridges (see Summary Sheet for Dunes - Crescentic - Transverse). Like transverse dunes, they typically occur as repeated, parallel ridges that can extend for hundreds of kilometers.

WIND REGIME: Of all dune forms, barchans and megabarchans have the best understood, least ambiguous relations to the directions of the winds that form them. The slip faces on these dunes are maintained by virtually unidirectional winds, and the arms (horns) of the dunes point downwind, unlike parabolic dunes, whose arms trail behind and point upwind (see Summary Sheet for Dunes - Parabolic). The presence of barchans, with their typically crisp, fresh outlines, indicates that strong, sand-moving winds blow frequently from one quarter. Where occasional or seasonal winds blow from an opposite direction, barchans and megabarchans can develop smaller, secondary slip faces oriented in a reverse direction from the main slip faces (see Summary Sheet for Dunes - Crescentic - Reversing).

ENGINEERING AND MILITARY USES: The grain size of these loose, well-sorted, very fine to medium sands is about 0.06 to 0.5 mm. In fields where barchans or megabarchans are isolated on a bare desert floor (bedrock or sand sheet), movement is generally easy, both in a down-field and cross-field direction. Movement becomes much more difficult where dunes are coalesced into a network pattern and interdunal spaces are enclosed. The best route from one barchanoid or megabarchanoid ridge to the next is along the horns that commonly extend downwind from one ridge to the next, thus avoiding the interdunal basins. The surfaces of the gentler slopes on the upwind sides of these dunes are wind-packed sand and are trafficable. The surfaces of the steep lee slopes are loose sand that will avalanche easily. Slip faces higher than a meter or two should be avoided. Descents straight down such short slip faces are possible, but they should begin very slowly from the dune brink to avoid the separation of the vehicle from the dune surface, with consequent crash-landing. This type of descent is not feasible for large or heavy vehicles, because sand avalanches will result that can cause overturning. Depending on the size of the dune and wind conditions, the floor inside the cusp, near the edge of the slip face, can be a good place to camp or effect repairs. If the wind picks up to above 20 kph some of the fine particles can settle out into the lee area. It also provides concealment from downwind travelers, because they must look back into the cusp to see the area. Trenching in these dunes is not generally practical unless they happen to be wet.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Crescent dunes, sand hills, barkans, demkhas, giant crescent, bourrelets, draas (for the large forms), megadunes.

REFERENCE:

[1]Simons, F.S. 1956. A note on Pur-Pur Dune, Viru Valley, Peru. Journal of Geology, v. 64, pp. 517-521.

DESCRIPTION: Transverse dunes are accumulations of loose, well-sorted, very fine to medium sand in ridges that have a gentle stoss (upwind) slope (usually less than 15°) and a steep (32°) slip face on the lee slope. The long axes of the ridges are perpendicular to the wind direction. In plan view these ridges are relatively straight or only slightly curved, and they look much like linear dunes. They differ, however, in some important aspects. First, the two flanks of a transverse ridge have different, rather than similar, angles of slope; the gentler upwind slope is composed of firmly packed sand and the steeper lee (avalanche) slope is soft and loose sand. Second, transverse dunes migrate laterally, toward the next dune ridge, instead of longitudinally down the long axis of the ridge. This means that low ridges or "thresholds" of sand may extend from the lee slope of one ridge across the interdune area and connect with the next ridge downwind. Transverse dunes are a variety of crescentic dune ridges similar to barchanoid or megabarchanoid ridges, but they are much straighter in plan view, so that on the ground the slight curvature of ridge segments is not apparent. Like other crescentic dunes, transverse dunes can become very large (segments as wide as 3 km from horn to horn) and commonly develop compound and complex forms.

WIND REGIME: Unidirectional winds that are transverse to the long dimension of the dune ridge.

ENGINEERING AND MILITARY USES: Grain size of these loose, well-sorted, very fine to medium sands is about 0.06 to 0.5 mm. Upwind slopes are firm and smooth and can be traversed by foot or by light 4-wheel-drive or dune-buggy types of vehicles. Lee slopes, composed of loose sand, are liable to avalanche and overturn vehicles. Thresholds (extended arms) between dunes can close an otherwise open and trafficable interdunal corridor between successive ridges, with the result that these corridors may become discontinuous basins that are difficult or impossible for wheeled vehicles to climb out of, once in. The thresholds, however, are about as firm as the wind-compacted slopes; their crests can provide good passage from the top of one dune to the next, so that the interdunal basins can be avoided. The horizontal field of view is restricted within these dune fields, so some level of cover and concealment is possible. Trenching is not advisable unless the dunes are wet.

DESCRIPTION: These forms result from a reworking of various dune types by secondary winds that blow occasionally (usually seasonally) from a reverse direction. They are accumulations of loose, well-sorted, very fine to medium sands. Both flanks are relatively steep because lee slopes occur on both sides in response to winds from opposite directions. Such wind variations can cause noticeable seasonal changes ranging from minor variations of a crest to major alterations in dune shape. In any case, the lower parts of both flanks are firmly packed, and their slopes are relatively stable throughout the seasons. The upper slopes and top are loose and soft, like the upper flanks of linear dunes and the arms of star dunes which are, by definition, subject to regular reversals. On the upper surfaces of the reversing dunes, i.e., in the seasonal wind streams, each slope is alternately a lee slope and a wind-packed slope. Because of this temporal variation, the current upwind slope is not as well packed and firm as the same slope on a barchan dune, which forms in a unidirectional wind regime and, therefore, continually faces the wind. Likewise, the lee slope is not as loose as the avalanche slope of a dune that is never wind packed. A reversing dune is seasonally topped by a peak, or crest (cornice), whose smaller slip face represents the most recent wind shift. Reversing dunes occur most often in fields of crescentic dune mounds or ridges, particularly near the downwind margin of the field near topographic barriers that interfere with the primary direction of the wind. Reversing dunes are common as intermediate forms between crescentic dunes in the center of a field or erg and star dunes along the outer margins. In some reversing dunes, internal bedding and grain size vary because the dune materials are transported by the winds from different sources. Like star dunes, reversing dunes grow mostly upward, some to heights of 300 m. Their forward migration is slower than that of nonreversing dunes. Their presence can signify a nearby topographic barrier to windflow and/or the outer, downwind margin of a dune field or erg.

WIND REGIME: Reversing dunes signify periodic directional shifts of about 180° in the effective winds. In some cases, as at Great Sand Dunes, Colorado, coarser grains may be deposited by winds from one direction, finer grains by winds from the other, and the two components can be recognized in the internal bedding of the dune.

ENGINEERING AND MILITARY USES: Grain size of these loose, well-sorted, very fine to medium sands is about 0.06 to 0.5 mm. Because of the somewhat loose and soft upper surfaces and the large sizes of these dunes (especially their height), reversing dunes can be difficult to cross, and such fields should be avoided whenever possible. This is, of course, good advice for any dune field. There is no sense in trying to cross them if there is no compelling reason to do so, and if there is a way around. If necessary to work your way up into such a field, go from crest to crest, staying as much as possible on the uppermost part of the current wind-packed surfaces. If you are traveling too fast, the crests can appear in unexpected orientations. Avoid going into conical and bowl-shaped depressions; entrance is easy, but exit can be difficult, and impossible for vehicles other than dune-buggies. These characteristics are well illustrated in the Algodones Dunes near Yuma, Arizona, and the Great Sand Dunes in Colorado.

DESCRIPTION: These are isolated, pyramidal, somewhat irregularly shaped to symmetrical mounds of sand with three or more arms radiating from a central high point. The arms can vary in length, width, number, and shape, but each has a slip face. These dunes frequently have an approximate radial symmetry, i.e., in plan view the symmetry of the pattern is oriented around a point. The simple forms have smoothly curvilinear arms, usually three, and because they have a high degree of radial symmetry, they resemble a pinwheel. Compound forms usually have more arms, some sinusoidal, and are less regular with less radial symmetry. In complex star forms, the basal mound shape is also less regular, at places domelike, and overall symmetry is poor because the arms are also irregular: some may be shorter and thicker than others, or they may be elongated and extend downwind in linear or barchanoid dunes. Star dunes also occur as secondary elements on top of, or in combination with, other dunes, especially complex linear or crescentic ridges. In these cases, star dunes perhaps signify a change in effective wind strength or direction (or both) since the basal (Pleistocene?) dunes were formed. Other star dunes occur in chains, like beads on a string, or in fields of isolated but almost regularly spaced star shapes.

WIND REGIME: We do not yet know the details of the wind regime and the sequence of events that are needed to develop and maintain these dunes, either as individuals or in groups. There is a paucity of observations and measurements, and therefore the processes that form these dunes have only been inferred from their shape. They appear to result from winds that blow from several opposing directions, either as a result of seasonal shifts, or where secondary windflow patterns are produced by topographic barriers. Such patterns may occur in valleys, adjacent to mountain fronts, or in topographic basins where funneling effects can interact with regional winds to produce multidirectional winds. For whatever reason, as the directions of the sand-moving winds shift around the compass, the end result is a constant shepherding of the sand back to a central point of deposition. Consequently, more than other dune types, isolated star dunes grow mostly upward; it is not unusual for them to reach heights of 200 to 300 m in the great deserts of the world and to represent true sand mountains. Their forward or lateral rates of migration, however, appear to be very low, probably only centimeters per year, and their interdunal areas tend to be swept clear of loose sand except for rippled aprons on the dune margins. No particular side of a star dune thus can be considered its "lee" or "upwind" slope, except in a temporary or local sense.

ENGINEERING AND MILITARY USES: The grain size of these loose, well-sorted, very fine to medium sands is about 0.06 to 0.5 mm. Shelter from wind in a star dune field may depend on temporal or local wind conditions and cannot be predicted from dune shape alone. On the other hand, lateral migration of dune sand should not be a problem. Trafficability depends on whether the star dunes are isolated or massed, as is common in valleys, or linked in aligned chains. Movement through fields of isolated star dunes on broad, open plains is easy, because interdunal plains are generally swept clear of loose sand except where rippled (see Summary Sheets for Ripples - Sand, and Granule (Megaripples). These interdunal spaces are continuous across the star dune field, generally either in a down-field or cross-field direction. Star dunes in chains, however, have difficult trafficability characteristics similar to those of massive linear dunes (see Summary Sheet for Dunes - Linear/Seif). Experiences in Peru, Iran, and the southwestern U.S. indicate that fields of star dunes that are massed or in chains, i.e., not isolated, are not crossable in any practical application of the term.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Pyramidal dunes, oghurd, draa, uruq (some), demkha (some), sand mountains.

DESCRIPTION: These are circular to oval mounds of loose, well-sorted, very fine to medium sand. Simple dome dunes are only a few meters in height and decameters in diameter. Slip faces are absent or ephemeral and only a meter or so high; they are transverse to the direction of the most recent effective sand-moving wind. These dunes are commonly found at the upwind ends of barchan fields and rarely at the downwind ends of linear dunes. Complex megadomes are broad features that are kilometers in diameter and have other types of dunes, usually barchanoid ridges, on their broad summits. Their average diameter is 1.5 km, but some coalesced domes are as broad as 8 km (Holm).[1] These giant domes are poorly understood. They have been identified on aerial photographs and Landsat images of ergs in several core deserts, where they are usually confined to broad valleys. Giant domes occur in parts of the northern Sahara (Algeria), the Tengger and Taklimakan areas (China), and the An Nefud ergs in the north-central Nejd (Arabian Peninsula). In the Nefuds, these giant domes are 100 to 150 m high.[1] They have coalesced into interconnected ridges having a netlike pattern. Scattered throughout are level areas of different sizes, the bottoms of which are flat desert floor, or infilling sand. In some of these interdunal hollows are small settlements (buildings, fields, tree plantings), which indicate at least a present stability and a source of water (see Summary Sheet for Interdune Areas).

WIND REGIME: Little is known and less is understood about this factor. Both simple and complex domes occur in areas where available wind data (Breed, et al.)[2] suggest that the winds are very strong and variable in direction, but with a dominant, and probably seasonal directional component. Small dome dunes at the upwind end of a dune field commonly grade into barchans in a downwind direction as they increase in height, and they consequently develop avalanche slopes.

ENGINEERING AND MILITARY USES: Information on these dunes is drawn from Holm[1] and brief ground observation of these forms in winter 1991 (by Rinker). Grain size was reported by Holm[1] to range from fine to medium (0.06 to 0.5 mm). Simple and isolated complex domes can be bypassed easily enough on the desert floor, except in sand or granule ripple localities (see Summary Sheets for Ripples - Sand, and for Ripples - Granule (Megaripples)). In dry years, some giant domes may be unclimbable because of loose sand on all sides and rows of active barchanoid dune ridges on their summits. Where there is evidence of stabilization such as scattered vegetation, flocks of grazing sheep, etc., the dome surfaces are firm enough to support light 4-wheel-drive vehicles. Slip faces of secondary dunes on the flanks and tops of the domes must be avoided. Topographically confined ergs (e.g., those in narrow valleys in Saudi Arabia) may contain closely spaced large complex domes; such ergs are best crossed by car along the elongate deflation hollows and hard-packed sand on the low ridges that connect the large domes.[1]

FOREIGN NAMES AND SYNONYMS (common names are underlined): Demkha (some).

REFERENCES:

[1]Holm, D.A. 1953. Dome-shaped dunes of the Central Nejd, Saudi Arabia. Comtes Rendus de la Dix-Neuvieme Session, Congres Geologique International, Alger, 1952, Fascicle VII, pp. 107-112.

[2]Breed, C.S., S.G. Fryberger, S. Andrews, C. McCauley, F. Lennartz, D. Gebel, and K. Horstman. 1979. Regional studies of sand seas using Landsat (ERTS) imagery. In A study of global sand seas, edited by E.D. McKee. U.S. Geological Survey Professional Paper 1052, pp. 305-397.

DESCRIPTION: These forms are accumulations of loose, well-sorted, very fine to medium sand that are piled up against a rock face (cliff or steep hill) and are encroaching on its summit. Climbing dunes range in size from a meter or two to hundreds of meters in height and breadth. The accumulation gradually increases at the base, building a ramp that is constantly enlarged by the sequential coalescence of oncoming dunes until it reaches the summit. In some localities, climbing dunes are in contact with the rock summit. The oncoming dunes are usually crescentic in shape (see Summary Sheets for Dunes - Crescentic, and for Dunes-Crescentic - Transverse). Climbing dunes have well-packed upwind slopes that are commonly steeper than those of the same types of dunes that are not climbing. Between the lee slope (slip face) of one dune and the upwind slope of the next, there is no flat interdunal space, because each oncoming dune is moving up the back of the one ahead. Between the high, steep slip face of the leading dune (or of the ramp end) and the cliff face on which it is climbing, there is commonly a moat or ditch, which is uncrossable. The presence or absence of a moat is probably a function of the slope of the rock mass being encroached upon. If slopes are greater than about 30°, a moat usually develops, and vehicles cannot traverse the sand ramp directly to the summit. If slopes are less than about 30°, no moat is present; if a climbing dune has reached the summit, it can be used as an access route to and from the top, particularly if the dune feeds to other upper-level sand bodies. At vertical or near-vertical faces, as the wind moves up the ramp surface, that part of the windstream that hits the face causes a turbulent eddy; part of the windstream is forced down the cliff face, across the bottom, and up the slip slope. This reversed current tends to reduce the rate at which sand accumulates on the lee slope. Once the ramp is as high as the cliff face, the back eddy does not form, and sand will eventually fill the moat and provide a usable ramp between the two levels.

WIND REGIME: Winds that maintain climbing dunes are strong and virtually unidirectional. They are particularly common in coastal deserts where there are strong sea breezes and an ample supply of beach sand.

ENGINEERING AND MILITARY USES: Grain size of these loose, well-sorted, very fine to medium sands is about 0.06 to 0.5 mm. Trenching is not feasible unless the dunes are wet. The wind-compacted ramp slope will support foot and light to medium vehicular traffic. As noted above, however, an uncrossable moat is common between the dune and the steep rock face that it is approaching if the slope of this face exceeds 30°. In some climbing dunes no moat is present and the climbing dune provides access to and from the top of the rock face. On detailed stereo air photos or other imagery, one can usually determine the presence of a moat.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Sand ramps.

DESCRIPTION: Falling dunes are accumulations of loose, well-sorted, very fine to medium sand on the downwind side of topographic highs, such as scarps, mesas, buttes, or hills. Falling dunes range in size from a meter or two to hundreds of meters in height and breadth. As the sand accumulates in the lee area, it eventually forms a continuous ramp that extends from the higher elevation to the lower surface. The gradient of this ramp is usually less than a slip-face gradient. Beyond the lee area, the wind currents converge and frequently shape the accumulated sand into an elongate dune that tapers downwind. Falling dunes are often feeders for dune fields of various kinds beyond the base of the falling slope--out on the basal slope or plain. Other falling dunes often calve into small isolated barchans or barchan trains.

WIND REGIME: Falling dunes accumulate in the lee of a topographic high where the divergence of a fairly unidirectional wind passing over the brink of the high produces a zone of lower air pressure and slower speed, causing the airborne load to be dropped when it enters that zone. Wind currents converging beyond this zone continue to move the accumulated sand and mold it into other forms.

ENGINEERING AND MILITARY USES: Grain size ranges from about 0.06 to about 0.5 mm. Because larger falling dunes are older than smaller ones, their surfaces are more packed and firm; if their ramps are continuous, they can provide a route for foot and vehicular traffic from the upper elevation to the lower.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Sand ramps.

DESCRIPTION: These dunes are accumulations of loose, well-sorted, very fine to medium sand on the downwind side of obstacles such as rock outcrops and boulders. Those that form in the lee of vegetation are called by other names (see Summary Sheets for Dunes - Coppice, and for Dunes - Vegetation Mounds). Dunes that accumulate as narrow, tapering ridges on the lee sides of obstacles are called lee dunes. Where the dunes extend tens to hundreds of meters downwind, they commonly resemble linear dunes of the seif variety. Very small (meter-size) accumulations are sometimes called shadow dunes, especially where the sand has piled up on the desert floor downwind of individual rocks.

WIND REGIME: These forms accumulate on the downwind sides of obstacles where the wind speed has lessened and the wind has dropped its sand load. These dunes show the resultant (net sand-moving) direction of the local winds, generally approximating the prevailing wind. Small dunes in the lee of grasses, small bushes, and pebbles are the most ephemeral of these features, and the direction of their elongation indicates the direction of the most recent sand-moving wind.

ENGINEERING AND MILITARY USES: Grain size ranges from about 0.06 to about 0.5 mm. Because of the small size of these dunes, they are seldom a problem to cross-country movement.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Sand shadows, sand tails, wind drifts, wind-shadow dunes, trailing dunes.

DESCRIPTION: In plan view, these are U-shaped or V-shaped mounds of well-sorted, very fine to medium sand with elongated arms that extend upwind behind the central part of the dune. Slip faces occur on the outer (convex) side of the nose of the dune and on the outside slopes of its elongated arms. These dunes occur in semi-arid areas, i.e., where some precipitation is common and near-surface moisture is retained in the lower parts of the dune and underlying soils. Parabolic dunes are always associated with vegetation--grasses, shrubs, and occasional trees, which anchor the trailing arms. In inland deserts, parabolic dunes commonly originate and extend downwind from blowouts in sand sheets only partly anchored by vegetation. They can also originate from beach sands and extend inland into vegetated areas in coastal zones and on shores of large lakes. Small sand mounds commonly form around bushes, such as mesquite (Prosopis), and are called coppice dunes (see Summary Sheet for Dunes - Coppice). They are frequently found on sand sheets and on and around larger parabolic dunes. Most parabolic dunes do not grow to heights greater than a few tens of meters except at their forward portions, where sand piles up as its advance is halted or slowed by surrounding vegetation. Simple parabolic dunes have only one set of arms that trail upwind, behind the leading nose. Compound parabolic dunes are coalesced features with several sets of trailing arms. Complex parabolic dunes include subsidiary superposed or coalesced forms, usually of barchanoid or linear shapes.

WIND REGIME: Parabolic dunes, like crescentic dunes, are characteristic of areas where strong winds are unidirectional. Although these dunes are found in areas now characterized by variable wind speeds ranging from low to high, the effective winds associated with the growth and migration of both the parabolic and crescentic dunes probably are the most consistent in wind direction.

ENGINEERING AND MILITARY USES: The grain size for these well-sorted, very fine to medium sands is about 0.06 to 0.5 mm. Parabolic dunes have loose sand and steep slopes only on their outer flanks (the lee slopes). The inner flanks are commonly well packed and somewhat fixed by vegetation, as are the corridors between individual dunes. Because all dune arms are oriented in the same direction, and (except for coppice dunes), the interdune corridors are generally swept clear of loose sand, the corridors can usually be traversed in a direction parallel to the long axes of the dunes. Travel in a transverse direction, across the lower parts of the trailing arms, can be very difficult. The noses of the parabolic dunes, which consist of soft sand, are not readily crossed with wheeled vehicles, but they can usually be bypassed without great difficulty. Some level of horizontal cover and concealment is frequently possible. Trenching may be done in the more firmly packed and older parts of the dunes that have been partly cemented by soil formation.

FOREIGN NAMES AND SYNONYMS (common names are underlined): U-shaped dunes, blowouts, banner dunes.

DESCRIPTION: Lunettes are accumulations of semiconsolidated fine sand, silt, and clay-pellet aggregates that form rounded, low (meters high) dunes on the downwind sides of playas. Like ordinary parabolic dunes, these dunes are transverse to the effective wind (see Summary Sheet for Playas), and their arms point upwind. The arms, however, are much shorter than those of parabolic dunes because lunette dunes are composed of cohesive materials deflated from the adjacent playa floor. Also, because they are composed mostly of highly cohesive clay particles rather than loose granular material, lunettes do not have slip faces. They are readily detected on aerial photos because of their relatively bright reflectivity, arcuate shapes in plan view, and proximity to the downwind borders of playas. Because of their low relief, they can be difficult to discriminate on the ground. Lunettes are common in semiarid regions such as Texas, New Mexico, southern Africa, and central Australia. Their size is roughly proportional to the size of the playa from which they grow.

WIND REGIME: Lunettes generally form in semiarid areas dominated by an effective unidirectional wind regime, which allows deflated particles to accumulate preferentially along just one side of playas.

ENGINEERING AND MILITARY USES: Grain size is about 0.002 to 0.3 mm. The presence of lunettes indicates a nearby clay playa that may be suitable for aircraft landings, or may be wet and sticky. The lunette itself may have a relatively soft surface, depending on the amount of loose sand and vegetation present. In general, lunettes are minor features that do not present significant impediments to cross-country movement.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Clay dunes.

DESCRIPTION: Coppice dunes are vegetated sand mounds that are commonly scattered throughout sand plains in semiarid regions where shrubs and blowing sand are abundant. They are composed of very fine to medium sand, and their side slopes are loose and soft. The size and shape of a coppice dune depend on the amount of sand available, the characteristics of the wind (speed, direction, intensity, constancy), structural properties and growth characteristics of the shrubs, and age of the sand accumulation. Coppice dunes can be incipient forms of parabolic dunes; both forms are always associated with vegetation, which anchors them. Any shrub sticking up into the airborne stream of sand is an impediment to the flow, and the resulting turbulence and speed losses cause sand grains to settle out on the downwind side of the shrub and around its base. The canopy structure of a shrub and its amount and distribution of openness, which vary from species to species, greatly influence the shape of the sand deposit. Only certain kinds of plants are associated with coppice dunes, because only those "edifying" species that can form new roots and shoots from buried branches can continue to grow as the sand accumulates around them. Plants associated with these dunes include Ephedra (Mormon tea), Prosopis (mesquite), Atriplex (saltbush), Acacia (tarfa), and Tamarix (tamarisk). Some of these have thorns. If the sand accumulates faster than the plant can grow, the plant will die, and the dune will usually be deflated by wind.

Coppice dunes range from about 0.5 to 3 m in height and from 1 to 15 m in breadth. Within any given field of coppice dunes, however, the dune size tends towards uniformity. Under certain conditions, individuals or clusters of dunes can become very large and are called vegetation mounds (see Summary Sheet for Dunes - Vegetation Mounds). Because the sand accumulates in piles around the plants and is swept from the surfaces between, a hummocky, rough topography develops that is very different from the smooth, flat, and locally gently undulatory surfaces of sand plains devoid of vegetation. The interdunal areas, which have very little vegetation and are frequently barren, typically have firm, troughlike, scoured surfaces of hard-packed soil, with thin patches of rippled sand or granules.

WIND REGIME: Details are not known.

ENGINEERING AND MILITARY USES: These dunes are obstacles to cross-country movement and prevent use of fixed-wing aircraft; however, rotary-wing aircraft can operate among coppice dunes that are small and widely spaced. Trafficability varies: if a field is composed of relatively small, closely spaced dunes, it may be impossible to find a path the width of a vehicle, and the going will be bumpy and slow even for foot traffic. Where the dunes are too high to be crossed over, they are usually spaced far enough apart to go between them. Although the interdunal surfaces are firm and will support vehicular traffic with a minimum of dust generation, the path will wind to avoid the dunes. Fields of larger mounds can provide cover and concealment in a horizontal direction. Because of the "speckled" pattern of the vegetated mounds against the interdunal surfaces, operational units can be obscured more than on a uniform and featureless plain. Although, on the larger dunes, one can crawl into the vegetation mass for concealment, there will be thorns, insects, snakes, and other forms of wildlife. Thorns found around the bases of the mounds can puncture shoes and tires. The tires do not instantly go flat, but they eventually develop slow leaks as the thorn tips work their way through.

DESCRIPTION: Vegetation mounds, commonly found on sand plains, are large clumps or clusters of small trees and shrubs such as Acacia (tarfa) and Tamarix (tamarisk) with accumulations of sand at their bases, trapped by the vegetation. In this respect they are similar to very large, solitary coppice dunes, or to parabolic dunes. They differ, however, in size and distribution. Their size range overlaps slightly that of coppice dunes (see Summary Sheet for Dunes - Coppice), but they may be as long as 80 m and as high as 20 m. Unlike coppice dunes, which are usually in a field of many individuals spread over a large area, vegetation mounds generally occur singly or in small groups that may have a lineal arrangement. These mounds are commonly aligned along the remnants of old water channels now buried beneath a sand sheet. Traces of these channels can be seen on some types of imagery, especially L-band radar. The shrubs that form these mounds are phreatophytes with very deep roots. Salts typically collect in surface crusts around certain types of shrubs that shed salt from their leaves during transpiration of water taken up by the plant roots. Much of the wildlife in deserts makes its home in the vegetation mounds--insects, birds, poisonous scorpions and snakes, rodents, and occasionally a pair of desert foxes.

WIND/WATER REGIME: It is likely that many vegetation mounds are relics of wetter environmental conditions, having started as coppice dunes formed around vegetation aligned along old water channels or around moisture-retaining basins. As the sand accumulated, the plants developed an ever more extended root system to reach water stored at the base of the mound. If the mounds build up beyond the ability of the plants to reach water, the vegetation will die.

ENGINEERING AND MILITARY USES: Vegetation mounds can be the only navigational points on a sand plain that can be recognized on both aerial photographs and satellite images such as Landsat and radar. On the ground, however, they may appear differently when viewed from different directions, which can be confusing. They are good sources of firewood, but because of the wildlife, particularly insects and snakes, they make poor places to camp. They offer almost the only areas for cover and concealment on sand plains, and they can also serve as observation posts. Shallow water can sometimes be found by digging beneath the sand in vegetation mounds, but it is likely to be saline. Also, there is a possibility of obtaining water from the old channels if mobile drilling equipment is available. The sand around Acacia mounds is frequently covered with fallen thorns, twigs, and branches that can produce annoying small puncture wounds in those sitting or lying on the surface. These thorns will easily puncture the soles of light desert boots with crepe soles, and they can cause leaks in tires.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Tarfa, nebkha, coppice dune, rebdou, parabolic dune (some).

DESCRIPTION: These features are so named because they look like water ripples. Our definition of the ripples described here, modified from Harms[1] follows: Ripples are depositional bedforms produced in loose, granular material by wind or water. Ripples formed by wind range in size from those only a few centimeters apart to giant ripples as far as 0.5 km apart. Fields of giant ripples resemble fields of small, low transverse or barchanoid dunes, and they are best developed on the sand sheets of the hyperarid core of the Sahara (Breed, et al).[2] Ripples are frequently described in terms of the distance between adjacent crests (wavelength) and their height (amplitude); the "ripple index" is the ratio of wave-length (spacing) to height (Sharp).[3] Although they can be asymmetrical in cross-section and have upwind slopes and lee slopes, ripples are formed without boundary-layer separation of the airflow. Thus they do not develop the slip faces (avalanche slopes) of dunes, and they travel differently than dunes.

Ripples are formed in materials ranging in grain size from silt to pebbles. Most of the fine to medium sand deposited by wind in deserts appears to be transported in sand ripples that migrate across surfaces to zones of accumulation, where the sand piles up in dune fields. Ripples composed of coarser materials are less mobile; once formed, they tend to stay put because they are in equilibrium with the strongest local winds. The coarsest grains usually accumulate on the ripple crests, not on the lower slopes as on dunes. At places, the ripple pattern contains dark tones, which are due to concentrations on the ripple crests of heavy minerals, e.g., ilmenite or magnetite, or fragments of mafic rock. The interiors of some ripples consist of thin layers of coarse and fine sediments that appear to be flat bedded or gently inclined, i.e., the bounding planes typically dip less than 15°. The mechanisms that produce the various types of ripples and account for differences in their size, shape, and grain-size distribution are not understood, and their classification is not agreed upon. With the exception of sand ripples, which are ubiquitous in deserts, the worldwide distribution of ripples is not known. Giant ripples and ripples of very coarse particles seem to be restricted, however, to hyperarid regions whose strongest winds are virtually unidirectional. To date, the most extensive and best known pebble ripples have been found in coastal Peru. The wind ripples listed below are classified on the basis of ripple shape, ripple size, and grain size.

- Sand Ripples
- Truncated Ripples
- Pebble/Gravel Ripples
- Granule Ripples (Megaripples)
- Giant Ripples

WIND REGIME: On open plains, ripples of various types occur in patches, and their orientations are generally transverse to the prevailing winds. In and near dune fields, and around clumps of vegetation and rock obstacles that produce secondary and reverse flow patterns, ripples are commonly oriented in various directions that reflect complex wind currents controlled by the local topography. Winds that move ordinary sand ripples must have a minimum speed of 24 kph (13 knots), the average threshold speed for moving loose, dry sand grains. Winds have not been measured during the formation of truncated ripples and granule ripples, but such winds are generally thought to have much higher speeds. Giant ripples probably accumulate under a combination of all sediment-transporting wind conditions, because they are built up of all the components of the smaller ripples in addition to fine grains deposited from suspension.

ENGINEERING AND MILITARY USES: By themselves, ripples do not present severe limitations to trafficability, but care must be exercised and, in some cases, progress will be slow. Only closely spaced pebble and granule ripples seriously impede ground traffic; the crests of such ripples are generally several meters apart and 30 cm or more high. These "washboards" have a relatively firm surface and can be traversed. However, they should be approached at an oblique angle and crossed at low speeds to prevent severe jarring and possible loss of vehicle control. The presence of abundant sand ripples generally indicates nearby patches of loose sand or dunes (soft terrain), and precautions that apply to dunes should be taken. Truncated ripples occur on flat sand plains and do not look hazardous, but they are difficult to cross with wheeled vehicles except at low speeds. Giant ripples are characteristic of gently rolling sand plains and generally can be easily traversed; they can also support limited aircraft operations. Helicopter operations are practical on all ripples common to sand plains, except those associated with the thick, loose sand of dune fields.

REFERENCES:

[1]Harms, J.C. 1969. Hydraulic significance of some sand ripples. Geological Society of America Bulletin, v. 80, pp. 363-396.

[2]Breed, C.S., J.F. McCauley, and P.A. Davis. 1987. Sand sheets of the eastern Sahara and ripple blankets on Mars. In Desert Sediments: Ancient and modern, edited by L.E. Frostick and I. Reid. Geological Society of London Special Publication, no. 35, pp. 337-359.

[3]Sharp, R.P. 1963. Wind ripples. Journal of Geology, v. 71, no. 5, pp. 617-636.

DESCRIPTION: Sand ripples are relatively small (centimeter scale), low, rounded, closely spaced features composed of sand-sized particles. They are ubiquitous in dune fields and on their aprons and trailing margins. Sand ripples are ephemeral features that represent the most recent effective wind directions, and their patterns can change in a single windstorm. Much of the fine to medium sand deposited in deserts by wind is transported across the surface by these ripples. They are significant in desert operations only because they are commonly associated with deposits of underlying, uncompacted loose sand.

WIND REGIME: The threshold wind speed for moving dry sand grains, about 24 kph (13 knots), is the minimum required to develop sand ripples. Prevailing wind direction is generally transverse to the long dimensions of the ripples, but perturbations of wind currents due to local slopes commonly produce local variations within a ripple field.

ENGINEERING AND MILITARY USES: Grain size ranges from about 0.06 to 0.5 mm. The presence of abundant sand ripples on a desert surface indicates that patches of possibly loose sand or sand dunes are underfoot or nearby. The ripples themselves are small, soft features that can be crossed in any direction by vehicles, but underlying loose sand can be a problem to vehicles and fixed-wing aircraft (see Summary Sheets for Dunes).

DESCRIPTION: These ripples are generally less than 1 m long, 5 to 10 cm high, and 30 to 100 cm apart; they are thus higher and more widely spaced than ordinary sand ripples. They are relatively straight, unconnected, and parallel. Their tops are flattened, as if planed. Truncated ripples are composed of sand grains and granules, have a firm surface, and seem to be most common on sand plains near dune fields and large bedrock obstacles where migrating sand is abundant. In plan view, these ripples are difficult to detect and identify even on large scale air photos, but they should be expected in areas that show dune fields, bedrock outcrops and obstacles, and wind streaking. Truncated ripples have been observed covering kilometer-scale patches of terrain in the deserts of southwestern Egypt and northeastern Sudan.

WIND REGIME: Unknown. Winds presumed to be stronger than those forming ordinary sand ripples.

ENGINEERING AND MILITARY USES: Truncated ripples do not look hazardous because they are small and flat, but the grooves between them are stable and just large enough to severely jolt passing vehicles. Consequently, they can be difficult to cross except at very low speeds and at oblique angles. Unless the illumination angle is just right, the ripple pattern is difficult to spot from the ground, especially when a vehicle is driven downwind. Inadvertent high-speed entry into a ripple field from an adjacent smooth area can end in roll-overs of jeep-type vehicles. These ripples also inhibit operations of small, fixed-wing aircraft. We do not know if they pose a problem to heavier, multi-engine aircraft, but those with larger wheels should operate more safely.

DESCRIPTION: Pebble or gravel ripples resemble ordinary sand ripples in that they are small (centimeter scale), low, closely spaced and flat, but they are made up of small pebbles or gravel. Such ripples have been seen in coastal Peru and the Dry Valleys of Antarctica, and they are common on the sand sheet of the eastern Sahara, where lag-gravel ripples form broad patches or pavements. Some of these patches cover several square kilometers and appear as dark areas on Landsat images. In Egypt's Western Desert, patches of these ripples are commonly overlain by thin, more mobile sand layers; the ripples and overlying sand layers appear as chevron-shaped features in small-scale imagery such as Landsat.

WIND REGIME: Unknown except that wind direction is down-ripple (or transverse to the long dimension). Pebble ripples are probably longer-lasting than sand ripples, because only strong winds can rearrange them.

ENGINEERING AND MILITARY USES: Grain size ranges from 4 to 30 mm. Pebble or gravel ripples form an ideal surface for foot traffic, wheeled vehicles, and aircraft operations of all kinds, because they are stable and have little dust potential (see Summary Sheet for Desert Pavement). With caution, these ripples can be used as landing areas for both light and heavy fixed-wing aircraft. They are the best places to stop when traveling across a sand plain, because they provide traction to wheeled vehicles.

DESCRIPTION: Although made up of particles in about the same size range as the smaller scale pebble/gravel ripples, granule ripples (Sharp)[1] are far more widely spaced (meters), higher (as high as 1 m), and less regular in shape. The average size of the coarsest grains is consistent for a given area and is probably that of the largest particles that can be moved by the strongest winds at that location. Whether the shape or size of these ripples varies as a function of grain size is not known. Neither do we know why or how large granule ripples and small gravel ripples can result from source materials of virtually the same grain-size range; it may be local variations in the windstream in response to differences in local surface relief. Granule ripples occur in fields that may cover only a few square meters in isolated patches, as in parts of the Sahara, or an entire plain of hundreds of square kilometers, as in parts of coastal Peru. In Peru they are at places aligned in long rows parallel to the windstream, i.e., the long axis of the row is perpendicular to the long axes of the ripples.

WIND REGIME: Granule ripples are transverse to the prevailing wind or to local wind currents near obstacles such as rock outcrops and dunes. Ripples of this type are often found where topographic funnels--typically valleys and gaps between dunes or yardangs--constrict the regional air flow, thereby increasing its speed.

ENGINEERING AND MILITARY USES: Grain size ranges from approximately 4 to 30 mm. Where possible, wheeled vehicles should cross granule ripples at oblique angles, because they are firm and large enough to make travel very jarring at even slow speeds, i.e., they are giant washboards. Like truncated ripples, they are particularly troublesome when a vehicle is driven downwind, because they are almost invisible until the vehicle has struck one, causing severe bouncing, loss of control, and possible roll-over. When a vehicle is driven upwind, they can generally be seen soon enough to slow down and maintain control. These ripples also present a problem to fixed-wing aircraft operations, and, depending on size and arrangement, they can prohibit them. Aircraft landings on these ripples should not be made in the usual direction (directly upwind): landings should have an upwind component, but at about a 45° angle to the pattern of the individual ripples. Once down, the aircraft has the same problem as wheeled vehicles, i.e., washboard terrain. The oblique landing pattern, however, will minimize this effect. DC-3 aircraft have operated from such surfaces in support of oil operations.

REFERENCE:

[1]Sharp, R.P. 1963. Wind ripples. Journal of Geology, v. 71, no. 5, pp. 617-636.

DESCRIPTION: Giant ripples are extremely large, low, flat undulations (a few meters high) spaced as far apart as 0.5 to 1.0 km; they produce a gently rolling topography over many sand plains in the eastern Sahara. Giant ripples were not recognized as widespread aeolian bedforms until they were observed on Landsat images of that region (Breed, et al.).[1] In size, these ripples resemble fields of small, very low relief transverse or barchanoid dunes on Landsat images and low-sun-angle aerial photographs. Like dunes, they are composed of loose granular material but in a much broader range of grain sizes (silt to fine gravel). Unlike dunes, giant ripples do not have avalanche slopes (slip faces). Their interiors are commonly composed of flat or gently inclined beds made up of very thin layers (laminae) of coarse and fine sediments that dip less than 15°, commonly less than 5°. The surfaces of the giant ripples are fairly firm, commonly composed of lag gravels, granules, or very coarse sand one grain thick, which may be locally organized into pebble, granule, or truncated ripples. Giant ripples are widely distributed on sand sheets that cover broad, open plains, as in the eastern Sahara. Rolling dunelike features without slip faces have been called "zibars" in other parts of North Africa and on the Arabian Peninsula (Warren[2]; Holm[3]). Zibars are generally smaller, less widely distributed, and of more definite shape; they are common on sand sheets in the U.S., where they are localized in and around dune fields. Present work suggests that giant ripples and zibars may be sufficiently dissimilar to justify a separate classification.[1]

WIND REGIME: The mode of origin of giant ripples is not known, but they seem to be actively forming only in areas without vegetation. Giant ripples signify the presence of winds that, at times, are capable of moving particles of all sizes from dust (coarse silt) to small pebbles.

ENGINEERING AND MILITARY USES: These surfaces can be easily traversed by wheeled vehicles, and will also support aircraft operations, especially on the lag surfaces. Large fixed-wing aircraft will usually generate dust because the wheels break up the surface and the propeller wash blows away the exposed fines. With such an aircraft, however, and a choice between landing on an unknown playa or on a plain covered by giant ripples, take the giant ripples. A sand plain surfaced with giant ripples can also affect cross-country movement because the relief variations can be used to tactical advantage. These subtle elevation changes commonly go unnoticed by people on the ground, because of the long spacing between ripple highs, and the extreme gentleness of the slopes. If observant, one might notice that, in places, the horizon seems closer when looking upwind or downwind, or that a vehicle moving across the terrain can appear and disappear. Thus, as with any gently rolling landscape, these features can provide some degree of horizontal cover and concealment if one travels along the lows. Travel across the ripple pattern will lead to alternate exposure and obscuration.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Sand sheets (SW Egypt and NW Sudan), zibars (some).

REFERENCES:

[1]Breed, C.S., J.F. McCauley, and P.A. Davis. 1987. Sand sheets of the eastern Sahara and ripple blankets on Mars. In Desert Sediments: Ancient and modern, edited by L.E. Frostick and I. Reid. Geological Society of London Special Publication, no. 35, pp. 337-359.

[2]Warren, A. 1972. Observations on dunes and bi-modal sands in the Tenere Desert. Sedimentology, v. 19, no. 1-2, pp. 37-44.

[3]Holm, D.A. 1960. Desert geomorphology in the Arabian Peninsula. Science, v. 132, no. 3437, pp. 1369-1379.

DESCRIPTION: Sand plains are flat or gently undulatory broad floors that are veneered by sand sheets (tabular deposits ranging in thickness from a few centimeters to a few meters). Some sand sheets, as in the southwestern U.S., are local deposits that extend only a few square kilometers in and around dune fields, where they are exposed on interdune floors and form the aprons or trailing margins of dune fields. Other sand sheets extend over thousands to tens of thousands of square kilometers. Such regionally extensive features occur in southwestern Egypt and northwestern Sudan (Eastern Sahara), where they are overlain by a few isolated dune fields. Some regional sand sheets have been given geographic names: in the Eastern Sahara, the Selima Sand Sheet extends over at least 100,000 sq km and ranges in thickness from 1 cm to at least 10 m (Breed, et al.).[1]

Sand sheets are probably built from successive deposits of sand left behind by the migration of ordinary small sand ripples (see Summary Sheet for Ripples - Sand), along with fine sediment (dust) deposited from suspension, and gravel or granules moved by creep. They are composed of gently inclined or nearly horizontal layers, each less than about a centimeter thick, of coarse silt and very fine to medium sand separated by layers, one grain thick, of coarse sand and granules. Unlike dune sand, the unconsolidated sand and granules are closely packed and firm underfoot. The surface is protected by a lag, one grain thick, of the coarsest particles that can be shifted by the wind, ranging from coarse sand to pea-size gravel. In any one place, however, the sizes of the lag particles are remarkably uniform, and the lag may be so closely packed that it forms a miniature desert pavement. With time, and under certain conditions of topography (nearby barriers) and supply of materials, the wind can shift the laq particles within an area and pile them up to form other landforms on top of the sand sheet, such as granule or pebble ripples (see Summary Sheets for these features). In many areas, the sand sheet surface is a series of gentle swells called giant ripples (see Summary Sheet for this feature). The relief of giant ripples changes as little as 3 m per kilometer, and they are barely perceptible on the ground. In traversing these features, one is aware of variations in the distant horizon but not of local elevation changes. Giant ripples show on low-sun-angle aerial photographs and, under the right conditions of illumination, make a distinct pattern on Landsat images. Fields of these giant ripples can cover many hundreds of square kilometers of sand plain, but they are not obstacles to cross-country movement.

Where a sand sheet is devoid of a pavement of coarse gravel, is dry, and is less than about 2 m thick, it is transparent to L-band (23 cm wavelength) imaging radar. Radar imagery of such areas shows the consolidated material under the sand sheet, such as caliche (in alluvial valley fills) or bedrock (see Summary Sheet for Duricrusts - Caliche). Areas of thicker but similar sand sheet deposits show as dark patches or areas of no radar return. These patterns can be useful for planning travel routes. To an observer on the ground or in an airplane, and on aerial photographs, the surface of the sand plain looks much the same regardless of the nature or depth of underlying materials.

Vegetation on sand sheets varies with annual precipitation. In semiarid regions, former sand plains often support grasses, shrubs, and occasional trees. On similar materials in arid regions, only a few scattered vegetation mounds may be seen. In very arid regions, grasses grow only in patches of loose sand and usually indicate soft surfaces and recent precipitation or near-surface water. As the amount and size of the vegetation elements increase, so does the roughness, because lee dunes form behind every obstacle to the airflow. With increasing roughness and more soft dune sand, coppice dunes form, and trafficability on the sand plain decreases accordingly.

WIND REGIME: Sand sheets in themselves indicate little about wind regimes, but the particle size of sand and gravel lag on ripple surfaces seems dependent on the strength of the winds in any given locality. In some places, many pebbles are ventifacted and oriented into the prevailing strong wind (see Summary Sheet for Ventifacts).

ENGINEERING AND MILITARY USES: Grain size is about 0.002 to 30 mm. The sand sheet deposits that form the surface of a sand plain range in thickness from about 1 cm to about 10 m. They are easily excavated, but side walls of trenches will collapse unless shored up. Beds of duricrusts (usually caliche or laterite) 2 to 3 m thick are often encountered in alluvial deposits beneath loose sand sheets, commonly within a meter of the surface. Digging into these rock-hard deposits usually requires mechanized trenching equipment (see Summary Sheet for Duricrusts). Such trenches will stand unsupported and can provide good cover. Although sand sheets themselves are usually not dust producers, they can conceal underlying dust-producing materials such as playa deposits or weathered shales (nafash). Some familiarity with the regional topography and rock units mantled by the sand sheets is needed to avoid these areas. Surface water is generally not available, but shallow subsurface water may occur near vegetation mounds or patches of grass. Sand plains underlain by bedrock or by duricrusts can support aircraft operations (fixed-wing and rotary), and they are ideal for cross-country movement on foot or in vehicles. Vehicles can attain speeds of 90 to 100 kph and easily maintain a constant pace for 60 to 90 km over these surfaces. One exception is where bedrock outcrops just graze the surface from below. Encountering these at a high speed from a smooth lag surface can cause vehicle damage or loss of control. These sharp, rocky, and rough areas are usually varnished and, thus, recognizable by their dark tones. Sand plains are remarkably homogeneous, bland topographic features that offer little opportunity for cover and concealment but provide good surfaces for rapid cross-country movement. In the Sahara, sand plains were used extensively by British forces during World War II to supply military operations along the Mediterranean coast from the south, across the Selima Sand Sheet, thereby avoiding population centers and unwanted reporting of their activities. On the other hand, sand sheets on coastal plains may conceal sabkhahs, which are hazardous to travel (see Summary Sheet for Sabkhahs).

FOREIGN NAMES AND SYNONYMS (common names are underlined): Sheet sands, cover sands, bahadas (some), zibars, dry interdunes, ripple ergs.

REFERENCE:

[1]Breed, C.S., J.F. McCauley, and P.A. Davis. 1987. Sand sheets of the eastern Sahara and ripple blankets on Mars. In Desert sediments: ancient and modern, edited by L. Frostick and I. Reid. Geological Society of London Special Publication, no. 35, pp. 337-359.

DESCRIPTION: These features are elongated, relatively thin drifts or patches of loose, windblown sand devoid of slip faces. They can be small (meters), and somewhat irregular in shape, or large (tens of kilometers long), forming well-defined patterns that can be seen on Landsat images. They commonly occupy low areas and have irregular outlines. They are more like sand sheets in composition and character than like dunes.

WIND REGIME: Not known. They probably indicate the net sand-moving direction, approximating that of the prevailing wind.

ENGINEERING AND MILITARY USES: In general, these streaks do not pose a problem to surface vehicles. They provide no cover or concealment and, when dry or when the wind is blowing, are poor areas in which to attempt trenching.

DESCRIPTION: Sand seas, also called "ergs" after the Arabic name for dune fields, are regional accumulations of windblown sand that contain numerous, very large dunes of compound or complex form. Individual dunes in sand seas typically have widths, lengths, or both dimensions greater than 500 m. Both the regional extent of their sand cover and the complexity and great size of their dunes distinguish sand seas from dune fields. The latter features are of local extent and contain dunes that are smaller and simpler in form. The term sand sea is applied only to areas where sand covers more than 20 percent of the surface. In both sand seas and dune fields, ridges or mounds of sand are repeated in rows that give the surface a wavy appearance.

Dune fields occur even at high latitudes and in any locality where loose sand can be blown by wind, but sand seas are concentrated in two broad belts between 20 to 40° N and 20 to 40° S latitudes, which include regions crossed by the dry, subsiding air of the trade winds. Active sand seas are limited to regions that receive, on the average, no more than 150 mm of annual precipitation. The largest sand seas are in northern and southern Africa, central and western Asia, and central Australia. In South America, they are areally limited by the Andes Mountains, but they contain extremely large dunes in coastal Peru and northwestern Argentina. The only active sand sea in North America is in the Gran Desierto of northern Sonora, Mexico, which extends northward into the Yuma Desert of Arizona and the Algodones Dunes of southeastern California. A sand sea that has been fixed by vegetation forms the Nebraska Sand Hills. Dune fields occur in the southwestern U.S. in intermontane basins such as Kelso and Death Valley, California.

Sand seas and dune fields generally occur in regions downwind of copious sources of dry, loose sand, such as dry riverbeds and deltas, floodplains, glacial outwash plains, dry lakes, and beaches. Almost all major ergs are located downwind from abandoned river courses in areas that are too dry to support extensive vegetative cover and are thus subject to long-continued wind erosion. Sand from these abundant sources migrates downwind and builds up into very large dunes where its transport is halted or slowed by topographic barriers to windflow or by convergence of windflow. Entire ergs and dune fields tend to migrate downwind as far as hundreds of kilometers from their sources of sand. Such accumulation requires long periods of time. Wilson[1] estimated that at least 1 million years are required to build ergs with very large dunes, such as those on the Arabian Peninsula, in North Africa, and in central Asia. Sand seas that have accumulated in subsiding structural and topographic basins, such as the Murzuk Sand Sea of Libya, may attain great thicknesses (more than 1000 m according to Glennie)[2] but others, such as the ergs of linear dunes in the Simpson and Great Sandy Deserts of Australia, may be no thicker than the individual dunes superposed on the alluvial plain. Within sand seas or dune fields in a given area, the dunes tend to be of a single type. For example, there are ergs or fields of linear dunes, of crescentic dunes, of star dunes, and of parabolic dunes, and these dune arrays tend to have consistent orientations and sizes (Breed and Grow[3]; Breed, et al.[4]).

WIND REGIME: Variations in dune shape and size occur mostly along the margins of ergs or dune fields and near topographic barriers within them, such as mountains, hills, and river valleys. This overall consistency of shape and size reflects a long-term constancy of wind direction and intensity when the basic dune types were being built. New dunes now being built in many sand seas are much smaller than older ones in the same sea, and some are of a different type, indicating changes in the conditions for dune building since the basic pattern of larger and older dunes was established. Differences in dune shapes and sizes around erg margins or near topographic barriers reflect local variations in the regional wind directions and intensities.

ENGINEERING AND MILITARY USES: Trafficability in ergs and dune fields depends on the type of dunes and their associated interdune areas. Interdune areas may consist of firm corridors between adjacent dune ridges, of open plains, or of enclosed basins between dune mounds (see summary sheets for Dunes - Linear/Seif, Crescentic, Star, and Parabolic, and for Interdune Areas).

FOREIGN NAMES AND SYNONYMS (common names are underlined): Nafud, nefud, medanos, alab, aklé, draa, mer de sable, sandveld, qoz (fixed erg), sahra.

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[1]Wilson, I. 1971. Desert sandflow basins and a model for the development of ergs. Geographical Journal, v. 137, Pt. 2, pp. 180-199.

[2]Glennie, K.W. 1970. Desert sedimentary environments: Developments in sedimentology 14, Enclosure 4. New York: American Elsevier Publishing Co.

[3]Breed, C.S., and T. Grow. 1979. Morphology and distribution of dunes in sand seas observed by remote sensing. In A study of global sand seas, edited by E.D. McKee. U.S. Geological Survey Professional Paper 1052, pp. 253-302.

[4]Breed, C.S., S.G. Fryberger, S. Andrews, C.K. McCauley, F. Lennartz, D. Gebel, and K. Horstman. 1979. Regional studies of sand seas using Landsat (ERTS) imagery. In A study of global sand seas, edited by E.D. McKee. U.S. Geological Survey Professional Paper 1052, pp. 305-397.

DEPOSITIONAL PATTERNS

TRANSPORTED MATERIAL - WATER

DESCRIPTION: Playas are enclosed shallow depressions in desert basins, tectonic lows, interdune flats, wadis, and abandoned channels, which contain deposits and evaporites from the impoundment of episodic stream flow or near-surface ground water. Playas can be entirely dry or seasonally filled with water. The sediment load carried into a playa from streams or blown in by wind characteristically includes clay, silt, and fine-grained sand. The evaporites, which come from runoff as well as from ground water, commonly contain chlorides, sulfates, nitrates, carbonates, borates, or other salts, including toxic ones such as cyanates or arsenates. Evaporation of water from playas leaves exposed surfaces of the resident material, which can be any mix of clay, silt, fine sand, and salt.

Playa surfaces change seasonally with addition or loss of water, and with wind activity. They can be smooth to rough, wet to dry, and hard to soft, puffy, flaky, cracked, ridged, and friable, and they can have hummocky relief of 1 to 2 m. Although dust generation by wind erosion of fine particles is common (see Summary Sheet for Depressions - Deflation Hollows/Basins/Blowouts), not all playas are equally susceptible to wind erosion. Hard, smooth, and dry playas with a high clay/low salt content seem to be more frequent along ephemeral, intermittent, and dry desert water courses (wadis). Soft, rough, wet playas with high salt/low clay content tend to occur in depressions whose floors intersect the water table (see Summary Sheets for Depressions and for Sabkhahs). Desiccation cracks, which are indicative of a high clay content, are common on playa surfaces. Such cracks are repeated in networks that break the surface into rectangular or polygonal-like blocks that range from millimeters to tens of meters across. Larger cracks can be 2 to 3 m deep and more than a meter wide at the surface. Large, long, relatively straight cracks also occur, presumably the result of subsurface sapping and subsequent collapse. Under other conditions of moisture and composition, the surface can be broken into relatively smooth polygonal pans, one to several meters wide, separated by sharp, hard ridges 10 to 40 cm high. The causes of this pattern are not known. Although vegetation is absent from the playa surface, it sometimes rings the playa in the form of shrubs, grasses, and reeds.

The downwind margins of many playas are bounded by low mounds of windblown sand, silt, and clay. These mounds are called "lunette dunes" and are built of fine particles and clay aggregates deflated from the playa sediments by wind. They have low relief and no slip faces (see Summary Sheet for Dunes - Lunette). Wind erosion of the semiconsolidated playa sediments, as well as of the lunette dunes, can produce deflation hollows, and wind-aligned hillocks known as yardangs, which can be a few meters high. These are common erosional remnants on playa surfaces in North Africa, Iran, and China, and at isolated localities on lunettes in the U.S., such as Rogers Lake, California.

WATER REGIME: Episodic streams may enter the playa from runoff during or shortly after rainfall in distant watersheds. Water may also appear due to rising ground water in localities where the basin floor or a channel intercepts the water table. Water in evaporitic playas can be highly mineralized, and generally needs treatment to be potable. In Saudi Arabia, silt and clay playas can often hold rainwater as pools floating on the brine below. This water remains very sweet for weeks as the pool evaporates--in fact until the last liquid is gone--and such sites are favorite places for Bedouins to collect drinking water and water livestock.

ENGINEERING AND MILITARY USES: Because of various surface conditions on playas (wet, dry, slippery, soft, sticky, hard, puffy, friable, ridged cracked, etc.), their use for foot and vehicular traffic and aircraft operation ranges from easy to impossible, and must be evaluated according to both composition and moisture. Dry playas produce extreme glare and are typically hot in the summer season.

Playas that are dominantly clay rich and dry will support foot and vehicular traffic as well as aircraft operations, and can generate dust. In photos, most of these playas usually have very light and relatively uniform tones. If wet, the same playas will not support traffic--foot, vehicular, or aircraft and will also show darker tones in an image. If but slightly wet, the surface can become slippery or sticky, and can seriously diminish the take-off capability of fixed-wing aircraft. Under some conditions of composition and moisture content not yet known, a playa crust can have a plasticity that affects fixed-wing aircraft operations, and can make it impossible for heavy aircraft to take off. At a speed well below take-off speed, the plastic deformation rate of the playa crust can be exceeded and, consequently, the crust continually fractures, preventing the airplane from accelerating to its take-off speed (Holt).[1] Both the desiccation cracks and the pan and ridge topography typical of some playas can impede vehicular traffic or prevent fixed-wing aircraft operations. The conditions responsible for these various characteristics are not yet known.

In general, image tones suggest the condition of a playa: bright-toned areas will probably be dry and the darker-toned areas will probably be wet. A very careful check should be made, however, because although the surface might indeed be dry, the material beneath the crust might be a wet, gumbo-like mass, or quicksand. Vehicles breaking through such a crust can become immobile. Playas that contain a mixture of mostly silt and salts present an irregular puffy surface, as do crust-surfaced flats that intersect the water table (see Summary Sheet for Sabkhahs). If dry, the surface can be crossed with wide-tired vehicles, although they will sink several centimeters into this layer. Any traffic, land or air, on these playas will generate a large amount of airborne dust. Aircraft operations should be avoided. If wet, these playas cannot be traversed. The factors that encourage or suppress dust generation and the relations between these factors and image pattern elements are not yet well established, nor are spectral reflectance characteristics that might serve as indicators of these conditions.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Dry lakes, pans, salt lakes, vlei (South Africa), faydah (Saudi Arabia), sabkhahs or chotts (North Africa), nor, nur, or bahir (China), takyrs (Soviet Central Asia), billabongs (Australia), kavirs (Iran), and salinas or salars (Central and South America).

REFERENCE:

[1]Holt, H., U.S. Geological Survey. Personal communication, August 1986.

DEPOSITIONAL PATTERNS

TRANSPORTED MATERIAL - WATER

DESCRIPTION: Sabkhahs (also spelled sabkha or sabkah) resemble playas in that they are depressions in desert floors, and contain fine-grained deposits (silt, sand, clay) and evaporites. Sabkhahs, however, differ enough from playas to warrant a separate description. The term sabkhah (Arabic, plural sibakh) denotes the presence of salt, and always refers to the saline, puffy, crust-surfaced flat basins that intersect the water table. In the Eastern Province of Saudi Arabia, such features are most common in low-lying coastal plains, but older ones can be found in places as far inland as the edges of the Summan Plateau, some 125 km from the coast. Nonsaline playas composed entirely of silt, fine sand, and clay, and which lie well above the water table, also occur in depressions and lows of wadi beds. Some maps have labeled these features incorrectly as "sabkhahs." The processes that form such playas, or "silt flats," differ from those that form sabkhahs. In Saudi Arabia, such nonsaline playas are called faydah (pl. fiyad). If vegetation is present, they might be referred to as rawdah (pl. riyad). These features, when dry, have a characteristic pale color, do not have crusted salts, and provide an excellent driving surface. When wet, they become soft, slippery, and sticky. Such playas frequently hold pools of rainwater which can remain sweet for weeks (refer to Summary Sheet for Playas). Even some sabkhahs with an obviously saline surface crust have shallow, hand-dug wells with drinkable, if brackish, water 2 to 3 m below the surface. When wet, a sabkhah surface shows dark tones in images; when dry, it shows a light-toned salt crust. This crust can be a thick armor plate of salt that will support a load, or a thin layer over quicksand. These surfaces are hygroscopic, and can absorb moisture from fogs and be sticky; in coastal Saudi Arabia fogs are quite common in late August to October. Many sabkhah areas are covered with sand sheet or with dunes. Areas that appear to be interdunal flats are commonly sabkhahs concealed by windblown sand. These areas should be considered nontrafficable until checked out. Sand around sabkhah edges is usually vegetated and hummocky (dikakah). The distribution of sabkhahs is topographically controlled, and borders are defined by beach ridges, marine terraces, discontinuous mesas and shoreline cliffs, old drainageways, or rock outcrops.

ORIGIN: Sabkhahs form where wind erosion removes surface materials down to the water table. Water is always associated with sabkhahs in the form of flooding, runoff accumulation, capillary rise, and tidal fluctuation. The sediments that fill sabkhahs consist of sand, silt, clay, and salts in varying combinations. Their flat surfaces mark the elevation to which soil moisture rises above the static water level: below this surface, the materials are damp, wet, or saturated; above, they dry out and blow away. According to Holm,[1] there are two types of sabkhahs on the Arabian coast: (1) arenaceous, or sand filled, and (2) argillaceous, or clay filled. The arenaceous sabkhah is formed by the in-filling of embayments of the sea with wind-borne sand, and the subsequent reworking of this sand by waves and currents. This type of sabkhah forms in areas downwind of major sand sources (i.e., dune fields), and is especially typical of the Eastern Province of Saudi Arabia. Many of the coastal sabkhahs show growth lines in subparallel arcs that mark former shorelines. The surface of the arenaceous sabkhah is flat and smooth, with gradients of less than 0.5 m per km. During dry periods, capillary water in the sand evaporates and concentrates to a saline brine, with eventual precipitation of salts near the surface. Water rising through pore spaces of the sand increases lubrication, and produces a soft quicksand of low bearing strength. Evaporation of standing water forms a coating of salt crystals, which can thicken into a thick armor plate of salt. If buried under sand this plate can be preserved until dissolved by a rise in water level.

Argillaceous sabkhahs form in sheltered coastal embayments by the manufacture of calcareous mud by algae or other organisms. This mud is wet, soft, sticky, has a low bearing strength, and flows under pressure. Wind-borne sand sticks to the mud and forms layers seldom over 1 m thick. Such a layer will support the movement of a light truck. Once wet, the sand softens so that a heavy vehicle, and sometimes a light one, will sink through until it rests on the frame. A thin sandy crust can appear safe, but should be tested before use. When not covered by sand, an argillaceous sabkhah dries in the summer heat, and, where packed by roadways, hardens to an asphalt-like consistency. Argillaceous sabkhahs are typical of coastal Arabia south and east of Qatar.

ENGINEERING AND MILITARY USES: Sabkhahs mean trouble for cross-country movement, regardless of vehicle type. Without detailed knowledge of the area and conditions, the best advice is to avoid them, even though the bypass route is longer and rougher. One exception is where repeated traffic has already established a compacted track across the flat. On Landsat Thematic Mapper images, many larger sabkhahs show such tracks. If one takes care in staying exactly on the tracks, they provide safe, smooth routes. This is true even when wet, although the surface will then be slippery and care must be taken in braking. A sabkhah in the dry season, if it is pale in color, can often safely be attempted by a light, four-wheel-drive vehicle in a lower gear. One must stop and back out immediately, however, if there is any tendency to sink as far as the differential. This is never safe in a heavy truck, and no attempt should be made on a sabkhah that has that menacing dark color indicating abundant moisture near the surface. Extrication of deeply-stuck vehicles from a sabkhah can be slow, tiring and messy work involving the use of jacks, and bushes, boards or sheet metal to support the vehicle at progressively higher levels. When extensive sabkhahs occur in rough, hummocky, trackless terrain, advantage can often be made of them by driving just inside their very edge, where sand has drifted down from higher ground. This edge will be firmer and provide a nearby escape if flotation is lost.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Playa (saline type), salar, salina (Central and South America), takyr (Soviet Central Asia), salt flat, chott (North Africa), kavir (Iran), salt pan.

REFERENCES:

[1]Holm, D.A. 1960. Desert Geomorphology in the Arabian Peninsula. Science, v. 132, no. 3437, pp. 1369-1379.

Much of the information on sabkhahs was provided by James P. Mandaville, ARAMCO, Dhahran, Saudi Arabia.

DESCRIPTION: Alluvial feature is a term for a landform built of generally unconsolidated and well- to poorly-graded sedimentary deposits of water-transported, detrital material, i.e., clay, silt, sand, gravel, and even larger fragments of rock. These features are associated with past or present drainage courses (see Summary Sheet for Drainage Courses), and they include the following landforms:

Fans
Bajadas
Gravel Plains

Fans form where sediment-laden streams leave their channels for more open areas, where they spread out, slow down, and dump their load, creating a mound that is fan-shaped in plan view. Bajadas are formed by the lateral coalescence of separate fans into a broad, continuous, alluvial slope. Gravel plains are level or gently sloping surfaces veneered with closely packed, rounded pebbles, cobbles, and boulders. They are found on pediments, large fans, terraces, in valleys, and on the floors of drainage courses.

WATER REGIME: Water transport is by episodic streamflow, flash floods, and sheet wash that, when abated, leave alluvial deposits in streambeds, on terraces and flood plains, and on pediments and the side slopes of valleys.

ENGINEERING AND MILITARY USES: Most alluvial surfaces can support vehicular traffic and aircraft operations. Dust can be a problem. Conditions for cover and concealment are variable; trenching is difficult, especially if caliche is present at shallow depth, or in very coarse-grained deposits close to the mountain front from which they came. These deposits can also be good sources for construction materials.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Alluvium, bolson plain, bajada, alluvial fan, alluvial fill.

DESCRIPTION: Alluvial fans are formed by the sequential deposition of sediments carried by episodic streams that issue from water courses in mountain fronts onto broad, open areas where the streams spread out, quickly lose their speed, and dump their sediment load. The load can be any mix of boulders, gravel, sand, silt, and clay, depending on the sources of the materials and the volume and speed of the stream. Because of the speed gradient, the particles are sorted: the largest are dumped near the channel mouth (where the first loss of speed occurs), and the finest particles are carried downslope to the outer reaches of the fan. These deposits radiate outward from their apex and have a fanlike shape in plan view. The transverse profile is arched and the longitudinal profile has a fairly uniform, gentle gradient. The fan shape is related to sediment grain size, in that the finer the particles in the sediment load, the lower, broader, and longer the fan; the coarser the material, the higher and more pronounced the profile arch. For a cobble fan this profile is almost hemispherical in shape, with steep flank slopes. For a silt/sand/fine gravel mix this profile is broad and flattened. Fans range from meters to kilometers in extent and from centimeters to meters in height.

In desert regions, alluvial fans are built by streams issuing from mountain canyons and ravines onto the surrounding plains. Individual fans coalesce downslope into larger, composite landforms called bajadas, or aprons, which cover the lower bedrock slopes of the mountains. Fans and bajadas are best developed in semiarid deserts, where elongate mountain ranges (basin-and-range topography) are subject to episodic heavy precipitation. The surfaces of alluvial fans are cut by distributary channels that radiate downslope from the apex, forming a braided pattern, and by secondary gullies that are carved by local runoff. These braided surface patterns change as the channels shift back and forth during floods. Many fans are partly or completely covered by a desert pavement, which is smooth on fine-textured, low-arched fans and rough on coarse-textured, high-arched fans (see Summary Sheet for Desert Pavement).

WATER REGIME: Episodic flow of sediment-laden water onto the fan comes from streams in the adjacent mountains. The water is runoff from precipitation in some part of the mountain watershed, which can be many kilometers away.

ENGINEERING AND MILITARY USES: Most low, arched fans and the outer parts of large fans have smooth gravel surfaces (desert pavement), which are suitable for vehicular and foot traffic, either for traversing the country or for passing from basin floors to the upper slopes of the mountains. Many of these areas can support some level of fixed-wing aircraft operations. These pavements can, however, be broken by heavy vehicles or by multiple passes of light vehicles, exposing a fine sediment that can produce dust or is soft enough to impede movement. Even where the pavement is not broken, its surface may bear residual dust and sand that becomes airborne when disturbed by fast-moving vehicles or aircraft. Most fan slopes are less than 10°. On highly arched fans, however, the pavements can contain fragments 40 cm across or larger that protrude significantly above the average surface. Because of the orientation of the channels and gravel ridges, there is a "grain" to the surface that, depending on the relief involved, can influence cross-country travel--making it easier going along the channels than across them. In deeply dissected fans, the numerous entrenched channels and tributary gullies form a badlands topography that can hinder cross-country movement and provide sites for ambush, and cover and concealment.

Fans can be so large that they have characteristics of a plain, such as the Dibdibah gravel plain that extends from northeastern Saudi Arabia into Iraq and Kuwait. Such features result from long-time accumulation and coalescence of braided channels and gravel trains, coupled to long-term weathering and reworking of the materials. A gently rolling topography develops, which, though not necessarily obvious to people on the ground, is sufficient to provide some degree of horizontal cover and concealment for radial travel. Conversely, travel across the radial structure can result in alternate exposure and obscuration. Where desert pavements are absent, fan materials can be loose, poorly consolidated, and unstable. Fans are a traditional source of engineering materials. Fans should be avoided during and immediately after thunderstorms in the mountains, when the water and mud of flash floods move violently and rapidly downslope in the fan distributary channels and gullies, carrying everything in their path, including vehicles. In many deserts, the rocky crevices of fans and outcrops are the preferred habitat of snakes, many of which are poisonous. Most snake encounters in arid and semiarid regions seem to be on the upper parts of bouldery alluvial fans.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Bahada, serir, reg, hammada (North Africa), gobi (China), gibber (Australia).

DESCRIPTION: Bajadas (also spelled bahadas) are formed by the lateral merging and blending of a series of alluvial fans. They extend from the base of a mountain range out onto the floodplain, most frequently into an inland basin. Such a basin is also called a bolson, and these coalesced fan deposits are also called a bolson plain. A bajada can be relatively narrow, made up of two or three fans, or a broad, extens ve, continuous alluvial slope consisting of many fans. If other factors are also involved, parts of the surface of an extensive bajada can take on the characteristics of a gravel plain, i.e., a pediplain. Bajadas have a progressively finer texture downslope, and they may blend into playas in the lowest parts of a basin. Because of the low, ridgelike mounds of the component fans, the surface is undulatory, and the amplitude of the undulations decreases downslope. The upper boundary of a bajada is commonly merged with a pediment slope.

WATER REGIME: Episodic flow of sediment-laden water.

ENGINEERING AND MILITARY USES: Aside from being sources of engineering materials, bajadas can support foot and vehicular traffic, as well as rotary-wing aircraft operations. Fast-moving vehicles and rotary-wing aircraft can, however, cause dust and fine sand to become airborne: the lower down the slope, the greater the dust problem. The intersecting, parallel-to-subparallel channels and gravel ridges provide a grain to the surface that may affect cross-country travel. Travel parallel with the grain, i.e., going down slope or up slope, can be easier than going across the grain. Because of the undulations and numerous small channels, travel across the bajadas can be slow, particularly on the upper slopes. Depending on the amount of relief, the channels and undulations can provide some degree of cover and concealment. The abundant loose gravel and rock fragments on the bajada are sources of secondary projectiles when hit with ordnance. Trenching is laborious, but the walls of the trench generally stand up well.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Alluvial apron, alluvial fan, <u>alluvial plain</u>, apron, <u>bolson plain</u>, debris apron, fan apron, gravel piedmont.

DESCRIPTION: Alluvial plains have level or gently sloping surfaces veneered by loose, rounded rock fragments (gravel- to cobble-size) that are commonly closely packed (see Summary Sheet for Desert Pavement). The plains overlie bedrock veneered by alluvium (as on pediments), parts of alluvial fans, and floodplains and terraces of drainage courses. Almost all extensive gravel plains are remnants of broad alluvial valleys. Therefore, the components typical of these plains are smooth and rounded because they were transported by running water, and deposits tend to be thick because in most places they are the upper parts of a valley-filling river deposit. Weathering and downslope movement of rock fragments that have not been transported and smoothed by running water produce pavements of rough, jagged rocks (talus slope debris). Slope wash and wind-deposited material fill pores between the stones with fine sediment, commonly producing a zone (accretion mantle) (McFadden, et al.)[1] a few centimeters to about a meter thick of fine soil between the desert pavement, which is one stone thick, and the underlying gravelly alluvium or bedrock. Some old alluvial plains from which streams have disappeared (due to increased aridity) are now covered with windblown sand sheets and are known as sand plains (see Summary Sheet for Sand Plains/Sand Sheets).

WATER REGIME: Alluvial plains typically occur in areas that, in the past, were subject to running water, and some areas may still receive occasional runoff from precipitation in distant watersheds (See Summary Sheets for Alluvial Features - Fans and for Drainage Courses).

ENGINEERING AND MILITARY USES: Gravel plains, like sand plains, are excellent routes for cross-country movement as illustrated by the Dibdibah Plain of northern Kuwait and southern Iraq during the Gulf War. Their surfaces will also support rotary-wing aircraft operations and, with the exception of areas of sharp-edged rock fragments, fixed-wing operations. Airborne loads of dust and fine sand can be caused by the passage of fast-moving vehicles and by aircraft. Tracks made on gravel plains with desert pavements may persist for decades, whereas tracks on sand plains generally disappear during windstorms. Vehicles crossing gravel plains do not have the problems of bogging down or running into truncated or granule ripples, as on sand plains, although breaking through the surface to the underlying fine, soft accretion mantle sometimes happens on desert pavement. Some gravel plains have sharp-edged rock (talus) fragments that will tear up tires. Gravel plains may have beneath the surface pavement a zone of packed, caliche-cemented, gravelly soil many meters thick, which can be trenched only with difficulty.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Hammada (North Africa), serir, gibber plains (Australia), desert pavement (some), reg, gobi (China), bahada.

REFERENCE:

[1]McFadden, L.D., S.G. Wells, and M.J. Jercinovich. 1987. Influences of eolian and pedogenic processes on the origin and evolution of desert pavements. Geology, v. 15, pp. 504-508.

EROSIONAL PATTERNS

RESIDUAL MATERIALS - WIND

DESCRIPTION: Interdune areas of the desert floor occur between individual dunes in fields or ergs. The dune pattern is reflected in the pattern of interdune areas: the type of dune determines whether the interdune areas are closed and basinlike or open and continuous (Breed and Grow).[1] Closed interdune areas are bounded on all sides by dune slopes. The bounding slopes tnat face upwind are gentle and have a firm surface; the lee slopes (avalanche slopes) are steep (32°), loose, and soft. Open and continuous interdune areas are more likely to be floored by dry, hard-packed sediment or bedrock than are closed interdune areas. Closed interdune areas may be poorly drained and contain playas. All interdune areas are typically flat. Where dry and floored by sandy sediment, they have many of the same characteristics as sand sheets. If near-surface moisture is present, interdune areas may contain grasses, shrubs, trees, or even settlements. Interdune areas range in size from a few to tens of square kilometers. In any given locality, the sizes and shapes of the interdune areas are similar, as are those of the intervening dunes.

WIND REGIME: Interdune areas are swept by the winds that transport sand from one dune to the next across the field or erg. Some sand grains are saltated (bounced), others rolled by creep (see Summary Sheet for Sand Plains/Sand Sheets - Streaks/Drifts). The sand grains are eventually deposited on upwind slopes of the next dune that bounds the interdune area.

MILITARY AND ENGINEERING USES: Interdune areas containing playas may have clayey or salty sediment on their floors, and their surface water, if fed by ground water is generally not potable without treatment. In some interdune areas, potable fresh water collects temporarily (from rainfall) on the surfaces of clay playas. Movement is easy through a dune field with open interdune areas, as in many fields of linear or transverse ridges, but visibility is restricted to the next dune ridge (see Summary Sheet for Dunes - Linear/Seif). Movement through a dune field with closed interdune areas requires repeated climbing and descending of dune slopes and may be impossible. From a closed interdune area, all routes out are uphill. Most dunes with closed interdune areas are barchanoid or megabarchanoid ridge types arranged in an aklé or network pattern.[1] These should be avoided.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Fulje, streets (straat in southern Africa), corridors, couloirs (North Africa), bahirs (China), interdune basins.

REFERENCE:

[1]Breed, C.S. and T. Grow. 1979. Morphology and distribution of dunes in sand seas observed by remote sensing. In A study of global sand seas, edited by E.D. McKee. U.S. Geological Survey Professional Paper 1051, pp. 253-302.

DESCRIPTION: Depressions are topographic basins having interior drainage, surrounded by higher country. They range from a few meters to tens and at places hundreds of kilometers in width and from a meter to many tens of meters in depth; some extend below sea level. They may be elongate and narrow or broad and nearly circular in plan. Their floors are typically nearly level or slightly inclined and commonly descend to marshy or saline ponds (see Summary Sheets for Playas and for Sabkhahs).

Depressions are formed in many ways: by wind excavating loose material (see Summary Sheet for Depressions - Deflation Hollows/Basins/Blowouts); by water dissolving and removing calcium carbonate-rich material to form sinkholes, solution pans, and solution valleys (if underground cavities are formed, the overburden may collapse); by collapse, as in volcanic craters; by melting of ice chunks imbedded in a glaciofluvial deposit to form kettles; by meteoritic impact to form craters; and by downwarping or faulting to produce rift valleys or grabens. Some of these depressions are very small, local features, some are seldom found in deserts, some are nearly imperceptible topographic lows with gentle slopes, and others are major topographic basins excavated in plateaus and bounded by steep, high cliffs. The sides and floors of depressions have generally been modified by a combination of weathering and erosion. For example, some of the great depressions in the Limestone Plateau of gypt and the chotts of Morocco and elsewhere were probably initiated by the dissolving and removing of calcium carbonate-rich materials by water, and they have since been modified by other processes, including localized runoff, mass wasting, and deflation. Regardless of the mode of formation, depressions in the desert have been, if not created by wind, at least modified by it to the extent that they can be considered deflation hollows. Where the deflated floors of the depressions intersect the ground water table, seeps and springs feed shallow ponds or marshes that tend to be saline (see Summary Sheets for Playas and for Sabkhahs). If underlain by weathered shale, such depressions will, when dry, be characterized by nafash (see Summary Sheet for Nafash). Occasional runoff from surrounding highlands can cut ravines in the depression walls, and can sometimes reach parts of the depression floor.

ENGINEERING AND MILITARY USES: Depressions that are cut to great depths can be extremely hot during summer months, and therefore many have been considered impassable because of the heat and the soft, marshy ground. The bad ground, however, seldom covers the entire floor, and paths do exist around and through such areas. For navigation across large depressions such as the Qattara in Egypt, aerial photos are essential. Although the soft, marshy ground is indicative of water, it is highly mineralized and not potable. It can be a source for evaporative distillation of small amounts.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Hollows, basins, shotts/chotts, sabkhahs (North Africa), dolines, oases (some).

DESCRIPTION: Deflation hollows are depressions caused chiefly by, or significantly modified by, the removal of loose particles by wind. They can be subtle topographic features that are hard to recognize on the ground. Their main characteristic is that they are closed basins that, although shallow, can collect runoff or intersect ground water at their bottom. They can be irregular in shape or smoothly symmetrical. Saucer-shaped hollows in bedrock are common in desert areas, particularly those underlain by sandstones that are easily deflated (Breed, et al.).[1] These depressions range from meters to kilometers in width and length and from centimeters to meters in depth. The larger ones are called basins. In semiarid deserts deflation hollows commonly form in semivegetated sand sheets. These depressions frequently contain water and are called pans (see Summary Sheets for Playas and for Sabkhahs). When the water evaporates, clay or various salts are left in the pan, giving it a distinctive signature on aerial and satellite imagery. Dry hollows in semivegetated sand dunes or sand sheets are usually called blowouts, and they are commonly source areas for parabolic dunes (see Summary Sheet for Dunes - Parabolic). Active, unvegetated dunes sometimes contain hollows that are maintained in the sand mound or ridge by localized deflation. Hollows can also be found where dunes have merged to surround an area of bare desert floor; these are not true deflation hollows, but interdune basins (see Summary Sheet for Interdune Areas).

WIND REGIME: Details unknown. Deflation hollows seem to occur in all types of wind regimes.

ENGINEERING AND MILITARY USES: Unless they contain water or evaporites, deflation hollows do not present problems to foot or vehicular traffic. If they contain clay or salt deposits, they can usually be crossed when dry but can be impassable when wet (see Summary Sheets for Playas and for Sabkhahs). Deflation hollows in semivegetated, sandy material (blowouts) can have sufficient loose sand to make them obstacles to foot and vehicular traffic, but most are small enough to be bypassed. Visibility from a hollow may be restricted to the surrounding higher rim.

REFERENCE:

[1]Breed, C.S., J.F. McCauley, and M.I. Whitney. 1989. Wind erosion forms. In Arid zone geomorphology, edited by D.S.G. Thomas. New York: Halstead Press, pp. 284-307.

DESCRIPTION: Grooved terrain is composed of bedrock or semiconsolidated material having a pattern of parallel ridges (yardangs or incipient yardangs) separated by troughs (see Summary Sheet for Yardangs). The ridges and troughs are carved from parent material by the dual wind actions of abrasion and deflation. Areas of grooved terrain range from a few square meters to hundreds of square kilometers. The ridges have varied lengths, because they tend to be broken into segments by joints. The troughs may have a shallow, U-shaped form or flat floors with a thin veneer of gravel; occasionally the troughs are invaded by dunes, mostly barchans (McCauley, et al.)[1] (see Summary Sheet for Dunes - Crescentic Barchan/Megabarchan and Barchanoid/Megabarchanoid).

Although sizes of the ridges and troughs are widely varied, their respective dimensions are consistent throughout any given field, probably controlled by joints and bedding planes in the rock. Relief between the trough bottoms and the ridge crests ranges from a few centimeters to many tens of meters. Although individual ridge segments may range in length from a few meters to kilometers, intervening troughs may be many times longer; some troughs are nearly continuous across a field. Widths of the troughs and ridges are a few centimeters to as much as 2 km. In stereo aerial photographs of appropriate scale, grooved terrain is readily identifiable. In small-scale imagery such as Landsat, however, grooved terrain can resemble a field of simple to compound linear dunes. They can be difficult to distinguish unless one has seasonal imagery. Under some conditions and in certain locations, unvegetated dune ridges tend to be uniformly brighter on Landsat images, whereas bedrock yardangs may be bright only in patches and dark where the rock has a patina of desert varnish. The bright dunes commonly contrast vividly with dark rock surfaces in the surrounding terrain, whereas yardangs generally do not. The margins of linear dune fields are usually constructional, and generally they can be clearly seen to have been built out onto a smooth plains surface, but the margins of grooved terrain are erosional and tend to appear less regular.

WIND REGIME: The development of grooved terrain requires very strong, unidirectional winds and an airborne sediment load. The load does not have to be unusually large or to consist of sand: windblown dust can erode rock surfaces over a very long time (Breed, et al.).[2] The frequency of such winds is unknown.

MILITARY AND ENGINEERING USES: The best practical advice for cross-country movement is to avoid going through an area of grooved terrain in any direction. Going across the pattern (transverse to the ridges) ranges from tedious, time-consuming, and difficult to impossible. Travel along the troughs is usually impractical: trough bottoms can be irregular and grooved and clogged with loose sand or granule ripples, as can passes between ridge segments. Any strong wind is extremely turbulent and abrasive, especially near ground level along the base of a ridge. Such advice must, of course, be considered in relation to the areal and internal relief of the grooved terrain. Some can be easily bypassed, and some can be crossed through narrow ridge breaks, even though the path is tortuous. Without stereo aerial photography, however, an evaluation cannot be made. When in doubt, avoid the area. A type of grooved terrain in Egypt, called kharafish, consists of very sharp ridges of limestone that are closely spaced (centimeters to a meter apart) and a few to tens of centimeters high. This terrain is almost impassable in wheeled vehicles because tire damage is severe, and foot travel is slow because the ridges are sharp. In general, small-scale grooved terrain should be avoided.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Kharafish (Egypt), yardang troughs, ridge-and-furrow topography, kalut et boulevards (Iran), barres paralles, cretes et couloirs (Sahara).

REFERENCES:

[1]McCauley, J.F., M.J. Grolier, and C.S. Breed. 1977. Yardangs. In Geomorphology in arid regions, edited by D.O. Doehring. Proceedings, 8th Annual Geomorphology Symposium, Binghamton, NY, pp. 233-272.

[2]Breed, C.S., J.F. McCauely, and M.I. Whitney. 1989. Wind erosion forms. In Arid zone geomorphology, edited by D.S.G. Thomas. New York: Halstead Press, pp. 284-307.

EROSIONAL PATTERNS

RESIDUAL MATERIAL - WIND

DESCRIPTION: Yardangs are streamlined hills carved from bedrock or any consolidated or semiconsolidated material by the dual action of wind abrasion (by dust and sand) and deflation. Unlike most hills carved by running water and mass wasting, yardangs typically are three or more times longer than wide. Individual yardangs range from a few centimeters to several kilometers in length and from a few centimeters to 30 m or more in height; within any one field the dimensions are generally consistent. Along the base of each yardang flank, especially in the larger yardangs, sizable grooves are common. These grooves, cut by abrasion, mark the location of the densest part of the airborne sediment load. Yardangs are typically highest and broadest at the blunt end that faces into the wind; most become characteristically lower and narrower toward the lee end (McCauley, et al.).[1] They may be isolated, or may occur in groups, called fields (or fleets because of the resemblance of the yardangs to inverted boat hulls). Yardangs form the ridges of grooved terrain (see Summary Sheet for Grooved Terrain). Small yardangs (about 2 to 4 m high) are most commonly carved in semiconsolidated playa sediments and other relatively soft, granular materials. Because these features are small, they are usually not visible on satellite images such as Landsat.

In arid regions with strong, unidirectional winds, kilometer-scale yardangs may be carved in siltstone, sandstone, shale, and limestone and rarely in very hard, crystalline rocks such as schist and gneiss.[1] Most of these large yardangs are part of a large area of grooved terrain; but fleets of yardangs without the associated troughs of grooved terrain are also found in isolated bedrock outcrops. Extensive fleets of yardangs occur in siltstone in the Ica Valley of Peru and in sandstone and shale below plateau scarps in the Kharga, Farafra, and Dakhla Depressions in southwestern Egypt. In the Kharga, Farafra, and Dakhla areas, yardangs also occur above the scarps in grooved terrain carved in the limestone cap rock of the plateau. Most yardang fields are in sand-poor areas, but the associated troughs, especially in grooved terrain, may be invaded by sand. This sand can accumulate to build shallow moats around the blunt, forward ends of the yardangs and to form sand tails streaming to leeward (Breed, et al.).[2]

WIND REGIME: The development of yardangs requires a very strong, virtually unidirectional winds and an airborne sediment load. The frequency of such winds is unknown. Wind speeds are highest along the flanks and upper surfaces at the highest and broadest part of the yardang. Turbulence increases at the tapering flanks toward the lee end.

ENGINEERING AND MILITARY USES: Because yardangs are formed in bedrock or consolidated and semiconsolidated materials, the surfaces between the yardangs are hard and firm. Therefore, vehicular traffic is possible through fleets of isolated, individual yardangs. The problem is primarily one of finding the "right" path through the branching, interconnected corridors between the yardangs. Where yardangs are part of grooved terrain, cross-country movement is generally impossible (see Summary Sheet for Grooved Terrain). Yardangs do not offer good shelter from wind and blowing sediment along their flanks.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Mud-lions, sphinxlike hills, mushroom rocks (some), inselbergs (some), koukour (Tunisia), kalut (Iran), cretes et couloirs (Chad).

REFERENCES:

[1]McCauley, J.F., M.J. Grolier, and C.S. Breed. 1977. Yardangs. In Geomorphology in arid regions, edited by D.O. Doehring. Proceedings, 8th Annual Geomorphology Symposium, Binghamton, NY, pp. 233-272.

[2]Breed, C.S., J.F. McCauley, and M.I. Whitney. 1989. Wind erosion forms. In Arid zone geomorphology, edited by D.S.G. Thomas. New York: Halstead Press, pp. 284-307.

DESCRIPTION: Hoodoos are irregularly shaped rock features that resemble misshapen pillars, spires, columns, or grotesque, animal-like figures. Their dimensions range from centimeters to meters. Hoodoos are usually attributed to differential weathering controlled by variations in rock resistance and by internal structure or joints. Layers of rock with different degrees of resistance to chemical and mechanical disintegration, and with a variety of joint patterns, can be wrought into very strange shapes by the forces of water or wind or both. Although hoodoos can develop in all kinds of rock and in semiconsolidated sediments, they are probably more common in sandstone, limestone, siltstone, and salt deposits. In arid regions, where loose, weathered material can be easily removed by the wind, hoodoos can develop over an area large enough to form a type of badlands topography.

WIND/WATER REGIME: In arid regions, hoodoos are formed primarily by a combination of running water and the action of strong, variable winds carrying an abrasive load and by deflation. Unlike yardangs, hoodoos are not streamlined in a preferred direction; consequently, their shapes are much more varied.

ENGINEERING AND MILITARY USES: Hoodoos can offer some degree of cover and concealment as well as potential sites for observation points and ambush. Travel through a field of isolated hoodoos is not a problem for foot and vehicular traffic, although along a cliff they can impede or prevent access to the top.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Demoiselles, pedestal rocks, mushroom rocks, tepees, dells, earth pillars.

EROSIONAL PATTERNS - WATER

DESCRIPTION: Badlands are extremely rough terrain found in arid and semiarid regions. They are best developed in sparsely vegetated, semiconsolidated materials that are soft and have low permeability and cohesion, and that are therefore easily removed by episodic running water. Erosional scouring develops an intricate drainage pattern of closely spaced gullies separated by sharp-crested ridges with steep slopes. The materials are typically fairly massive, relatively young (geologically), interbedded clay shale, silty shale, and sandy/gravelly units. Badlands National Monument in South Dakota, USA, has typical examples.

WATER REGIME: The development of badlands requires infrequent but intense rain showers (gully washers) and little or no vegetation to stabilize the slopes. Most materials do not hold surface water.

ENGINEERING AND MILITARY USES: This landform is well named. Other than foot or horse movement up and down some lower gullies or across some low, outlying ridges, cross-country movement is not feasible. Although in dry weather foot travel is possible along many ridges and in some gully bottoms, side slopes are too steep and the material too loose to allow much cross traffic. In wet weather the high clay content can make the area impassable.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Mauvaises terres pour traverser (French), haystacks, castelletes, clay hills, buttes (some).

EROSIONAL PATTERNS

RESIDUAL MATERIAL - WATER

DESCRIPTION: A pediment is a broad, gently sloping surface of low relief eroded in bedrock at the base of a much steeper mountain slope. It is commonly covered by a thin, patchy veneer of alluvial sand and gravel that thickens downslope to merge with the alluvial fill of the valley. Pediments are prominent landscape features in arid and semiarid regions. In contrast to depositional piedmont plains, pediments are erosional, although the processes that formed them are poorly understood and remain controversial. Parallel to the mountain front, the pediment profile is commonly smooth. The gradient of the slope toward the valley is [illegible] to as steep as about 10°; average gradient is about 3 to 6°.

In some areas of the Sahara and central Australia, pediments form extensive plains of very low gradient--they appear nearly flat. Such coalesced pediments of regional extent are termed pediplains. Pediment surfaces typically are cut across rocks of different types and ages, and the same erosional surface may thus be traced across several different localities within a region. Pediments commonly contain inselbergs (isolated hills or mountains), drainage channels, and well-developed soil profiles in the alluvial veneer. The inclined bedrock surfaces of the lower pediment slopes commonly continue at depth beneath the adjoining alluvial plain. Upper slopes abut the adjacent mountain at what is typically an abrupt break in slope (piedmont angle); occasionally the abutment is gradual or is masked by alluvial fans. Where pediments merge between two side mountains or two inselbergs, they form a pediment pass. Terrace pediments occur in sequences of stair-step topography along many major rivers in desert areas.

WIND/WATER REGIME: Unknown and controversial.

ENGINEERING AND MILITARY USES: In basin-and-range deserts, pediments are excellent routes for vehicular and foot travel, because they do not have the hazards of the lower basin floors (see Summary Sheets for Playas, Drainage Courses, and Depressions), and because pediment passes may be routes to, and at places across, mountain ranges. Air photos can be used to identify pediment surfaces and particularly areas of coalesced pediments (pediplains) along mountain fronts, where the surface is not too deeply or intricately dissected by drainage channels. The surface typically is a gravel plain (see Summary Sheets for Alluvial Deposits - Fans, Gravel Plains, and for Desert Pavement). The alluvial veneer on pediments is generally better consolidated and more trafficable than on alluvial fans. Unlike fans, where depositional processes are generally more active, pediment alluvial surfaces are generally stable; they commonly have a relatively dense cover of grasses, shrubs, and a few trees. Pediments generally lack sources of surface water, and bedrock occurs at shallow depths, shallowest at the upslope margin. Pediments are, therefore, difficult areas to trench, and they make poor defensive positions.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Bench, terrace (some).

DESCRIPTION: Drainage courses may be dry or they may contain intermittent, ephemeral, or perennial running water (for definitions of these terms, see Water Regime below). Drainage courses range in size from large, broad valleys to long, narrow channels. A valley is an elongate depression that may be broad and shallow or narrow and deep. Valleys may or may not contain rivers flowing in channels, which are conduits cut into the lowest part of the valley floor. Rivers are confined to their channels except during floods, when water escapes the channel banks and flows over the floodplain. The floodplain is the portion of a valley floor adjacent to the main channel, and its nearly level surface is generally crisscrossed by channels. From the floodplain, paired terraces commonly rise like stairsteps on both sides of the valley to the upper slopes and divides between adjacent valleys. Except for older channels in the floodplain, valley surfaces are usually smooth, level, and covered by river sediments (gravel, sands, silt, and clay). These materials are generally tightly packed and firm except where fine particles have accumulated in the channels or have been reworked by wind into fields of sand dunes. Such dunes are common on the downwind sides of channels and in sheltered areas along the valley sides and on the floodplain. The upwind areas may be free of dunes but locally covered by loose, soft, windblown sand. Shinglelike, overlapping deposits of gravel and cobbles may form a pavement on terraces, floodplains, and channel floors; these are called imbricated deposits.

As yet, there is no universally accepted definition of terms, let alone a universally accepted classification of drainage courses. There are many examples in the literature and on maps where, because of differences in local usage, regional usage, and foreign terminology, the same names are used to denote different things and different names are used for the same thing. We have classified drainage courses as follow:

- Rivers (perennial streamflow)
- Wadis (dry or with intermittent or ephemeral streamflow)
    - Washes
    - Gullies
    - Arroyos
    - Ravines/Canyons
    - Inverted

Rivers are perennial waters flowing in channels through valleys. Wadis are dry or have intermittent or ephemeral streamflow; they range in size from small gullies to large, deep canyons. In the southwestern U.S. a colloquial term for a wadi is a "wash" or "dry wash." A gully is the smallest of the drainage courses. An arroyo is a small, flat-bottomed, steep-walled channel in semiconsolidated sediments. A ravine, also small, is a V-shaped, steep-sided erosion channel common in mountainous terrain. A canyon, the largest of the drainage courses, is commonly cut into plateaus of nearly horizontal rock layers. Canyons are also cut into crystalline rock, where their cross-sectional profile tends to be less regular. Inverted wadis are ridges that trace out former drainageways. The tops of the ridges were once the bottoms of channels. The surrounding ground has been removed by erosion. The ground under the channel was shielded from erosion by the protective nature of the stream gravel deposits in the bottom of the channel. Inverted wadis are included here because, though ridges, their patterns in airborne and satellite imagery most often resemble drainage systems, which they once were. In monoscopic small scale imagery, it can sometimes be difficult to decide which of these two features the pattern represents.

WATER REGIME: A water regime is defined in terms of the occurrence of running water in channels. Rivers are perennial streams, i.e., they flow year-round. The few perennial streams that do occur in desert regions have a water source in run-off of precipitation or snowmelt in distant highlands. Because their water originates outside the desert, these rivers are called exotic (or foreign) streams; examples are the Nile, Niger, Colorado, Tigris, and Euphrates Rivers. Most desert drainage courses are ephemeral, containing running water only seasonally and not necessarily every year. Some drainages are intermittent, containing water only in certain segments fed by springs or ground water and dry for long distances between. Desert drainage courses commonly are at least sparsely vegetated along their channels. Because it signifies near-surface water, this vegetation is the most reliable indicator of the locations of recently active channels. In many deserts, drainage courses are always dry and are known as abandoned, fossil, or "paleo" drainages. They may have little or no topographic expression but may contain water at depths of a few meters. Some ancient drainage courses have been abandoned and later buried by windblown sand (see Summary Sheet for Sand Plains/Sand Sheets). They are not visible on air photos or Landsat; but under certain circumstances their characteristic patterns can be seen on L-band radar images (McCauley, et al.).[1]

ENGINEERING AND MILITARY USES: Drainage courses provide both advantages and disadvantages. At times, some provide relatively easy travel and readily available sources of engineering materials such as gravel and sand. Under other conditions, they are impossible to traverse, dangerous because of potential for flash floods, and sources of blowing dust and sand. Although the surface of a channel in a wash may be dry, the fine sediments below the surface can be saturated to form a quicksand. Hand-dug pits in selected parts of apparently dry channels can sometimes provide potable water, particularly in the vicinity of local patches of vegetation. Both typical and inverted wadis have potential for cover and concealment and as sites for ambush and defilade.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Wadi, wady, ouadi, wash, gully, arroyo, barranca, draw.

REFERENCE:

McCauley, J.F., G.G. Schaber, C.S. Breed, M.J. Grolier, C.V. Haynes, B. Issawi, C. Elachi, and R. Blom. 1982. Subsurface valleys and geoarchaeology of the Eastern Sahara revealed by Shuttle Radar. Science, v. 218, no. 4576, pp. 1004-1020.

DESCRIPTION: Rivers are perennial streams of water flowing in channels through valleys. Their flow is confined to the channels except during floods, when it overflows the riverbanks and covers parts of the adjacent floodplain. Lakes are found along rivers where the flow of water is slowed by natural or artificial dams. In high or hilly areas, rivers tend to flow in narrow, steep valleys, and thus the flow is very fast. Here the streambeds contain rounded boulders and cobbles and are very rough. On lower ground, rivers tend to flow more smoothly, although some stretches can have swift currents. Their streambeds contain smooth, rounded gravel and cobbles as well as sand and mud distributed according to the velocity and other characteristics of the streamflow (Leopold and Maddock).[1] River channels tend to broaden and become less steep with distance downstream toward their junction with a master stream. Master streams eventually discharge into the sea, large lakes, or basins of internal drainage (see Summary Sheet for Depressions). In deserts, perennial streams are rare; most drainage courses are ephemeral, intermittent, or dry (abandoned) (see Summary Sheet for Drainage Courses - Wadis); vegetation is generally densest along streams having at least some flow.

WATER REGIME: The few perennial streams that do exist in deserts derive their water from areas of greater precipitation that are commonly tens to hundreds of kilometers away. Little new water is added to them from local sources, and many desert streams just disappear into sand, or sometimes into low, marshy areas. This effect is enhanced in many parts of the world, including the U.S., because of the removal of water for irrigation and urban use along the lower courses of the rivers.

ENGINEERING AND MILITARY USES: Rivers are reliable sources of water, though possibly somewhat mineralized and frequently contaminated. Rivers are both barriers to cross-country movement and avenues for transportation. Because water volumes vary with precipitation far upstream, water depths and widths can alter without warning, and speed of flow can change quickly from placid to furious. The deepest part of the channel is commonly sinuous and constricted by sand bars marked by riffles on the water surface. Rapids occur in rivers where tributary streams enter the valley from side canyons and dump their boulders, which are too large to be washed downstream. Such rapids are extremely dangerous and should be avoided, although some can be negotiated by experienced boatmen. Most river water, even in U.S. deserts, contains Giardia micro-organisms that can cause serious diarrhea. Such water should be boiled for at least 15 minutes or treated with chemicals such as iodine or chlorine before drinking.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Stream, creek.

REFERENCE:

[1]Leopold, L.B. and T. Maddock, Jr. 1953. The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey Professional Paper 252, 55 pp.

DESCRIPTION: Wadis are dry or have only intermittent or ephemeral streamflow. They range in size from small gullies, through large, broad valleys, to large, deep canyons. Consequently, the term covers a broad range of characteristics. For the present we are using the following classification:

- Washes
- Gullies
- Arroyos
- Ravines/Canyons
- Inverted

The term "wash" is used colloquially in the southwestern U.S. and on maps to indicate an intermittent or ephemeral stream, e.g., "dry wash." In sedimentological terms, "wash" refers to the material deposited on the floors of gullies, arroyos, ravines, and canyons. It also forms more-or-less unconfined deposits on valley floors or outwash plains where it marks the location of former streamflow. A gully, the smallest of the drainageways, can be a feeder to a canyon, ravine, or arroyo or part of a drainage channel within a wash. An arroyo is a flat-bottomed channel with steep to vertical sides incised in semiconsolidated sediments. A ravine is a steep-sided, V-shaped erosion channel common to mountainous terrain. A canyon is the largest of the drainage valleys, but no dimensional boundaries between a ravine and a canyon have been established. A canyon is commonly cut into plateaus consisting of nearly horizontal rock layers. Canyons also occur in crystalline rock, where their cross-sectional profiles are less regular. A canyon can have steep sides and a V shape like a ravine. A canyon having near-vertical walls and flat floors, and that terminates upstream in a steep headcut is called a "box canyon." Inverted wadis are ridges that trace out former drainageways. The tops of the ridges were once the bottoms of channels. The surrounding ground has been removed by erosion. The ground under the channel was shielded from erosion by the protective nature of the material in the bottom of the channel. Inverted wadis are included here because, though ridges, their patterns in airborne and satellite imagery most often resemble drainage systems, which they once were. In monoscopic small scale imagery, it can sometimes be difficult to decide which of these two features the pattern represents.

WATER REGIME: Wadis may carry runoff from rain resulting from thunderstorms in distant headwater regions. These streams are generally loaded with silt and sand. Intermittent streams carry runoff from springs where ground water intersects the surface. Thus, these streams commonly contain high amounts of dissolved salts and may have a milky or green hue.

ENGINEERING AND MILITARY USES: Many dry wadi courses on broad, open alluvial plains are floored by packed gravelly sediment and can provide good surfaces for cross-country movement. Where the washes are not flattened out and are aligned with the slope of a plain, they provide a "grain" to the surface and, depending on the roughness of the wash, travel can be easier parallel to the slope than across it. Channeled wadis such as arroyos, if choked with bouldery deposits or invading sand dunes, are unsuitable for cross-country movement. Steep-walled channels should be traveled with caution because of the potential for flash flooding. Such floods can result from rains in headwaters only a few kilometers or 100 km away. [illegible] front can move down a wadi as a high wall of muddy water traveling at [illegible] km per hour, depending on the gradient of the channel and the volume [illegible] water. [illegible] water can often be found in braided wadi channels, [illegible]. The most saturated fill in wadi channels can usually be easily dozed and excavated. These materials can, however, be saturated and quick even beneath a dry surface (see Summary Sheet for Drainage Courses - Wadis - Arroyos). Both typical and inverted wadis have potential for cover and concealment and as sites for ambush and defilade. The gravel deposits in the channel can be sources of secondary projectiles when impacted with ordnance.

FOREIGN NAMES AND SYNONYMS (common names are underlined). Dry wash, wady, ouadi, creek, gulch.

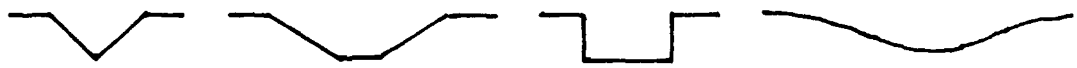
DESCRIPTION: A wadi type wash is a dry, intermittent, or ephemeral drainage course marked by deposits of alluvial material that are not confined to a specific channel. The channels are commonly shallow and braided and can cover a wide area, particularly where they occupy the floor of a broad alluvial valley. The channels are nearly level with the surrounding floodplain and are separated by flat, low-lying segments. The floodplains and channels are typically surfaced by clay-poor sediments that are mixtures of silt, sand, gravel, and larger rock fragments. Because these deposits are loosely consolidated, they are vulnerable to sudden and abrupt washouts by episodic floods.

WATER REGIME: Wadis (dry washes) result from episodic flooding induced by seasonal runoff from rainfall, usually in distant headwater regions. Because the streams are laden with sediment and are of high volume, and because relief is sufficiently high, the slurry leaving the upslope channel cannot be confined to a thin deposit but continues down the slope as a broadening stream, at places coalescing with other streams, until the flood impetus is spent and the material settles in place. Repeated cycles of flooding, even though infrequent, change the form of the wash. Over time, alterations in intensity, duration, and frequency of flooding, as well as sheet flooding and wind action, can rework the surface into a gravel plain.

ENGINEERING AND MILITARY USES: These broad deposits on open valley floors are generally good surfaces for travel, which, depending on surface roughness and irregularities, is easier up or down slope than across it. Even though removed from their upland channel sources, washes can be subjected to flash flooding induced by rainfall in distant parts of the watershed. Wash deposits are usually good sources for engineering materials.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Dry wash, ouadi, vlei (Southern Africa).

DESCRIPTION: A gully is the smallest of the drainage channels and is usually dry. It can be a feeder to a canyon, ravine, or arroyo and part of the drainage net within a wash, fan, or bajada. Larger gullies may be called ravines, although there is no agreed-upon size distinction between the two. The term gulch is sometimes used to indicate a size between a gully and a ravine. In semiarid and arid regions where runoff is infrequent, gully shapes can be modified by the wind, and gullies can be filled by aeolian deposits. The basic cross-sectional profiles shown below and the channel gradients of a gully incised in a soil mantle are determined mainly by soil characteristics, by rainfall intensity and occurrence, and by position on the slope.



A B C D

In general, V-shaped gullies (type A) with short, steep gradients are indicative of granular and semigranular, nonplastic, noncohesive soils, i.e., sand, gravel, and combinations of the two. As silt and clay particles are added, the V-shape broadens and becomes rounded, the gradient shallows, and the slope lengthens. Alluvial fans are common at mouths of A-type gullies. V-shaped gullies with steep sides and flat bottoms (type B) have long slopes and gentle gradients ending in steep faces. This type of cross section is characteristic of many loess deposits. Alluvial fans are not formed at the mouths of these gullies. Box-shaped gullies (type C) with vertical sides, and flat bottoms with long, gentle gradients are characteristic of water-deposited silt and marine sand and clay, as on the eastern U.S. coastal plain. This shape is also characteristic of subsurface drainage or ground water sapping, and it is found in granular and silty soils resting on a nonpermeable or semipermeable layer. Saucer-shaped gullies (type D) with gentle side slopes and broad, rounded cross sections are characteristic of nongranular, cohesive, plastic soils, i.e., clay and silty clay. Gradients of these gullies are very gentle, and the gully extends for great distances, gradually feathering out to become indistinguishable from the surrounding terrain. The basic shape of all gullies persists, but it can be modified by rainfall and runoff characteristics: one "gully washer" a year develops patterns that differ from those caused by the same amount of water from several storms distributed throughout the year.

WATER REGIME: Episodic runoff, usually from seasonal rainfall.

ENGINEERING AND MILITARY USES: Gully shape in semiconsolidated materials, which is best evaluated in stereoscopic imagery, can indicate the presence of engineering materials such as gravel and sand. Gullies can impede cross-country movement: the extreme case is the intense gullying of badlands, which are impassable. Gullies on fans and bajadas are aligned with the slope, which makes cross-slope movement slower than movement up and down the slope. Cover and concealment are possible in gullies, particularly where vegetated. Trenching in the soil mantle is generally easy.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Gulch, creek, runnel, arroyo (some).

DESCRIPTION: Arroyos are drainage courses incised into semiconsolidated alluvium on valley floors and fans. They lie below the level of the surrounding plains, and the smaller ones are usually not visible from a distance of more than a few hundred meters. They are boxy in shape, having flat bottoms of gentle gradient and steep to vertical side walls and headwalls about half a meter to many meters high. The walls of shallow arroyos are commonly steep but not vertical. Although some arroyos are tens of kilometers long, most are tens of meters to about 3 km long. Arroyos can contain a wide range of wash materials, such as clay-poor sediments, silt, sand, gravel, and, less commonly, boulders. Many wash deposits confined in an arroyo are reworked to form a narrow floodplain, which can be dissected by one or more channels that are relatively shallow. In areas of occasional runoff, quicksand may occur beneath a dry crust on the arroyo bed.

WATER REGIME: Ephemeral streams in arroyos are the result of thunderstorms in commonly distant headwater regions. These streams are generally loaded with silt and sand. Few arroyos have intermittent flow, because springs are rare in semiconsolidated sediment except where arroyos cut into impervious rock such as shale. After the wet season, when the water table drops, interconnected subsurface narrow tunnels and conduits called pipes are common. These underground passages are produced by the liquefaction and removal of weakly consolidated sediments beneath the water table.

ENGINEERING AND MILITARY USES: Arroyos can provide good surfaces for travel in a defined direction, cover and concealment for movement, and sites for ambush and defilade. They can also be barriers to cross-country movement--hazardous barriers, because one can encounter them without warning in what appears to be unbroken, flat terrain, especially when visibility is poor. Even on a clear day, proximity to a steep-walled arroyo may not be apparent until the traveler is on its brink. Arroyos only a meter or so deep are relatively easy to cross, but deeper ones are more difficult to impossible. To avoid overturning, vehicles should be driven straight down or straight up the face, not obliquely. Some higher walls can be trimmed back to provide access. Because of the potential for flash floods and the difficulty of escape posed by high, vertical walls, larger arroyos must be considered dangerous. Never underestimate the potential for flash floods. Another problem is quicksand beneath a dry crust. One or two vehicles might cross in convoy, but once the crust is broken, others will be trapped. Such crusts can frequently be seen to undulate slightly when walked on, and even foot traffic across them must proceed with care. The broad, hard, smooth floodplain surfaces of some arroyos are excellent for fast movement; but, before attempting such use, the problems of quicksand, flash floods, and vertical headwalls should be considered.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Barranca, <u>dry wash</u>, gulch, <u>box canyon</u> (some).

DESCRIPTION: We combined ravines and canyons because they have the same characteristics except for size. A canyon is larger than a ravine, but no specific cut-off has been agreed on. The following descriptions are given for canyons, but they apply equally well to ravines.

Canyons are steep, V-shaped valleys incised in rock, commonly in plateaus. Although the rock that forms a plateau is usually a sedimentary sequence of limestone, sandstone, shale, or conglomerate, layers formed by basaltic lava flows are also common, particularly as protective cap rocks. Canyons cut in flat-lying rocks have steep side walls composed of alternating cliffs and slopes with a step-like profile. The cliffs are formed by the harder, more resistant rock strata, and the slopes by softer, less resistant layers. Canyons in crystalline rock tend to have less regular cross-sectional profiles. Most canyons have narrow to non-existent floodplains between their channel and the side walls. Canyons with near-vertical headwalls are called box canyons, from which there are no upstream exits. Canyon floors can be fairly level for long stretches, particularly near their mouths. They have a depositional cover of sand, gravel, and boulders. Boulders and large talus fragments predominate in their upper reaches but are sparse and scattered in their lower sections. Cap rocks composed of lava flows commonly contain columnar basalt, which forms layers of closely packed, vertically oriented, polygonal shaped columns. Where such layers are present, fallen rock debris on the canyon floor consists of a jumble of loglike rock columns of different lengths. If the channel is incised into a sequence of layered rocks, the channel typically takes on a flat-bottomed, boxy shape, more like an arroyo.

WATER REGIME: A canyon may contain a perennial river (e.g., the Grand Canyon of Arizona contains the Colorado River), ephemeral water, or intermittent water. In the arid to very arid deserts, most canyons are dry. All, however, are subject to flash flooding after rain falls in the watershed, which can be the surrounding highlands or a distant mountainous area.

ENGINEERING AND MILITARY USES: The steep walls, absence of broad floodplains, and presence of rock debris makes much of a canyon floor unsuitable for travel or camping. In the upper reaches, vehicular travel is not possible and foot travel can be difficult. These same characteristics make the canyon hazardous because of the potential for flash floods. Isolated thunderstorms, either local or in the upper reaches of the watershed, can quickly cause flash floods in side canyons and waterfalls over canyon walls; both can produce torrential flows that may rapidly fill the canyon from wall to wall to depths of many meters. Travel into or out of the main canyon is best done via the smaller side canyons, climbing in and out by means of the canyon walls requires ropes, pitons, etc. Box canyons end upstream in vertical cliffs that are difficult to climb and impossible for vehicles to negotiate.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Canõn, ravine, gorge, barranca, chasm, arroyo (some), wadi (some).

DESCRIPTION: Former drainage courses that now stand as ridges above the level of the surrounding terrain are fairly common in arid regions of the world. Although residual in nature and positive in relief (ridges), inverted wadis are included here because of their origins as drainageways, and the fact that on airborne imagery and satellite imagery their patterns often resemble drainage systems. In small scale monoscopic imagery it can be difficult to decide which of the two features the pattern represents, i.e., a channel or a ridge. The ridges often occur in swarms and have curvilinear, meandering, or branching patterns; individual ridges come and go, depending on their resistance to erosion. Typically, the ridges rise from 1 to 10 m above their surroundings. Cross section profiles range from convex to trapezoidal with relatively steep side slopes--between 10 and 20°. Individual ridges and assemblages of ridge segments can be kilometers to tens of kilometers in length, reflecting their origin as gravel beds in stream channels.

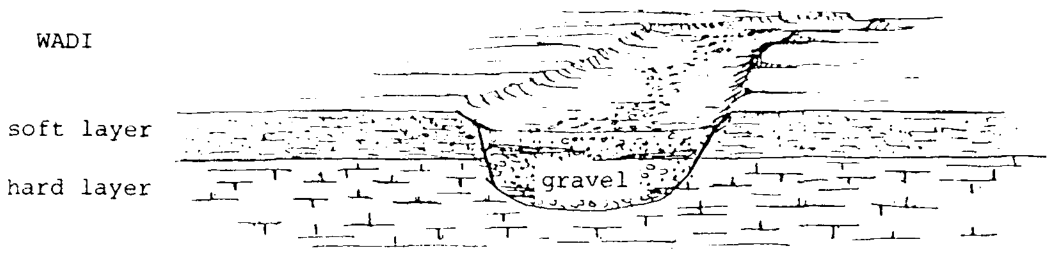
ORIGIN: One type of relief inversion occurs where erosion removes the ground around the central parts of dry stream channels that contain coarse gravels and cobbles. Parts of the original stream channel deposits must be more resistant to erosion than the surrounding matrix. The erosion of the surrounding matrix occurs primarily by wind action, whereby small, loose particles are picked up by the wind and transported elsewhere (deflation). Sheetwash can also contribute to lowering the areas adjacent to the channels. Inverted wadis seem to occur preferentially on the plains near highland sources of gravels and other coarse, hard to erode materials. They may extend for hundreds of kilometers away from the source areas.

Another type of relief inversion occurs where parts of a stream channel become cemented by minerals such as calcium carbonate, commonly carried to the site by percolating ground water, or by soil forming processes, so as to be resistant to deflation. A third type of inverted relief results from accumulation rather than from erosion and deflation. An example occurs in the Sechura Desert of Peru, where the old channel of the Rio Casajal (6°S 80°15'W) is marked by concentrations of bushes that grow preferentially along its prior course. Blowing sand from the surrounding flat terrain, moving inland with the prevailing wind, accumulates around the bushes and builds coalesced coppice dunes that form elevated ridges, which mark the earlier course of this river.

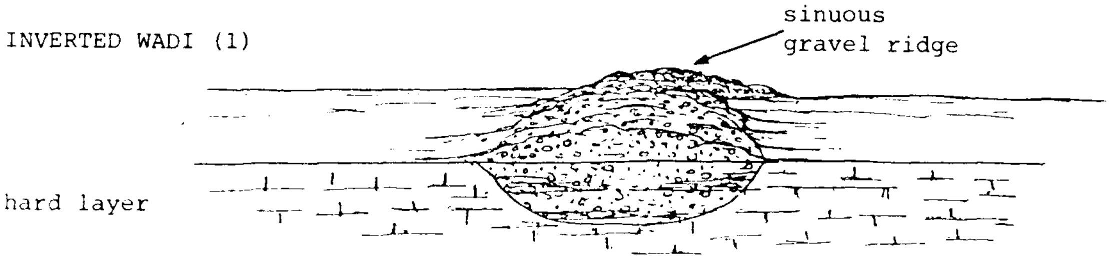
ENGINEERING AND MILITARY USES: Where composed of unconsolidated gravels, these ridges can be excavated, but where cemented, digging will be difficult. They can usually be crossed with both wheeled and tracked vehicles. In places along larger ridges, the resistant cap sometimes forms a small vertical face of a few centimeters to a meter or so, which can effectively block vehicular traffic. In some locations, such ridges serve as roadways. They can provide local cover and concealment, as well as sites for observation, ambush, and defilade.

(See back of sheet for illustrations.)

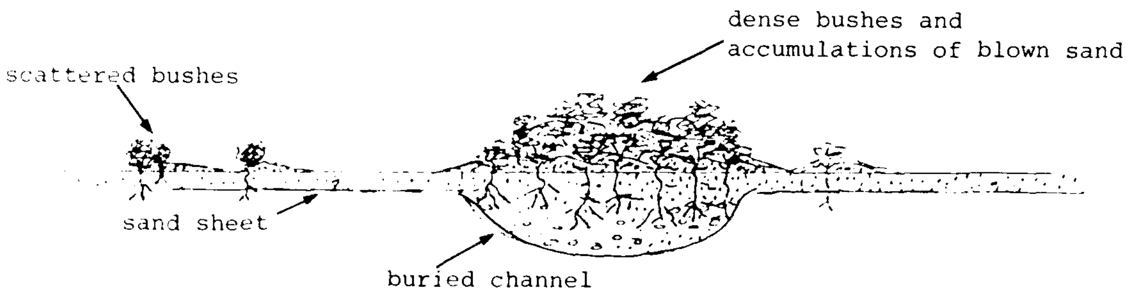
WADI



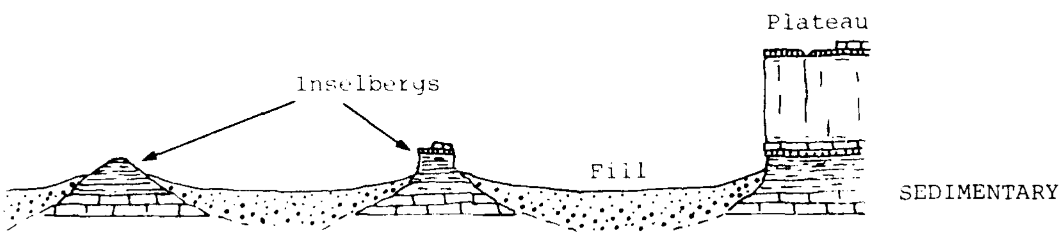
INVERTED WADI (1)

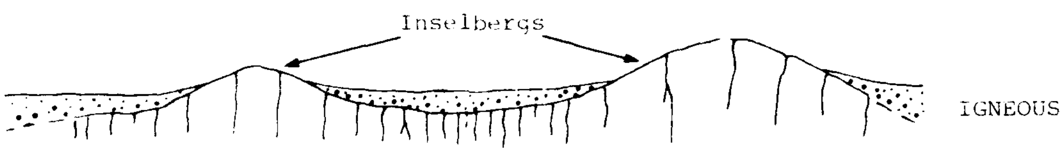


INVERTED WADI (2)



DESCRIPTION: An inselberg is a residual relief feature--an isolated hill, knob, ridge, or small mountain that rises abruptly, like an island, from a gently sloping or virtually level surrounding plain (inselberg is a German word meaning "island mountain"). A confusing collection of concepts, definitions, terminology, and hierarchical classification is associated with the isolated remnant features known as inselbergs, monuments, monadnocks, stacks, buttes, bornhardts, tors, etc. For the purposes of this guide, these features have been divided into two classes: inselbergs and monuments (see separate sheet). Both are erosional outliers being slowly buried in debris, including their own, and are characteristic of arid landscapes in a late stage of an erosional cycle. They may occur as individual hills but are more common in groups. Inselbergs are considered a characteristic granitic landform, but they are not limited to granites. As granitic landforms they tend to be equidimensional in length and width. As sedimentary landforms they are frequently ridges. In height, they range from small knoblike features to small mountains, i.e., from a few meters to thousands of meters. In profile, they have a very sharp break in slope where their base meets the flat plain. Inselbergs eroded in crystalline rocks are generally smoothly rounded, whereas inselbergs eroded in sedimentary rocks tend to have blocky slopes. Inselbergs formed by erosion of a plateau have the same composition as rocks exposed in the cliffs of the adjacent, parent plateau; they show the same structural characteristics, such as horizontal, tilted, folded, or fractured beds. The resistant cap rock of the plateau may occur as small nubbins on adjacent inselbergs or be eroded away entirely, exposing the lower and less resistant rocks to accelerated erosion.



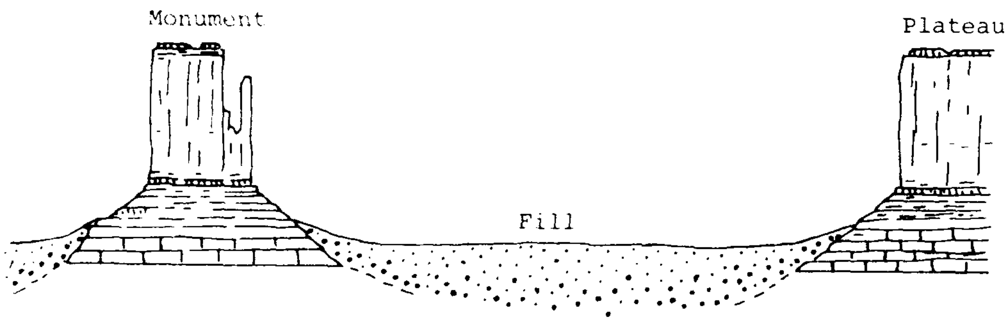


ORIGIN: Inselbergs are the result of fluvial action and mass wasting. They can be protruding remnants of an igneous mass, erosional outliers of nearby plateaus, or remnants of former stream divides (highlands). Unlike yardangs, they are not obviously streamlined by wind, although wind probably contributes to the removal of weathered slope debris.

ENGINEERING AND MILITARY USES: The presence of inselbergs on an otherwise flat desert plain usually indicates proximity to a plateau or highland or to highland remnants. This is particularly true if the inselbergs are composed of sedimentary rocks. On satellite imagery, arrangements of inselbergs are commonly associated with faint traces of drainage patterns that indicate wadi systems carrying ephemeral water (see Summary Sheet for Drainage Courses - Wadis). Shallow ground water might be available in some of the more conspicuous drainages, especially those that contain vegetation. Inselbergs that have small-scale roughness can provide some level of cover and concealment. Because of their commanding positions over the surrounding desert terrain, they have often been used as observation posts during desert warfare. Although seldom trafficable by wheeled vehicles, they can be climbed on foot. Some larger inselbergs are shown on maps and appear on many forms of imagery, which makes them useful for navigation.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Bornhardts, domes (some), tors, conical hills, peaks.

DESCRIPTION: A monument is a detached or semidetached, towerlike, residual structure that rises abruptly from its surroundings, has a regular shape, and is most commonly hundreds of meters high. Monuments are like inselbergs in that most are isolated outliers of plateaus (see Summary Sheet for Inselbergs/Hills/Knobs). Many plateaus consist of horizontal beds, and their erosion results in the classic monument shape. Unlike inselbergs, whose shapes are conical or pyramidal, monuments tend to have vertical sides. These vertical pillars typically rise from a sloping base of talus and resemble a man-made structure. Monument dimensions differ considerably, depending on the amount of fracturing and the stage of erosion, but the obelisk and towerlike shapes are dominant. Pinnacles and monumentlike features can occur in columnar basalt, in volcanic rocks (as volcanic necks), in highly fractured granite, etc., but the classic monument shape is most often associated with massive, jointed sedimentary beds (layers). Depending on the homogeneity of the rock, monument sides are continuously vertical, a series of stairsteps, or modified in other ways. In composition and structure, they resemble the adjacent plateau, and they stand no higher than that plateau. Outstanding examples of tall, massive, steep-sided monuments, resulting from erosion of thick, nearly horizontal beds of sandstone, can be seen in Monument Valley, Arizona. If the beds are tilted or folded, or otherwise internally inhomogeneous, the isolated erosional remnants show these characteristics by their less regular shapes, and they do not resemble a true monument. The distance of a monument from the parent plateau ranges from meters to kilometers.



ORIGIN: Monuments are the result of external erosion by running water and mass wasting, and of weathering along joints and other fractures within flat-lying sedimentary rocks, generally in a plateau. Erosion gradually separates sections of the plateau from its parent mass. As weathering and erosion continue to shrink the margins of the plateau and detached outliers, the breaches become deeper and wider. Eventually the isolated, towerlike features are far removed from the retreating plateau front.

ENGINEERING AND MILITARY USES: The presence of monuments on an otherwise flat desert plain indicates proximity to a plateau. They are commonly remnants of former drainage divides, so on a satellite image an arrangement of monuments may be associated with faint drainage patterns of wadi systems containing ephemeral water (see Summary Sheet for Drainage Courses - Wadis). Shallow ground water may be available in some of the larger drainages on the desert floor, especially those that contain vegetation. Monuments are among the few desert features that can give significant shade, and groups of them can provide some degree of cover and concealment. Although they can be excellent observation posts, access to their tops will usually have to be by helicopter. Climbing is not feasible except by trained personnel with special gear. Large monuments show on satellite images, and some are noted on maps; if so, they can be navigational aids.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Buttes (some), towers, pinnacles, peaks.

DESCRIPTION: Though found in deserts, these features are not formed under arid conditions. Their formation requires the presence of slightly acidic water to dissolve a slightly soluble material, usually limestone (calcium carbonate). Surface dissolution by rainwater leads to the formation of usually shallow pits or panlike depressions that range in diameter from a meter or so to tens of meters. Dissolution at intersections and along cracks develops depressions that may gradually deepen and enlarge from centimeters to hundreds of meters in diameter, and to tens of meters in depth. Large solution hollows are called sinkholes, or dolines. They are usually funnel-shaped, and tend to be aligned along the regional bedrock fracture pattern. The rate of dissolution for sinkholes is faster than for enclosed pans because the sinkholes are constantly drained through a network of underground caverns, which can carry fairly sizable streams. Where limestone beds are relatively flat-lying, the solution hollows (depressions) are circular. Where the beds are dipping, the depressions are elliptical. When clogged with sediments, sinkholes develop into ponds and small lakes. Meanwhile, the intricate three-dimensional subterranean drainage system of drips, trickles, and streams continues to enlarge the subsurface channels and cavities, which can range from finger-size to caverns such as Mammoth Cave in Kentucky. Some blocks are so undermined that they collapse to form isolated holes, coalesced holes, and long sinuous troughs or valleys conforming to underground streams. The resulting landscape is called karst topography. In time, as the landscape is altered and lowered, the karst features are enlarged and softened into hollows, large basins, and long broad valleys which may or may not be enclosed. They can become so modified by cycles of climate, including dry windy conditions, that their mode of origin is obscure. In desert regions, the larger hollows typically contain playas.

ORIGIN: Limestone is soluble in rainwater because this water is enriched with carbon dioxide (CO_2) from the atmosphere, as well as from plant material, to form a weak carbonic acid that reacts with the calcium carbonate ($CaCO_3$) of the limestone to form calcium bicarbonate ($Ca(HCO_3)_2$). This compound is dissolved by the water and carried away by surface and subsurface drainage. The rate of dissolution, as well as the resultant shapes, depend on: composition of the rock, type of bedding (thin, massive, interbedded, etc.), structure (flat, dipping, folded), extent of fracturing, height above the water table, temperature, water flow and turbulence, and the carbon dioxide concentration.

In desert landscapes, solution features usually are relicts from an earlier time and a different climate. Wherever calcium carbonate is part of the rock, such as limestone, sandy limestone, limy sandstone, or limy conglomerate, etc., some solution can take place where water is episodically present. Dolomitic limestone, which contains magnesium, is the least soluble of these rocks. Although limestone is generally hard, resistant to erosion, and impermeable, its fractures and bedding planes make it susceptible to erosion, weathering, and solution. Slightly acidified rainfall reacts with the limestone at the surface and along the cracks, slowly dissolving the calcium carbonate and carrying it away in solution along the drainageways it has established and is ever enlarging. Solution features can also be found in gypsum (calcium sulphate dihydrate or $CaSO_4 \cdot 2H_2O$). Refer to the Summary Sheet for Duricrusts - Gypcrete.

ENGINEERING AND MILITARY USES: Exposed, deeply etched limestone surfaces that occur in desert regions can hinder cross-country movement, even making it impossible, and be very hard on tires and equipment. During rainy seasons, pans can be a source of water. Massive units such as plateaus and plateau outliers (mesas) that have been pitted by solution can provide cavities and passages for shelter, habitation, storage, and cover and concealment.

DESCRIPTION: Beach ridges are elongated, narrow mounds of unconsolidated or semi-consolidated materials such as gravel, sand, and shells. They are located at the back of an active beach above the mean high tide and storm wave zone, and roughly parallel to the waterline. Commonly, they comprise most of the terrain on barrier islands along sandy coasts (Stapor).[1] As a coastal plain undergoes uplift, the changes are preserved as a succession of alternate ridges and swales. The swales may appear dark on photographs, and commonly contain swamps, or sabkhahs, and organic matter. Depending on the rate of uplift and the nature of the beach materials, beach ridges range in height from centimeters to several meters; in width, from a meter or so to several tens of meters; and, in length, up to several kilometers. Windblown sand frequently accumulates on tops of the ridges, giving the surface a hummocky appearance like that of a foredune (Price).[2] Many foredunes are built on old beach ridges, and thus have a semiconsolidated core of coarse sediment.

ORIGIN: Beach ridges are formed by wave action on resident materials and on transported materials brought in by streams and tidal currents. Multiple beach ridges were formed along many coasts during the advances and retreats of the sea associated with interglacial and glacial episodes (Quaternary period), or with uplift of coastal regions due to tectonic plate movements, as in western South America.

ENGINEERING AND MILITARY USES: Beach ridges and associated sand cover can be excavated, and are sources of engineering and commercial materials. They can also provide some degree of cover and concealment during amphibious operations. Loose particles such as gravel and sea shells can become projectiles when hit with explosives.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Barrier beach, beach ridge plain, chenier plain, foredune (some).

REFERENCES:

[1]Stapor, F.W., Jr. 1982. Beach ridges and beach ridge coasts. In Encyclopedia of Beaches and Coastal Environments, edited by M.L. Schwartz, pp. 160-161. Encyclopedia of Earth Sciences, Vol XV. Stroudsburg, PA: Hutchinson Ross.

[2]Price, W.A. 1982. Beach ridge plain. In Encyclopedia of Beaches and Coastal Environments, edited by M.L. Schwartz, pp. 159-160. Encyclopedia of Earth Sciences, Vol XV. Stroudsburg, PA: Hutchinson Ross.

DESCRIPTION: Burn scars are bare patches of ground where some of the vegetative cover has been burned off by either controlled or uncontrolled fires. When seen in an image, especially a Landsat scene, burn scar patterns can be startling to the first-time observer. Scars occur as isolated patches, as somewhat orderly clusters, or as an interconnected series. Scars can be of any shape, and they range in size from small patches of less than an acre to large patches and streaks tens of kilometers long. Most edges are sharply defined, although the downwind border can be diffuse. During and for some time after a burn, the patch typically is darker than the surrounding area, because it is covered with dark ash and soot. This dark tone persists until the wind or rain sweeps the surface clean. Then the tones reverse and the exposed soil mantle appears brighter than the surrounding soil, vegetation, and ground litter. With time, the patch again may darken as vegetation is reestablished. Consequently, aerial photos and images commonly show an historical assemblage of burn scars that range in tone from very dark to very bright.

ORIGIN: Burn scars can be found in any region that has enough vegetation and litter to support a fire, but they are typically characteristic of semiarid plains such as in central Australia and the Sahelian zone of North Africa. Fires are caused by natural events such as lightning and by both accidental and deliberate human activities such as campfires, slash-and-burn agriculture (common in tropical forest regions), and the burning off of old plants to encourage new growth for grazing cattle (common in semiarid regions).

ENGINEERING AND MILITARY USES: Assemblages of burn scar patterns on images, particularly clusters with a variety of tones, indicate the presence of people and grazing animals. Depending on soil type and condition (wet, dry, etc.), the exposed soil mantle of a recent burn scar can be softer and less stable than mantles of more heavily vegetated areas, although it should not pose a problem to cross-country movement. The camouflage characteristics of burn areas are different than those of unburned terrain: people and vehicles can be conspicuous against the light-toned, uncluttered background of a bright burn scar. People who walk across newly burned areas emerge covered with soot.

DESCRIPTION: Desert pavements are surfaces of closely packed angular or rounded rock fragments, commonly only one or two fragments thick, that form a mosaic in a matrix of fine sediment, i.e., sand, silt, and/or clay (definition modified from Cooke and Warren).[1] Coarse fragments are alluvial pebbles, gravel, and cobbles, or debris weathered from bedrock (talus). Desert pavements cover areas ranging from a few square meters to hundreds of square kilometers. They occur mostly in sand-poor regions, such as desert plains near bedrock outcrops, on plateaus, in dry wadis and terraces, and on alluvial fans. The mechanics of the evolution of the surface are controversial; current theories include accretion and deflation due to wind action (McFadden, et al.),[2] water sorting, and upward migration of coarse particles by freezing/thawing or by wetting/drying cycles.

Some older pavement areas are remarkably smooth and flat with no large fragments protruding above the surface. Such areas are commonly found on smaller fans; low, arched fans; the outer reaches of large fans and outwash flats; and terraces and flood plains along drainage courses. In other, younger pavement areas, many of the larger fragments are cobbles and boulders about 15 to 30 cm across and even larger, which protrude significantly above the surrounding terrain. This irregular surface occurs most commonly on highly arched fans and the upper reaches of large fans and outwash flats. Exposed surfaces of the coarse fragments are commonly coated with a black or brown patina called desert varnish; their buried undersides may be stained orange brown. Little vegetation is present except where soils have developed beneath the pavement.

ENGINEERING AND MILITARY USES: In general, desert pavements are ideal for cross-country movement and aircraft use because they are usually dry, fairly smooth, and hard. However, aircraft operations or the passage of fast-moving vehicles can raise clouds of dust. Also, thin pavements can be broken by heavy vehicles or multiple passes of light vehicles, exposing fine sediment that may be soft or produce dust. In areas of cobbles and boulders, vehicular traffic must follow a zigzag path in accordance with the vehicle's ground clearance. See Summary Sheets for Alluvial Deposits - Fans and Gravel Plains.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Hammada, serir, reg, gobi, gibber, stone pavement.

REFERENCES:

[1]Cooke, R.U., and A. Warren. 1973. Geomorphology in deserts. London: B.T. Batsford Ltd., p. 120.

[2]McFadden, L.D., S.G. Wells, and M.J. Jercinovich. 1987. Influences of eolian and pedogenic processes on the origin and evolution of desert pavements. Geology, v. 15, pp. 504-508.

DESCRIPTION: Dikes are low, steep-sided, vertical, or steeply inclined walls that are formed by natural processes and cut across the landscape. In plan view, dikes form continuous or discontinuous, linear or curvilinear ridges that occur in isolation, in sets, or as intersecting networks. A group of dikes is called a swarm. In cross section, and aside from adjacent rubble, they range from rather boxlike shapes with steep sides, to fairly thin slabs. In height, they range from centimeters to 2 or 3 m; in width, from centimeters to 2 or 3 m; and in length, from meters to kilometers.

ORIGIN: Dikes are made by filling steeply dipping to vertical fractures in the surounding rock or sediment with another material. Clastic dikes are made by filling in fractures with detrital material, usually sand. With time, the filling material becomes indurated or cemented. It is then more resistant than the surrounding rock matrix, which erodes away and exposes the filling material as a wall, or dike. Dikes are also formed by the intrusion of molten (igneous) rock into fractures. The subsequent eroding away of the softer, surrounding formation exposes the intrusion as a dike. Igneous intrusions also occur in relatively flat fractures and bedding discontinuities, and these are called sills.

ENGINEERING AND MILITARY USES: Dikes are made of hard, resistant material and generally cannot be excavated, but as with other ridgelike structures (gravel trains, inverted wadis, beach ridges), dikes can be obstacles to cross-country movement, as well as provide cover and concealment, and sites for observation, defilade, and ambush.

DESCRIPTION: Duricrust is a term applied to all types of surface or near-surface, hard, roughly horizontal layers produced by the transportation and subsequent deposition, or by the precipitation, of dissolved or airborne salts and other minerals within soils and unconsolidated sediments, and decomposed or permeable rocks. Exposed duricrusts have a protective effect similar to that of a resistant cap rock in sedimentary sequences, and they can produce topographically significant landforms in much the same way. These landforms include plateaus, mesas, and buttes ("breakaways" in Australia) in flat-lying units, and hogbacks or cuestalike forms in tilted or folded units. Duricrusts are named for their major constituent. Those discussed here are:

Caliche or calcrete ($CaCO_3$)
Gypsum or gypcrete ($CaSO_4 \cdot 2H_2O$)
Laterite or ferricrete (Fe_2O_3 and Al_2O_3)
Silcrete (SiO_2 and TiO_2)

Other saline crusts cemented by salts other than calcium sulfate are common, but because they are not sufficiently resistant to erosion to persist as landscape features, they are not considered to be duricrusts. Many duricrusts show evidence of replacement of one type by another (e.g., calcrete replaced by silcrete), indicating a complex history of formation under changing conditions of climate and chemical processes. Because duricrusts are a barrier to the infiltration of water, they increase surface runoff--thereby contributing to flooding.

ORIGIN: Among pedologists, chemists, and geologists, agreement is not complete as to the mode of formation of the duricrusts. In general, they are formed beneath the surface, and result from the deposition, and/or precipitation, of transported salts and other minerals that come from the physical and chemical weathering of soils and rocks. The salts and minerals can be carried as airborne dust and carried down into the surface materials by rainfall, or they can be carried in solution in the ground water. The solutes and suspended micro-matter can be moved up and down by an oscillating water table and redeposited or precipitated at different levels in the soils, unconsolidated sediments, and permeable rocks at the same site, or they can be carried down the drainage system and deposited or precipitated far from the source. Thus, the composition and character of the resulting duricrust is determined by atmospheric and climatic conditions, hydrologic conditions, nature of the source materials, topography, and local physical/chemical conditions within the host materials and the invading solutions. Duricrust layers can be extensive in area, and within a unit vary in thickness and properties. Duricrusts form in lowlands during long periods of stability that allow the redeposited or precipitated materials to slowly accumulate in place. Many duricrusts are "fossil" deposits unrelated to present conditions.

ENGINEERING AND MILITARY USES: Duricrust layers at or near the surface can provide good conditions for travel. Even though covered with a sand/gravel layer, up to a foot or so in thickness, a duricrust unit can provide the needed support for passage of heavy trucks, tanks, etc., by limiting the distance a vehicle can sink into the soft surface materials. As an exposed unit, the surface characteristics can vary from a relatively smooth cover of gravel-sized fragments that allows for relatively high speed travel, to a surface so broken and dissected and littered with such large rock fragments that vehicular traffic is not feasible. In advanced cases of dissection and long-term weathering, the duricrust winds up as islands of rubble in an intricate, and sometimes angular, network of channels or wadis filled with finer cuts of gravel as well as sand and silt. Barring rains and floods, these channels provide the preferred routes for travel. In time, the islands of rubble become further reduced in particle size and can be traversed. The more water soluble duricrusts, such as calcrete and gypcrete, can have solution holes or pits. Where covered with a veneer of sand and gravel, these pits, now filled with loose material, cannot be seen, and become obstacles to cross-country movement. For a line of vehicles advancing, some will miss the holes and proceed on; others will hit the holes and become stuck in loose sand. Buried layers of duricrust, or hardpan, can restrict access to ground water, and can be a problem in engineering excavations. They can be so hard that they can be attacked only with heavy duty power equipment.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Billy, calcrete, caliche, carbonate platform, croute calcaire, croute de nappe (Algeria and Tunisia), croute gypseuse, ferricrete, grey billy, gypcrete, gypsite, hardpan, ironstone, kankar, kunkur, silcrete, gres polymorphe, porcellanite, sarsen, puddingstone, meulieres.

DESCRIPTION: Caliche is a general term for any secondary calcium carbonate ($CaCO_3$) that forms in sediments or in voids and crevices within bedrock just below the surface in semiarid regions, as a result of soil-forming processes (pedogenic caliche) or ground-water evaporation (ground-water caliche); it is material left behind by the evaporation of ground water or soil moisture that is no longer present at that level, although ground water may be present at much lower depths beneath the caliche. Caliche has several forms: thin, white crusts or rinds on individual pebbles and fillings in pores and crevices in soil or bedrock; discrete, hard, white nodules or lumps; or thick, massive, rock-hard accumulations that cement gravel, sand, and fines of a sediment, producing a dense and impermeable layer that resembles fresh-water limestone. Such massive caliche layers (calcretes) are common in deserts at depths of a few centimeters to about 2 m. The layers are a few centimeters to several meters thick. Occasionally, caliche acts as a barrier to percolation of soil moisture from precipitation, helping to retain seasonal moisture near the root zone in vegetated areas. Some alluvial fans eventually become so plugged with caliche that surface runoff can no longer percolate into the gravel, producing short-lived but disastrous flooding in their terminal regions.

ORIGIN: In arid and semiarid regions, the $CaCO_3$ comes from capillary rise and evaporation of $CaCO_3$-charged ground water, from calcareous dust blown by wind and then driven into the soil by episodic rainfall, and from infiltration of soils, sediments, and rocks by runoff from areas containing sources of $CaCO_3$ (primarily limestones). In vegetated areas, $CaCO_3$ can precipitate out around the roots of plants. The relative contributions to caliche formation by these various processes, and the time relations represented by the different types of caliche in general, are not well defined. Because water must be present in the soil or at the water table to evaporate and leave behind the $CaCO_3$, formation of caliche requires a climate that is semiarid to subhumid, but caliche commonly persists as a relict feature in areas whose climate has changed to arid or extremely arid, as have parts of the Sahara and the southwestern U.S. It does not persist in areas that have become wetter, because there it is dissolved and leached from the soil. In the Sahara, the removal of overlying soil layers by wind has exposed the calichified zone of underlying alluvial sediment. The exposed caliche (calcrete) weathers to a dark-gray, very hard "kunkur" that resembles bedrock. In many areas, especially in broad alluvial valleys, it is only thinly veneered by windblown sand and provides a solid substrate beneath the sand plain. The presence of caliche less than a meter beneath loose sand in arid regions can be detected on many L-band radar images acquired by spacecraft. Certain tones, textures, and colors on Landsat multispectral images can also be used to delineate large exposed areas of caliche deposits.

ENGINEERING AND MILITARY USES: Because caliche is common in sediments of alluvial plains, these plains will support vehicular traffic, and movement across areas underlain by caliche can be rapid. The presence of massive, hard caliche (calcrete) beneath a few centimeters of loose surficial sand makes these surfaces easily trafficable, for the caliche will support trucks and other wheeled vehicles, whereas deep, soft sand will not (see Summary Sheet for Sand Plains/Sand Sheets). For trenching, such caliche is an impenetrable barrier to all but mechanized equipment. Trenches dug with a backhoe in a thick caliche zone have vertical sides that stand up with little support. Sediments below the caliche, however, are likely to be loose. In semiarid areas, downward percolation of water from rainfall and runoff is inhibited by the presence of caliche layers, and grasses and shrubs in these areas may be sustained by soil moisture from precipitation better than vegetation in areas lacking the caliche at shallow depths. Caliche at depth, however, prevents ground water from rising to the surface. Where caliche is nodular or broken by erosion, gravels of rounded caliche are a common surface lag, whose presence is highly indicative of a caliche layer at some depth. In some areas, such as parts of northeastern Saudi Arabia and southwestern Iraq, thick layers of calcrete have been partially dissolved by rain and ground water, and have developed solution pits (sinkholes) that can be hazards to cross-country travel (Chapman[1]; Felber, et al.[2]).

FOREIGN NAMES AND SYNONYMS (common names are underlined): Hardpan, calcrete, kankar or kunkur (India, Egypt), duricrust (some), croute calcaire (Tunisia), carbonate platform (Egypt).

REFERENCES:

[1]Chapman, R.W. 1971. Climatic changes and the evolution of landforms in the Eastern Province of Saudi Arabia. Geological Society of America Bulletin, v. 82, pp. 2713-2728.

[2]Felber, H., H. Hötzl, H. Moser, W. Rauert, and J.G. Zötl. 1978. Karstification and geomorphogeny of As Sulb Plateau. In Sedimentological, hydrogeological, hydrochemical, geomorphological, and climatological investigations in Central and Eastern Saudi Arabia, edited by Al-Sayari, S.S. and J.G. Zötl, pp. 166-172. Quaternary period in Saudi Arabia, Vol. 1. New York: Springer-Verlag.

DESCRIPTION: Gypcretes are surface or near-surface layers, a few millimeters to several meters thick, composed of soils and unconsolidated sediments cemented by gypsum, i.e., calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$). At least three types have been identified (Watson, 1979).[1] Surface crusts, the first type, may be either powdery (see Summary Sheet for Nafash) or indurated. These evaporitic deposits are generally associated with lagoons, playas, and sabkhahs (see Summary Sheets for Playas and for Sabkhahs). Extensive, massive subsurface layers (deb-deb, croutes de nappe), the second type, are precipitated from gypsum-rich ground water, and they typically contain interlocking twin crystals that are called "sand roses" or "desert roses." The third gypcrete type is described as "mesocrystalline" (Watson, 1983);[2] it is typically 0.5 to 2 m thick, generally lies no more than a meter below the surface, and appears unrelated to the local water table. It commonly occurs on slopes and hill crests and may result from capillary rise of soil moisture or, more likely, from blanketing by windblown deposits.

Evaporitic gypsum deposits, both surface and subsurface, are common in the American Southwest. Subsurface horizons seem to be best developed in the northern Sahara, especially in Tunisia, Algeria, and in the coastal Namib Desert (Africa); in the Rajasthan Desert of west India; in various Middle Eastern deserts; in the Atacama Desert of South America; and in parts of Australia.[2] In Iraq, crusts cover the lower parts of pediments, where they are characterized by patterned ground (polygonal cracks) (Tucker).[3] Because of their diffuse nature and solubility, gypsum crusts are not commonly eroded into landform elements as are crusts formed of more resistant materials such as calcrete, silcrete, and laterite.

ORIGIN: In general, gypcrete forms beneath the soil surface in topographically low parts of desert basins by the evaporative and/or precipitative cementation of unconsolidated sediments by calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). Gypsum cement results from the leaching of deposits of airborne dust from dried salt lakes, from the evaporation of runoff carrying sulfate solutes, or from subsurface precipitation from saline ground water; such precipitates can be extensive and massive. Gypsum crusts formed by evaporation of saline surface water are associated with lagoons, playas, and sabkhahs. Purer gypsum, devoid of sand, is associated with ancient lake deposits. Gypsum crusts are typically found in hot deserts that receive an annual rainfall of 50 to 175 mm, but they can be found also in hot deserts that receive as much as 300 mm of rain. Although topography and water are the primary controls, a soluble compound such as gypsum cement cannot survive except in an arid region.

ENGINEERING AND MILITARY USES: Gypsum crusts are not as extensive as other duricrusts. Where they are of significant extent, such as in coastal regions, they can provide a relatively hard surface for travel. Even though covered with a sand/gravel layer, up to a foot or so in thickness, gypcrete can provide the needed support for passage of heavy trucks, tanks, etc., by limiting the distance a vehicle can sink into the soft surface materials. As an exposed unit, the surface characteristics can vary from a relatively smooth cover of gravel-sized fragments that allows for relatively high speed travel, to a more rugged surface that can impede traffic. Being soluble, gypcrete can develop solution holes or pits. Where covered with a veneer of sand and gravel, these pits, now filled with loose material, cannot be seen, and become obstacles to cross-country movement. For a line of vehicles advancing, some will miss the holes and proceed on; others will hit the holes and become stuck in loose sand. Buried layers of gypcrete can restrict access to ground water, and can be a problem in engineering excavations.

They can be so hard that they can be attacked only with heavy duty power equipment. Gypsum crusts can also be associated with playas, and these are apt to be soft, easily broken, and a major source of dust. When wetted after a rain, these surfaces are very slippery and gooey. When splashed into vehicle parts, such as wheel wells, gypsiferous clays can harden into a cementlike cake that is difficult to remove, even with high-pressure hoses. If thick enough, such an accumulation can impede wheel movement.

FOREIGN NAMES AND SYNONYMS (common names are underlined: Salt pans, playas, croute de nappe, desert roses, gypsite (west India), croute gypseuse zonee, debdeb (Algeria), sabkhahs (some).

REFERENCES:

[1]Watson, A. 1979. Gypsum crusts in deserts. Journal of Arid Environments, v. 2, pp. 3-20.

[2]Watson, A. 1983. Gypsum crusts. In Chemical sediments and geomorphology; precippitates and residua in the near-surface environment, edited by A.S. Goudie and K. Pye. San Diego: Academic Press, pp. 133-162.

[3]Tucker, M.E. 1978. Gypsum crusts (gypcrete) and patterned ground from northern Iraq. Zeitschrift fur geomorphologie, v. 22, no. 1, pp. 89-100.

DESCRIPTION: Laterite is an old term for a heavily weathered subsoil, rich in oxides of iron, aluminum, or both, ranging from reddish yellow to dark brownish red in color. In panchromatic imagery laterite surfaces show as dark tones. In natural-color imagery, they are generally dark red. Such areas have little or no vegetation. Because it hardens when subjected to wetting and drying, it can be cut, cured, and used as bricks; and thus the name, which comes from the Latin word for brick. It can also harden in place. Although laterite does not develop in arid regions, it is found in them as a relict from earlier, wetter climates. The name covers a broad range of materials, the origins of which are not well understood. There is still disagreement, especially between pedologists and soil chemists, over naming and classifying lateritic materials. In this guide, they are considered to include the material called ferricrete, or ferruginous duricrust, which is a hard conglomerate of sand and gravel cemented by iron oxide. Laterite can be found just below the surface as a loose, soillike material or in exposures having a hard, pavementlike surface. Incision of this hard surface by streams can leave the laterite as resistant cap rocks on upland mesas and plateaus. Such cap rocks are common in sub-Saharan Africa as well as in western and central Australia, where they are called "breakaways." A common type of laterite consists of closely packed, round pellets of iron, manganese, or aluminum ores. The pellets are also called pisoliths, because they are like peas in size and shape. Such pellets can be cemented together into a rocklike mass or distributed within a soil matrix; where eroded from this matrix, the pellets form a surface rubble. Another type, vermiform laterite, has a tubular, wormlike structure. Laterite deposits range in thickness from a few centimeters to tens of meters, are roughly horizontal, and can cover thousands of square kilometers. Laterite can be found in areas that are no longer subject to laterite formation because of changes in climate, hydrological conditions, or topography. Where climates have again become wetter, caves can form as a result of ground water solution and sapping beneath an old laterite crust.

ORIGIN: Laterite develops beneath the surface in soil zones, unconsolidated sediments, or decomposed rocks where interrelations of ground water, soil/water table, and topography are favorable. A critical factor in its formation is an alternating or variable moisture cycle, and it is formed in association with grasslands and forests on lowland surfaces in tropical and temperate regions. Precipitation from the water table is now generally considered to be of much greater importance as an effective agent in laterite formation than capillary action. Pisolithic laterite is associated with an oscillating, but slowly lowering water table. Vermiform laterite is thought to be formed when the water table is oscillating but stable. Pedogenic pisoliths, formed in soil, increase in number downward, but pisoliths formed in the underlying saprolite (decomposed rock) decrease in number downward. In homogeneous materials, pisoliths may occur in upper zones and vermiform structures beneath them. Although formed beneath the surface, these materials are commonly exposed by the removal of vegetation and subsequent soil erosion to form hard, impermeable crusts.

ENGINEERING AND MILITARY USES: Laterite crusts that have been widely exposed by erosion and are not too deeply dissected can provide good, hard surfaces for travel. These crusts can be so hard that blasting is needed to break them up. The material is often used as building blocks and as a base and subgrade for roads.

GENERAL REFERENCE: McFarlane, M.J. 1976. Laterite and Landscape. San Diego: Academic Press.

DESCRIPTION: Silcretes are very hard layers of silica-enriched materials formed beneath the surface in soils, unconsolidated sediments, and permeable rocks. These materials range from silica-cemented sand and gravel to an amorphous matrix enriched with small silica particles. There is little agreement as to their classification and origin. A minimum silica (SiO_2) content of 85 percent by weight has been proposed by Summerfield (1983a)[1] to distinguish silcretes from other duricrusts. Although not restricted to arid regions, silcrete zones are found in many deserts, and they are most extensive and prominent topographic features in Australian deserts. Silcrete tends to form roughly horizontal, highly resistant layers generally less than 5 m thick. When exposed by erosion, silcrete forms highly resistant cap rocks of scarps ("breakaways" in Australia). These cap rocks resemble quartzite. Many talus slopes and gravel plains in areas of exposed silcrete consist of silcrete fragments eroded from the cap rock. Buried silcrete layers thicker than 3 m are rare, and they are generally not laterally continuous over large areas. In the Kalahari Desert of southern Africa, they occur widely as layers within sandy surface deposits, and they are also found along old, dry river courses such as the Molopo River (Summerfield, 1983b).[2] These buried silcrete layers can be virtually impenetrable.

ORIGIN: The origin of silcrete is still controversial, as are sources of the silica, its transport, and the conditions or chemical processes responsible for its subsequent alteration, deposition, or precipitation. Chemical analyses have also shown that for a large variety of silcretes, from a broad range of environments, aluminum, iron, and titanium can be present in significant amounts, with more of an abundance of titanium. The climatic conditions under which it accumulates are uncertain, because nearly all silcrete occurrences are "fossil"--they do not seem to be forming extensively today. At least two types have been identified by Summerfield.[2] One type may be the product of precipitation from ground water or of capillary rise of silica-rich water into the soil above the water table, most likely in arid to semiarid climates. The second type is associated with soil weathering in a warm, humid climate.

ENGINEERING AND MILITARY USES: Silcretes are not as apt to be encountered as other duricrusts. Where exposed, these hard surfaces will support vehicular traffic, but broken fragments, like those of other highly siliceous rocks, are razor sharp and can severely damage the tires of wheeled vehicles. Well-developed silcretes are impediments to traveling.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Grey billy, breakaways, gibber (Australia), hardpan (some).

REFERENCES:

[1]Summerfield, M.A. 1983a. Silcrete. In Chemical sediments and geomorphology, edited by A.S. Goudie and K. Pye. San Diego: Academic Press, pp. 59-92.

[2]Summerfield, M.A. 1983b. Silcrete as a palaeoclimatic indicator: Evidence from southern Africa. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 41, pp. 65-79.

DESCRIPTION: Particles of silt and clay 0.005 to 0.05 mm in diameter are commonly lifted from dry desert surfaces by wind and suspended in the air as dust. Particles 0.02 mm or larger remain in the atmosphere only minutes to hours and travel a few tens to hundreds of kilometers, but smaller particles can remain suspended for weeks and travel thousands of kilometers--for example, from the Sahara Desert to Florida (Prospero)[1] or from deserts in northwestern China to Hawaii. Tops of dust clouds may reach altitudes of 6 km. The top of a dust layer over Texas, produced by a dust storm on the U.S. southern high plains in 1977, reached altitudes between 4 and 5 km (McCauley, et al.).[2] Dust eventually falls out of suspension and infiltrates surface materials, forming deposits (accretion mantles) in stony areas, and contributing calcium carbonate, various clay minerals, and iron oxides to soils. In some areas, so much dust is deposited that it forms a blanketing sediment called loess.

Areas particularly vulnerable to the generation of dust are desert surfaces of loose, dry sediment that receive less than 250 mm of annual rainfall and that, consequently, support little or no vegetation. In some areas, vegetation has been stripped off by overgrazing, by attempts at dry farming, or for construction, leaving barren surfaces vulnerable to wind erosion. Major source areas for dust are such disturbed areas, unpaved roads, dry washes, playas, and sabkhahs.

The undisturbed desert surface generally develops a crust of lag gravel (desert pavement) that stabilizes it and prevents wind erosion and dust production. Underlying the surface pavement, which is generally only one stone thick, is a layer of fine sand and silt that is built mostly of dust that has infiltrated the surface (McFadden, et al.).[3] When the surface stones are disturbed this sediment can again become airborne.

The composition of dust depends on its source material. Because most sources are alluvial deposits consisting largely of quartz grains (SiO_2) with associated clays and evaporites, dust most commonly consists of these quartz grains, various clay minerals, and salts. Volcanic dust is a special type of aerosol produced by explosive eruptions such as that in 1980 at Mount St. Helens, Washington.

WIND REGIME: Aside from that produced by vehicle and aircraft operations, dust can be generated by any wind strong enough to initiate bouncing (saltation) of sand grains, whose impact causes emission of the finer particles that become suspended in the air as dust. Dust storms in deserts are produced mostly by one of two types of meteorological events: (1) the downdraft of cool air from a convective thunderstorm (cumulonimbus clouds) associated with summer heating of the desert surface; or (2) the passage of a cold front associated with low-pressure systems driven by high-level jet streams. In both cases, heavy cooled air strikes the ground and churns up loose surface material, setting sand grains in motion that bounce along the surface.

Dust storms caused by convective storms are called "haboobs," an Arabic term for violent winds (Idso).[4] They are typical of parts of North Africa and southern Arizona. In Arizona, they accompany squall lines generated by the summer monsoonal flow of moist tropical air from the Gulf of Mexico, and Pacific tropical storms from the Gulf of California. Haboobs can move cross-country at speeds greater than [illegible] kph (internal gusts may reach 37 kph), with sudden drops in temperature of 5 to 10 C and drops in visibility to one quarter of a mile or even to zero. Commonly, the dust cloud is followed by a thundershower that clears the air; otherwise, visibility may not be restored for 1 to 3 hours.[4] Generally, in any given region the same kinds of duststorms occur year after year, associated with regional wind regimes that are fairly predictable as to season and time of day.

ENGINEERING AND MILITARY USES: Dust is ubiquitous in deserts and should always be considered likely, especially around surfaces disturbed by vehicles, construction, or excavation. Dust can also be blown into an area from nearby sources such as dry washes, playas, and sabkhahs. Dust will enter every orifice and penetrate equipment, clothing, tents, etc. Electronic components will be damaged by dust to some degree unless they are sealed. Therefore, spare equipment is vital, and the simpler and fewer the moving or exposed parts, the better. Plastics are especially vulnerable to scratching by dust.

Personnel must have head cloths to protect their faces from stinging dust. In World War II, the German desert units considered goggles an essential item. Cattle have been known to suffocate during exposure to dust storms. Shelter is essential, as are heavy canvas covers for vehicle radiators. Tents are likely to be blown down by the strong, gusty winds that typically accompany dust storms. Vehicles in transit usually must halt and wait out the storm. Dust storms often wipe out all tracks in loose sandy surfaces, so navigation cannot rely on the following of tracks.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Haboob, khamsin (Sahara, Arabian Peninsula), dirty wind, bad kessif (Iran), whirlwind, dust devils.

REFERENCES:

[1]Prospero, J.M. 1979. Dust from the Sahara. Natural History, v. 88, no. 5, pp. 55-61.

[2]McCauley, J.F., C.S. Breed, M.J. Grolier, and D.J. MacKinnon. 1981. The U.S. dust storm of February, 1977. In Desert dust: Origin, characteristics, and effect on man, edited by T.L. Pewe. Geological Society of America Special Paper 186, pp. 123-147.

[3]McFadden, L.D., S.G. Wells, and M.J. Jercinovich. 1987. Influence of eolian and pedogenic processes on the origin and evolution of desert pavements. Geology, v. 15, pp. 504-508.

[4]Idso, S.B. 1976. Dust storms. Scientific American, v. 235, no. 4, pp. 108-114.

DESCRIPTION: Escarpments are breaks in slope that separate one level of terrain from another. Generally, these breaks have steep to vertical slopes (cliffs), and they separate relatively flat units (plains or plateaus, buttes, or mesas). The difference in elevation between the two terrain units can range from centimeters to hundreds of meters. The escarpment face may strike across country for meters, or for tens of kilometers to form the boundary of an extensive plateau above a lower plain. As the areas bounded by escarpments become smaller, they are called mesas, buttes, and monuments; and smaller yet, they are called pinnacles. Steep to nearly vertical escarpments are common in desert regions where soil and vegetation are sparse. They commonly develop in rocks subject to vertical jointing, such as layered sedimentary rocks, columnar basalt, or in massive deposits of loess. Many escarpments include talus slopes along the base of their cliffs, especially in basalt, or interbedded sedimentary units of soft and harder materials. The base slope material can be rough and rocky, with larger rock boulders tumbled about helter-skelter.

ORIGIN: Escarpments are formed by fault movements (fault scarps), by erosion, by coastal erosion (sea cliffs), or by some combination of these processes. Escarpments formed by differential erosion are usually aligned parallel to major stream valleys. Fault scarps commonly cut across, and disrupt, drainage channels. Older fault scarps are frequently modified by erosion, and may even be eroded to an inverted relief, where the former upland block is eroded to a lower elevation than the former lowland block (Fairbridge).[1]

ENGINEERING AND MILITARY USES: Escarpments are often major obstacles to cross-country movement, and may require lengthy travel before finding access between the two levels. The base slope below a columnar basalt escarpment can be rough going, or even impossible to traverse. Depending on the size and arrangement of the talus blocks, cover and concealment can be found for personnel, and sometimes for light vehicles. Such rocky areas are often preferred habitat of snakes (especially rattlesnakes in arid terrain of the American West). Escarpments of sedimentary units also commonly have a rough, rocky base, which impedes travel. The upper level of the escarpment (plateau, mesa, or butte) provides key terrain for observation, and fire control. As most show on both maps and imagery, they can be used for navigation.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Buttes, cliffs, cuestas, hogbacks, horsts and grabens, mesas, rock walls, scarps, spurs.

REFERENCE:

[1]Fairbridge, R.W. 1982. Fault scarp, fault-line scarp. In Encyclopedia of Geomorphology, edited by R.W. Fairbridge, pp. 346-451. Encyclopedia of Earth Sciences, Vol. III. New York: Reinhold Book Corp.

NAFASH
(SOFT/BAD GROUND)

DESCRIPTION: Bad ground is a general term for surfaces of extremely poor trafficability due to the ground being soft and sticky, or powdery. In Egypt, the powdery material is called "nafash." Fragments of shale litter the surface, giving it the appearance of an ordinary lag-gravel plain. Nafash, with its shaley lag-like surface, is frequently concealed by a thin cover of windblown sand. Nafash accumulations are most likely to be encountered in shallow topographic depressions near outcrops of clay-rich rocks, such as the Dakhla Shale in Egypt. In a less arid climate, runoff from occasional precipitation would produce playas in such depressions (see Summary Sheet for Playas).

ORIGIN: Nafash is the product of in-place weathering, in poorly drained areas, of loose shale fragments, which results in a local accumulation of very soft, fine particles in a layer several centimeters to meters deep.

ENGINEERING AND MILITARY USES: Because the laglike cover of shale fragments and the veneer of windblown sand present a surface that is similar to a normal gravel plain or sand plain, a traveler can misinterpret the area and head into trouble. The first clue to the presence of nafash is that the laglike surface is composed largely of fragments of shale, instead of other rocks. A second clue is the sudden generation of thick clouds of powdery dust. By this time, of course, the traveler is already into the stuff. If the nafash is more than a few centimeters thick, it can bog down any wheeled vehicle, and one cannot determine its depth by its appearance. The best thing to do is to keep going at a good speed making a broad, 180° turn until one is out of the area. The worst thing to do is to stop. These areas will not support aircraft operations.

DESCRIPTION: Tafoni are deep cavities or hollows produced by cavernous weathering in the sides, including the undersides, of rock outcrops and boulders. They were originally described on the island of Corsica, but they are also found in many tropical to subtropical and coastal humid areas, as well as in arid to semiarid areas. They occur in many kinds of rocks, but are pronounced in granular or crystalline rocks such as sandstones or granites, especially in arid to semiarid coastal deserts. Tafoni usually occur in groups. Individual hollows range in depth and diameter from a few centimeters to several meters. They are enlarged inward with arch-shaped entrances, overhanging rims, and fairly smooth, convex walls and floors, and they are separated by walls of varied thickness. Honeycomb weathering is an apt descriptor for the pattern of parallel rows of smaller pits characteristic of sandstone faces.

ORIGIN: The origin of tafoni is not well understood. The consensus is that they result from weathering initiated along joints, fractures, and other lines of weakness, especially those where water can reside. The hollows are thought to be enlarged by progressive flaking of the interior surfaces and their granular disintegration, probably as a result of crystallization of saline material dissolved from the rock, carried to the rock by wind, or splashed on the rock by sea water. Case hardening of the outer surfaces is common, but the walls separating the cavities are not altered. Wind probably removes loosened material from the cavities.

ENGINEERING AND MILITARY USES: Large tafoni can provide cover, concealment, and shelter from the sun and wind for small groups of personnel, and their temperature may be fairly constant.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Honeycomb weathering (some), alveolar weathering, gnammas (Australia), weather pits, fretted rocks, stone lattices.

DESCRIPTION: Desert varnish is a dark-brown or black, commonly shiny coating on the exposed surfaces of rock fragments or outcrops. It is common on alluvial fans, gravel plains, and desert pavement. The colors tend toward black and darkish red and the surface can be lustrous or dull. This coating is independent of the composition of the host rock (Potter and Rossman).[1] Layers are relatively thin, commonly 0.005 to 0.5 mm thick, but thickness can vary from locality to locality as well as over the surface of a single stone. The varnish develops best on rough or porous surfaces of resistant materials that do not disintegrate rapidly, such as sandstone, basalt, and some metamorphic rocks. Limestones that are not silicified do not support a varnish because the surfaces dissolve faster than the varnish can develop. The surfaces of coarse-grained rocks such as granites weather by granular disintegration, which is slow enough that a thin patina of varnish can develop. Little if any varnish develops on the smooth, hard surface of pure quartz; if these white fragments are present, they are easy to spot. Because varnish is thought to form slowly (over decades), its presence on gravel plains, desert pavements, and alluvial fans probably indicates stability of the land surface.

ORIGIN: The details of varnish formation and its rates of development are not known, and they are subjects of considerable argument (Whalley).[2] The outer layer of most varnish is enriched with hydroxides of manganese (black tones) and iron (red tones). Varnish commonly forms on rocks that contain little or no iron or manganese, indicating that these elements are carried to the rock surface by wind, water, or both. If the rock contains iron and manganese, the process is presumably faster and the coats heavier. The development rate is, however, relatively slow, i.e., measured in years, decades, and millennia. One item of interest associated with the lore of desert varnish is that British fuel cans left in the eastern Sahara since World War II have been found that have a well developed layer of varnish on their upwind sides (Eastes, et al).[3]

ENGINEERING AND MILITARY USES: The dark tones of desert varnish, which can be seen in air photos and some Landsat images, are generally indicative of a firm, stable, and trafficable surface. Except for areas of steep slopes or of roughness due to rock fragments, these surfaces can support vehicular traffic--not because of the varnish, but because of the nature of the substrate associated with it. Generally, surfaces stable enough to develop varnish also have developed an accretion mantle of fine sand and silt, which immediately underlies the surface layer of varnished rocks or pebbles (see Summary Sheet for Desert Pavement). Repeated passes or vehicles tracking each other can disrupt the surface and expose the underlying dust, producing fines. In some cases, a single pass of a vehicle can leave a track that persists for years, because overturned rocks leave a bright trail among the varnished rocks.

FOREIGN NAMES AND SYNONYMS (common names are underlined): Desert lacquer, patina, Wustenlack, vernis desertique, patine du désert, weathering rinds (some).

REFERENCES:

[1]Potter, R.M., and G.R. Rossman. 1979. The manganese and iron-oxide mineralogy of desert varnish. Chemical Geology, v. 25, pp. 79-94.

[2]Whalley, W.B. 1983. Desert varnish. In Chemical sediments and geomorphology, edited by A.S. Goudie and K. Pye. San Diego: Academic Press, pp. 197-226.

[3]Eastes, J.W., P.P. Hearn, Jr., C.S. Breed, and J.F. McCauley, 1988. Weathering of a metal artifact in a Saharan environment: evidence of a novel form of desert varnish. Applied Spectroscopy, v. 42, no. 5, pp. 827-831.

DESCRIPTION: Although a minor feature and not of use in remote sensing applications, ventifacts do occur in many arid regions and may be useful in determining prevailing wind direction. They are individual rocks a few centimeters in size that have been shaped by wind erosion (Breed, et al.).[1] The shaping involves pitting, fluting, and faceting, depending on the type of rock exposed to abrasion and deflation. Fine-grained, homogeneous rocks eroded by strong, unidirectional winds generally develop blunt, high faces on the windward end, a keel on top, undercut zones on the lee flank, and a tapered, lower profile extending to leeward beyond the undercut zone. These rocks, except for their size, resemble yardangs (see Summary Sheet for Yardangs). Less homogeneous rocks and those eroded by multidirectional winds develop less symmetrical shapes. On fine-grained rocks such as limestone and siltstone, pitting is common and fluting and polishing are obvious. Many ventifacts have a "grain" or alignment of grooves and pits that records the direction of the prevailing wind. Rocks shaped by winds with more directional variability have multiple sets of facets and undercut zones, and they are much more difficult to use as indicators of wind direction. Keels commonly develop along the ventifact axes; because these keels may be parallel or transverse to the dominant wind direction, they should not be relied on for directional information.

WIND REGIME: Can be produced in all winds. Ventifacts can be formed from any type of solid material subject to strong winds, and their erosional flutes and undercut zones are the products of complex aerodynamic flow patterns (Whitney and Dietrich).[2]

ENGINEERING AND MILITARY USES: In regions of strong prevailing winds of known direction where surface rocks are undisturbed, ventifacts can provide a quick visual clue as to the direction of the prevailing winds. They are most useful when visibility is poor and other information is not available.

REFERENCES:

[1]Breed, C.S., J.F. McCauley, and M.I. Whitney. 1989. Wind erosion forms. In Arid zone geomorphology, edited by D.S.G. Thomas. New York: Halstead Press, pp. 284-307.

[2]Whitney, M.I., and R.V. Dietrich. 1973. Ventifact sculpture by windblown dust. Geological Society of America Bulletin, v. 84, pp. 2561-2582.

DESCRIPTION: Drastic changes in the desert landscape can result from a sporadic event, such as an unusually prolonged wet or dry season, or from cyclic events measured in weeks, years, or decades. Such changes range from minor and subtle variations in tone and texture to dramatic transitions, in which barren dunes and flats are transformed by vegetation growth over an entire region. The latter commonly takes place in as little as 8 weeks when the season changes from dry to wet. This type of change and its reverse--wet to dry--is an annual event where intensity varies from year to year. Perhaps the most dramatic of such changes are presently encountered in central Australia, particularly in its northwestern part: some areas of sandy and gravelly flats and dunes, which were arid and barren as a result of drought 20 years ago, have recently received sufficient rainfall to support a vegetative mantle throughout the year.

ORIGIN: Changes in desert landscapes result from seasonal and long-range variations in moisture, temperature, and wind. The seasonal changes are well recognized, documented, and fairly well understood. The long-range changes, including "desertification," are less well recognized and documented and are poorly understood.

ENGINEERING AND MILITARY USES: These changes greatly alter desert surfaces with respect to cross-country movement. Analysis and interpretation of dry-season or arid-climate imagery are rarely applicable to an activity planned for the wet season or for what turns out to be a different rainfall, temperature, or wind regime. In hyperarid regions, the changes are less dramatic than in semiarid regions, and imagery from any season can be used. Whenever possible, however, use imagery that was taken during the same season as that in which the planned activity will take place.

DESCRIPTION: Patterns of human activities, ancient and modern, occur in desert regions, and, as elsewhere, they indicate terrain characteristics and composition, and suggest potential engineering problems and uses, and possible military applications. Large scale industrial/urban complexes and metropolitan areas are not considered here. Examples of useful patterns include abandoned settlements and ruins, isolated water wells, roads and trails, pipelines, irrigation canals, quarries and mines, and fences. Abandoned settlements and ruins commonly show on imagery and are noted on maps. Such settlements were often abandoned because their water supply was lost owing to climate change, overuse, or because the water table sank below their capability to reach it. Field Army equipment can easily reach such a water table. Isolated water wells are sometimes noted on maps, and usually show on larger scale imagery such as aerial photography. If the spoil is of a different color than the surface material, and has been spread about over a large area around the well, the spot might be depicted on a Landsat Thematic Mapper image, which has an instantaneous field of view of about 30 m. Although depicted, the spot might not be identifiable as a well without auxiliary information. Trail patterns that converge on a point from all directions are also indicative of a potential water source. The patterns and concentrations of roads and trails indicate terrain characteristics associated with cross-country movement. For example, a well defined track crossing a sabkhah indicates a safe path of traverse. Pipelines can be obstacles to cross-country movement. Irrigation patterns indicate a water source and a potential for flooding the terrain to create an obstacle. The presence of center point irrigation systems indicates that the terrain is level and flat. Quarrying and mining patterns suggest certain types of surface composition. For example, salt extraction patterns on flat coastal areas suggest not only saline flats, but the possibility of sabkhahs. Aside from being obstacles, fence patterns can indicate sand control and areas of loose sand.

ORIGIN: Cultural features and patterns are related to:

- Abandoned Settlements/Ruins
- Agriculture
- Encampments/Settlements
- Fencelines
- Industrial (pipelines, oil fields, etc.)
- Transportation
- Water

ENGINEERING AND MILITARY USES: These patterns can serve as indicators to water sources, obstacles to cross-country movement, safe passages in problem areas, terrain characteristics, and engineering materials.

[illegible] LINEAR - SIMPLE

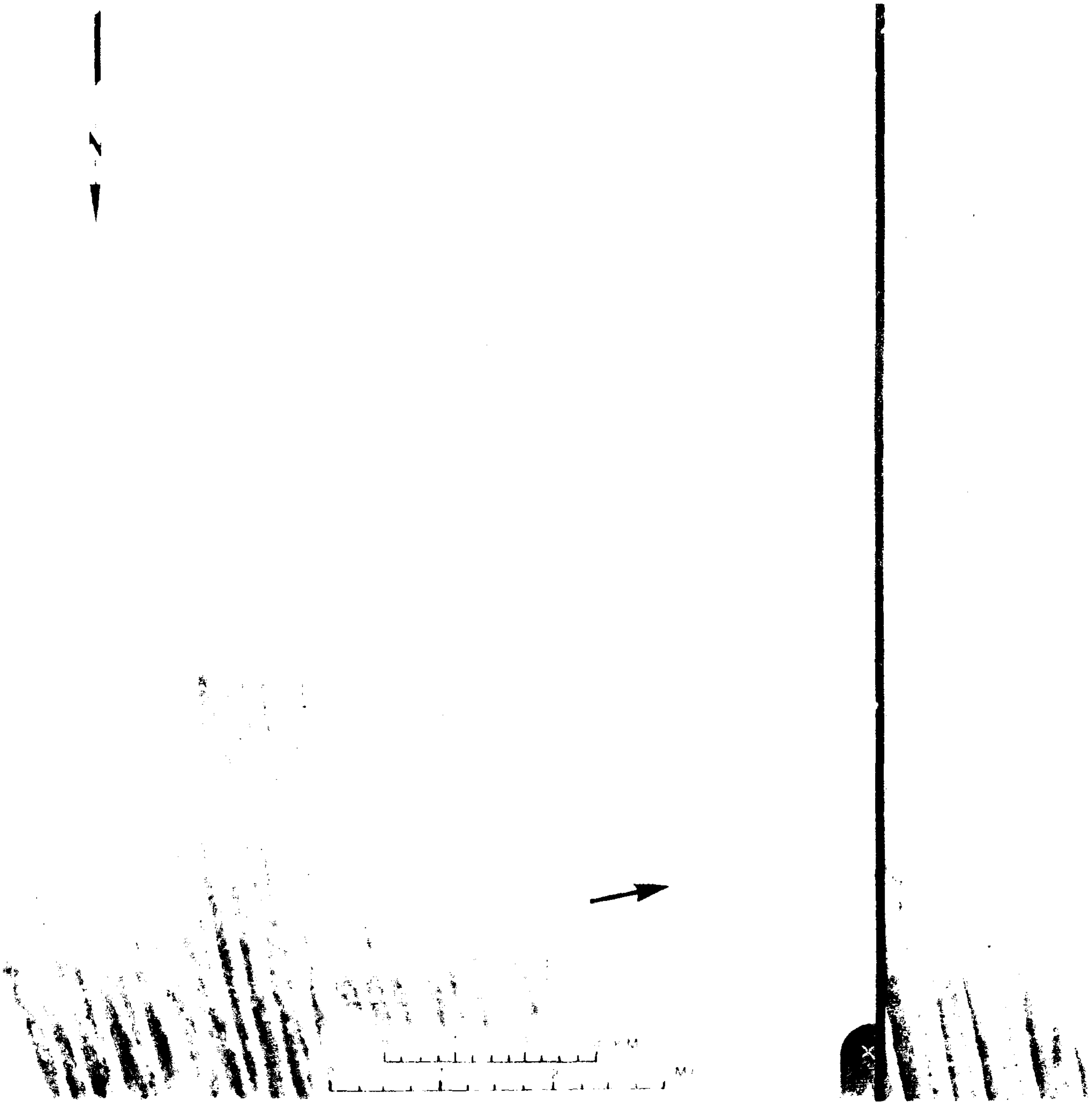
LOCATION: [illegible]

CLIMATE: [illegible] Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:

[illegible] Australia, [illegible] National Mapping, McGillis Run 871-872, [illegible]

[illegible] Desert Studies Group, Flagstaff, AZ, [illegible]



A

Comments on back.

[illegible] PROCESSES WORKING GROUP

B

[illegible]MMENTS: [illegible] are characteristic of large areas of the Simpson Desert. They [illegible] m and in spacing from 300 to 500 m, and they extend for [illegible]. In the area of these photos, C. Breed[2] reported an av[illegible], an average spacing of 400 m, and an average length of 14 [illegible] the result of strong, steady winds in a direction roughly parallel [illegible] of the dunes (from the south-southeast in this area). [illegible] (arrow, photo A) is indicative of wind dir[illegible] [illegible]ward. The tops of the dunes, light-toned streaks in photo [illegible] wide of brick-red loose sand. The middle and low[illegible] are smooth, and stabilized by a cover of grasses, shrubs, and [illegible], as are the interdunal areas, as indicated by the mottled dark tones and [illegible] A. These characteristics can also be seen in photo B, but here [illegible] area appears lighter because of the oblique view of the light-toned [illegible], which [illegible] dark spots. Spinifex vegetation mounds, ranging in [illegible] meters, also occur throughout the area. In the interdunal [illegible] is compact, hard, and clayey, and has a heavy scattering of dark peb[illegible], which partly accounts for the dark tones in the air photo. The irregular pat[illegible] of the bottom of photo A is due to a veneer of irregular dunes on an old fluvial [illegible]face.

ENGINEERING AND MILITARY USES: The light-toned streaks in photo A indicate areas of loose dune sand. These surfaces are soft and relatively smooth. Travel by foot is possible but slow and tiring. Travel by 4-wheel-drive vehicles, although possible, will be difficult in places. In either case, crossing the dune surface obliquely from one interdunal area to another is possible. Except during very dry years when the vegetation is sparse and the sand slopes are loose and soft, the vegetated interdunal surfaces and lower slopes of the dunes are firm and will support vehicular traffic, including 2-wheel-drive vehicles driven with caution. These surfaces will support rotary-wing aircraft operations and, in some locations, fixed-wing aircraft operations. Rough areas and obstacles such as coppice dunes, shrubs, and trees are present but can be bypassed.

REFERENCES:

[1]Mabbutt, J.A. 1968. Aeolian landforms in central Australia. Australian Geophysical Studies, v. 6, no. 2, p. 141.

Breed, C.S., and T. Grow. 1979. Morphology and distribution of dunes in sand seas observed by remote sensing. In A study of global sand seas, edited by E.D. McKee. U.S. Geological Survey Professional Paper 1052, p. 266.

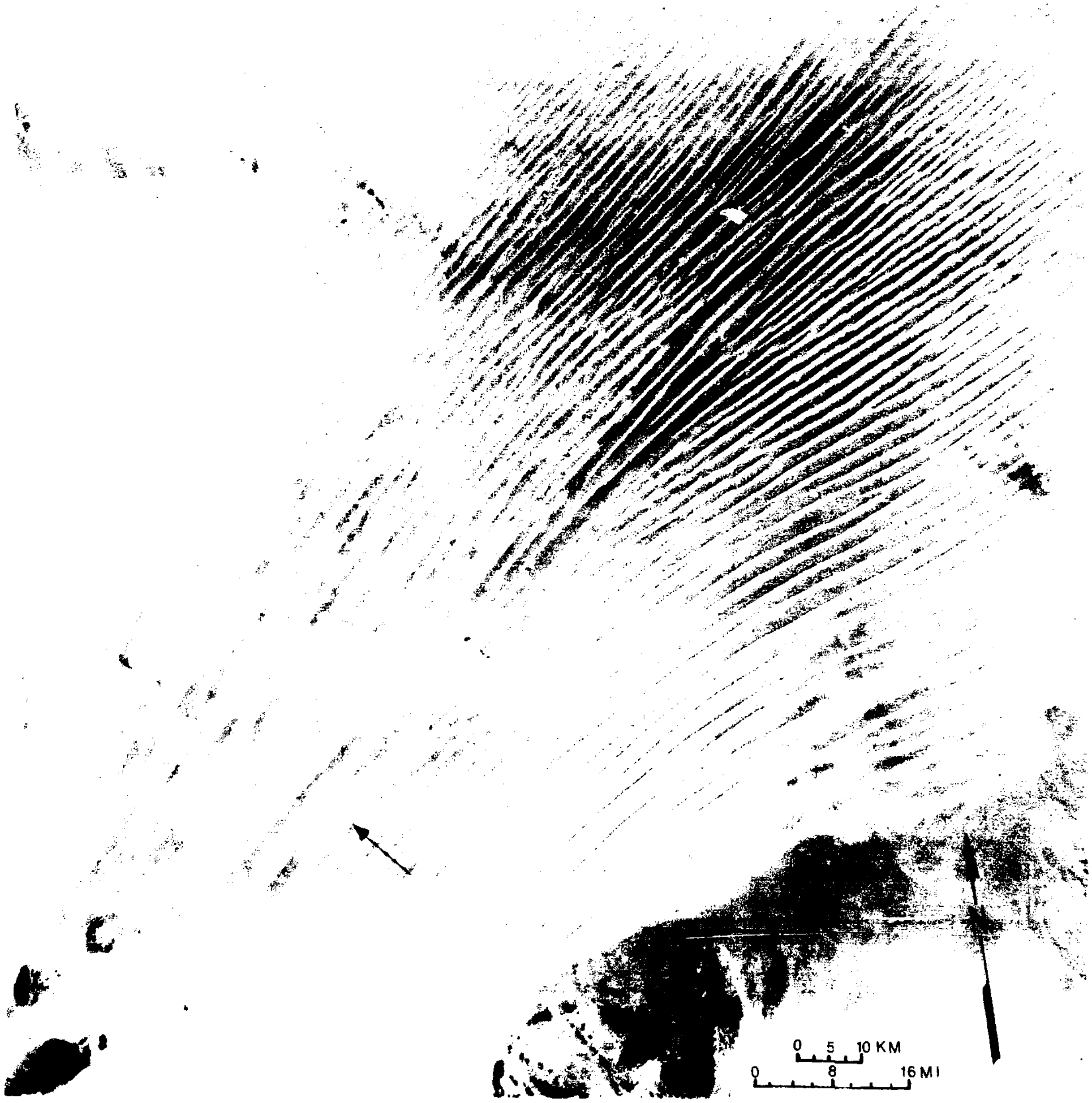
LANDSAT: MSS

LINEAR/SEIF - COMPOUND

LOCATION: Saudi Arabia
17°22'N 46°11'E

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene No. E-1152-06494, Band 7, 22 Dec 1972, scale 1:1,000,000.



Comments on back.

COMMENTS: The ground dimensions of this scene are 185 x 185 km, but some of the dunes shown are even longer. Their widths are varied, generally less than about 1 km. Their maximum height is unknown but is probably 100 m. Interdunal areas range in width from less than 300 m to about 4 km; a few are as wide as 6 km. The long axes of the dunes are aligned with the prevailing northeast wind and the dunes drift southwest. The Y junctures where two dunes merge (arrow) indicate wind direction: the open arms point upwind. A compound linear dune has smaller, ridgelike dunes superposed on its crest, a characteristic of the dunes in this area, especially in the upper left quadrant of the illustration. The light tones along the crests are indicators of loose, active sand. The interdunal spaces, which are darker in tone, provide a firmer and more stable surface. Although we have not visited this area for ground truth, we predict that the dark tones represent a lag gravel surface, which is a good surface for cross-country movement. Because of the hyperaridity, the area could not support the vegetal cover required to make such a dark tone. The dark diffuse streaks trending northwest-southeast are probably soot and smoke plume traces from oil well fires. This wind direction is obviously 90° off from the prevailing wind direction indicated by the dunes.

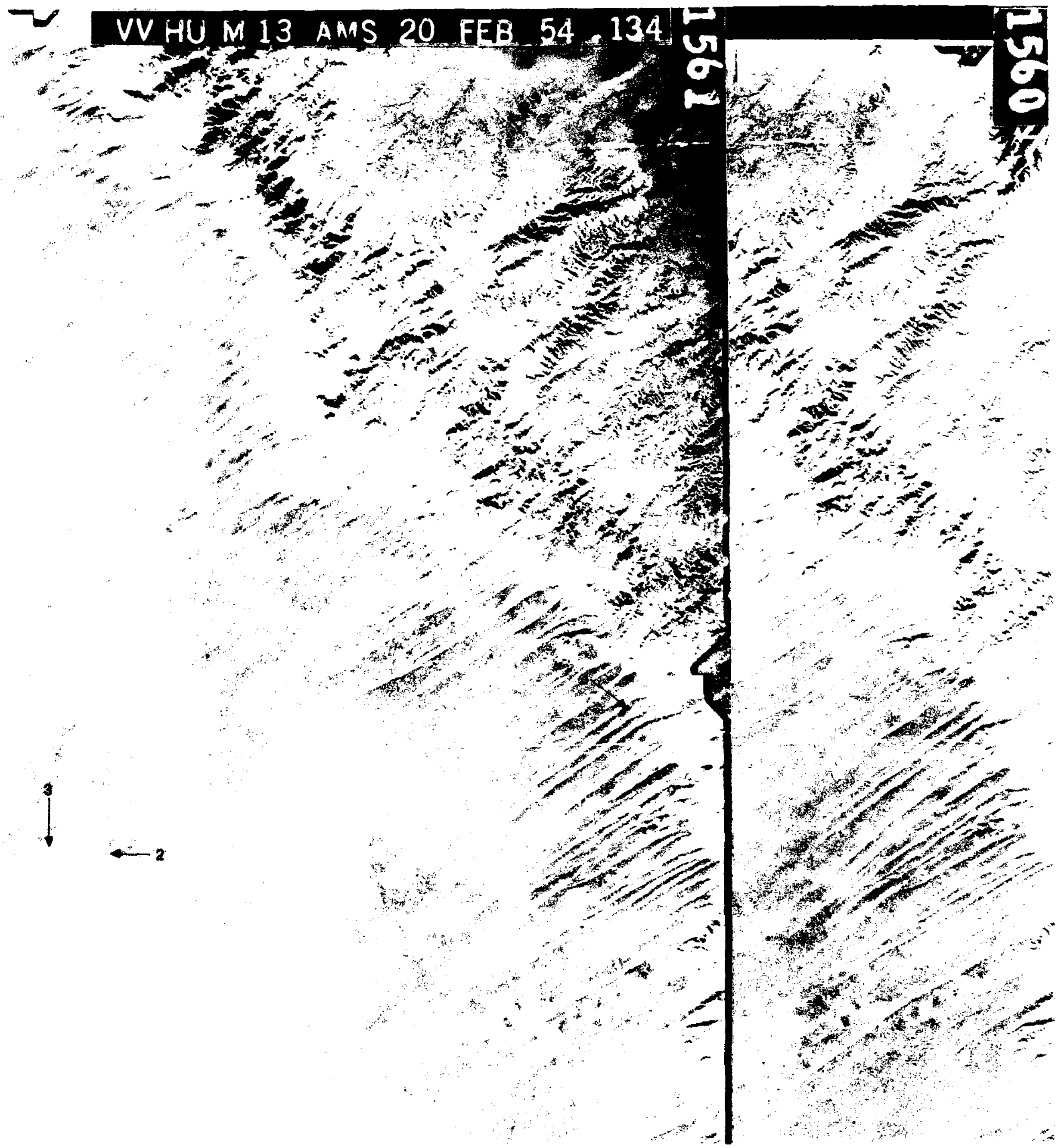
ENGINEERING AND MILITARY USES: The light-toned streaks are the dune crests, and indicate the probable presence of loose active sand. Being compound dunes the surface is extremely irregular in relief. Travel on these surfaces is probably impossible, even with light 4-wheel-drive vehicles. In some areas one can perhaps force their way across the loose sand crest, but in practical terms, such cannot be relied on. The surfaces of the interdunal areas are firm and will support vehicular traffic, and, depending on size, will support both fixed-wing and rotary-wing aircraft operations. Any movement through this area must follow the grain of the land, i.e., southwest-northeast. Finding the "right" path through this region is the problem--i.e., where to cross over to another corridor, via a ridge break, to avoid a blind alley. Without imagery, or prior knowledge, this cannot be done. The best way out of such an area is to head upwind. This will avoid the blind alleys.

PHOTOS: AERIAL (VERTICAL) LINEAR/SEIF - SIMPLE

LOCATION: USA, Arizona, Coconino Co.
Moenkopi Plateau, Adeii Eechii Cliffs, Navajo Indian Reservation

CLIMATE: Semiarid
Trewartha 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Stereo, Army Map Service, VV HU, Project 134, M13 1560-1561, 20 Feb 1954, approximate scale 1:54,000.



Comments on back.

COMMENTS: These long, narrow, closely spaced, linear hills, with smooth, gentle relief are composed of windblown sand. They are about 2 to 10 m high, 60 m to several kilometers long, and 90 m apart (Hack).[1] Most of the particle sizes are in the very fine to medium sand range, about 0.06 to 0.5 mm, with about 10 percent of the plastic fines, i.e., clay. These dunes are characteristic of a relatively strong, steady wind and a supply of loose sand. The slight sinuosity of the ridge lines indicates that seasonal winds have shepherded the sand alternately from side to side of the long axes of the dunes at oblique angles of about 30°. The average direction of these winds is parallel to the long axis of the dunes (Breed, et al.).[2] The Y-shaped junctures of the ridgelines (arrow 1) also indicate wind direction: the open arms of the Y point upwind. These long, linear dunes, which extend for several kilometers across the plateau, are old, derived from sand that came up from the southwest in the form of climbing dunes reaching the plateau surface.[2] Although all vestiges of the climbing dunes have long since vanished, their "offspring," the linear dunes, remain in evidence. They now support a vegetative cover and are stable. The shorter, light streaks at the cliff edge are superposed on the old dunes and represent new deposits of sand deflated from the light-toned rocks exposed at the cliff edge. In the central part of the plateau, a sand sheet has covered the dunes. The sand sheet contains a playa (arrow 2) and some wind-abraded parabolic dunes (arrow 3). The interdunal areas and the sand sheet have a vegetative cover, which is suggested by the mottled, dark tones of their surfaces. Although at this scale individual shrubs do not show, one can assume that they are there and that many have trapped blowing sand to produce coppice dunes.

ENGINEERING AND MILITARY USES: The light streaks extending from the cliff edge part way along the old dune crests are loose sand. Their surfaces are smooth but soft. When they are dry, as in late spring in this area, vehicular travel along or across them is difficult or impossible. When wet, the surfaces are passable to 4-wheel-drive vehicles. The dark areas of the old dunes, the interdunal spaces, and the sand sheet have some vegetative cover, and thus they are relatively stable and firm. Vegetation clumps and coppice dunes may be obstacles, but, because they cannot be seen as individuals on the photo, they are relatively small and can be easily bypassed. Under wet conditions and with care and judgment, much of the dark area is traversable with 2-wheel-drive vehicles. In dry conditions, if three or four vehicles are tracking each other, the surface can become broken, loose, and nearly impassable. The playa surface (silt and clay) is slippery and impassable when wet, but excellent for travel when dry. In this geographic region, the wet winter months provide the best conditions for cross-country movement by foot or vehicle; travel is often possible also after late-summer rains.

REFERENCE:

[1]Hack, J.T. 1941. Dunes of the Western Navajo Country. Geographic Review, v. 31, no. 2, pp. 240-263.

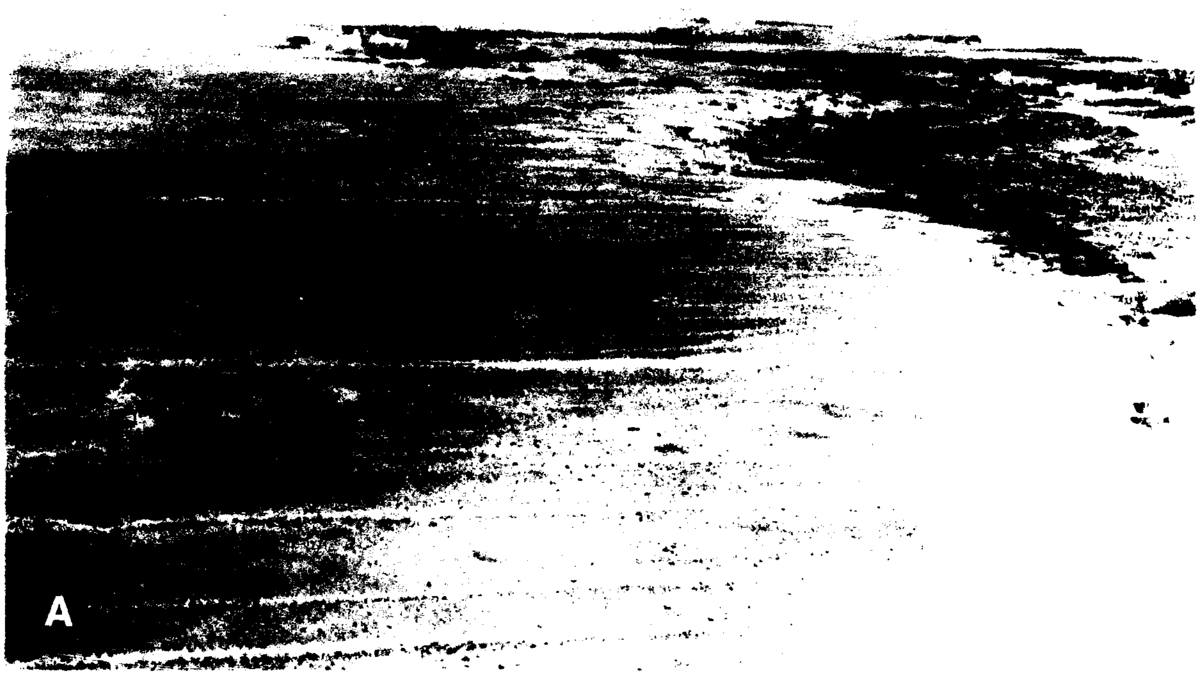
[2]Breed, C.S., J.F. McCauley, C.K. McCauley, and A.S. Cotera, Jr. 1984. Eolian (wind-formed) landscapes. In Landscapes of Arizona: The geological story, edited by T.L. Smiley, J.D. Nations, T.L. Pewe, and J.P. Schafer. San Diego, Academic Press, pp. 359-413.

PHOTOS: AERIAL (OBLIQUE AND VERTICAL) | LINEAR/SEIF - SIMPLE

LOCATION: USA, Arizona, Coconino Co.
Moenkopi Plateau, Adeii Eechii Cliffs, Navajo Indian Reservation

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS:
A. U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1977, view to SE.
B. Stereo, U.S. Geological Survey, GS-VBZY, 1-352, 353, 28 May 1968, scale 1:25,000.



COMMENTS: These long, narrow, closely spaced, linear hills with smooth, gentle relief are composed of windblown sand. They are about 2 to 10 m high, 60 m to several kilometers long, and 90 m apart (Hack).[1] Most of the particle sizes are in the very fine to medium sand range, about 0.06 to 0.5 mm, and there is about 10 percent of the plastic fines, i.e., clay. These dunes are characteristic of a relatively strong, steady wind and a supply of loose sand. The prevailing wind is from the southwest (from the right in photo A), nearly parallel to the axial trend of the dunes. The slight sinuosity of the ridge lines suggests that the seasonal winds have shepherded the sand alternately from side to side of the long axes of the dunes at oblique angles of about 30°. The Y-shaped junctures of the ridge lines (arrow, photo B) also indicate prevailing wind direction: the open arms of the Y point upwind. The old, stabilized dunes begin at the edge of the cliffs and extend over the plateau for several kilometers. The lighter tones on the upwind sections of the ridge crests represent more recent deposits. This younger material is being deflated from the lighter-toned rocks exposed at the cliffs' edge. The dark spots on the plateau are vegetation (mostly Mormon tea, *Ephedra* sp.).

ENGINEERING AND MILITARY USES: The interdunal spaces have a vegetative cover (darker tones) and thus, their surfaces are relatively stable and firm. The shrubs trap active blowing sand and produce small coppice dunes, which, if large, can be obstacles to cross-country movement; usually they can be easily bypassed. Because of the stabilizing influence of the vegetation, corridors between the dunes provide a good surface for cross-country movement. Although 2-wheel-drive vehicles can traverse some of these corridors, under some conditions their cross-country capability is extremely limited. The corridors, wet or dry, provide good passage for 4-wheel-drive vehicles. If dry, however, the surface breaks and becomes nearly impassable when three or four vehicles are tracked [illegible] one another. Travel over the light-toned areas of the linear dunes is nearly impossible when they are dry, but, because of the [illegible] grain size of the sand and [illegible] clay content, travel is feasible when the dunes are wet. In [illegible], the wet winter months provide the best conditions for cross-country movement by vehicle [illegible].

REFERENCE:

[illegible], T.T. 194[illegible]. Dunes of the [illegible] country. Geographic [illegible], v. [illegible], no. 2, pp. 240-263.

PHOTO: AERIAL (OBLIQUE) CRESCENTIC - BARCHAN/MEGABARCHAN

LOCATION: Peru
About 8 km southeast of Chimbote, inland of Semanco Bay

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Oct 1971.

COMMENTS: This group contains small simple barchans (1), a large simple barchan (2), and a large compound barchan or megabarchan (3). Depending on wind regime and sand load, the upper surfaces of large barchans frequently develop secondary dunes, as on the megabarchan marked by arrow 3.

ENGINEERING AND MILITARY USES: Being isolated, these dunes do not present a problem to cross-country movement. Such dunes can serve as observation points. Access to the top can be had by means of the relatively firm, wind-packed slope facing upwind. This will support foot traffic, dune-buggy-type vehicles, and light 4-wheel-drive vehicles. The plain supporting the dunes is firm and, with some restrictions, will support foot and vehicular traffic, rotary-wing aircraft operations, and, under certain conditions, fixed-wing aircraft operations. The restrictions are on vehicle speed and on the direction for fixed-wing aircraft landings and takeoffs. The pattern of lineal arrangement of granule ripples is evident throughout the plain. The area indicated by arrow 4 is one example of the ripple pattern. Depending on the height of the ripples, vehicle speeds might be as slow as 3 to 6 kph. Fixed-wing aircraft will have to land at about 45° to the lineal pattern and to the wind direction, which is from right to left. See Summary Sheet and Indicator Sheets for Ripples - Granule. Dust should not be a problem. In high winds there will be blowing sand. A good campsite can be found in the lee cusp of the large dune, which is protected from wind and blowing sand. The upper dune (2) shows evidence of sand spilling into the lee.

PHOTOS: AERIAL (OBLIQUE AND VERTICAL) CRESCENTIC - MEGABARCHAN - COMPOUND

LOCATION: Peru, coastal part of the Viru Valley, Pur-Pur Dune
Near Pan American Highway between Km 514 and 515, approx. 8°24'S 78°52'W

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS:
A. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Nov 1973.
B. Servicio Aerofotografia Nacional del Peru (on back).

COMMENTS: This dune is a type example of a megabarchan compound crescentic dune--compound because of the small crescentic (transverse) dunes on the surface (arrow 1). Note also the giant ripples along the upwind flanks of the dune (arrow 2). According to Simons and Ericksen[1] the distance from the apex to the highway at the dune axis (photo B) is about 2100 m; the width between the horns is about 550 m. Chains of small, isolated barchans are calving downwind from the horns of the parent dune (arrow 3) and feeding sand into another set of megabarchan dunes (see photo B). These forms are associated with strong unidirectional winds.

ENGINEERING AND MILITARY USES: Being isolated, these dunes can be avoided. Access to the top for observational purposes, etc., can be gained on the windward slope. The upper compound surface will probably be limited to foot traffic, and dune-buggy-type vehicles. The lee in the cusp of the dune provides shelter from wind and blowing sand.

REFERENCE:

[1]Simons, F.S., and G.E. Ericksen. 1953. Some desert features of northwest central Peru. Boletin de la Sociedad Geologica del Peru, Tomo XXVI, pp. 241-246.


78°51'
8°22'
78°51'
8°24'
0
1000M
B

PHOTOS: AERIAL (OBLIQUE) CRESCENTIC - BARCHANOID

LOCATION: Australia, Northern Territory
Great Victoria Desert, near Ayers Rock

CLIMATE: Arid to Semiarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Jun 1980. A. Distant view; B. Close-up view.

Comments on back.

COMMENTS: These dunes form a network pattern (called aklé in the Sahara) consisting of sand ridges that enclose shallow, bowl-shaped interdune flats. In this low plains region, seasonal rainfall collects in the interdune flats, sufficient to support the growth of grasses, bushes, and low trees. Silt and clay, washed or blown (as dust) into the flats, collects in their central portions. The dune ridges are only 2 to 3 m high, and they, too, support considerable vegetation, particularly trees. As a result of climate change since they were formed, the dunes have been fixed in place by vegetation, and have a greatly degraded appearance. Active dunes of the same morphologic type are forming today in more arid regions, where vegetation is far more sparse or absent. When active, such dunes are characterized by steep lee slopes (slip faces) and gentle upwind slopes. The vegetated dunes shown here undoubtedly were formed under much more arid climatic conditions than the semiarid to arid monsoonal climate which pertains today.

ENGINEERING AND MILITARY USES: During the dry season (Southern Hemisphere fall and winter, June through September), these dunes can be traversed on foot and in 4-wheel-drive vehicles and the interdune flats will support fixed-wing and rotary-wing aircraft. During the wet season (Southern Hemisphere summer, when rainfall of about 400 mm occurs between November and April), the interdune flats become very sticky and ground travel is difficult or impossible. In this area, the residents equip their vehicles with "bush-catchers" to avoid collecting dry brush around the axles and catching on fire. Caution is advised against thorns on acacia trees, spikey Spinifex bushes, and several different types of venomous snakes, as well as swarms of flies wherever cattle or people congregate.

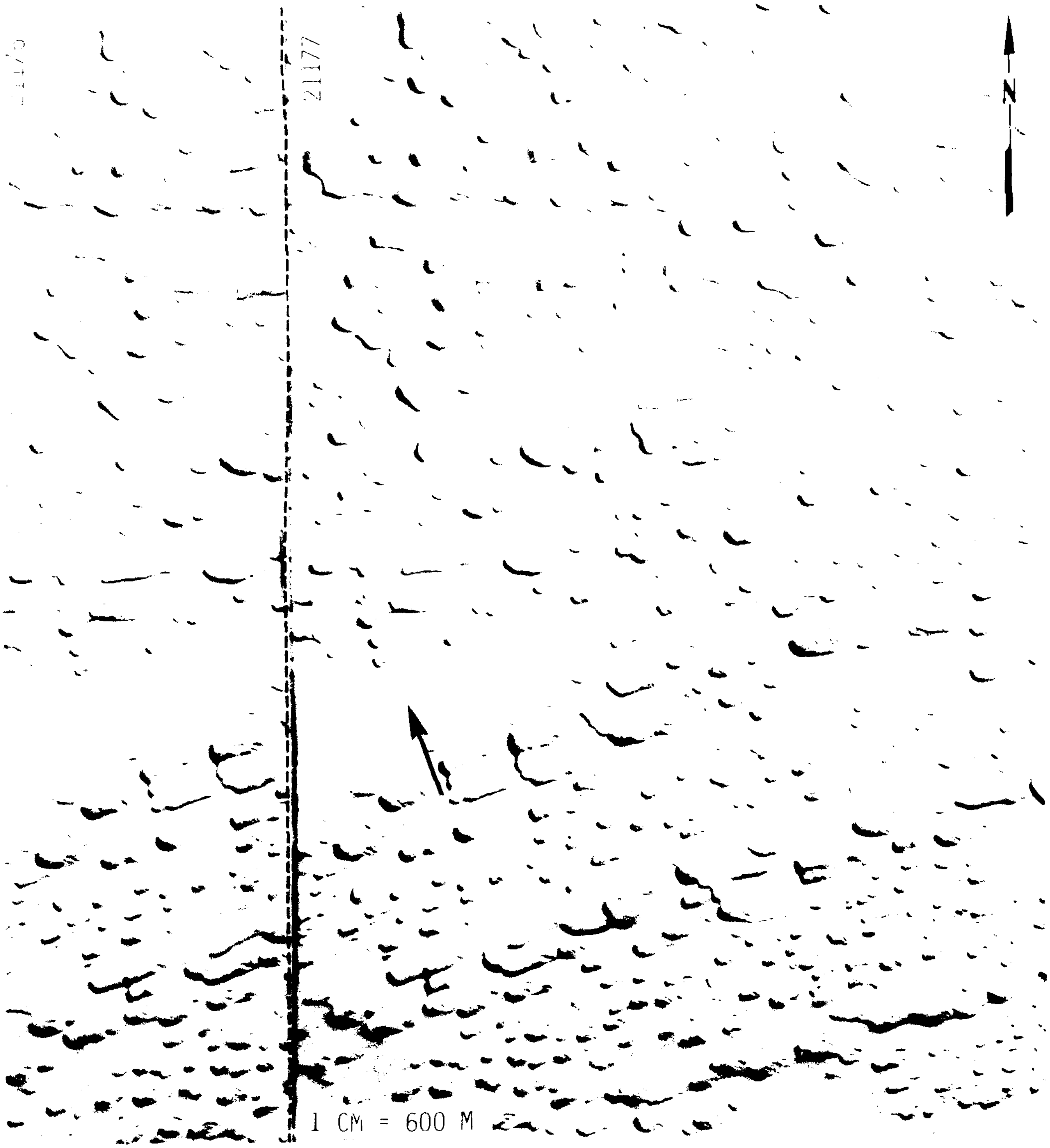
PATTERN INDICATOR SHEET - DESERT | DUNES

PHOTO: AERIAL (VERTICAL) | CRESCENTIC - BARCHANOID - COALESCED

LOCATION: Saudi Arabia
Western Shield, approx. 28°35'N 40°30'E

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Stereo, Army Map Service, WSA, Roll 136, 21176-21177, 8 Oct 1958, approximate scale 1:60,000. Index Sheet 14.



DESERT PROCESSES WORKING GROUP

COMMENTS: The coalescing of these dunes has left horseshoe-shaped hollows, called "fuljes" or "faluj." These pits occur in sand plains in parts of the Arabian Peninsula and in smaller form elsewhere. In this image the prevailing wind is south-southwest. Each crescent-shaped pit is bounded on the upwind side by a steep curved headwall which is the remnant of a barchan dune slip face. On monoscopic aerial photographs these hollows commonly give the false impression of being positive relief features, i.e., hillocks, rather than pits. The floors of the deepest pits are the last exposed parts of the desert floor underlying the invading dunes. This floor is almost totally submerged beneath a sand sea of coalesced barchanoid dunes. The floors of the shallower pits are surfaces of lower lying dunes. In places, the dune field has been overlain by a new, more planer sand blanket filling in the pits and providing a smoother surface (arrow). These blanket features are indicative of regions where the sand supply is so great that it overwhelmed the earlier formed, slow moving, coalesced barchan fields. The upwind source areas (off the image to the south-southwest) were probably old river channels that have undergone new pulses of depositional activity, thereby greatly increasing the regional sand supply. Note, however, that exposed surfaces, including portions of the gently sloping pit walls, are covered with vegetation. Individual bushes and clumps are discernible. Consequently, not much sand has blown over this area in recent times; vegetation and the passage of time have likely made these surfaces firm and trafficable.

ENGINEERING AND MILITARY USES: We have not had experience in this area, but we think that the rolling and lightly vegetated surfaces will carry foot and light vehicular traffic, although it would take imagery of this type to work out a path. Near the headwalls of the pits, the sand is likely to be soft enough to avalanche under load.

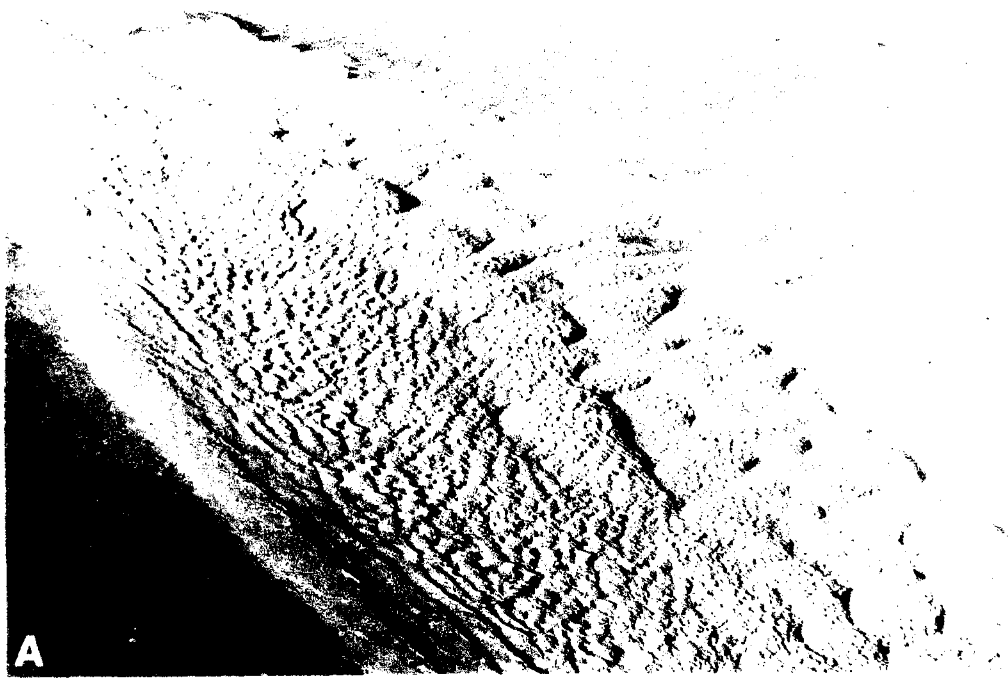
PHOTOS: AERIAL (OBLIQUE) | CRESCENTIC - MEGABARCHANOID - COMPOUND

LOCATION: USA, California
Imperial Valley, Algodones Dunes

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

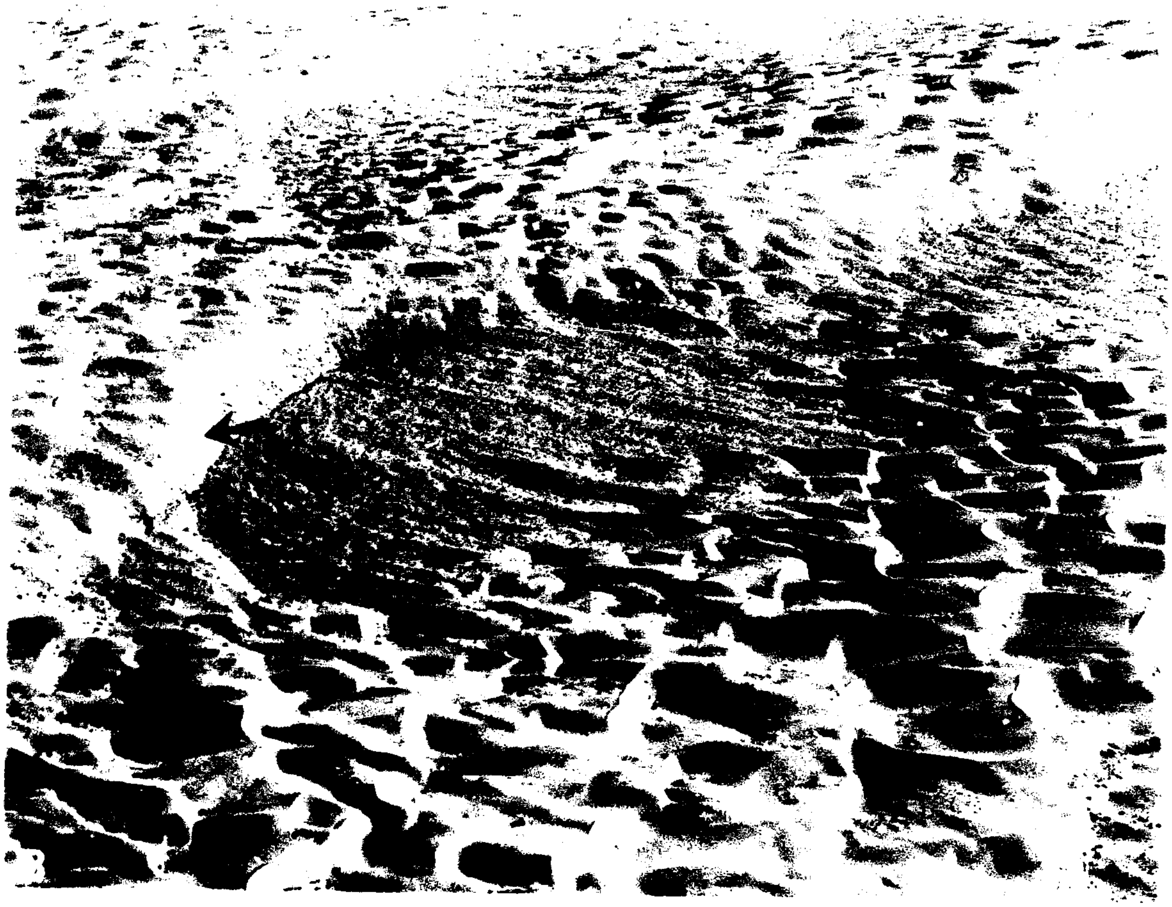
IMAGE CREDITS:

A. William J. Breed, Museum of Northern Arizona, Flagstaff, AZ, 1980.
B. Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 27 Jun 1983.



COMMENTS: [illegible] dune field in southeastern California is the upwind end of [illegible] Mexico, and is composed mostly of compound transverse to megabarchanoid [illegible] ridges. Photo A shows one portion of this field. At this point, the field [illegible] km wide. In the case of the megabarchans, each is separated from the next [illegible] by [illegible] fully enclosed interdune flat-floored basin. A typical interdune [illegible] shown in photo B. Each large, curved ridge segment is bounded on the lee [illegible] slip face (arrow in photo B). This slip face is about 15 to 20 m high, and the depression is about 100 to 120 m across.

ENGINEERING AND MILITARY USES: The interdune basins are fairly firm and will support [illegible] and rotary-wing aircraft operations. The basins, however, are surrounded by dunes, and although the gentle upwind slopes are firm, the steep lee slopes are soft and will likely avalanche, except after a rain. Consequently, the field can be crossed only by dune-buggy-type vehicles, or on foot.



PATTERN INDICATOR SHEET - DESERT | DUNES

PHOTOS: AERIAL, VERTICAL | CRESCENTIC - REVERSING

LOCATION: USA, Colorado, Saguache and Alamosa Counties
Great Sand Dunes

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGERY CREDITS: Stereo, U.S. Dept. of Agriculture, ASCS, CWQ-1P-49, 50, 1955, scale 1:20,000. Index sheet No. 2.

COMMENTS: The slip faces of these reversing dunes change their orientation due to winds that shift direction by 180°, usually on a seasonal basis. These directional changes have caused the development of sharply-crested, scalloped and cuspate ridgelines with steep slopes on both sides and high, peaked summits. Many of the ridge sections show cornicelike patterns. Many of the peaks, resulting from the coalescing of dune forms, resemble the peaks of individual star dunes, which are also caused by sand deposition from shifting winds. Like star dunes, reversing dunes tend to grow to great heights rather than to migrate. In this location the dunes rise about 210 m from the valley floor.

ENGINEERING AND MILITARY USES: Because of the large sizes of these dunes (especially their height), the field is difficult to cross. Unless there is a compelling reason to enter the field, stay out. In working up into such a field and going from crestline to crestline, stay as much as possible on the uppermost part of the current wind-packed surfaces. If traveling too fast, the crests can appear in unexpected orientations. Avoid going into the conical and bowl-shaped depressions; entrance is easy, but exit can be difficult, and impossible for any vehicle except dune-buggies.

PATTERN INDICATOR SHEET - DESERT

DUNES

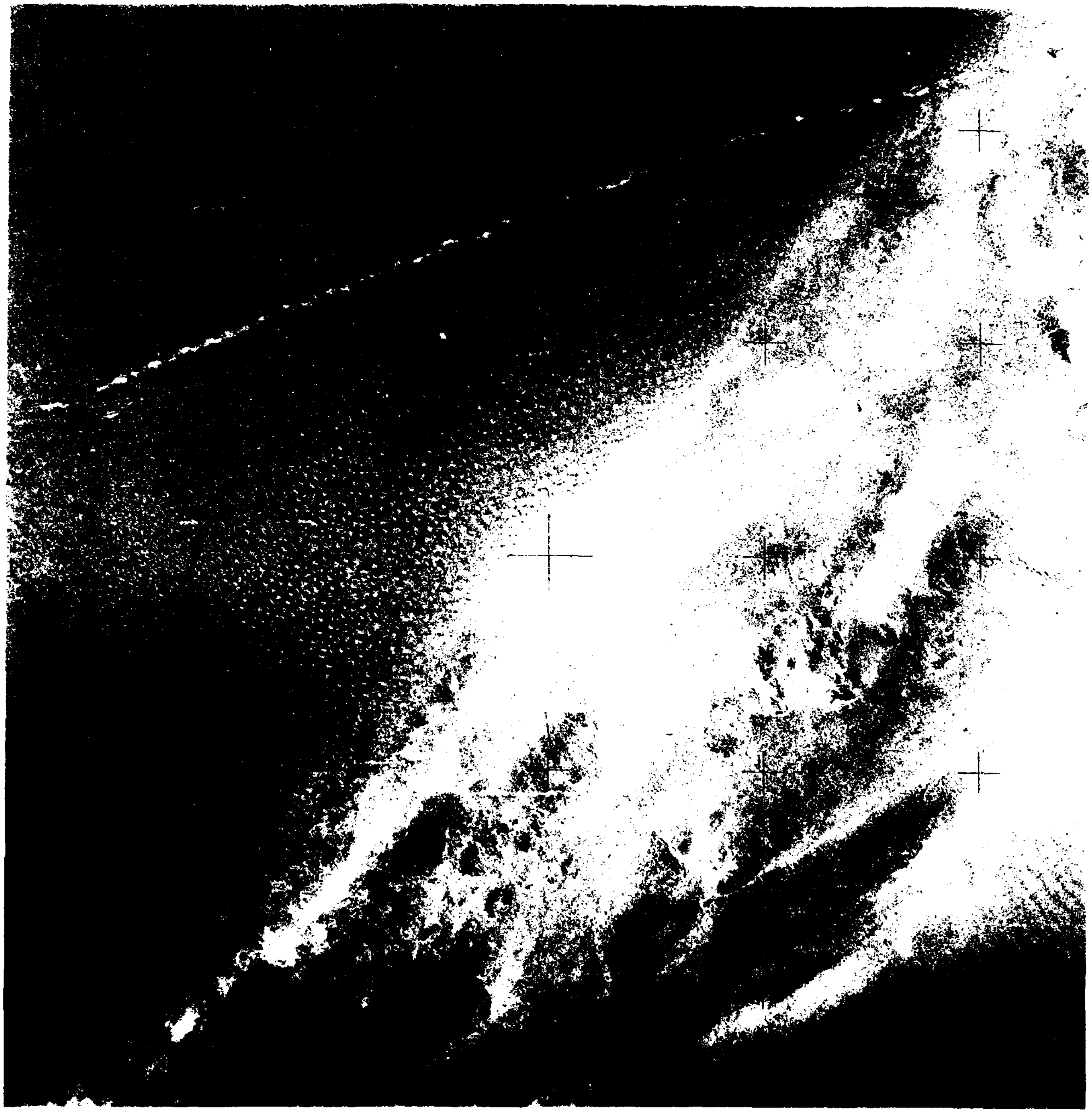
SKYLAB

STAR - COMPOUND

LOCATION: Algeria (Southeastern)
Grand Erg Oriental

CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: High Altitude Vertical Photo, SL4-141-4352, 1974, scale approx. 1:1,000,000.



Comments on back.

COMMENTS: The area of the star dunes is that area which contains all the bumps, i.e., the upper left triangular-shaped half of the image. Each bump is a compound star-shaped pyramidal sand dune consisting of several arms surrounding a high central peak. The bases of the larger dunes are typically as much as a kilometer or two in diameter. The larger dunes are 100 to 200 m high and consist of steep, soft slopes on all sides. They are evenly spaced on a flat plain consisting of firmly-packed sand a few meters thick over a bedrock floor. The sand sea and the dune pattern end abruptly at the edge of a plateau. The white spots on the plateau adjacent to the dunes are evaporite deposits in playas along ephemeral drainage courses (wadis).

ENGINEERING AND MILITARY USES: The star dunes are easily avoided by traversing the plains between them. Little or no vegetation or surface water occurs in this sand sea. In some areas the dunes are linked in chains and are thus barriers to travel except in a direction parallel to the dune chains.

PATTERN INDICATOR SHEET - DESERT DUNES

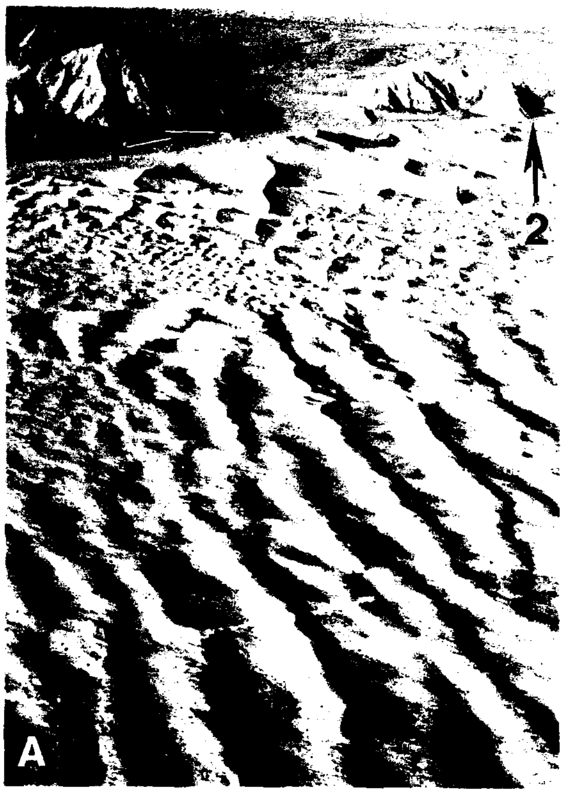
PHOTO: AERIAL (OBLIQUE) STAR - COMPOUND

LOCATION: Mexico (Northern)
El Gran Desierto

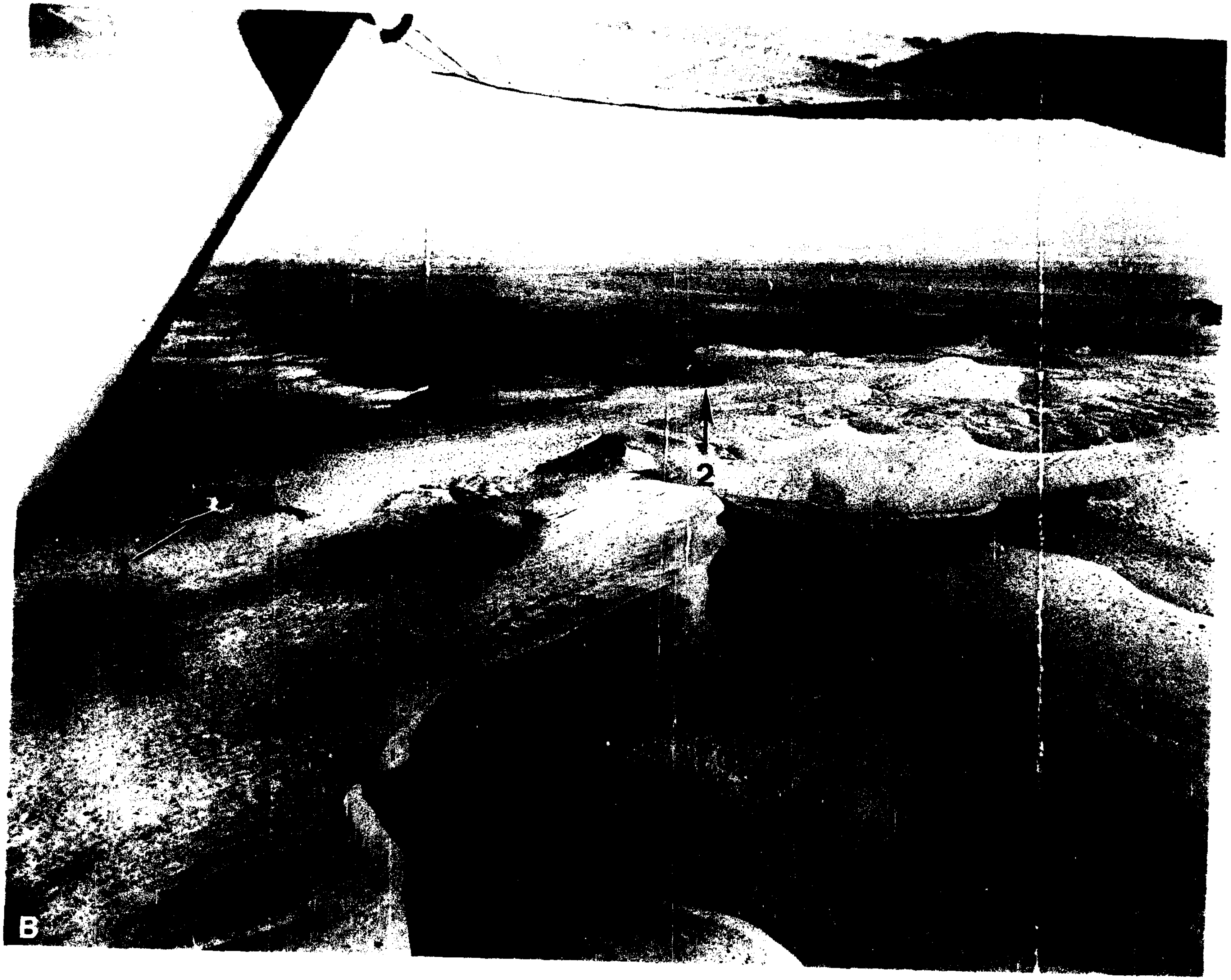
CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. Peter Kresan, Univ. of Arizona, Geology Dept., Tucson, AZ, early 1980's.
B. E. Tad Nichols, Tucson, AZ, late 1960's/early 1970's.

COMMENTS: In the mid background of photo A is a field of compound star dunes. This field is in the central part of El Gran Desierto about 20 km south of the Arizona-Mexico border. Photo B (on back) is a closer view. For orientation, arrows 1 and 2 point to features common to both photos. The larger dunes are 15 to 20 m high. The lower slopes are firmly packed and lightly vegetated with grass and shrubs. The upper slopes, i.e., the narrow sinuous ridges, are loose, soft, and steeper (32°) and are the active zones of the dunes. The ridges join to form a sharp central peak. The vegetation pattern and slope relation are better shown in photo B. The encroachment of vegetation on the higher slopes suggests that the dunes are gradually becoming stable. The low rolling sand ridges in the foreground of photo A are ripples (see Summary Sheet for Ripples - Giant).



ENGINEERING AND MILITARY USES: This dune field can be traversed by dune-buggy-type vehicles and by foot. With stereo imagery, or reconnaissance, a path through can likely be found for light 4-wheel-drive vehicles. Because of the lag surfaces on the giant ripples they can be easily traversed, and will also support rotary-wing aircraft operations. Once the lag surface is broken, dust will be generated, and soft sand will likely be encountered.


2
B

PATTERN INDICATOR SHEET - DESERT

DUNES

PHOTO: GROUND

STAR - COMPOUND

LOCATION: Peru
About 30 km northwest of Chala looking east from Pan American Highway

CLIMATE: Extremely arid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

COMMENTS: These dunes rise abruptly from the adjacent bedrock plain and have the high central peaks, multiple arms, and smaller, secondary dunes on their lower slopes typical of compound star dunes. The height of the dune mass is about 150 m. The lower portion of the photo is a gravel plain with patches of drift sand. The irregular surface is controlled by the underlying bedrock. The larger dark mounds are bedrock outcrops.

ENGINEERING AND MILITARY USES: High dunes such as these coalesced sand mountains are virtually impossible to traverse, as their slopes on all sides are steep (32°) and soft.

PATTERN INDICATOR SHEET - DESERT | DUNES

PHOTO: AERIAL (LOW ALTITUDE) | STAR - COMPOUND

LOCATION: Peru (Coastal)
About 5 km south of city of Ica

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

COMMENTS: This low altitude, near-vertical aerial photo shows the high peaks formed by the multiple arms of a compound star dune. The usual first reaction is "which way do I hold the photo?" The sun illumination is from the upper right, and the bright areas are those surfaces facing the sun. This makes the more or less central feature a depression (arrow).

ENGINEERING AND MILITARY USES: These slopes are steep (32°) on all sides and rise to sharp crests. They are composed entirely of soft sand, and are ascended only with difficulty.

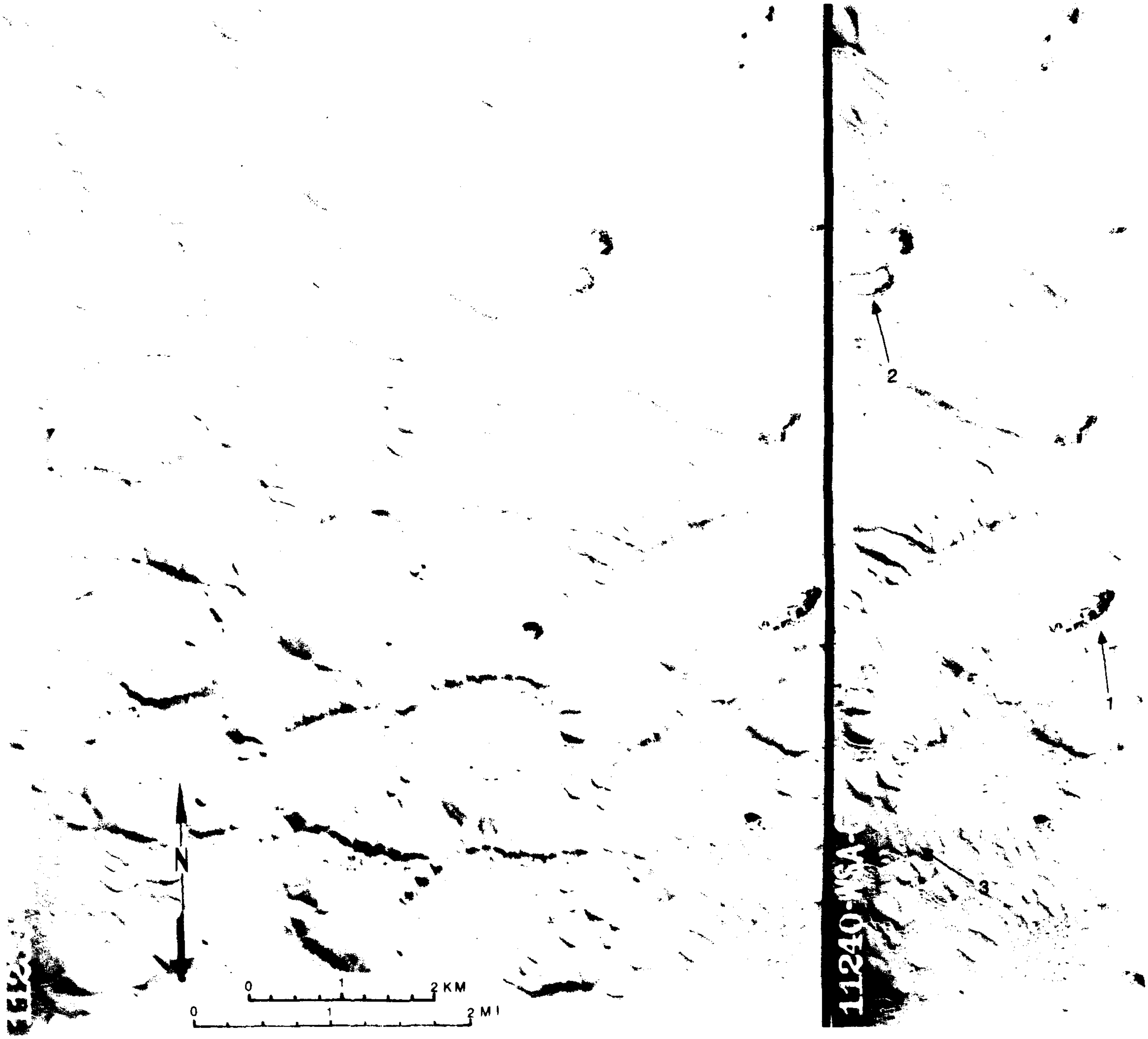
PATTERN INDICATOR SHEET - DESERT DUNES

PHOTOS: AERIAL (VERTICAL) DOME - COMPLEX

LOCATION: Saudi Arabia, Western Shield Area
26°45'N 44°30'E

CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Stereo, Army Map Service, WSA, Roll 68, 11239-11240, 11 Oct 1956, approximate scale 1:60,000. Photo Index Sheet 31.



Comments on back.

DESERT PROCESSES WORKING GROUP

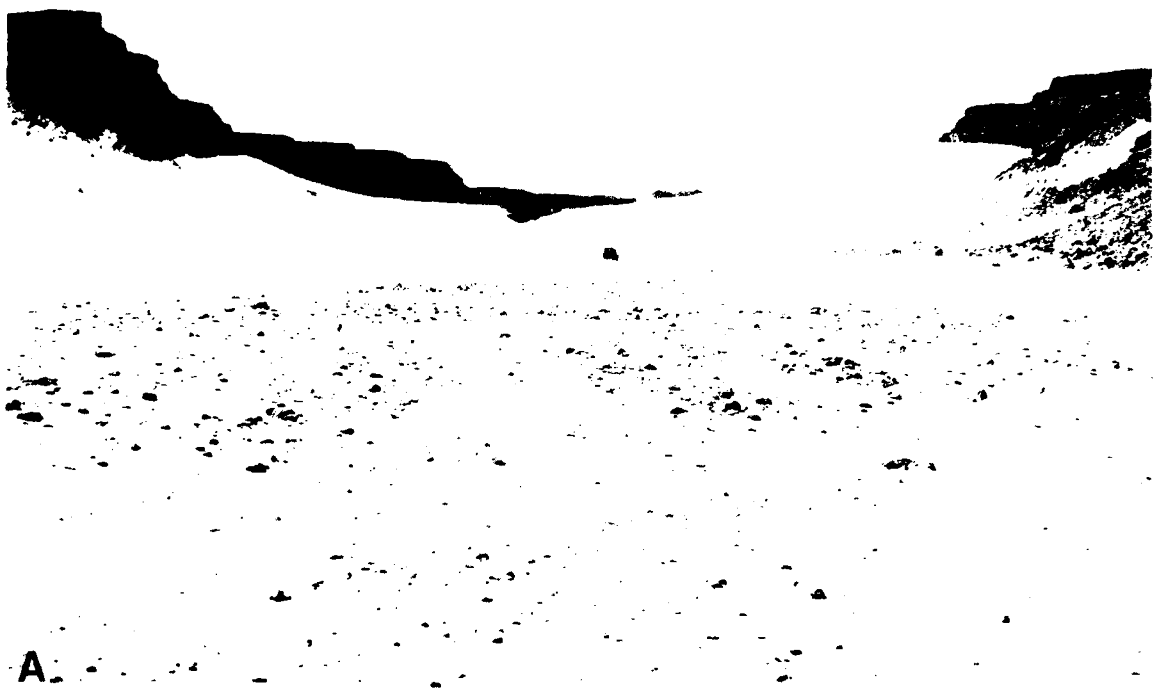
COMMENTS: Although in the photos this appears to be very rugged terrain, it is not as rugged as it looks. The air photos were taken with a 6 inch focal length lens which, for 9x9 inch format, is a wide angle lens. This introduces a longer base separation, which causes an apparent vertical exaggeration, i.e., things look two to three times steeper and taller than they really are. These closely spaced, coalescing mounds of sand with barchanoid ridges on their broad summits are examples of complex domes. In this example, the sunlight is from the south (bottom of the photos), and the highlight areas are southerly facing slopes. Map information (ONC H-6) indicates an average height of 146 m for dunes in this area. The domes are partly separated by interdune hollows which are enclosed by subsidiary dunes of hard-packed sand. The flat bottoms of the deeper interdunal hollows probably represent the base surface, and are thus areas wherein the coalescing dunes have not yet encroached. On the bottoms of many of the deeper interdunal hollows are trees, date farms, and small settlements or villages, as in the depression marked by arrow 1. Arrow 2 points to a depression that contains a similar collection plus a playa. The fact that these settlement patterns exist suggests that the region is stable. If the sands were loose and active there would be drift patterns in the settlements. Throughout the interdunal area and on the adjacent flanks there are mottled darker tones and scattered dark dots that are typical of short, surface vegetation and isolated shrubs. Arrow 3 indicates one such area. There are even vestiges of this pattern on the barchanoid surfaces of the broad summits. The presence of the vegetation indicates a relatively firm and stable surface, and such is the case. Very little is known about the wind regime associated with these forms. What thoughts are expressed tend to support the notion of strong, nearly unidirectional winds.

ENGINEERING AND MILITARY USES: The flatter surfaces of the larger interdunal hollows will support wheeled traffic and rotary-wing aircraft, although the latter are likely to stir up sand and dust in the dry season. Some of the larger hollows are oblong and have lengths of 400 to 600 m. These can probably support some kind of STOL aircraft operations. Light 4-wheel-drive vehicles can traverse these dome dunes in most any direction, taking care to avoid slip faces of superposed surface dunes. Obviously, at least some amount of water is available in the vegetated and developed hollows.

LOCATION: Egypt (Southwest)
Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Sep 1978.



A.

COMMENTS: A dry valley (Wadi Bakht) incised into the Gilf Kebir Plateau of southwest Egypt. In this photo, the observer is facing west, and north is to the right. This wadi is oriented transverse to the prevailing wind, which is from the north, and falling dunes have accumulated on the lee sides of cliffs bordering the valley. Matching climbing dunes pile up against the opposite cliffs. These dunes lie on an apron of slope wash that helped to create a temporary dam behind which a playa lake existed about 5,000 years ago. A jeep on the wadi floor provides scale. Photo B (on back) is another view of falling dunes in the same area, looking in the upwind direction, i.e., northerly.

ENGINEERING AND MILITARY USES: Falling dunes and climbing dunes can provide access for foot traffic up from the floors of dry valleys and bordering steep cliffs to the top of the plateau. However, these ramps frequently abut steep cap rock ledges that remain as impediments to movement as in photo B; or, in the case of climbing dunes, have a ditch at the top.

B

LOCATION: USA, Arizona, Coconino Co.
Southeast side of Paiute Trail Point, about 60 km NE of Flagstaff

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Dec 1979.

COMMENTS: Falling dunes occur where windblown sand cascades over the edge of a cliff and builds a ramp to the surface below. In this illustration, the sand is coming from climbing dunes on the right side of this plateau, just off the photo. The cliffs in the foreground are about 60 m high. Because the sand falls over the lee edge to settle on the floor, the ramp that is formed usually stays in contact with the cliff face, so that when the ramp finally reaches to the upper level, it forms a continuous surface, as shown in the illustration. A climbing dune, on the other hand, frequently has a steep-sided moat (several meters in depth) separating the ramp end from the upper surface. Being in the lee of the cliff these accumulations of loose, well sorted, windblown material, mostly very fine to medium sand, are sheltered from further movement, have become more compact and firm, and in this instance have developed at least some vegetative cover, which further stabilizes the surface. The darker tones on the slopes are the areas with vegetation, and individual shrubs can also be seen. These areas are firm and stable, especially the lower slopes. The bright-toned ridges and fan-like humps extending down from the upper surface are areas of active accumulation and are looser, softer, and generally steeper.

ENGINEERING AND MILITARY USES: Although these dunes can provide passage between the upper and lower units for both foot and vehicular traffic, stay off the light-toned areas as much as possible. In this instance, foot traffic can go either of the two routes indicated by the arrows (1 and 2). Dune-buggies, or possibly light 4-wheel-drive vehicles, can probably make it via route 2, particularly if the sand is damp from a recent rain. During the spring dry season (April-June), there could be a problem with loose sand at the very top.

PATTERN INDICATOR SHEET - DESERT DUNES

PHOTOS: GROUND LEE - SIMPLE

LOCATION: Egypt (Northern)
North of Bahariya Depression

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Oct 1978.

Comments on back.

DESERT PROCESSES WORKING GROUP

COMMENTS: Like falling dunes, lee dunes form by the accumulation of sand in zones of lesser wind speeds behind (in the lee of) obstacles such as hills, bedrock outcrops, or vegetation. They are basically linear in shape, become narrower and lower in the downwind direction, and frequently have slip faces that shift with changes in seasonal wind directions. The overall direction, however, is parallel to the prevailing wind. In photo A the obstacle that created the lee dune is the rock ledge in the foreground and the prevailing wind blows towards the horizon, i.e., along the lee dune. The cross sectional asymmetry of the dune, with the slip faces on the right and the gentler slopes on the left, indicates that the most recent sand-moving wind was coming from the left. The ripple pattern on the dune surface also indicates crosswinds. The tallest parts of the dune are 3 to 4 m high. The dark, conical-like mounds on either side of the dune are bedrock outcrops and the overall dark, flat surface is a gravel plain. In photo B the same dune is shown from the opposite view, looking toward the obstacle (bedrock outcrop on the horizon) causing the lee dunes.

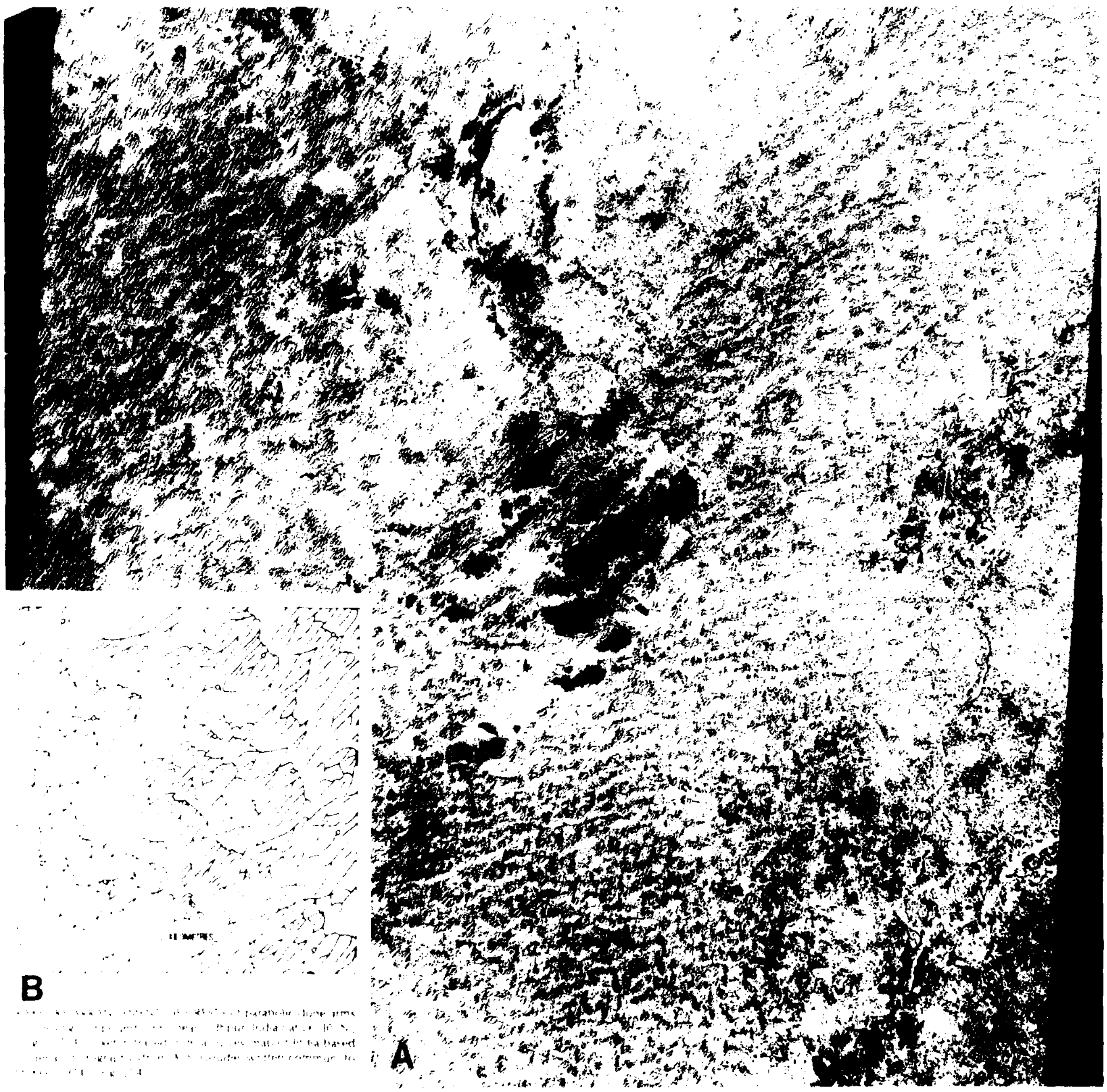
ENGINEERING AND MILITARY USES: As obstacles, these dunes can be avoided by simply going around. There are probably areas on them where one can drive up the firm, wind-packed, gentle slope and descend down the lee slope, but care must be taken because the lee slopes are loose sand.

LOCATION: India (Northwest) and Pakistan (Northeast)
Rajasthan (Thar) Desert

CLIMATE: Semiarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:

A. Scene 2726-04495, Band 7, 17 Jan 1977, 25°45'N 71°20'E, Scale 1:1,000,000.
B. Goudie, A.S. Sketch (written communication to E.D. McKee, 1974). In A study of global sand seas, edited by E.D. McKee. 1979. U.S. Geological Survey Professional Paper 1052, p. 380.
C. & D. Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Jan 1980.



COMMENTS: The Landsat image (A) is nearly filled by a sand sea of compound parabolic dunes which cover an estimated 100,000 km^2 in the low desert along the border of India with Pakistan. Each dune is rake-shaped, with multiple arms that trail behind the advancing dune nose, and which point upwind (see sketch B). The wind is from the lower left to the upper right. Each cluster is commonly 1 or 2 km wide and about 1 to 5 km long, and is separated from the next cluster by a fairly flat sand plain. The noses of the dunes point northeast, in the downwind direction; they are as much as 10 to 15 m high and have steep (32°) slip faces on their outer (convex) slopes. These dunes are vegetated with grass, bushes, and some trees, except near villages where the bushes and trees have been stripped by browsing goats and by people gathering firewood. This region exemplifies an extreme case of desertification brought on by man's activities. Photo C shows an area of low dunes devoid of grass. This area is in the upper right corner of the Landsat scene, northeast of the town of Barmer, which lies in the center of the image. Photo D is an area not on the Landsat scene. It is near the town of Bikaner, about 250 km to the northeast of Barmer, and shows a cover of grass, shrubs, and trees, with sheep overgrazing the dune surface.

ENGINEERING AND MILITARY USES: Although these parabolic dunes have high noses and numerous arms and are barriers to travel by ordinary vehicles, the clusters are separated sufficiently so that slow, winding progress can be made through them by utilizing the flat sand plain interdune spaces. The light-toned areas (image A), however, are mantled with loose, soft, drift sand and should be avoided.

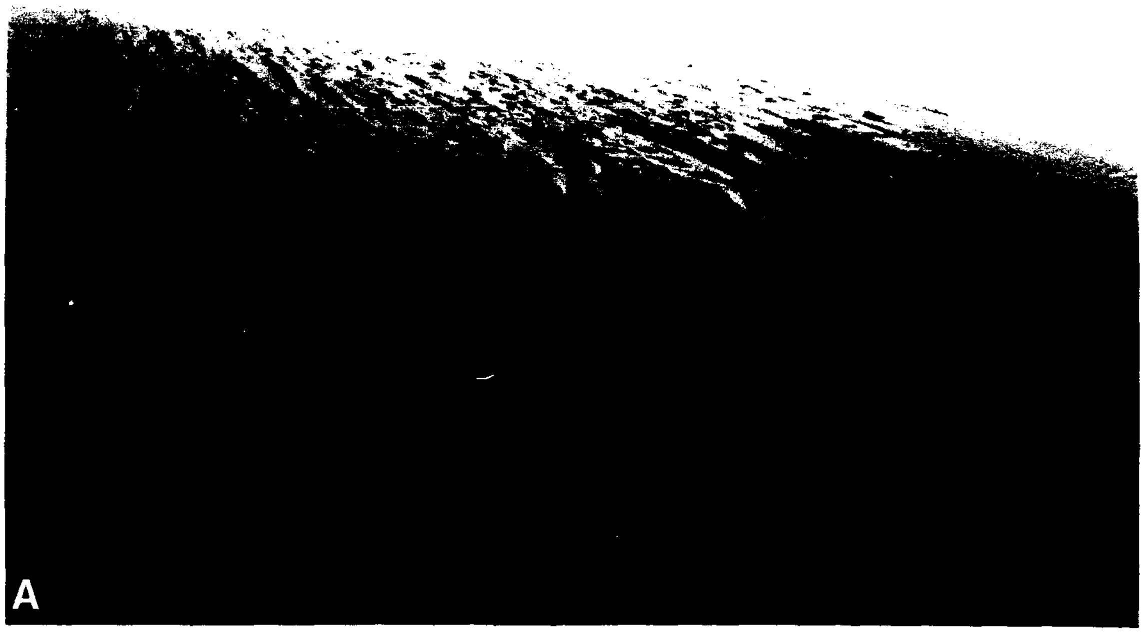

C


D

LOCATION: Peru (Coastal)
Near Casma in north

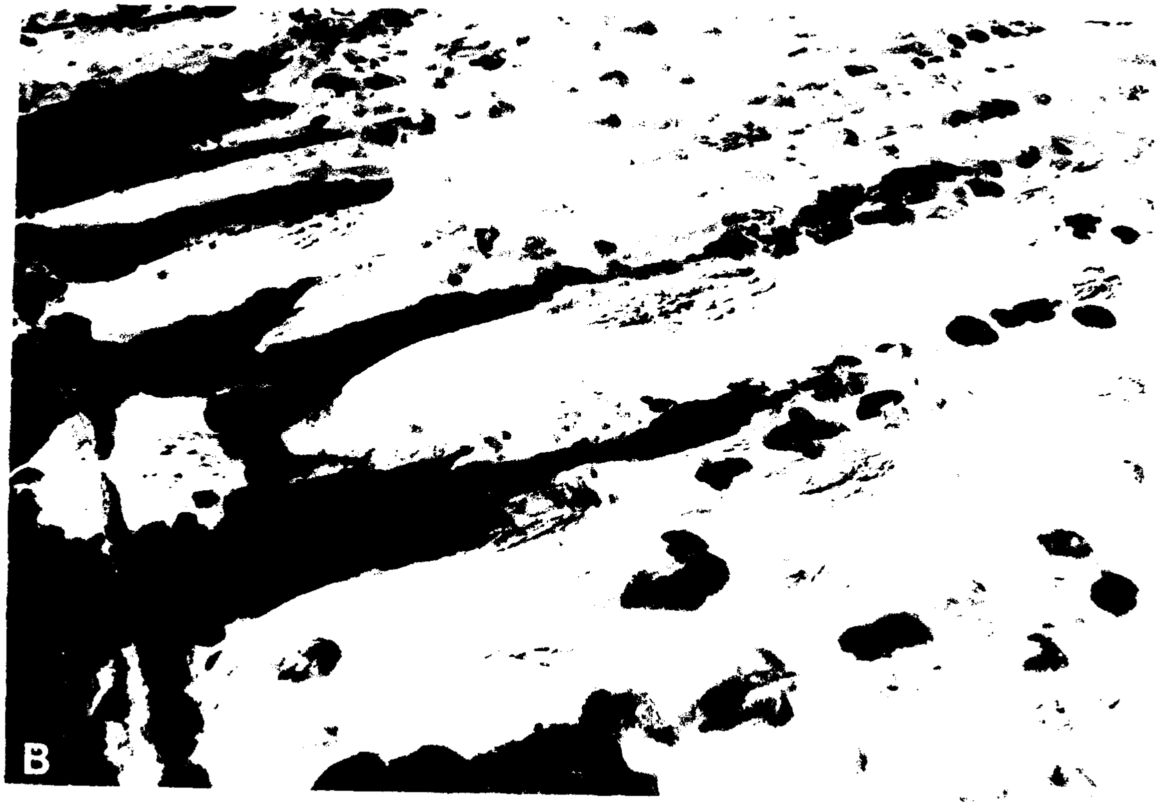
CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.



COMMENTS: The source of these very juvenile parabolic dunes is beach sand driven inland by the prevailing offshore winds from the south. In spite of the hyperaridity of this desert, moisture from dew is sufficient to allow "lomas" (low shrubs) to grow on these dunes. As in fields of parabolic dunes elsewhere, the noses point downwind and the long arms, here as yet poorly developed, trail upwind (photo A). The white line above the arms in photo A is the surf. The haziness is coastal fog, and is very typical of this area. Photo B (on back) shows more mature parabolic dunes several kilometers inland from the coast.

ENGINEERING AND MILITARY USES: These dunes are coalesced and because of the sparse vegetation they are mostly loose, soft sand. Areas that look like this should be avoided.

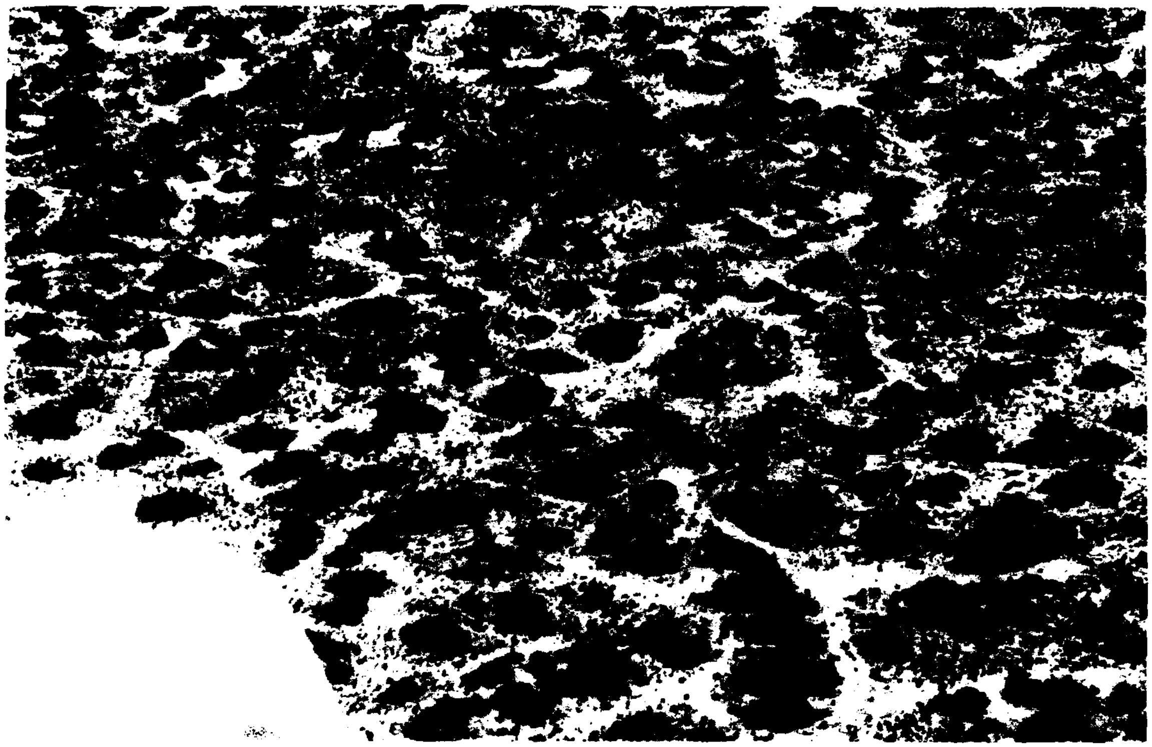


B

LOCATION: USA, Texas
Near El Paso

CLIMATE: Semiarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1986.



COMMENTS: Coppice dunes are vegetated sand mounds, and are formed by sand accumulating around the lower parts of bushes such as the mesquites (Prosopis) shown in the photo. Coppice dunes are a form of parabolic dune that typically develops on sand plains in semiarid climates, where numerous bushes grow and windblown sand is abundant. In extremely arid regions, only a few isolated vegetated mounds can grow. Because sand piles up around the plants, and is deflated from the spaces between, a hummocky topography develops that differs from the smooth, flat, or gently undulatory surfaces of sand plains that are not vegetated. The swales between coppice dunes are generally firm and hard packed, but sand on the slopes of the mounds can be soft and loose.

ENGINEERING AND MILITARY USES: Coppice dune fields are bumpy and uneven for travel, but generally not hazardous for foot traffic or vehicles, although the path of travel will be a circuitous one, as can be seen from the vehicle tracks in the photo. Much of the interdunal surface is firm enough to support traffic, but there is sufficient loose sand that caution is required when selecting a route. Such fields provide some degree of horizontal cover and concealment as well as a background pattern that makes it more difficult to detect ground units from the air. Many types of bushes associated with coppice dunes have sharp thorns that can puncture tires and tear skin and clothing, e.g., mesquite, many acacias, Spinifex.

LOCATION: Egypt (Southern)
About longitude 27°30'E, near the Sudan border

CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Maurice J. Grolier, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1981.

COMMENTS: These low mounds, usually no more than about 1 to 5 m high, are formed by clumps of bushes (occasionally small trees) that have accumulated sand aprons around their bases, as can be seen in both photos. In very dry regions, such as the southern Egyptian Sahara, only a few such vegetation mounds have survived as isolated clusters, and usually they are located along old, dry drainage lines (abandoned wadis), or geologic faults, where ground water levels are within reach of their deep tap roots. Such ground water may be several meters deep and highly saline. In less arid deserts such vegetation occurs more abundantly, and there it forms fields of coppice dunes. From a distance, isolated vegetation mounds are often difficult to distinguish from small bedrock hills (inselbergs), except that the vegetation mounds are commonly more irregular in outline.

ENGINEERING AND MILITARY USES: From the standpoint of surface travel or aircraft operations these mounds do not present a problem. The fields are not extensive in size and the mounds are spaced far enough apart that they can be avoided. They do have, however, some bearing on field operations; they can provide some daytime shelter from the sun, provide a degree of cover and concealment, and they are a source of firewood. Larger ones can also be used as observation points. They are not good campsites because they harbor insects, scorpions, snakes, and other wildlife. Depending on the vegetal cover, the sand can contain thorns that can inflict small puncture wounds. Such thorns can easily penetrate the soles of light desert boots and can also cause leaks in tires. The larger mounds show on Landsat and radar, and can be used as navigation reference points.

PATTERN INDICATOR SHEET - DESERT | RIPPLES

PHOTO: GROUND | SAND

LOCATION: USA, Arizona, Coconino Co.
Moenkopi Plateau, 80 km northeast of Flagstaff

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1976.

COMMENTS: These small scale wavelike forms are "normal" sand ripples which are typical of the surfaces of sand dunes and sand drifts. In this locality the sand has a clay content which ranges from about 1 to 2 percent in the upper portion of a dune to 10 to 13 percent at the base. This example is on the upper surface of a dune and the clay content is about 2 percent, which is enough to allow shrinkage to occur when dry and thereby produce the pattern of polygonal desiccation cracks. Most dune sand has far less clay content, i.e., less than 1 percent, which does not produce cracks when dry.

ENGINEERING AND MILITARY USES: The ripples themselves do not present any problem to cross-country movement, but they do indicate the presence of loose, soft sand. The dune surfaces in this area have enough clay to produce slipperiness, and also to ball up on tires, when damp.

PATTERN INDICATOR SHEET - DESERT

RIPPLES

PHOTOS: GROUND

TRUNCATED

LOCATION: Egypt (Southwest)
Western Desert, Sand Plain near Gilf Kebir

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed and John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

COMMENTS: These large scale ripples, spaced a few tens of centimeters to a meter apart, have developed in a sand sheet on top of a gravel plain near the plateau. In places, the tops of the ripples appear to have been sheared off, leaving a flat surface that is broken at irregular intervals by the steep (32°) lee slopes of the ripples. These steep slopes are only a few centimeters high but can be closely spaced. The dark materials are parts of the underlying gravel plain, exposed where the sand sheet is very thin or absent. Truncated ripples form most often near bedrock outcrops and vegetation mounds.

Truncated ripples

ENGINEERING AND MILITARY USES: The truncated ripples produce extreme shaking vibrations in any type of wheeled vehicles traveling across them at speeds greater than about 5 or 10 kph. These ripples are hard to see at a distance, but should be suspected near bedrock hills and plateaus and in areas near vegetation mounds or other irregular topography on the sand plain. They are no problem to foot traffic or rotary-wing aircraft.

PATTERN INDICATOR SHEET - DESERT

RIPPLES

PHOTO: GROUND

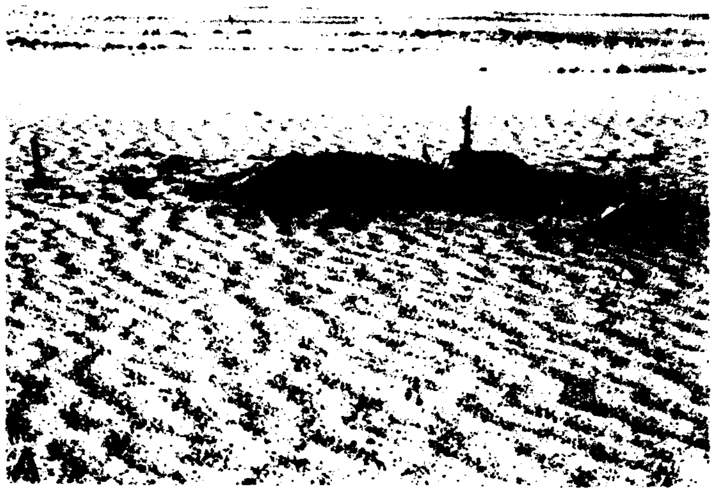
PEBBLE/GRAVEL

LOCATION: Egypt (Southwest)
On sand plains, about 60 km south of Bir Tarfawi

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1983.
B. C. Vance Haynes, Univ. of Arizona, Tucson, AZ, 1981.

COMMENTS: Loose gravel, typically 1 to 3 cm in diameter, derived from old, dry alluvial deposits and eroded from bedrock outcrops, has been reworked by wind into low ripples that cover parts of the sand plain. Desert varnish on the gravel gives it a dark appearance in contrast to the lighter sand (Photo A). Patches of these gravel ripples are often overlain by thin, more mobile sand layers that together appear as chevron-shaped features on Landsat images of Egypt's Western Desert. The interweaving of patches of gravel ripples and sand layers is shown in photo B. The material taken from the pits is a soil with gravels interspersed throughout. These gravels, which are part of the ripple source, are much lighter than the varnished surface component, although this is not obvious from the photos.



ENGINEERING AND MILITARY USES: These ripples provide a firm, stable surface for foot traffic, wheeled vehicles, and rotary-wing aircraft, and with only a slight potential for dust generation. With care, they can serve as landing areas for both light and heavy fixed-wing aircraft. If vehicles must stop when traveling over the open sand sheet a patch of gravel ripples is the best place to do so in order to avoid getting stuck in loose sand.

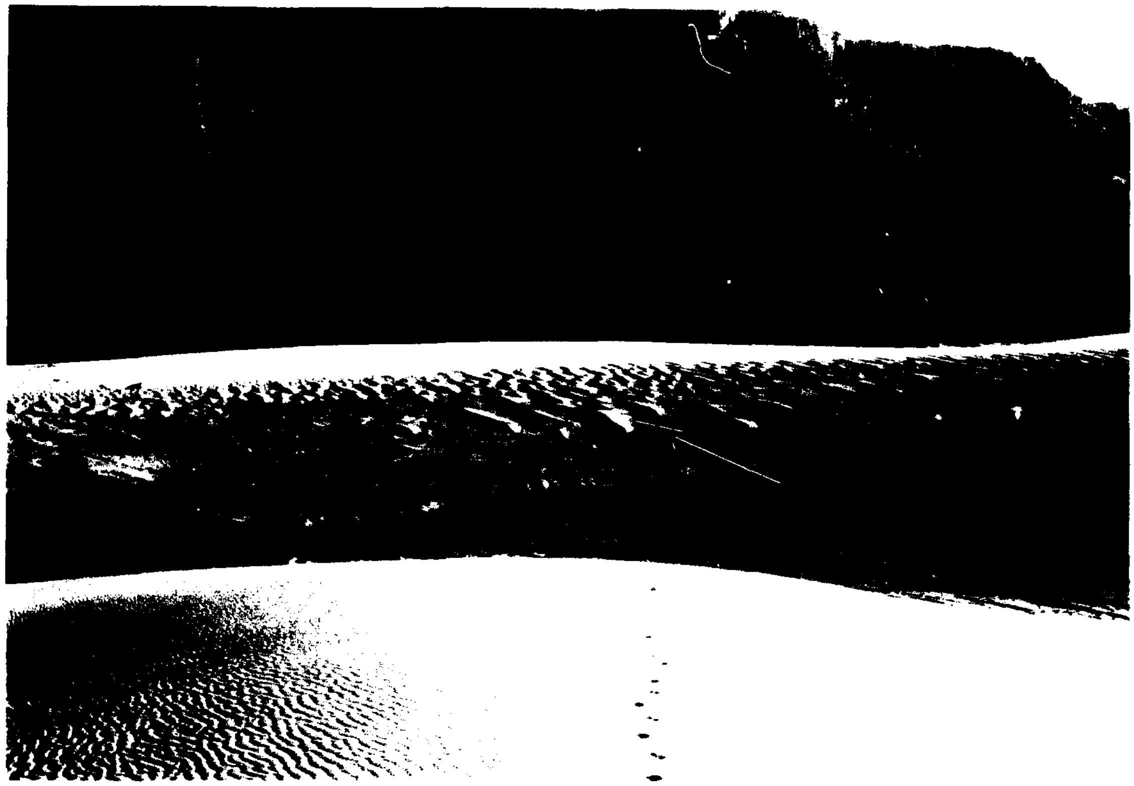
PHOTO: GROUND

GRANULE (MEGARIPPLES)

LOCATION: Egypt (Southwest)
Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.



COMMENTS: These meter scale ripples (arrow), generally known as granule ripples, are composed of relatively coarse grains (2 to 30 mm). These features occur in groups (fields) near topographic obstacles to windflow, such as edges of dune fields, or on the floors of narrow canyons, as in this example. In the foreground, the footprints approaching the camera cross the upwind slope of a climbing dune along the canyon wall (out of view, behind the photographer). This dune surface is covered with sand ripples, which are much smaller than the granule ripples on the valley floor.

ENGINEERING AND MILITARY USES: Although their surfaces are relatively soft, the granule ripples are solid and unyielding and are an impediment to vehicular travel. In this instance, the ripples can be avoided.

LOCATION: Egypt (Southwest)
Near Sudan border, south of Bir Tarfawi

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1982.
B. Maurice Grolier, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1982.

COMMENTS: These meter scale ripples, generally known as granule ripples, are composed of relatively coarse grains (2 to 30 mm). These ripples are on a sand plain near a dune field in southwest Egypt. Photo A: Large granule ripples on a sand plain between individual barchans that are up to about 10 m high. The low leading edge of a horn of one of the barchans can be seen as a bright streak in the background (upper right of photo). The effective wind is from right to left. The lees of the ripples consist of light-toned, finer grained sands. In addition to shadow effect, the crests of the ripples are dark because of an accumulation of coarse-grained dark minerals. Photo B (on back) is an upwind view of some ripples at this locality whose crests are marked by the dark streaks that cross the entire picture. The smaller ripples, which lie at right angles to the larger ones, are sand ripples which are diurnal features, whereas the granule ripples are at least seasonal, if not semi-permanent landscape features.

ENGINEERING AND MILITARY USES: Although their surfaces are relatively soft, these structures are rather firm and do not squish out when a load is applied. Although they can support a load, the overall surface is bumpy and corrugated, and vehicles can be limited to 3 to 6 kpm. Relatively small fields, such as in the photographs, can be skirted by ground vehicles, and avoided by aircraft. Entering such a field while traveling at good speed across the plain, which is easy to do at nighttime, can cause vehicle damage and personnel injuries. Such ripples are likely to be encountered on the aprons of dune fields and near bedrock hills.


B

LOCATION: Egypt (Southwest)
Wadi Bakht, Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

COMMENTS: In contrast to dunes, which can have multiple sets of steeply dipping layers (32°) that are commonly cross-bedded, the internal structure of granule ripples is relatively consistent and simple. This picture shows a cut through a layered arrangement typical of granule ripples. In this instance the prevailing wind is from the right. These inclined layers of coarse and fine sediments contrast with layers of similar sediments in sand sheets, which usually dip less than 5° and appear almost flat-bedded. As yet, there isn't agreement as to how granule ripples are formed. As stated in the Summary Sheet for granule ripples, the maximum sizes of the particles range from 2 to 30 mm, although the average size of the coarsest grains is consistent for any given area. In this illustration, the average size of the coarse grains is on the small side.

ENGINEERING AND MILITARY USES: Although the surface is soft, as seen from the footprints on top of the ripple, the mass itself is firm and unyielding. Consequently, an area of such ripples can be rough terrain for vehicles and fixed-wing aircraft.

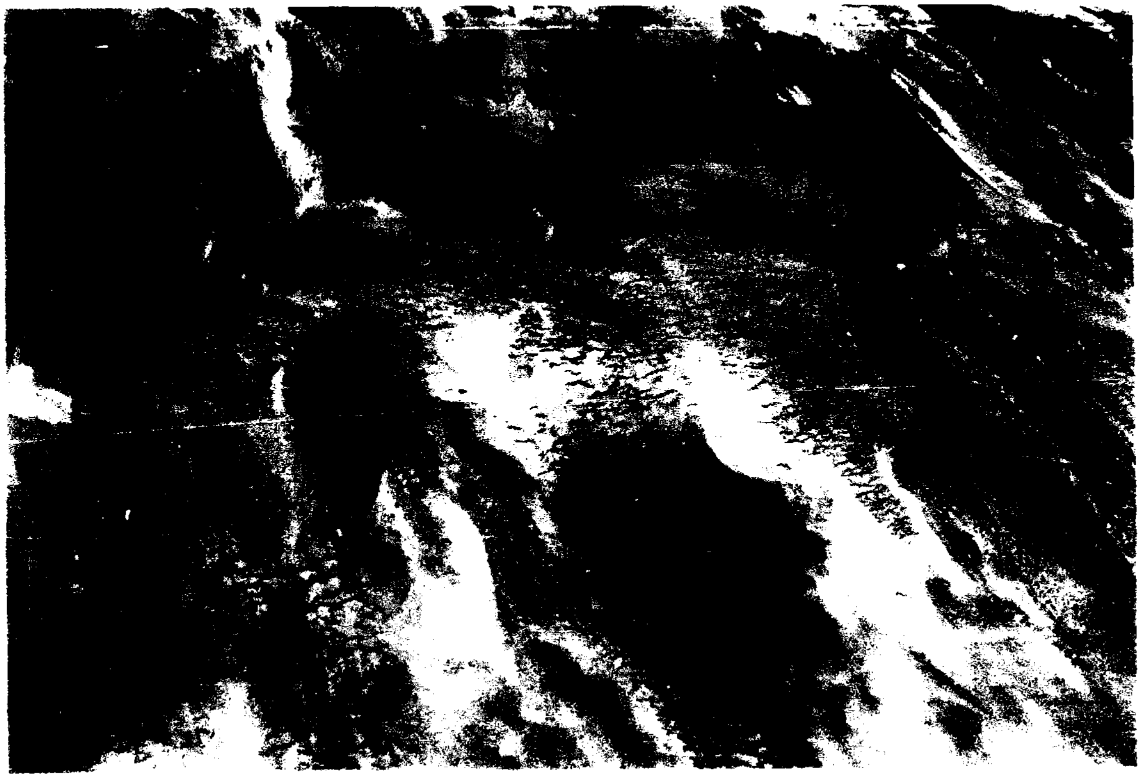
PATTERN INDICATOR SHEET - DESERT RIPPLES

PHOTO: AERIAL (OBLIQUE) GRANULE (MEGARIPPLES)

LOCATION: Peru (Central coast)
Paracas Peninsula, central Peru, south of city of Pisco

CLIMATE: Hyperarid
Trewartha, 1957: BWn: *Tropical and Subtropical Desert, cool coastal, frequent fog*

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.



COMMENTS: This low altitude oblique photograph shows a portion of the coastal platform, which is composed of soft sedimentary rocks (Pisco Formation) blanketed with granular rock and mineral debris. The width of the photograph represents about 1 km on the ground. The relief in the background is provided by small outcrops and lee dunes. In the middle ground a field of transverse granule ripples can be seen, which are developing into more organized ripple trains in the foreground. These trains are aligned parallel to the prevailing wind, which is from the top towards the bottom in the photograph. The irregularly shaped lighter-toned areas are thinly mantled outcrops of wind beveled, or eroded siltstones of the coastal platform (Pisco Formation).

ENGINEERING AND MILITARY USES: Although such granule ripples impede cross-country movement and place restrictions on aircraft operations, they can, in this instance, be avoided by going around the area, or through those parts where the ripples are well separated. As evidenced by the highlight and shadow pattern in the lighter-toned areas in the lower half of the photo, these areas have some relief.

PATTERN INDICATOR SHEET - DESERT

RIPPLES

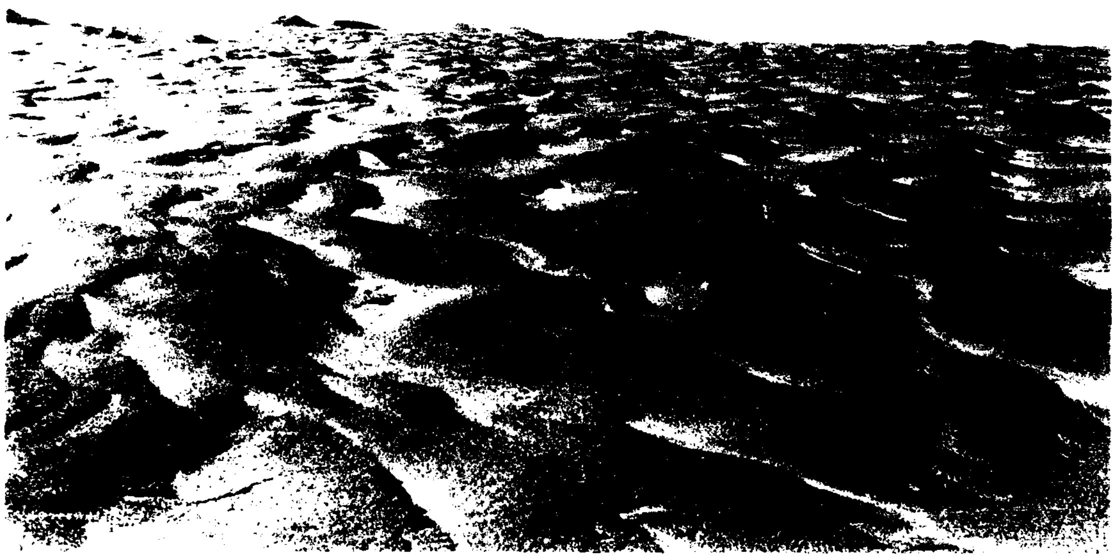
PHOTO: GROUND

GRANULE (MEGARIPPLES)

LOCATION: Peru (Central coast)
Near the mouth of the Rio Ica

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.



COMMENTS: The large catenary type granule ripples do not have pronounced downwind alignments. The crest heights range up to about 0.5 m, and the crest-to-crest distances are 1 to 2 m. The coarser and darker minerals and rock fragments tend to concentrate on the crests and the lighter-toned, finer particles tend to concentrate in the lees.

ENGINEERING AND MILITARY USES: These surfaces are relatively firm and will support any kind of traffic; but, when the ripples are of this size, the surface will be extremely bumpy and can be traversed at only slow speeds, 3 to 4 kph. Dust will not be a problem. This surface will support rotary-wing aircraft, but with this size ripple, not fixed-wing aircraft.

PATTERN INDICATOR SHEET - DESERT | RIPPLES

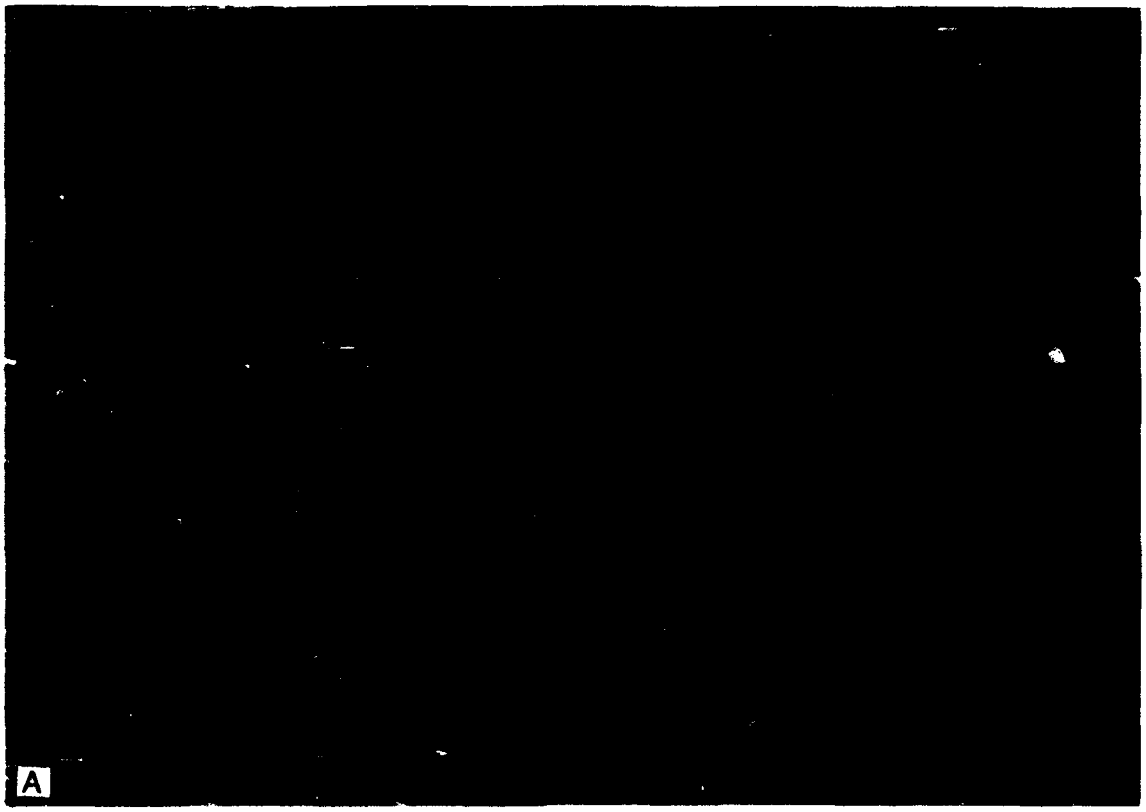
PHOTOS: AERIAL (OBLIQUE) AND GROUND | GRANULE (MEGARIPPLES)

LOCATION: Peru (Coastal)
Paracas Peninsula, central Peru, south of city of Pisco

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

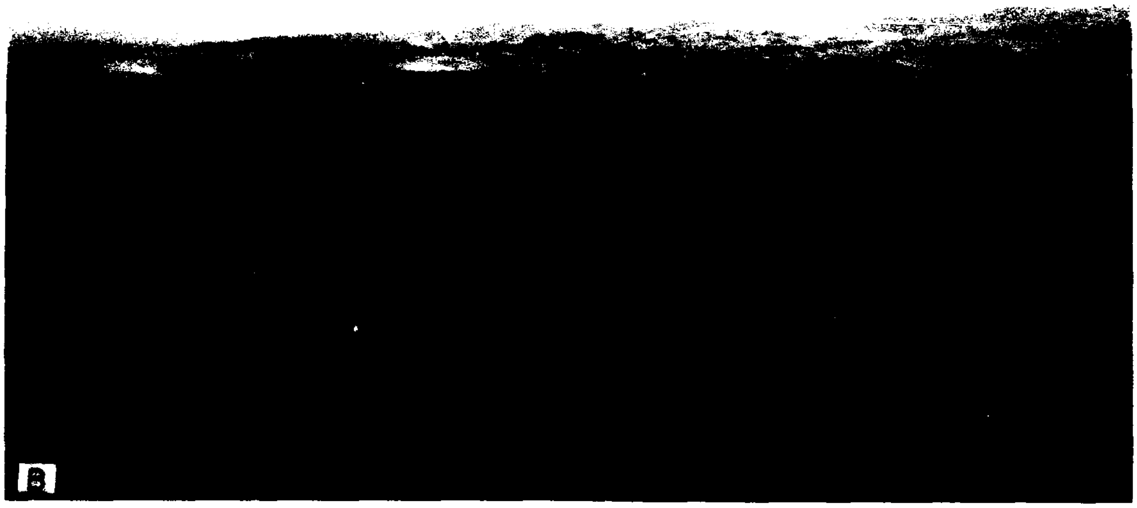
IMAGE CREDITS:

A. George Ericksen, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1971.
B. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1971.



COMMENTS: Photo A is an oblique aerial view of granule ripple trains on a dark, coarse sand to granule blanket that thinly veneers flat-lying sedimentary rock. Wind direction is from top to bottom. The dark cross patterns are the crests of individual ripples, which are 1 to 2 m wide. The bright stripes are the lees of these asymmetric bedforms, where finer and lighter-toned sand has temporarily accumulated. These ripples are organized into parallel trains that extend inland for tens of kilometers on the platforms of coastal Peru where blanketed by granular material. This parallel organization is thought to be almost unique to this desert where a very strong, regular, unidirectional wind regime prevails. The picture covers an area almost 0.5 km wide. Photo B is a ground view in the upwind direction of ripple trains in the same general area as photo A. Granitic terrain and coastal fog typical of this unusual desert can be seen in the background. The ripples are highest where the darkest rock fragments occur.

ENGINEERING AND MILITARY USES: This pattern indicates that caution is in order when evaluating the terrain for cross-country movement or aircraft use. Although the



B

ripples are firm and can support any reasonable load, their surfaces provide a very irregular, or bumpy terrain. The most severe bumpiness is found when going directly upwind or downwind, i.e., perpendicular to the ripple pattern. The next class of irregularities, or bumps, will be found when going perpendicular to the ridge lines formed by the crests. This is also perpendicular to the wind direction. Although vehicles can traverse this area in any direction, the easiest route will be about 45° to the ridge lines. Large fixed-wing aircraft (DC-3 type) can, and do, operate in such areas, but landing and takeoff should be about 45° off the upwind direction.

PHOTO: GROUND GRANULE (MEGARIPPLES)

LOCATION: Peru (Northern coast)
About 10 km south of city of Chimbote

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

COMMENTS: This photo is an upwind view of granule ripples on the coastal platform of northern Peru. Although there is a tendency toward longitudinal alignment, these ripples are not as large, nor as well organized, as the train on the Paracas Peninsula of central coastal Peru. These have heights of about 0.3 m and crest-to-crest distances (wave lengths) of about 1 to 2 m. The coarser and darker minerals and rock fragments tend to concentrate on the crests of these features. The finer materials are concentrated in the lees of the ripples. Toward midday in this region strong diurnal winds can pick up these fines and produce temporary ground-hugging sandstorms.

ENGINEERING AND MILITARY USES: These firm ripples present a bumpy irregular terrain. The bumpiness will be most pronounced when traveling directly upwind or down. The ripples are firm enough to support either 2-wheel- or 4-wheel-drive vehicles, rotary-wing aircraft, and, under some conditions, fixed-wing aircraft. Although some dust will be generated by aircraft (rotary- and fixed-wing), there will be little dust generation by wheeled or tracked vehicles traveling at slower speeds. Because of the bumpy, irregular surfaces of a granule ripple field, high speed surface travel by wheeled or tracked vehicles is not feasible. One can easily be limited to 3 to 4 kph. If the ripples have a longitudinal organization, then travel perpendicular to the wind direction will also be bumpy. The features are best traversed at about a 45° angle to the prevailing wind direction. DC-3 type aircraft flown by pilots skilled in rough terrain conditions have operated in such areas, and land and take off at 45° to the side of the upwind direction.

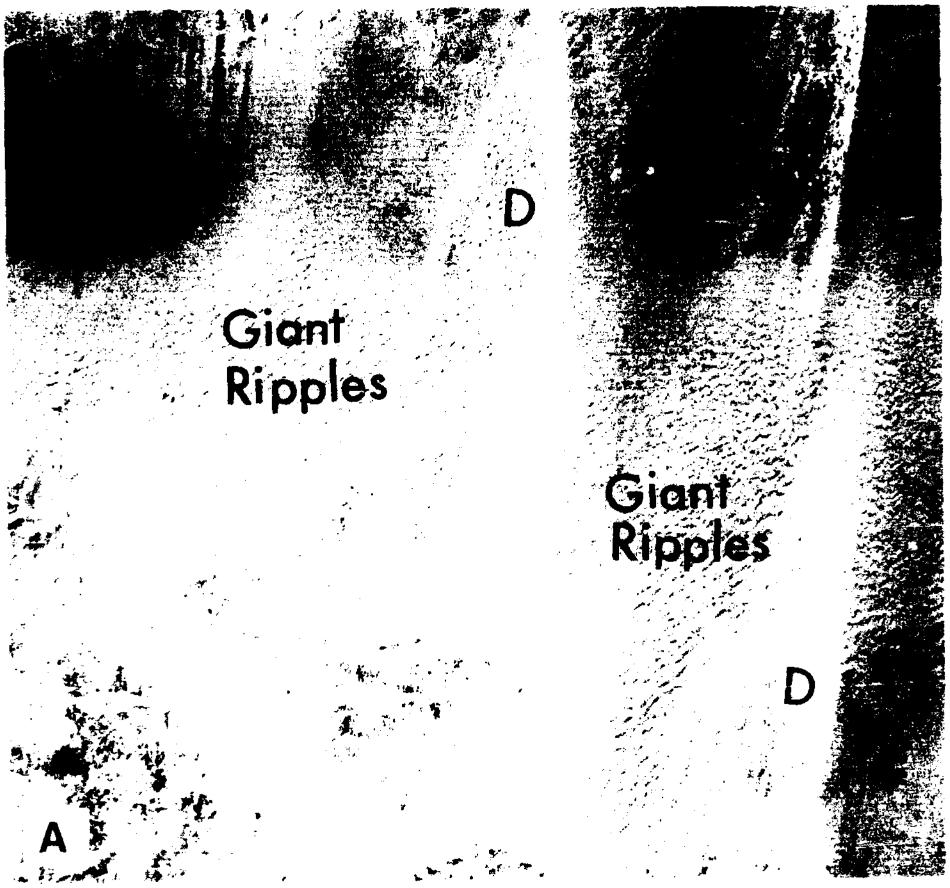
PATTERN INDICATOR SHEET - DESERT | RIPPLES

LANDSAT: MSS; PHOTOS: GROUND | GIANT

LOCATION: Egypt (Southwest) and Sudan (Northwest)

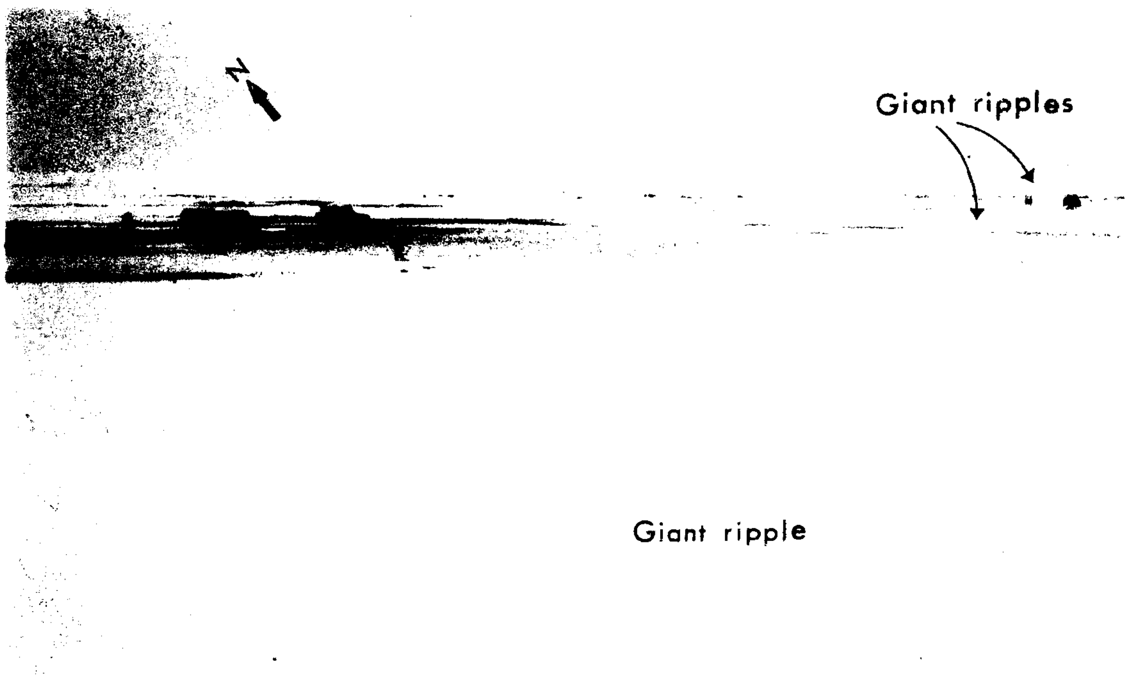
CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. Scene 1112-08085, Band 7, 11 Dec 1972, Path 191, Row 45, approx. 21°N 27°30'E, Scale 1:1,000,000.
B. & C. Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ.



COMMENTS: The partial Landsat image (A) shows the Selima Sand Sheet in the Eastern Sahara, North Africa. There is very little relief in this region except for scattered low bedrock outcrops (lower left corner) and trains of sand dunes (bright features marked "D"; individual dunes at arrow are about 500 m wide and 50 m high). The sand sheet is flat in some areas (F) and appears flat or slightly undulating even in the areas where it is organized into giant ripples. The ripples, like the rest of the sand sheet, consist of horizontally-laminated deposits of sand, silt, and pebbles (photo B), typically armored by a surface (lag) layer of the coarsest particles (see Summary Sheet for Sand Plains/Sand Sheets). The ripples form low, rolling plains that extend for hundreds of kilometers. The relative relief of the ripples swells and hollows (shown in photo C) in some areas is as much as 10 m, and average spacing (wavelength) is just under 0.5 km (Breed, et al.).[1] The sand sheet is thickest (as much as a few meters)

B



C

in the swells of the ripples, and as thin as a centimeter or so in the hollows, where an underlying calichified alluvium in bedrock is commonly exposed (see Summary Sheets for Sand Plains/Sand Sheets and for Duricrusts - Caliche). Unlike transverse sand dunes, whose patterns they superficially resemble on Landsat images, giant ripples have no slip faces (avalanche slopes). Their mode of origin is not known, but they seem to be actively forming only in areas without vegetation. Farther south in the Sudan, similar rolling but inactive topographic features have been stabilized by vegetation; these features have been called "qoz" and "zibar" (Warren).[2]

ENGINEERING AND MILITARY USES: Giant ripples are not hazards to cross-country travel and aircraft operations; they are, in fact, indicators of excellent surfaces for transport in this part of North Africa because here they are underlain by hard materials. Very thick ripple swells, however, may bog down heavy vehicles, which should always stop pointing downhill on the ripples, or on exposed hard surfaces in the hollows.

REFERENCES:

[1]Breed, C.S., J.F. McCauley, and P.A. Davis. 1987. Sand sheets of the eastern Sahara and ripple blankets on Mars. In Desert Sediments: Ancient and modern, edited by L.E. Frostick and I. Reid. Geological Society of London Special Publication, no. 35, pp. 337-359.

[2]Warren, A. 1972. Observations on dunes and bi-modal sands in the Tenere Desert. Sedimentology, v. 19, no. 1-2, pp. 37-44.

PHOTOS: GROUND

LOCATION: Egypt (Southwest)
Western Desert, 60 km S of Bir Tarfawi, 22°15'N 28°30'E

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Feb 1984.

COMMENTS: The sand plains in southwestern Egypt consist of thinly-layered horizontal sheet deposits of sand, coarse silt, and granules. In some areas the sand sheets are very thin and cover a substrate of calcified alluvium, or caliche (Photo A). In these areas, shallow trenches can be dug to depths of 1 or 2 m in the caliche and the walls will stand until drifting sand fills the trench. In other areas, the sand sheets are too thick to allow trenching as the soft sand walls will quickly collapse (Photo B). It is difficult to tell from photography or Landsat images whether the sand sheet is thick or thin. One clue to identifying such areas is the presence of giant ripples. This pattern can be seen in Landsat images and, where present, the sand sheet is meters thick and too soft to dig in except in the flats. Ripple crests are typically spaced about 0.5 km apart.

A

B

ENGINEERING AND MILITARY USES: In localities where the sand sheets are thin and cover a calcified, or otherwise consolidated, alluvium, these flat sand plains are easily trafficable by wheeled vehicles and are suitable for fixed-wing aircraft operations.

PHOTOS: GROUND

LOCATION: Egypt, Western Desert
Between Bir Tarfawi and Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.
B. C. Vance Haynes, Univ. of Arizona, Tucson, AZ, 1981.

A

B

COMMENTS: Photo A shows a portion of a sand plain that extends over thousands of square kilometers in the Western Desert of Egypt. Very little dust is being raised by the vehicle because the plain is built of thin, nearly horizontal layers of silt, sand, and fine gravel covered with a closely-packed layer, one grain thick, of the coarsest particles (see photo B). Except for areas of granule or truncated ripples, this provides a smooth, flat surface. Patches of granule ripples or truncated ripples will severely restrict vehicle speed if they have to be crossed (see Summary Sheets for these features). These areas occur mostly near fields of sand dunes and bedrock outcrops, but seldom on unobstructed parts of the sand plain. In areas where the sand sheet is arranged into low and very broad giant ripples, the surface takes on a gentle undulatory characteristic, but this does not cause problems for cross-country movement.

ENGINEERING AND MILITARY USES: Except for areas of granule or truncated ripples, a sand plain provides an excellent surface for support of aircraft operations, both fixed-wing and rotary-wing, and for vehicular traffic of all kinds, i.e., from jeep-type vehicles to heavy trucks, and at their top speeds. Vehicular traffic will generate little dust. Vehicles should not track each other; repeated passage and use by heavy trucks, etc., can break up the surface and subsurface layers and turn them into a soft, loose mass that can impede or bog down the following vehicles, even those with 4-wheel-drive. This breakup of the surface also provides a dust source. Such disturbed areas can be obscured with a veneer of drift sand and are hazardous to vehicles entering them at higher speeds. Water is not available, except in isolated oases where sparse vegetation occurs, or in shallow, braided, old stream channels that can be detected at a depth of 1 to 2 m below the surface by L-Band radar imagery.

PATTERN INDICATOR SHEET - DESERT

SAND PLAINS/SAND SHEETS

LANDSAT: MSS

STREAKS

LOCATION: Botswana, Namibia, & South Africa
Border region, 27°24'S 19°28'E

CLIMATE: Arid
Trewartha, 1957: BW: Tropical and Subtropical Desert

IMAGE CREDITS: Scene E-1109-08054, Band 6, 9 Nov 1972, Scale 1:1,000,000.

Comments on back.

DESERT PROCESSES WORKING GROUP

COMMENTS: Broad, elongate patches of windblown sand without obvious slip faces are sand streaks. Some undoubtedly include small dunes and ripples that are below the level of resolution, but these are not characterized by the development of major slip faces, e.g., their slopes will be gentle, not steep. Sparse vegetation may be present in less arid localities. These sand streaks extend in a downwind direction across bedrock plains, plateau scarps, and old, dry drainage lines and playas, indicating drier conditions now than in the past. Elongation is parallel to prevailing wind direction, from west to east in this area, i.e., slanting up from left to right.

ENGINEERING AND MILITARY USES: Very little is known of these elongate features, but they appear to offer avenues of cross-country transport across otherwise broken ground.

LOCATION: Egypt (Southwestern)
Western Desert

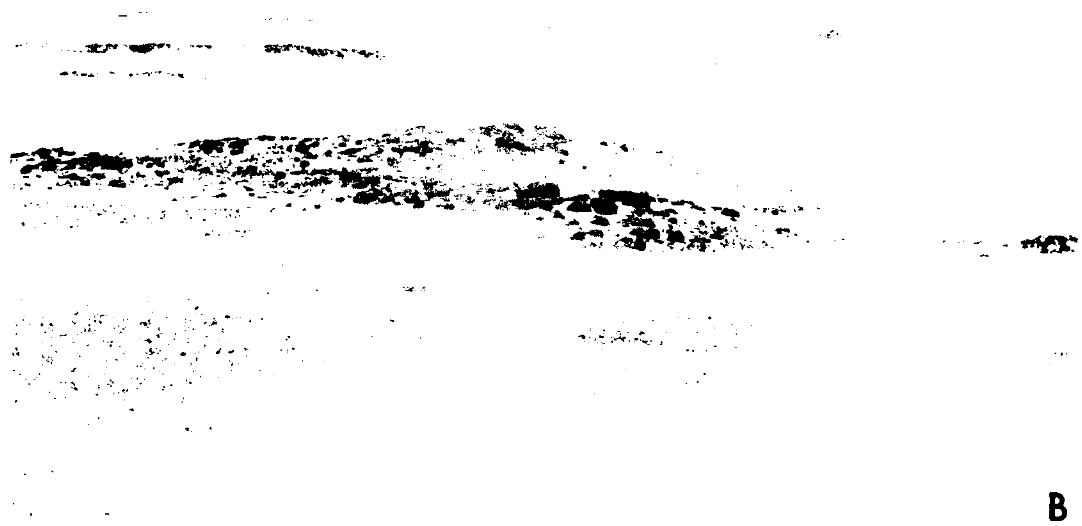
CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1984 (A) and 1982 (B).

COMMENTS: Patches of sand sheet deposits over areas of broken ground with scattered bedrock outcrops are sand drifts. On the ground these outcrops have no discernible pattern, but on air and satellite photos often can be recognized as the erosional remnants of local drainage divides.

ENGINEER AND MILITARY USES: These broken plains are typically underlain by solid, rough bedrock rather than by alluvium, and are therefore unsuitable for trenching or for fixed-wing aircraft operations. They are trafficable by ground vehicles and will support rotary-wing aircraft. Locally they present bumpy going when the rocky ridges must be crossed. If going too fast, the sharp, wind-eroded rock outcrops can cause tire damage. Stops should be made on the darker patches, which have a veneer of talus or gravel.

A



B

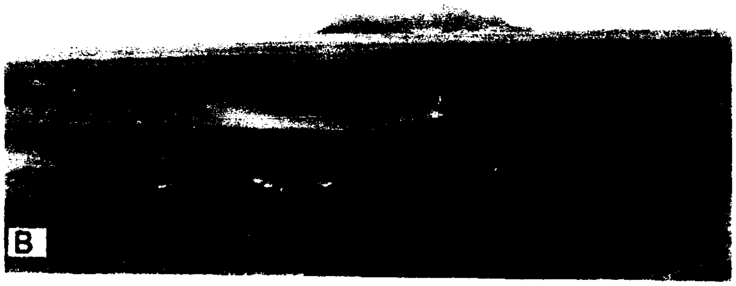
LOCATION: Africa, Sudan (Northwest)
Near border with Libya and Egypt

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Maurice J. Grolier, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1981.

COMMENTS: Gravel plains are areas of bedrock, or alluvium, veneered with rock fragments. They cover large parts of desert areas, especially areas adjacent to plateaus and other highlands. In photo C a plateau edge can be seen on the far right-hand horizon. The only significant topographic relief on these plains consists of isolated vegetation mounds, dunes, and isolated bedrock hills (see Summary Sheet for Inselbergs/Hills/Knobs). All three photographs show examples of inselbergs. Although thin drifts of windblown sand can form a veneer on the gravel plains, as shown in photo A, these drifts do not cause problems. The gravel plain surface can be cut by shallow drainage gullies coming from the highlands. These gullies are generally dry, as shown in photo C. The inselbergs are remnants of old drainage divides.


A


B


C

ENGINEERING AND MILITARY USES: Gravel plains that are adjacent to sandstone, limestone, granite, and basalt outcrops produce little dust as a result of vehicle traffic, as shown in photo B. Gravel plains adjacent to outcrops of shale or chalk can conceal deposits of soft weathered material (nafash) that produce clouds of dust in response to traffic, and can also bog down vehicles (see Summary Sheet for Nafash). In general, gravel plains provide good surfaces for fast travel by light and heavy vehicles and for aircraft operations of all types. Areas where the gravel veneer covers a fine-grained alluvium can become difficult to traverse, if not impassable, especially to lighter vehicles, wherever the surface has been broken and exposed the soft underlying sediments. These sediments are also a dust source. Vehicles should not travel the same track, as this can break up the surface. Heavy truck maneuvers can also chew up the surface. Such has occurred around oil rigs, making the immediate area impassable to light vehicles. Hitting a soft area, such as an old truck rut, while traveling at high speed can cause problems. Isolated hills offer some cover and concealment, can serve as observation points, and also can serve as navigational aids when tied into Landsat or radar images.

PATTERN INDICATOR SHEET - DESERT

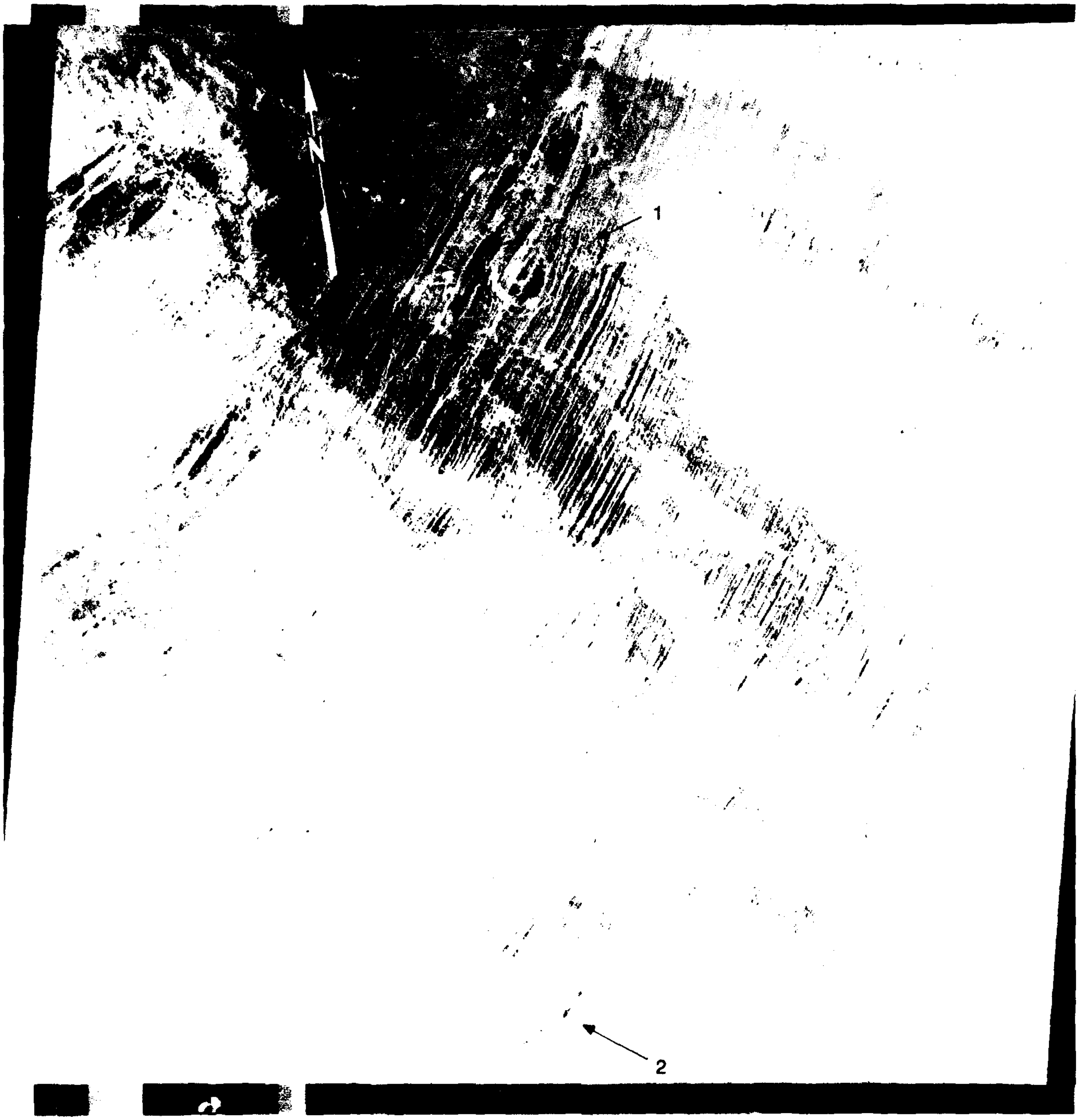
GROOVED TERRAIN

LANDSAT: MSS

LOCATION: Africa, Chad, Tibesti Region
18°40'N 19°12'E

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene E-1099-08381, Band 7, 30 Oct 72, scale 1:1,000,000.



Comments on back.

COMMENTS: This Landsat image shows very large scale grooved terrain in massive sandstones along the east side of the Tibesti Plateau in Chad. The distance across the photo represents about 185 km. Although the streaked, or linear pattern, extends beyond this scene, the individual ridges are not continuous, but broken up into various length segments. The largest ridge sections are about 2 km in width and 30 km long. Be careful not to confuse this pattern with a similar scale scene of long linear dunes. Similar wind-carved terrain is developed in siltstones in the Lut Desert of Iran, and in crystalline rocks (granites and metamorphic rocks) in the southern coastal Namib Desert of southwest Africa. All of these occurrences are in arid climatic zones characterized by strong, unidirectional winds; which, in this case, blow from the upper right to lower left, parallel to the bedrock ridges and grooves. Blunt ends of the individual ridges generally face into the wind, and the ridges commonly taper in a downwind direction. In this picture, the whitish areas are softer rock (mudstones and siltstones) that are eroded remnants of playa sediments. These softer rocks, like the sandstone ridges, have been carved by wind into streamlined hills (yardangs); although similar in shape, they are much smaller than the bedrock ridges. The circular structure in the upper part (arrow 1) is an igneous intrusive feature in the process of being exhumed by wind erosion of the sedimentary cover. The dark tones of the ridges and some of the background surrounding the circular feature could be indicative of extensive desert varnish. Near the bottom (arrow 2) is the settlement of Largeau (Faya).

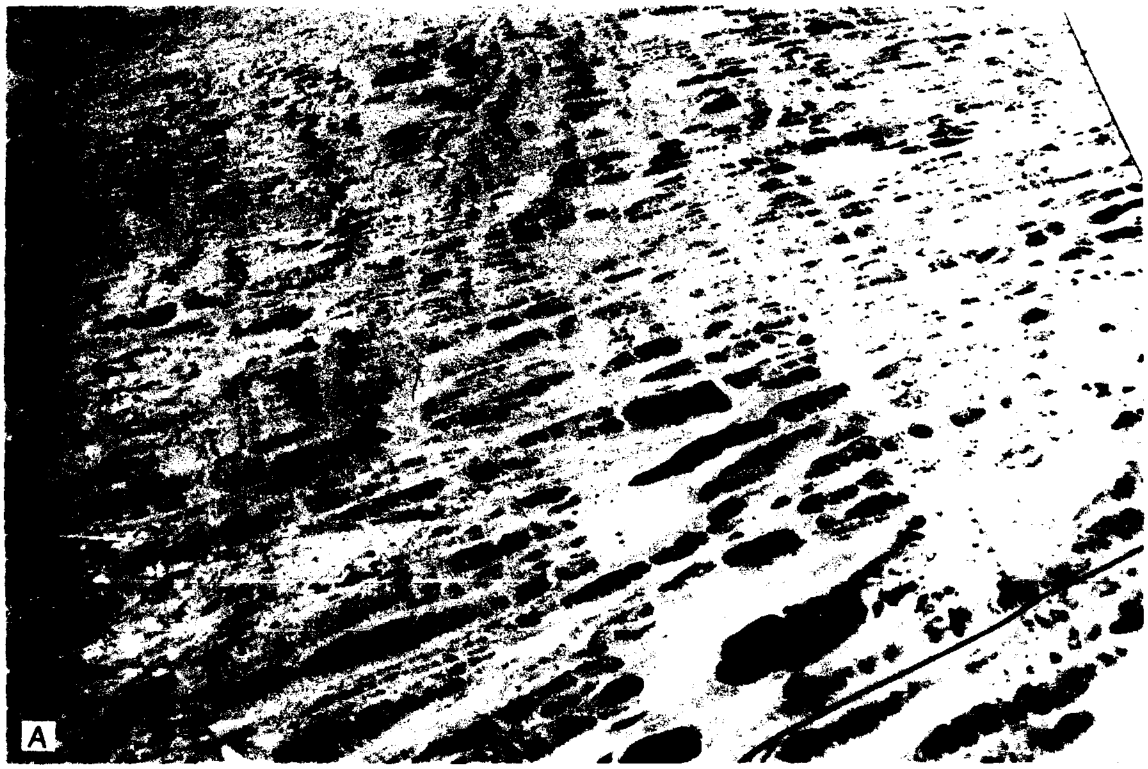
ENGINEERING AND MILITARY USES: Surface travel across the large ridges in the dark area is out of the question. Travel between these dark ridges in a northeasterly or southwesterly direction might be possible in some instances in the far southeast portion of the dark area. In the light-toned areas trending NW-SE the ridges are smaller and more segmented and a path through might be found for foot and camel traffic, if not vehicles. The grooved terrain area will not support fixed-wing aircraft operations, but there will be sites that can support rotary-wing aircraft. Field units operating in the adjacent area can find some degree of cover and concealment in the periphery of the grooved area.

PHOTOS: AERIAL (OBLIQUE) AND GROUND

LOCATION: Egypt (South-central)
Limestone Plateau northeast of Kharga

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.
B. Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.



COMMENTS: Wind erosion of the bedrock on top of the Limestone Plateau in south-central Egypt has produced large scale ridge-and-groove topography with a strong regional north-south grain. Individual ridges carved in hard crystalline limestone (marble) are meters to kilometers long and as much as tens of meters wide (note road in aerial photo for scale). In some places the grooves (troughs between ridges) have a fairly flat bedrock floor veneered with thin drifts of windblown sand. These bare trough floors are passable where they form continuous corridors between adjacent ridges (note tracks in ground photo). In other places the troughs are floored with extremely sharp-edged, small scale rock ridges ("kharafish" in Egypt) that will easily cut shoes and tires. Where the individual rock ridges are streamlined, they are called yardangs. Thus, grooved terrain is commonly synonymous with fields of large scale bedrock yardangs (see Summary Sheet for Yardangs). Occasionally, windblown sand invades grooved terrain and builds barchan dunes in the troughs, as well as lee dunes behind the yardang tails, and sand moats in front of the yardang noses.

ENGINEERING AND MILITARY USES: Grooved terrain can be impossible to traverse in vehicles except along the troughs, and only in a direction parallel to the ridges, and for

distances only as long as the troughs are linked in continuous corridors. Depending on size and other terrain features, going across the pattern, i.e., across the ridge line, ranges from doable, through difficult, tedious, and time consuming, to impossible. In this instance, such a path could probably be found, but without stereo aerial photography any such attempt would not be practical. Although the trough floors provide good support, they frequently have accumulations of loose sand, as do many of the passages between segments. Some horizontal cover and concealment is provided, and the irregularities of the shape and tonal patterns in plan view give some obscuration or masking potential for field units. Grooved terrain areas are frequently extremely windy and offer little or no shelter from blowing sand and dust. From the troughs, visibility is limited to the sidewalls and tops of the adjacent ridges (much as in fields of linear sand dunes). Grooved terrain is not suitable for fixed-wing aircraft. Some sites in this area could support rotary-wing aircraft, but blowing sand and dust would probably mark such use.

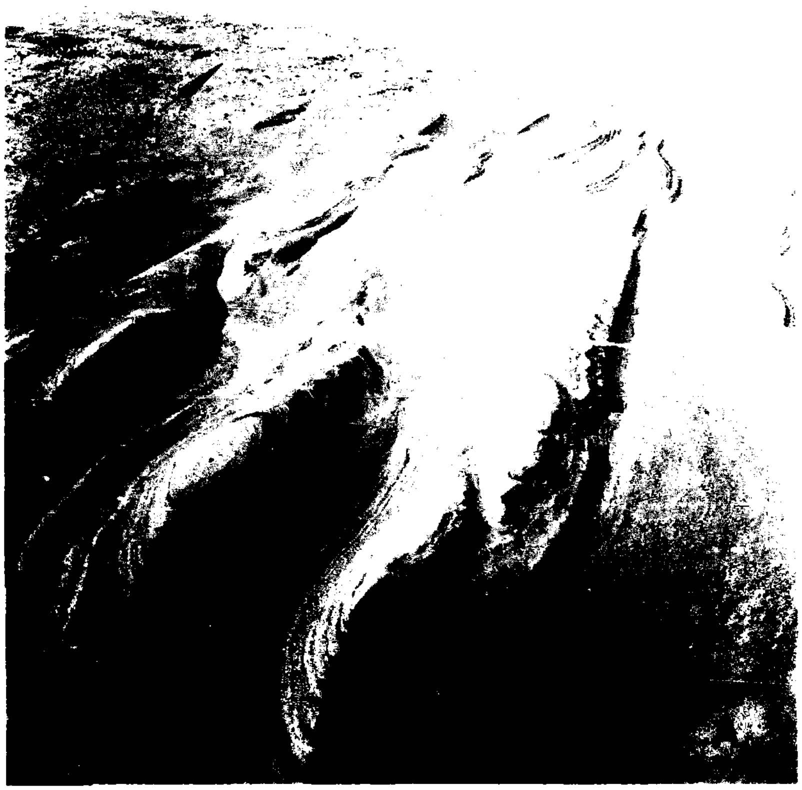
PHOTO: AERIAL (OBLIQUE)

LOCATION: Peru
Ica Valley, Cerro Yesera Yardang Field

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

COMMENTS: Yardangs are elongate, tapering, streamlined bedrock hills eroded by wind. Typically these hills have high, blunt forward ends (bows) that face into the prevailing wind, and they become lower and narrower to leeward. Yardangs commonly occur in groups of parallel hills called "fleets," such as shown in photos A and B. In this instance the bedrock is mostly a fine-grained sedimentary series (the Pisco Formation), and the contour-like pattern of the beds is very apparent. The hills in the foreground of photo A are probably on the order of 60 m high, and the largest single yardang is about 2 km long. The prevailing wind is from the south, i.e., from the lower left. The broad, flat valley (to the right in photo A) is a more resistant bed, and as the softer units on top of it are removed, that surface becomes even more exposed. The dark patches in the upper left are exposed igneous bedrock, probably andesite, underlying the Pisco Formation. The dark tones in the valley are produced by dark igneous particles, probably andesite, moved in from the south by the wind. This material is in the form of granule ripples (see Summary Sheet for Ripples - Granule (Megaripples)). When the yardangs are numerous and closely adjacent, the result is grooved terrain. Yardangs are most common in soft sedimentary rock such as siltstones and claystones, but they also occur in sandstones, limestones, and even in granite under conditions of extreme aridity and strong, unidirectional winds.



ENGINEERING AND MILITARY USES: Crossing this yardang field, especially in the cross-wind direction, will be difficult. Imagery will be needed to find a route. Vehicle movement over the granule ripples on the valley floor is possible, but because of jolting and jarring, speed will be limited to that of a fast walk. The ripples will also influence fixed-wing aircraft operations. The landing should have an upwind component, i.e., about 45° to the ripple train; but the confines of the valley wall prevent this approach.

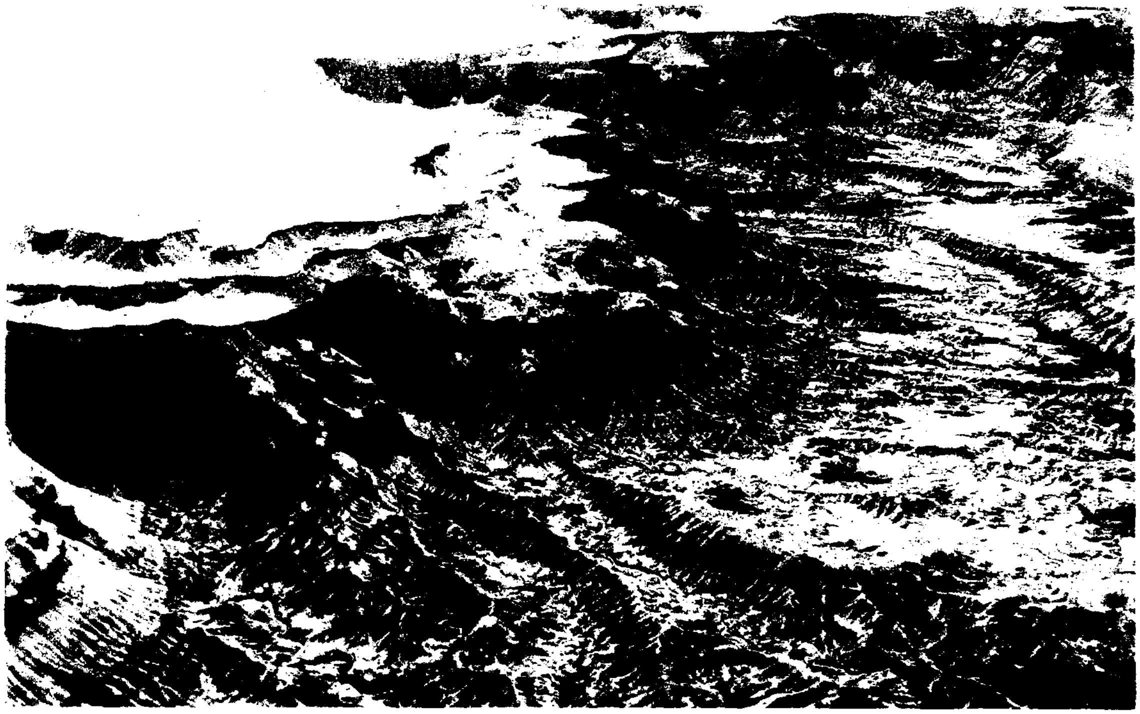
PATTERN INDICATOR SHEET - DESERT BADLANDS

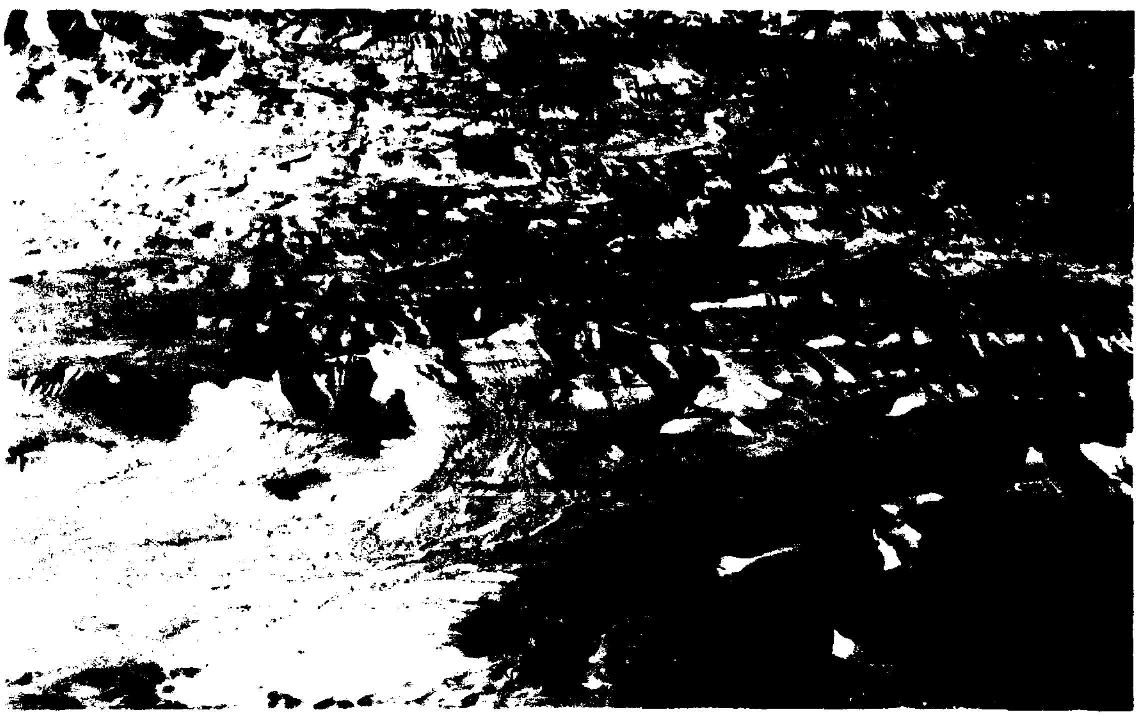
PHOTOS: AERIAL (LOW ALTITUDE)

LOCATION: USA, Arizona (Northeastern)
Ward Terrace, about 65 km north northeast of Flagstaff

CLIMATE: Semiarid
Trewartha, 1957): BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Aug 1974.





Comments on back.

COMMENTS: This intensely dissected terrain developed from erosion of sandstones, siltstones, and claystones by ephemeral running water from the Moenkopi Plateau to the terrace below, and from local rainfall on these slopes. They are characterized by short, steep slopes and very narrow divides. Little or no vegetation can become rooted on these unstable surfaces because soils cannot form under such rapid rates of erosion.

ENGINEERING AND MILITARY USES: Because of the intense and intricate gullying and the steepness of the slopes, these badlands are impassable to vehicles, even when dry. When wet, these slopes and gully bottoms become soft and sticky because of the high clay content.

PHOTO: AERIAL (OBLIQUE)

LOCATION: USA, Nevada
North of Las Vegas

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1974.

COMMENTS: These badlands have developed from the dissection of alluvial fan deposits of calcified, consolidated sand, silt, and gravel by running water. Although vegetation is evident on the flat areas, it cannot establish itself on the steep, intricately gullied slopes cut below the vegetated plains' surfaces. Downcutting below the original fan surface was probably initiated by uplift of the area along faults, which began a new cycle of erosion by increasing the gradient of runoff channels on the fan. Sapping may also have contributed to this erosional pattern.

ENGINEERING AND MILITARY USES: These channels and badland slopes present severe obstacles to cross-country movement. They offer some cover and concealment, but also are vulnerable to flash flooding after rains on the upper surfaces, or in the headwaters of the fan.

LANDSAT: MSS | WADIS - WASHES

LOCATION: Egypt (Southwestern)
Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene E-1131-08141, Band 7, 1 Dec 1972, approximate scale 1:600,000.

Comments on back.

COMMENTS: The edges of the 100 m high erosional remnant of near-horizontal sandstone layers are cut by numerous dry washes, or wadis, that connect the innermost regions of the plateau with the surrounding plains. Some, such as Wadi Wassa (arrow 1), allow passage of vehicles to the opposite side. Most of the old stream courses have been widened by basal sapping of the valley walls. Their floors have been partly filled by alluvial deposits and a veneer of windblown sand. Residual hills on the surrounding plains are remnants of former divides between stream courses that formerly extended beyond the present physiographic margins of the plateau onto the surrounding plain of coalesced pediments (pediplain) (Breed, et al.).[1] Except for clouds on the left side of the image, the light materials are windblown sand plains and sand dunes.

ENGINEERING AND MILITARY USES: Several good surface transport routes can be selected on this image by evaluating the patterns of bedrock and windblown sand. Light-toned streaks and wavelike forms on the plain signify thick sand deposits and dunes that should be avoided. Dark, serrated features are cliffs and outliers (inselbergs) of sandstone bedrock that offer some cover and concealment (arrow 2). Medium gray, smooth-textured areas are gravel plains and firm sand plains that are easily trafficable and also are suitable for fixed-wing and rotary-wing aircraft operations except where cut by truncated or granule ripples (see Indicator Sheets for these features). Ground reconnaissance showed that some of the wadi floors have clumps of dead vegetation as well as gullies, all of which are presently dry. These are remnant indicators of rainfall and local runoff prior to the last 20 years or so (Boulos).[2] Both features could provide obstacles to cross-country movement.

REFERENCES:

[1]Breed, C.S., J.F. McCauley, and M.J. Grolier. 1982. Relict drainages, conical hills, and the eolian veneer in southwest Egypt--applications to Mars. Journal of Geophysical Research, v. 87, no. B12, pp. 9929-9950.

[2]Boulos, L. 1980. Botanical results of the expedition (to the Gilf Kebir and Uweinat). Section IV of Journey to the Gilf Kebir and Uweinat, Southwest Egypt, 1978, by F. El-Baz, et al. Geographical Journal, v. 146, Part 1, pp. 68-71.

LOCATION: Egypt (Southwest)
Wadi Mashi, Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Sep 1978.

COMMENTS: This broad dry valley contains no runoff except after local rainfall, perhaps once every 25 years. It is now an ephemeral drainageway, or "dry wadi." Under formerly less arid climatic conditions, however, streamflow carved numerous such valleys into this plateau, and these form integrated networks that extend along graded valleys from the plains outside the plateau to the innermost reaches of the plateau and its summit.

ENGINEERING AND MILITARY USES: This kind of wadi offers the best routes of passage into the central parts of the plateau, its summit, and in some cases, to the opposite side. The floors are firm gravel with a thin and easily avoided veneer of sand drifts in places. The wadi offer some horizontal cover and concealment. They contain almost no vegetation. Near-surface water may be available in a few localities, but in general this area is bone dry, except after infrequent rains which occur on the order of once every 20 years.

LOCATION: USA, Arizona (Northeastern)
Little Colorado River

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 26 Jun 1983.

COMMENTS: Canyons are steep-walled, narrow valleys incised in bedrock. They have only very narrow floodplains, if any (Photo A), and therefore develop steep valley-side cliffs that rise abruptly from the stream channel. Where canyons are incised in near-horizontal sedimentary rock layers of varying resistance, a vertical series of alternating steep and gentle slopes results, as shown in photo A. Consequently, a cross-country approach to the edge of a canyon is seldom marked by any distinctive warning signs. Shallow gullies generally run right to the edge and then drop precipitously, as shown in photos B and C.

ENGINEERING AND MILITARY USES: Access in and out of canyons is difficult at best, commonly requiring climbing gear (ropes, pitons, etc.). The best route is generally by way of a side, or tributary channel, such as shown in photo C. Such channels may or may not contain active streams. Canyons are subject to flash flooding that can, without warning, fill the valley from wall to wall. This occurs after rainfall in the headwaters area, which is commonly many kilometers away. The edges of canyons are rarely seen from any distance across plateau surfaces, especially at night.

B

C

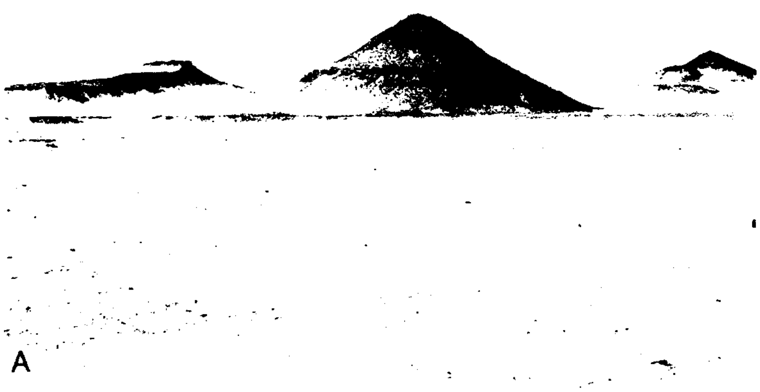
PHOTOS: GROUND

LOCATION: Egypt, Western Desert
A: near Bir Shab, south-central Egypt; B: near border of Sudan with Egypt and Libya

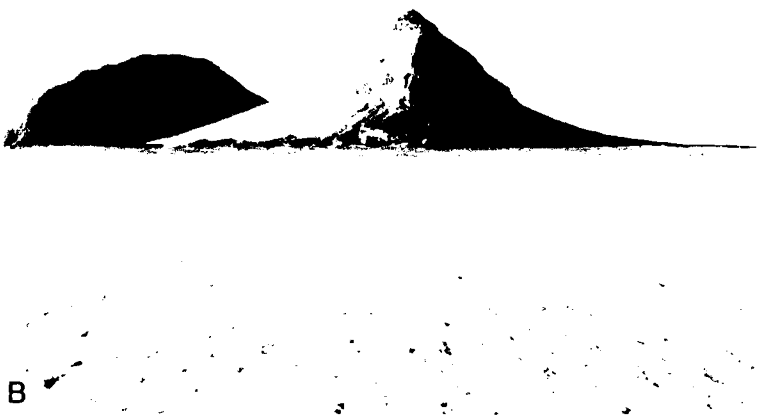
CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.
B. Maurice Grolier, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1981.

COMMENTS: These isolated conical or pyramid-shaped bedrock hills generally occur in groups as erosional outliers of nearby plateaus and other highland areas. The hills are eroded remnants of the divides between former watercourses that drained the highlands. Although windblown sand can pile up in lee zones near the isolated hills as in photos A and B, the plain surrounding them generally consists of planed bedrock with a thin veneer of alluvial gravels (see Summary Sheets for Pediments, and Alluvial Features - Gravel Plains).



A



B

ENGINEERING AND MILITARY USES: Because the inselbergs are outliers of nearby highland areas, their presence, when coming on them while crossing the plain, indicates that highland areas, or plateaus are not far away, perhaps 2 to 8 km. These features show up on Landsat MSS and TM images, as well as on satellite radar, and sometimes are plotted on maps. Consequently, they can provide some navigational aids. The hills offer at least some cover and concealment on an otherwise empty, flat plain. They also shelter poisonous snakes on their rubbly slopes. If vegetation occurs on any of the faint drainage lines between the inselbergs, or between them and the highlands, there might be some usable shallow water. If no vegetation is seen, the courses are dry. They also make excellent observation posts and strong points in defensive positions, and were so used during World War II military operations in the North African desert.

PATTERN INDICATOR SHEET - DESERT

BURN SCARS

PHOTOS: AERIAL (OBLIQUE)

LOCATION: Australia (Western)
Great Sandy Desert, south of Fitzroy River

CLIMATE: Arid to Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 25 Aug 1981.

COMMENTS: These light, rectangular patches across the sand plain and linear dunes are areas where deliberate burning of natural vegetation is done episodically by the aboriginal inhabitants. They burn the mature vegetation (primarily Spinifex), which is inedible, to encourage growth of tender green shoots attractive to the wildlife, which they hunt, and to domestic cattle and sheep. Wildfires occasionally occur, and commonly rage out of control over wide areas. These patterns can also be seen on satellite imagery, where they are characterized by apparently random occurrence and angular but irregular outlines.

ENGINEERING AND MILITARY USES: Potential for cover and concealment will obviously be different, depending on one's position inside or outside of the burn scar. Travel through freshly burned areas will coat personnel and equipment with soot.

LOCATION: Egypt
Western Desert, about 60 km south of Bir Tarfawi

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:

A. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Feb 1984.

B. & C. Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Feb 1984.

COMMENTS: The solid material lying a few centimeters to a meter below the surface of loose, windblown sand sheet deposits is alluvium (sand and gravel) cemented into a rock-hard layer by calcium carbonate. This material, known as caliche or calcrete (and locally as "kunkur"), is formed by precipitation of $CaCO_3$ from ground water or by accumulation of $CaCO_3$ from windblown dust and occasional rainfall. Generally, caliche forms in soils only where annual rainfall is greater than 175 mm but less than 500 mm (Goudie).[1] In this part of North Africa, rainfall is less than 1 mm per year, and therefore the caliche here is a relict feature of earlier, less arid climatic conditions. Here, the caliche is regionally distributed in the alluvium that fills old, broad valleys that have little if any surface expression, but in this hyperarid region the caliche is detectable beneath the thin veneer of windblown sand on Shuttle Imaging Radar images (McCauley, et al., 1982, 1986; Schaber, et al.).[2,3,4] In this area, the caliche layer (arrow on photo A) is 20 cm or so below the sand sheet surface.

ENGINEERING AND MILITARY USES: The near-surface, regional distribution of caliche beneath the sand sheets on plains in much of the Sahara and in other deserts (such as

the Kalahari in Botswana) allows easy cross-country movement of vehicles and fixed-wing aircraft operations. Trenching into the caliche, however, requires mechanized equipment such as a backhoe. Such trenches will stand indefinitely (until filled by drifting sand, which can occur during a single windstorm). The caliche here is 1 to 2 m thick. Beneath the caliche is more unconsolidated (soft) alluvium.

REFERENCES:

[1]Goudie, A.S. 1983. Calcretes. In Chemical sediments and geomorphology: Precipitates and residua in the near-surface environments, edited by A.S. Goudie and K. Pye. San Diego: Academic Press, pp. 59-92.

[2]McCauley, J.F., G.G. Schaber, C.S. Breed, M.J. Grolier, C.V. Haynes, B. Issawi, C. Elachi, and R. Blom. 1982. Subsurface valleys and geoarchaeology of the Eastern Sahara revealed by Shuttle Radar. Science, v. 218, no. 4576, pp. 1004-1020.

[3]McCauley, J.F., C.S. Breed, G.G. Schaber, W.P. McHugh, B. Issawi, C.V. Haynes, M.J. Grolier, and A. El Kilani. 1986. Paleodrainages of the Eastern Sahara - The radar rivers revisited (SIR-A/B implications for a mid-Tertiary Trans-African Drainage System). IEEE Transactions, Special Issue, pp. 624-649.

[4]Schaber, G.G., J.F. McCauley, C.S. Breed, and G.R. Olhoeft. 1986. Space Shuttle Imaging Radar: physical controls on signal penetration and subsurface scattering in the eastern Sahara. IEEE Transactions, Special Issue, pp. 603-623.

stones and claystones, but they also occur in sandstones, limestones, and even in granite under conditions of extreme aridity and strong, unidirectional winds.

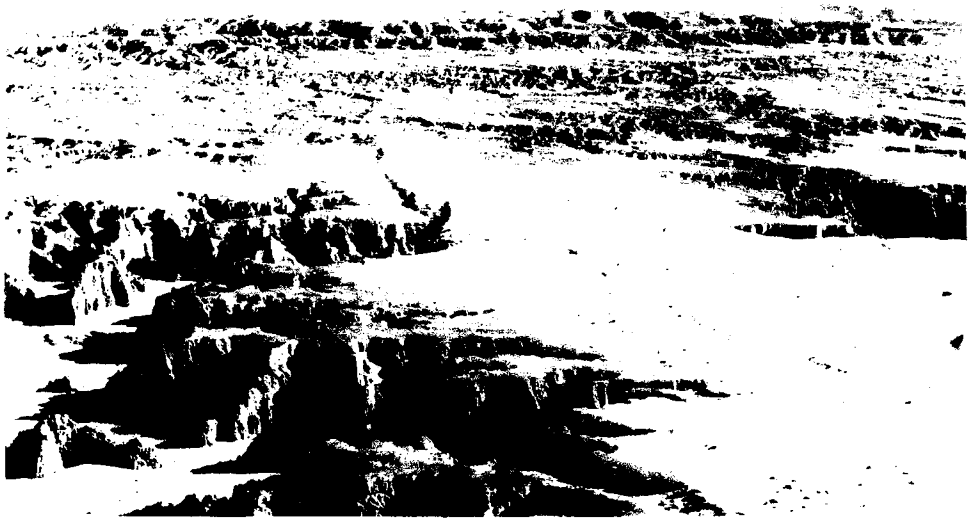
PATTERN INDICATOR SHEET - DESERT | ESCARPMENTS

PHOTO: AERIAL (OBLIQUE) | EROSIONAL

LOCATION: USA, Arizona, Coconino Co.
Painted Desert, east of Cameron

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1974.



COMMENTS: Differential erosion of a series of hard and relatively soft, nearly horizontal layers of sedimentary rock (sandstones, shales, and siltstones) in the valley of the Little Colorado River, has produced a stair-step topography. This series of escarpments separated by nearly level slopes, leads upward a total of nearly 300 m in elevation, from just below the escarpment in the foreground (Red Rock Cliffs) to the far middle ground (Moenkopi Plateau). The mesa bounded by the steep escarpment in the foreground is capped by a siliceous duricrust (silcrete), which is extremely resistant to erosion. The rock layer that originally covered the silcrete has been mostly stripped back and virtually removed, mostly by running water, leaving only a few residual hills on a broad, nearly level surface. The next escarpments in the series are formed from sandstone layers (far middle ground). Note the sand dunes migrating across the top of the lowest mesa (in foreground).

ENGINEERING AND MILITARY USES: In this photo, there is no obvious access between the upper and lower surfaces. Someplace along the crenulated and dissected border, there might be a ravine with a rubbly route climbable by personnel, or a ramp formed from a moat-free climbing dune that would be suitable for vehicles. Cover and concealment in the ravines and notches of the lower level is possible for small units, although the cover of loose sand and coppice dunes might impede traffic. The upper edge provides observation sites, as well as cover and concealment for observers in assorted notches and steps along the rim.

PATTERN INDICATOR SHEET - DESERT NAFASH

PHOTO: GROUND (SOFT/BAD GROUND)

LOCATION: Egypt (South-central)
East of Bir Kiseiba

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1982.

COMMENTS: This nafash-filled depression is adjacent to a bedrock plateau where clay-rich shales have been exposed to weathering. Because little or no running water was available to carry away the loose, weathered material, it accumulated in place. It is sheltered from removal by wind because of the protective lag of shale fragments and a thin veneer of windblown sand, which also give the surface the appearance of a normal gravel plain or sand plain. Both of these features show in the photograph. The light-toned patches are the sand.

ENGINEERING AND MILITARY USES: In the photograph, a cloud of dust has been raised by the passage of a light 2-wheel-drive vehicle (Volkswagen) over an area of nafash (bad ground) which has accumulated in a shallow topographic depression. The first clue to a potential problem is the litter of shale fragments (as opposed to other types of rock); the second is the generation of thick clouds of powdery dust. Where nafash is more than a few centimeters thick, it will bog down wheeled vehicles. Visually, one cannot tell how thick the layer is. The best way out is to keep going until out of the depression. The worst thing to do is to stop. This area will not support fixed-wing aircraft operations. Helicopters might enter and exit, but they will generate dust. It will support foot traffic, but the going can be slow and tiresome.

IMAGE FILE SHEET - DESERT | DUNES

PHOTO: AERIAL (VERTICAL) | LINEAR/SEIF - COMPOUND

LOCATION: Egypt (Northwest)
North of Bahariya Depression, 28°36'N 29°00'E

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Egyptian-American Oil Co., 1954:
A. Approximate scale 1:220,000.
B. Approximate scale 1:100,000 (on back).

COMMENTS: Arrow in Photo A points to the feature.

PHOTO: GROUND | LINEAR/SEIF - SIMPLE

LOCATION: Egypt (Southwestern)
East of Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

IMAGE FILE SHEET - DESERT DUNES

LANDSAT: MSS LINEAR/SEIF - COMPOUND

LOCATION: Saudi Arabia
17°26'N 47°35'E

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene E-1187-06435, Band 5, 26 Jan 1973, Scale 1:1,000,000.

IMAGE FILE SHEET - DESERT

DUNES

PHOTO: GROUND

CRESCENTIC (REVERSING CRESTS)

LOCATION: USA, California (Southeastern)
Algodones Dune Field

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

PHOTO: GROUND CRESCENTIC - BARCHAN - SIMPLE

LOCATION: Egypt (South-central)
Kharga Depression

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

IMAGE FILE SHEET - DESERT DUNES

PHOTO: GROUND CRESCENTIC - BARCHAN - COMPOUND

LOCATION: Egypt (Southwestern)
Near Bir Misaha

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Feb 1984.

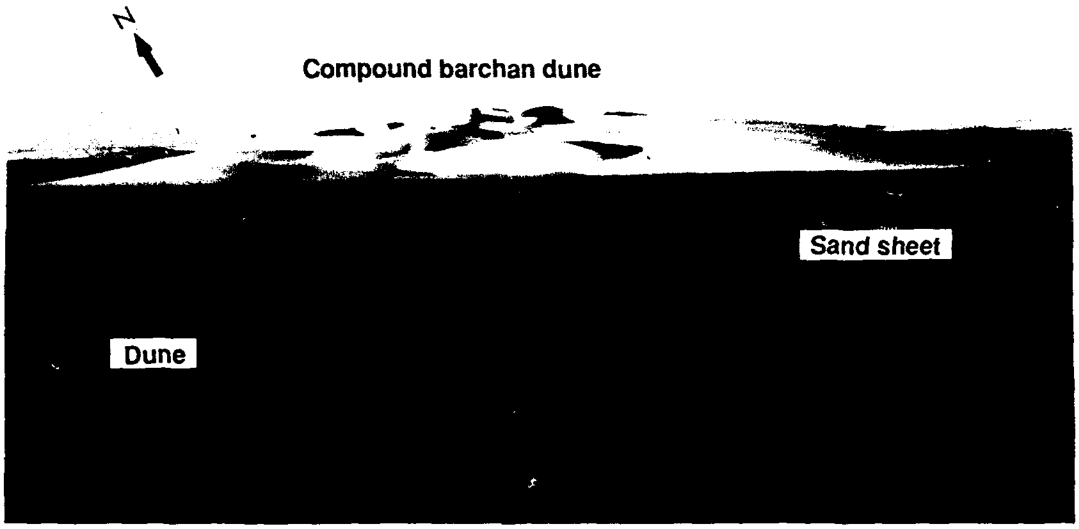


IMAGE FILE SHEET - DESERT

DUNES

PHOTO: GROUND

CRESCENTIC - BARCHAN - COMPOUND

LOCATION: Egypt (Southwestern)
Western Desert, near border with Sudan

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Maurice J. Grolier, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1981.

IMAGE FILE SHEET - DESERT | DUNES

PHOTO: GROUND | CRESCENTIC - BARCHAN - SIMPLE

LOCATION: Peru (Coastal)

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: G. E. Ericksen, U.S. Geological Survey, Reston, VA, 1973.

IMAGE FILE SHEET - DESERT

DUNES

PHOTO: AERIAL (OBLIQUE)

CRESCENTIC - BARCHAN - SIMPLE

LOCATION: Peru (Coastal)

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1971.

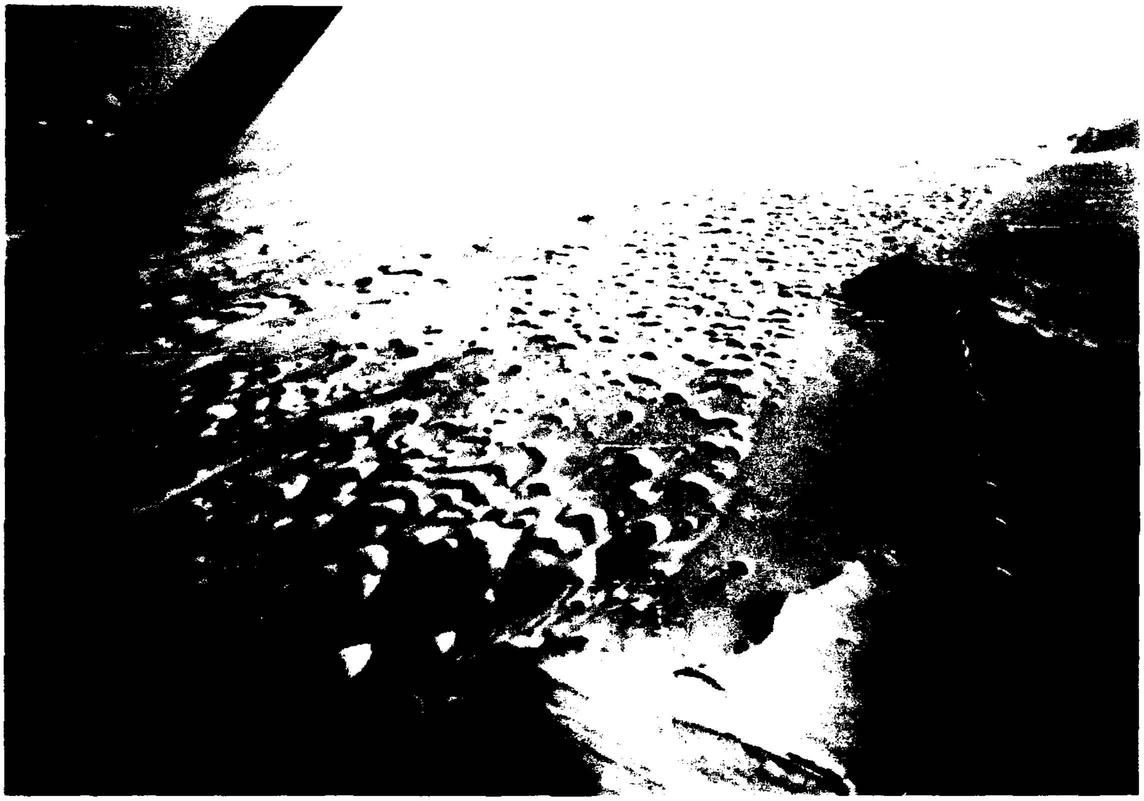


IMAGE FILE SHEET - DESERT

DUNES

PHOTOS: AERIAL

CRESCENTIC - BARCHAN - SIMPLE

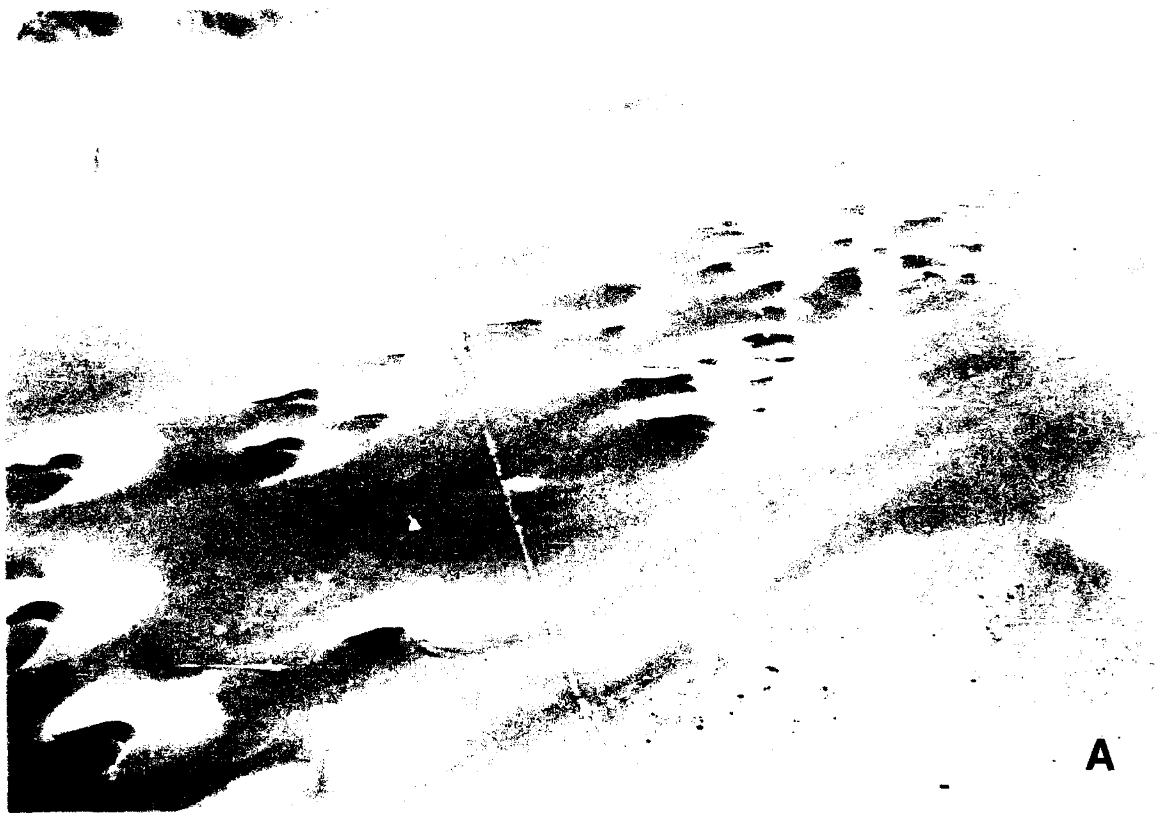
LOCATION: Peru (Coastal)
Sechura Desert

CLIMATE: Arid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

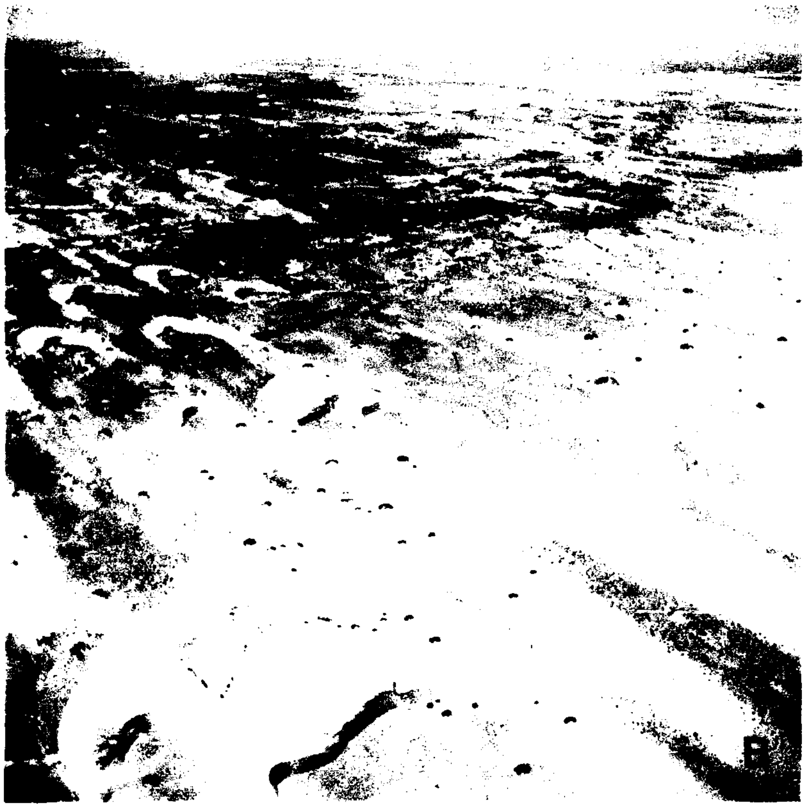
IMAGE CREDITS:

A. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

B. G.E. Ericksen, U.S. Geological Survey, Reston, VA, 1971.



A


B

LOCATION: Saudi Arabia
Eastern Province, between Abqaiq and Dhahran

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: Photograph courtesy of S.G. Fryberger, Desert Engineering, Golden, CO, early 1980's.

COMMENTS: Dunes advancing over a vegetated sand sheet (dikakah). Note that dunes can reduce clearances below power lines, increasing danger of contact with vehicles and equipment.

VIKING (SATELLITE); PHOTO: AERIAL (OBLIQUE) CRESCENTIC - BARCHAN AND BARCHANOID

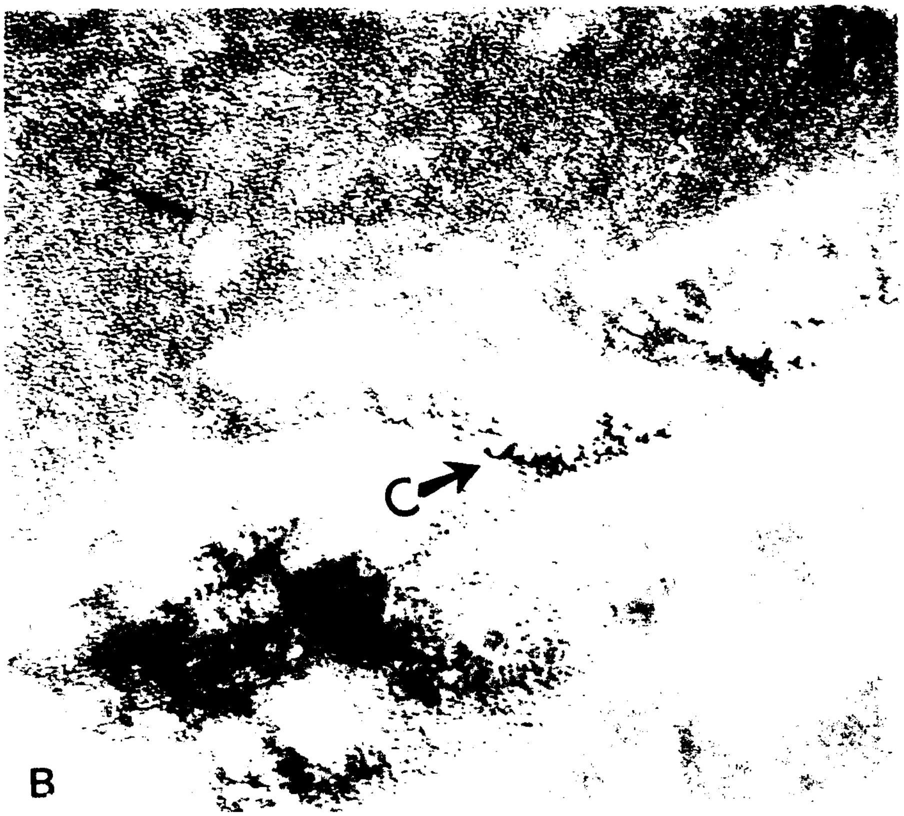
LOCATION: A. Mars, North Polar Region, 79°2'N 5°W
B. Mars, North Polar Region, 71°N 50°W
C. Peru, Sechura Desert

CLIMATE: Extremely arid
Trewartha, 1957: A. & B. Not applicable
C. BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS:
A. Orbiter 2, Image ID 069B01, 1976.
B. Orbiter 2, Image ID 488B30, between Aug 1976 and Jul 1978.
C. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Oct 1971.

COMMENTS: In image A, arrows A and B point to examples of large individual barchan dunes. In image B, arrow C points to an example of coalesced barchan dunes; compare with D in image C which shows coalesced barchans in coastal Peru. Unlike dunes on Earth, which are composed mostly of quartz sand, the dunes on Mars are generally dark against the surrounding terrain.[1]

[1] Breed, C.S., J.F. McCauley, and M.J. Grolier. 1979. Morphology of common "sand" dunes on Mars: Comparison with the Earth. Journal of Geophysics, v. 84, no. B14, pp. 8183-8204.



B

C

[illegible]

[illegible] - BARCHAN AND BARCHAN II

LOCATION: [illegible]

[illegible], Dhahran area

CLIMATE: Arid

Trewartha, [illegible] Tropical and Subtropical Desert, hot and dry, coastal [illegible]

IMAGE CREDITS: [illegible] S.G. Fryberger,[1] Desert Engineering, Golden, [illegible]

COMMENTS: A. [illegible] barchan and [illegible] Aeolian [illegible] in dark area [illegible] B. Barchanoid dunes. Left center dark area [illegible] in background, right side. [illegible]

[1] [illegible], [illegible], and T.J. [illegible]. 1983. Eolian dune, interdune, sand [illegible] of an offshore prograding sand sea, Dhahran [illegible], Saudi Arabia. American Association of Petroleum Geologists Bulletin, v. 67, [illegible]

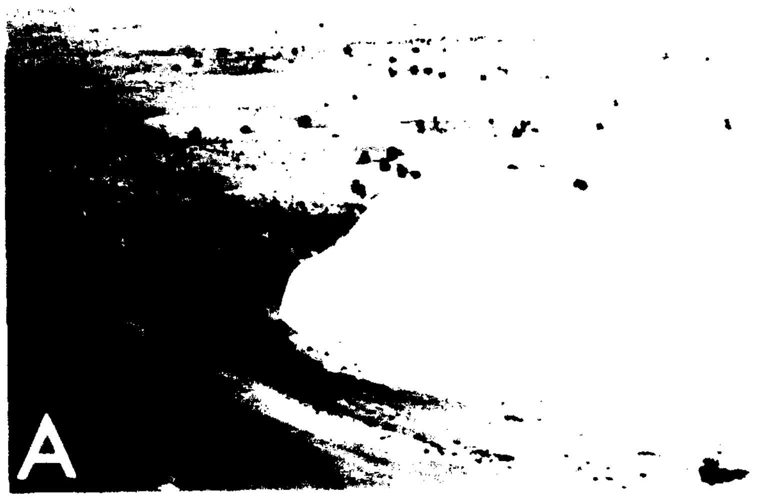


PHOTO: AERIAL (OBLIQUE) CRESCENTIC - BARCHANOID - SIMPLE

LOCATION: Peru
Sechura Desert

CLIMATE: Arid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

LANDSAT: MSS

CRESCENTIC - BARCHANOID

LOCATION: North Africa, Tunisia
South of Chott Al Djerid, 32°56'N 08°48'E

CLIMATE: Extremely Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene E-1109-09313, black and white print of color composite of bands 4, 5, and 7, 9 Nov 1972, Scale 1:1,000,000.

COMMENTS: Probably contains simple and compound forms.

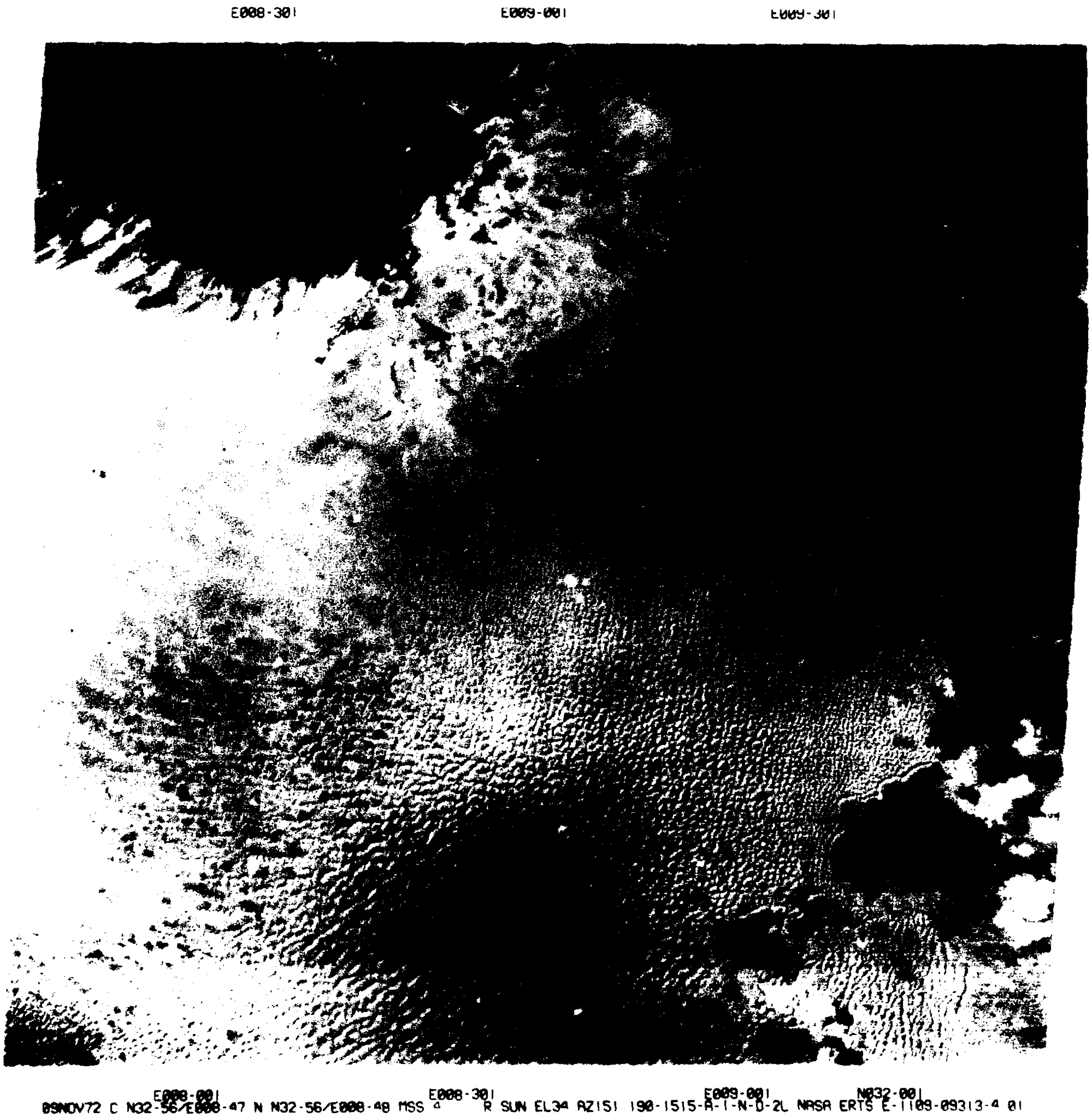


IMAGE FILE SHEET - DESERT

DUNES

PHOTO: AERIAL (OBLIQUE)

CRESCENTIC - BARCHANOID - SIMPLE

LOCATION: USA, California
Palm Springs, Mojave Desert

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1972.

IMAGE FILE SHEET - DESERT DUNES

PHOTO: AERIAL (OBLIQUE) CRESCENTIC - BARCHANOID - SIMPLE

LOCATION: USA, California and Nevada
Death Valley, Mojave Desert

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey Desert Studies Group, Flagstaff, AZ, July 1972.

IMAGE FILE SHEET - DESERT

DUNES

LANDSAT: MSS

CRESCENTIC - MEGABARCHANOID - COMPOUND

LOCATION: Saudi Arabia and Oman
Eastern Rub Al Khali

CLIMATE: Extremely Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene E-1147-06195, Band 7, 17 Dec 1972, 21°35'N 54°22'E, Scale 1:1,000,000.

DESERT PROCESSES WORKING GROUP

IMAGE FILE SHEET - DESERT

DUNES

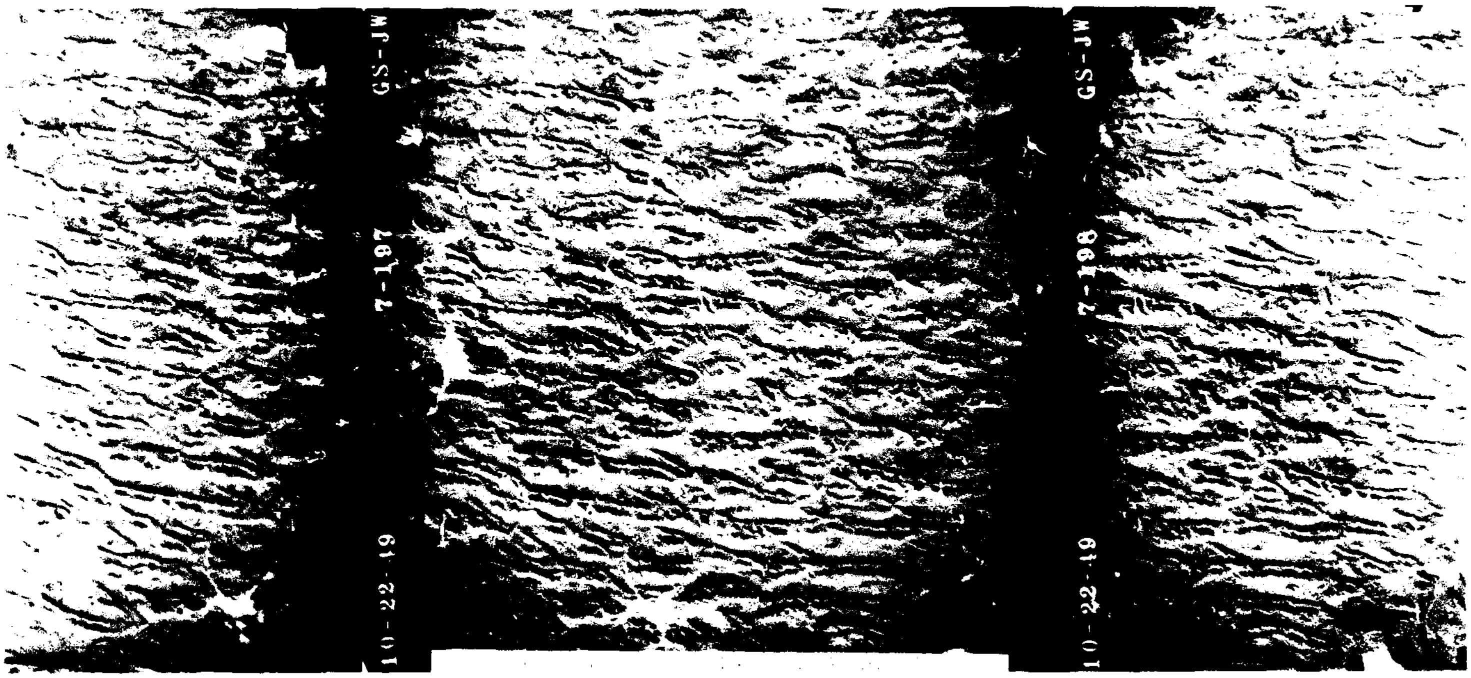
PHOTOS: AERIAL (VERTICAL)

CRESCENTIC - TRANSVERSE
(STABILIZED - VEGETATION)

LOCATION: USA, Nebraska
Custer Co.

CLIMATE: Subhumid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: U.S. Geological Survey, GS-JW, 7-196, 197, 198, 22 Oct 1949, Original Scale 1:19,615. This scale approx. 1:49,000.



DESERT PROCESSES WORKING GROUP

IMAGE FILE SHEET - DESERT

DUNES

LANDSAT: MSS

CRESCENTIC - TRANSVERSE
(STABILIZED - VEGETATION)

LOCATION: USA, Nebraska
NW Corner, Grant Co., 42°11'N 101°27'W

CLIMATE: Subhumid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Scene E-1026-17012, Bands 4, 5, and 7 (B&W copy of color composite), 18 Aug 1972, Scale 1:1,000,000.

DESERT PROCESSES WORKING GROUP

IMAGE FILE SHEET - DESERT | DUNES

PHOTO: AERIAL (OBLIQUE) | CRESCENTIC - REVERSING

LOCATION: USA, Colorado
Great Sand Dunes, near Alamosa

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: John F. Shelton, U.S. Geological Survey and Pomona College, CA, between 1946 and 1965.

IMAGE FILE SHEET - DESERT DUNES

LANDSAT: MSS STAR - COMPOUND

LOCATION: Algeria (Southeastern), SE Quad
Grand Erg Oriental, 30°06'N 07°56'E

CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene E-1109-09322, Band 5, 9 Nov 1972, Scale 1:1,000,000.

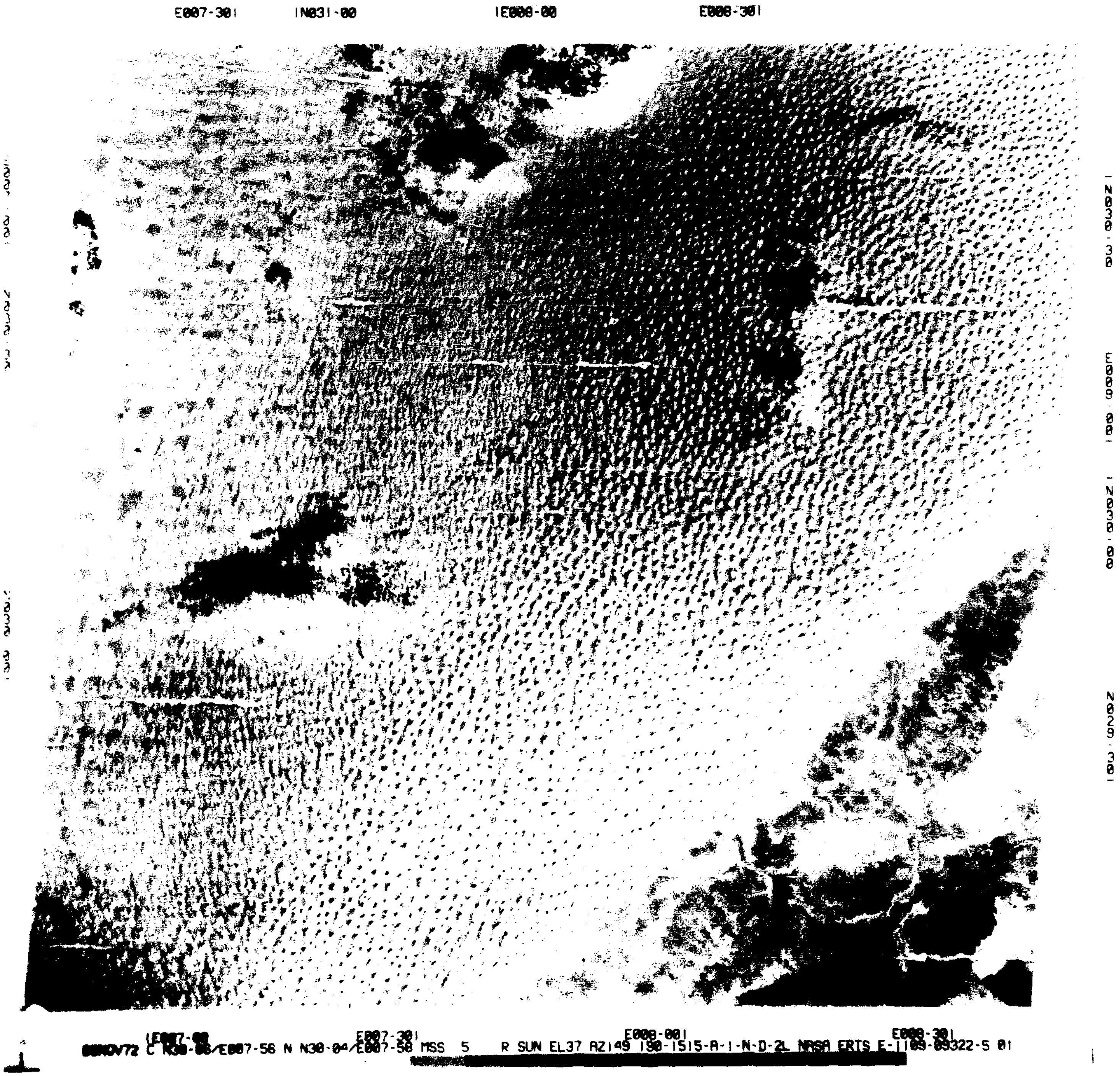


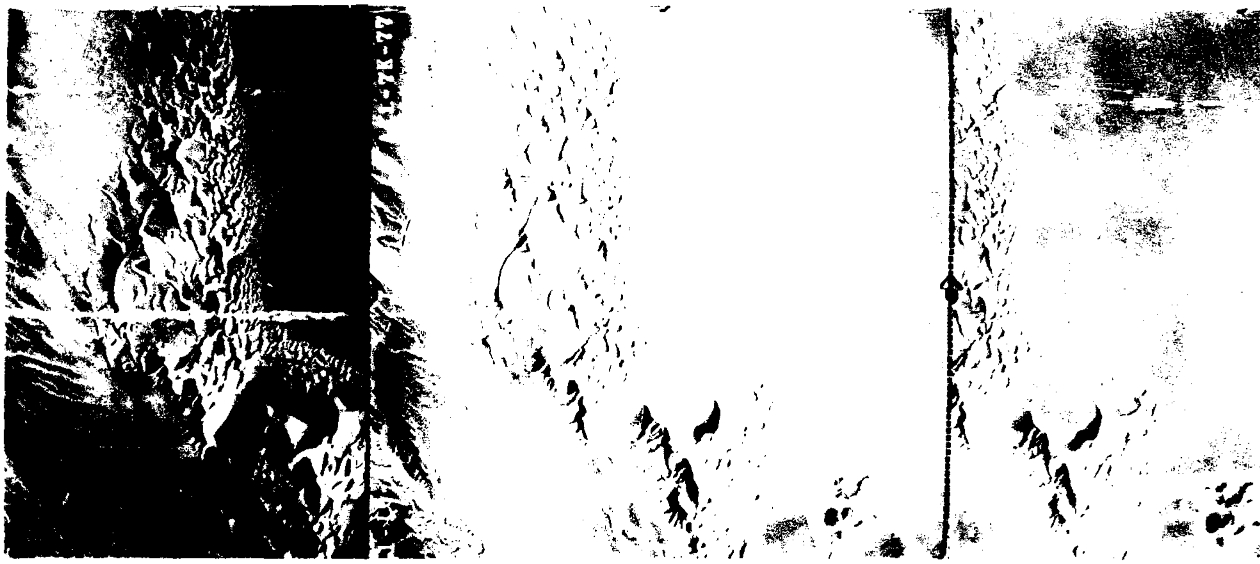
IMAGE FILE SHEET - DESERT DUNES

PHOTOS: AERIAL (VERTICAL) STAR

LOCATION: USA, California
San Bernardino Co.

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Dept. of Agriculture, ASCS, 1952:
A. Stereo, AXL-7K-76, 77, 78, Original Scale approx. 1:20,000. This scale approx. 1:53,000.
B. AXL-7K-77, Scale 1:20,000 (on back).



A


AXL-7K-72

IMAGE FILE SHEET - DESERT DUNES

PHOTO: GROUND DOME

LOCATION: Egypt (Northwestern)
Plateau on northwestern edge of Bahariya Depression

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Oct 1978.

IMAGE FILE SHEET - DESERT

DUNES

PHOTO: GROUND

DOME

LOCATION: Saudi Arabia
Northwest cf Al Majma'ah

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

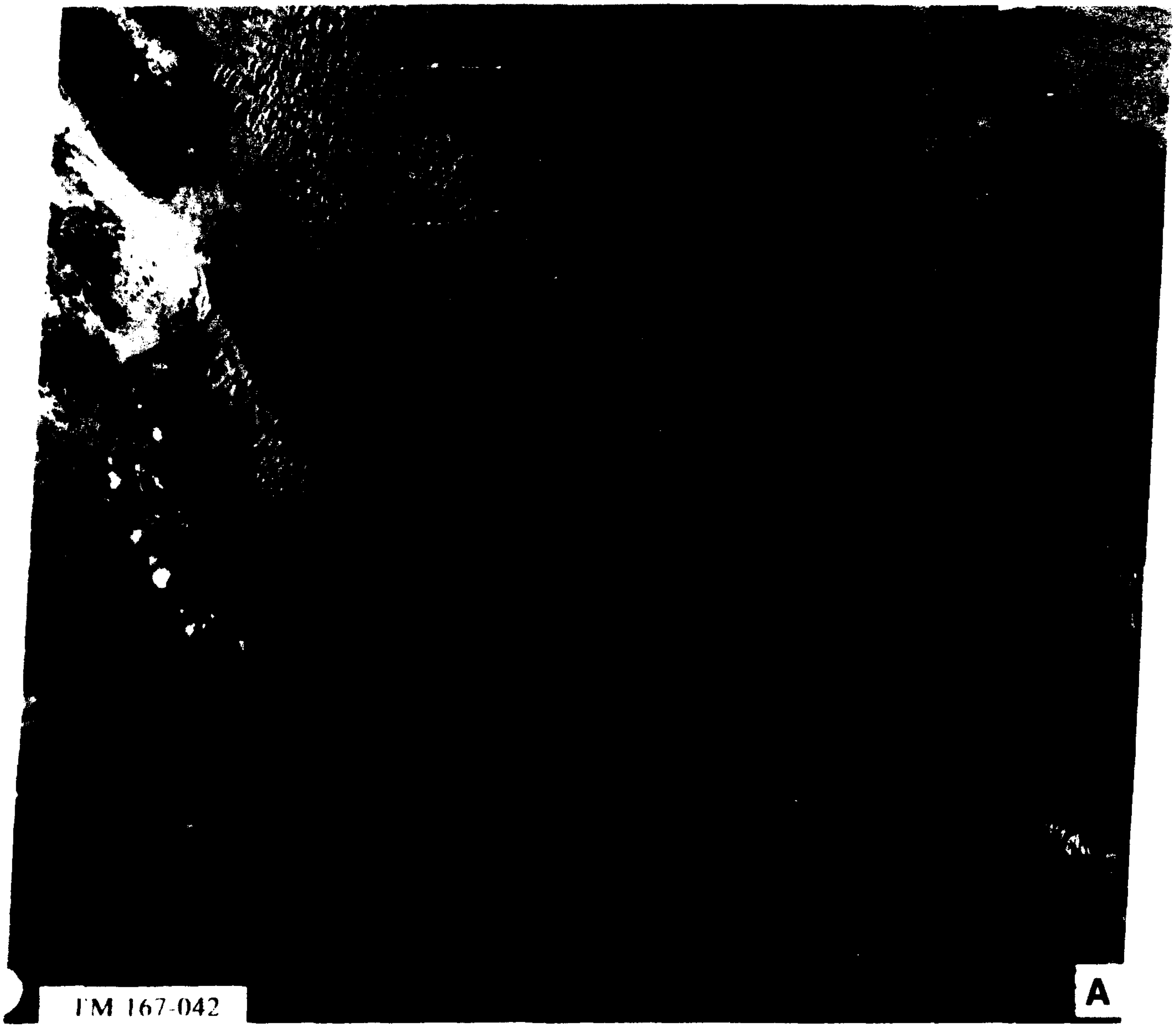
COMMENTS: Interdunal sand plain and oases.

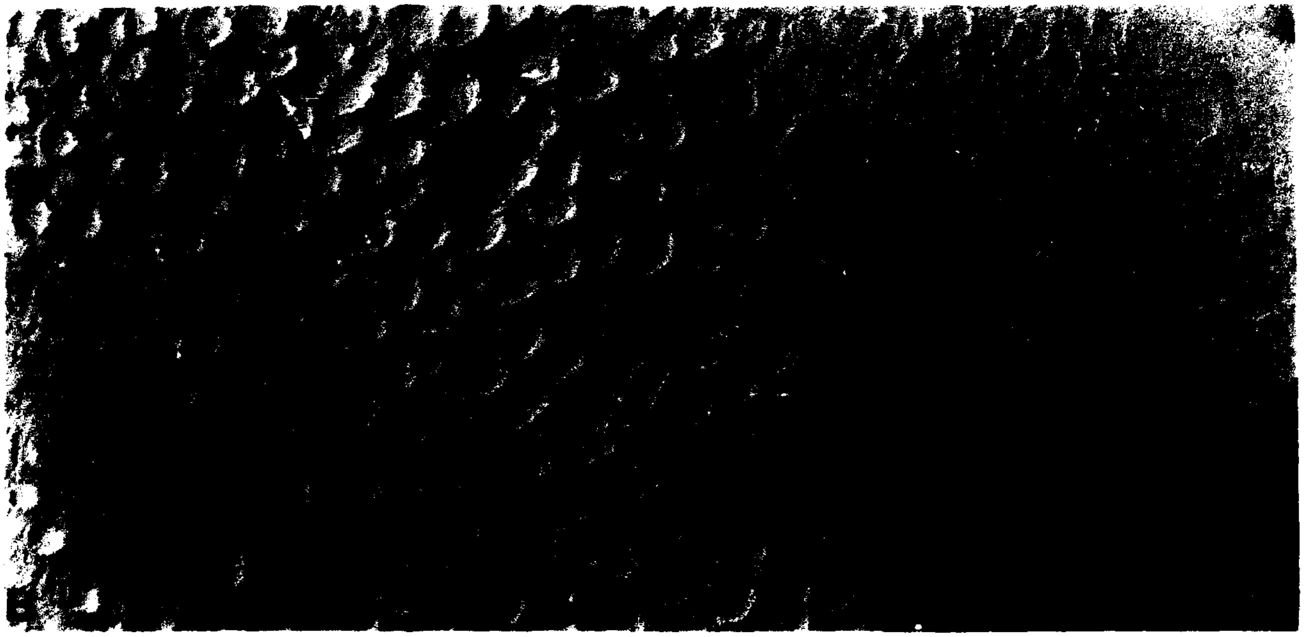
LOCATION: Saudi Arabia, Western Shield
Landsat center 25°55'N 44°45'E; center of area C 26°30'N 44°40'E

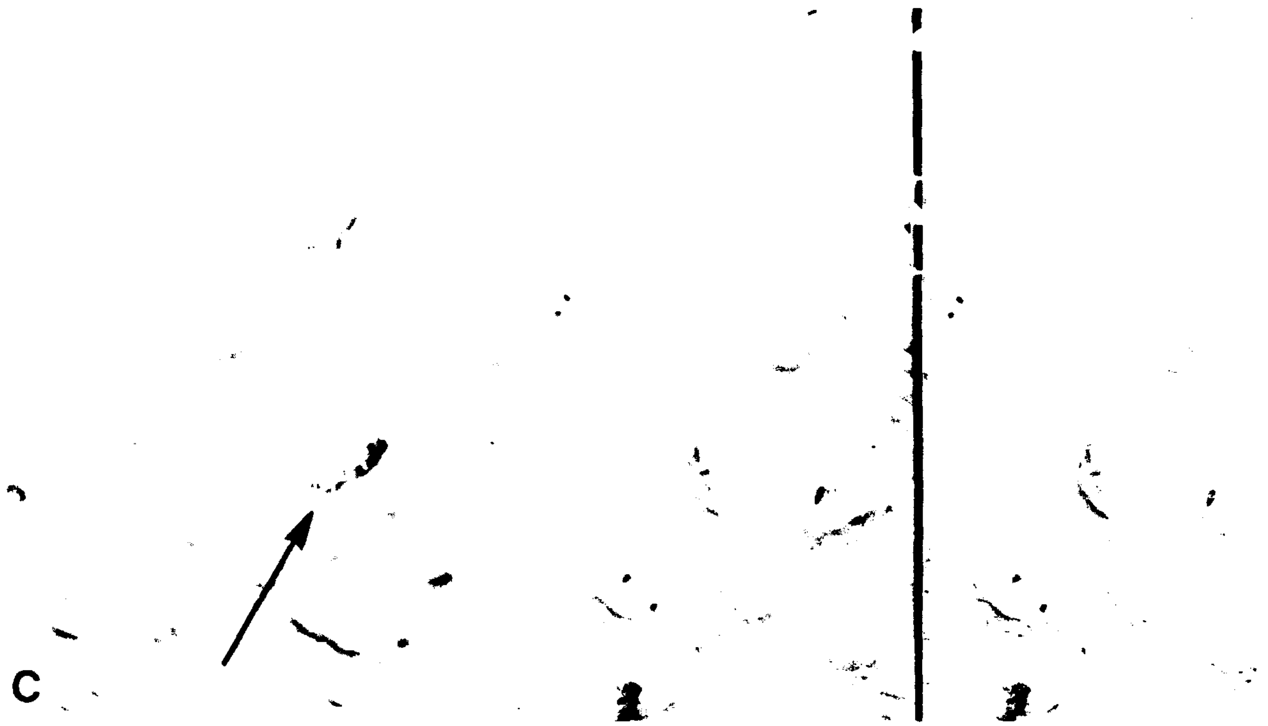
CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:

A. Path/Row 167-042, 1990, Bands 2, 4, 7 (blue, green, red), Scale 1:1,000,000.
B. A 1:250,000 scale image of the area denoted as B in image A.
C. A stereo image of area outlined as C in image B. Army Map Service, WSA, Roll 68, 11239-11240, 11 Oct 1956, Scale 1:60,000, Photo Index Sheet 31. Arrows on B and C point to a common feature.
D. Jack N. Rinker, U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, 24 Mar 1991. Encircled area noted by arrow D on TM image A denotes the location of the ground photograph.







C

IMAGE FILE SHEET - DESERT | DUNES

PHOTO: GROUND | CLIMBING

LOCATION: Morocco (Coastal)
East of Tarfaya, Sabkha Tayra

CLIMATE: Arid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 10 Jan 1988.

COMMENTS: Climbing dune provides access as ramp from sabkhah floor (left background in photo) to limestone plateau (right foreground in photo).

IMAGE FILE SHEET - DESERT

DUNES

PHOTOS: AERIAL (OBLIQUE)

CLIMBING

LOCATION: Peru
South of Lima, foothills of Andes Mountains

CLIMATE: Hyperarid to arid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

IMAGE FILE SHEET - DESERT | DUNES

PHOTOS: AERIAL (OBLIQUE) | CLIMBING

LOCATION: USA, California
Mojave Desert

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Semitropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1982.

IMAGE FILE SHEET - DESERT | DUNES

PHOTOS: AERIAL (OBLIQUE) | FALLING (left)
CLIMBING (right)

LOCATION: Peru
Near Lima, foothills of Andes Mountains

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

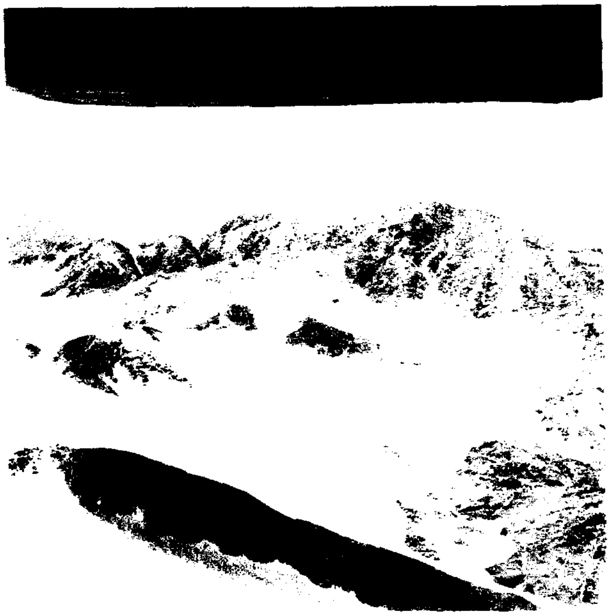


IMAGE FILE SHEET - DESERT | DUNES

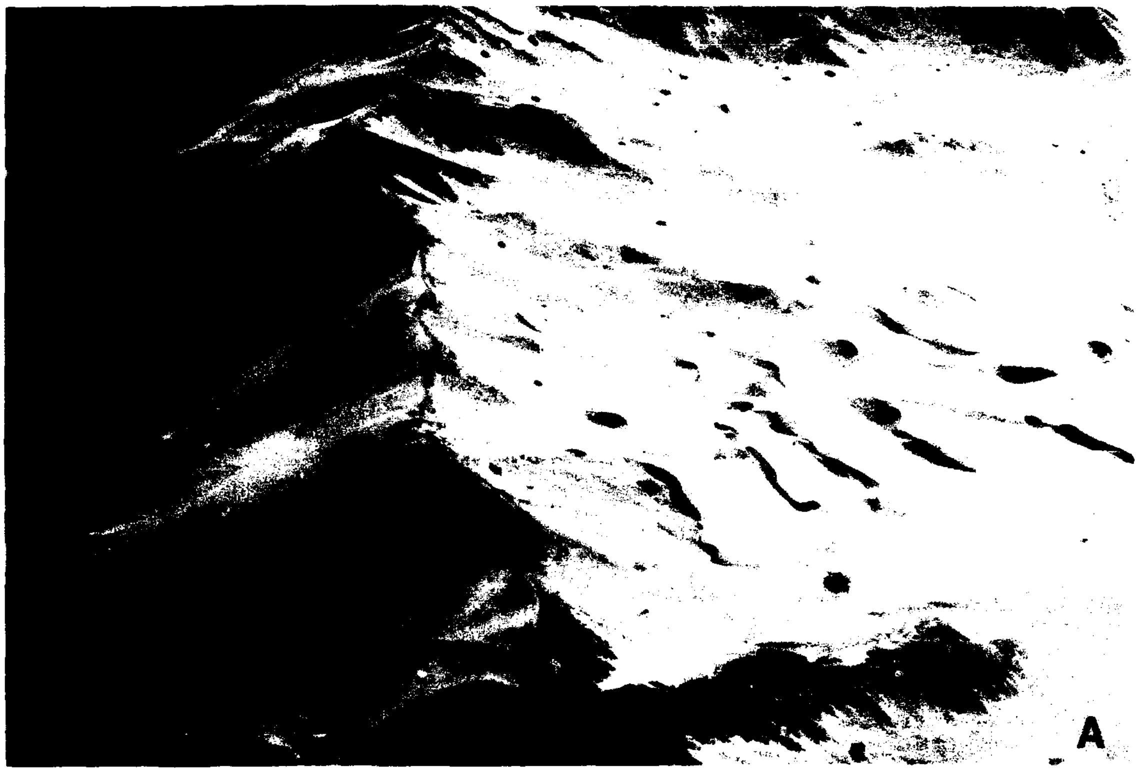
PHOTOS: AERIAL (OBLIQUE) AND GROUND | CLIMBING AND FALLING

LOCATION: Peru
North of Lima

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS:
A. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.
B. E.C. Morris, U.S. Geological Survey, Flagstaff, AZ, 1973.

COMMENTS: A. Falling dunes on left side, climbing dunes on right side.
B. Climbing dunes.



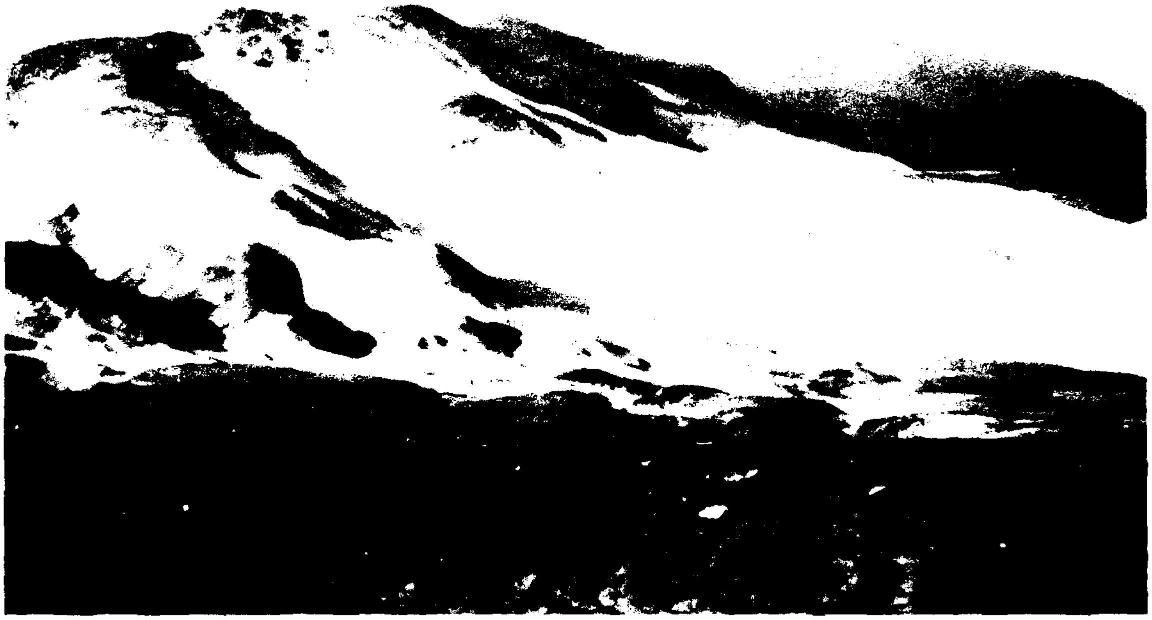


IMAGE FILE SHEET - DESERT

DUNES

PHOTOS: AERIAL (OBLIQUE)

LEE - SIMPLE

LOCATION: Peru (Coastal)
North of Lima

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS:

A. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1971.

B. E.C. Morris, U.S. Geological Survey, Flagstaff, AZ, 1971.

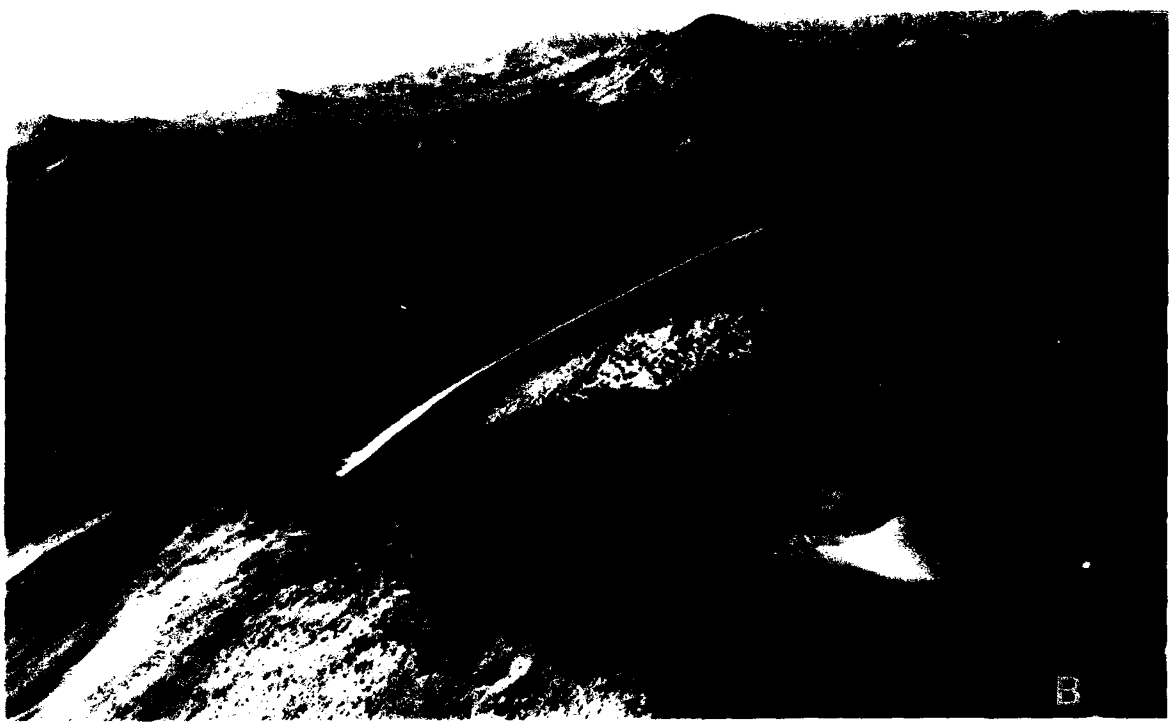


IMAGE FILE SHEET - DESERT | DUNES
PHOTOS: AERIAL (OBLIQUE) | LEE - COMPLEX

LOCATION: Peru (Coastal)
North of Lima

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

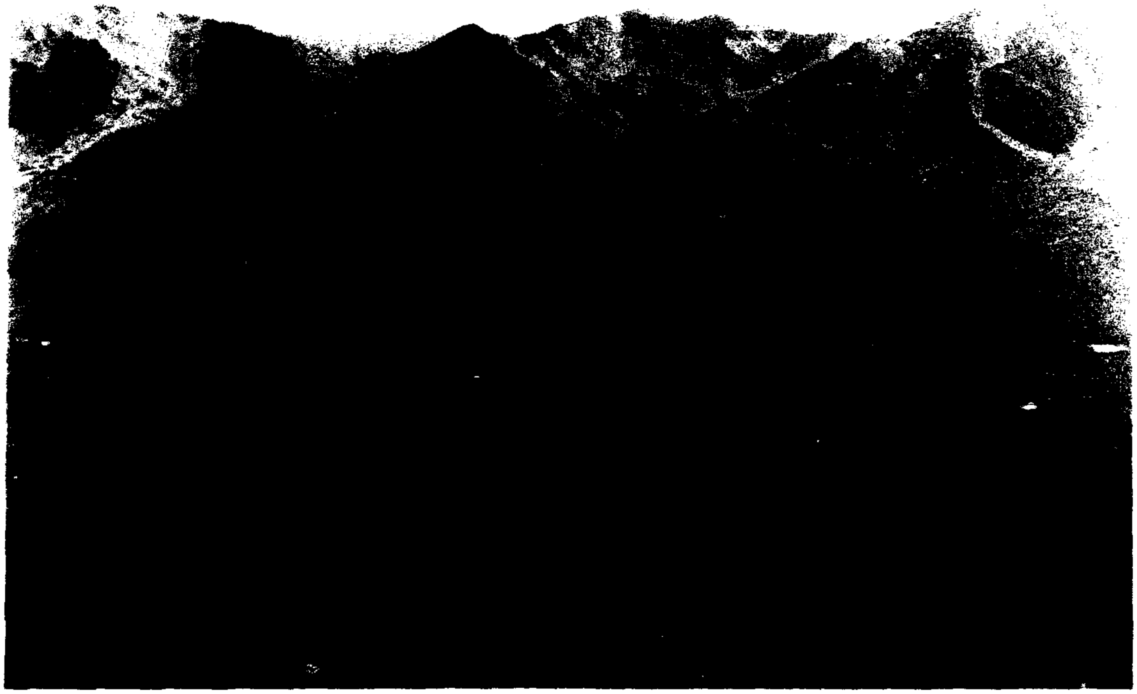


IMAGE FILE SHEET - DESERT

DUNES

PHOTO: AERIAL (OBLIQUE)

LEE - COMPLEX

LOCATION: USA, California
Mojave Desert

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1977.

IMAGE FILE SHEET - DESERT

DUNES

PHOTOS: AERIAL (OBLIQUE)

PARABOLIC

LOCATION: Peru (Coastal)
Sechura Desert

CLIMATE: Arid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

IMAGE FILE SHEET - DESERT | DUNES

PHOTO: AERIAL (OBLIQUE) | COPPICE

LOCATION: Saudi Arabia

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: C.A. Kemp (retired ARAMCO), Redwood City, CA, early 1950's.

COMMENTS: This extensive development of coppice dunes results in a vegetated sand sheet, which is called dikakah in Saudi Arabia. Arab tents in midground.

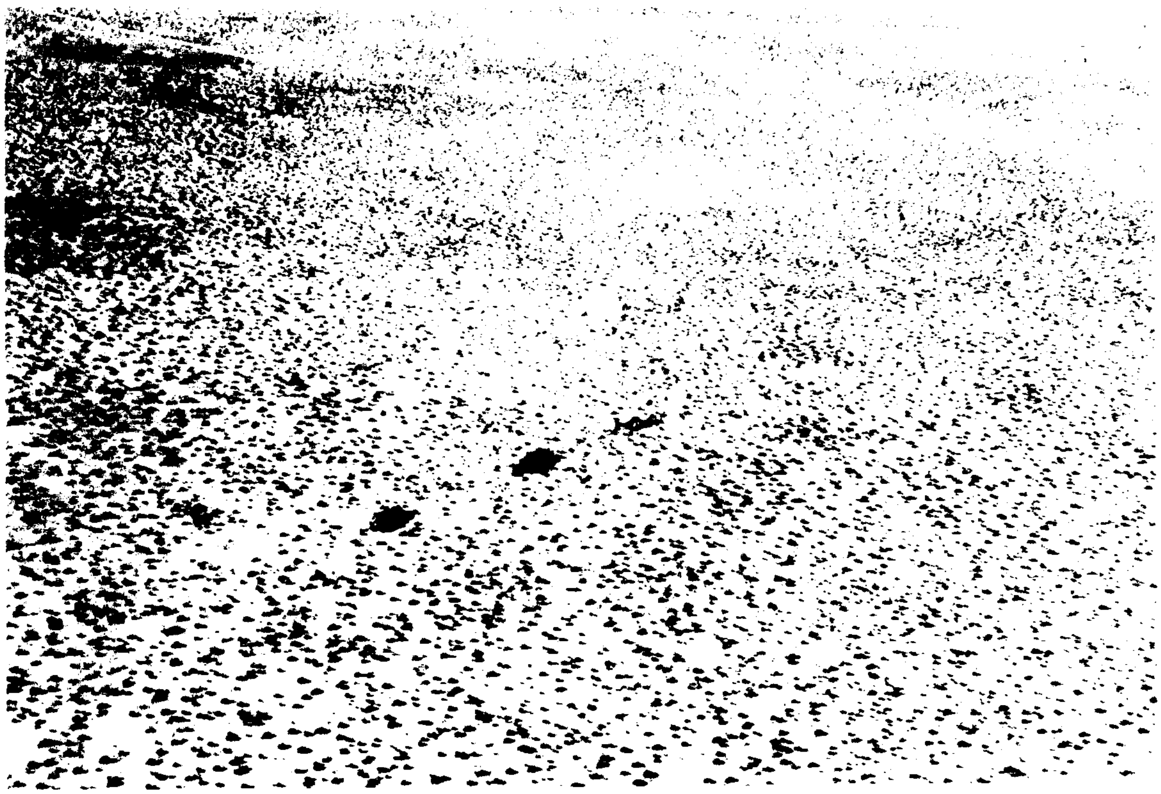


IMAGE FILE SHEET - DESERT

DUNES

PHOTO: GROUND

COPPICE

LOCATION: Saudi Arabia
Eastern Province, north of Al Qatif, near pipeline road

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: Photograph courtesy of S.G. Fryberger, Desert Engineering, Golden, CO, early 1980's.

COMMENTS: A sabkhah surrounded by coppice dunes with coastal dunes in the background. In Saudi Arabia such areas of coppice dunes are called dikakah.

IMAGE FILE SHEET - DESERT | DUNES

PHOTOS: AERIAL (OBLIQUE) | COPPICE

LOCATION: Saudi Arabia
Eastern Province, Dhahran area

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: Photographs courtesy of S.G. Fryberger,[1] Desert Engineering, Golden, CO, early 1980's.

COMMENTS: C. Near Dammam, looking southeast. Dome dune (arrow 1), coppice dune area (arrow 2), and aeolian siliciclastic sabkhah (arrow 3). Note irregular distribution of sand sheet. D. View to northeast near Dammam, showing extensive plain of coppice dunes with parabolic dunes (left center). In Saudi Arabia such areas of coppice dunes are called dikakah.

[1]Fryberger, S.G., A.M. Al-Sari, and T.J. Clisham. 1983. Eolian dune, interdune, sand sheet, and siliciclastic sabkha sediments of an offshore prograding sand sea, Dhahran area, Saudi Arabia. American Association of Petroleum Geologists Bulletin, v. 67, no. 2, pp. 280-312, Feb 1983.

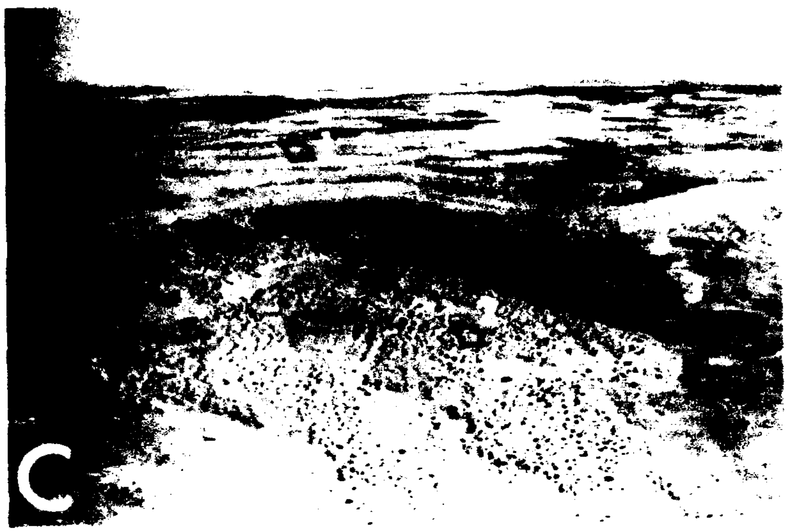


IMAGE FILE SHEET - DESERT

DUNES

PHOTO: GROUND

COPPICE

LOCATION: Saudi Arabia
Southwest of Dhahran, north of Buqayq

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

COMMENTS: In Saudi Arabia this is called dikakah.

IMAGE FILE SHEET - DESERT

DUNES

PHOTOS: GROUND

COPPICE

LOCATION: A. Saudi Arabia, 26°08.1'N 49°25.2'E
B. Saudi Arabia, approx. 50 km west of Dhahran on the Riyadh-Dhahran expressway
C. USA, Arizona, Monument Valley

CLIMATE: A. & B. Extremely arid; C. Semiarid
Trewartha, 1957: A. & B. BWh: Tropical and Subtropical Desert, hot and dry
C. BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Stereo, Jack N. Rinker, U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, 1991: A. 18 Mar; B. 1 Apr; C. 18 May.

COMMENTS: In stereo photos A and B, the dune heights are in the 1-2 m range. In C, they are mostly 1 m or less.

IMAGE FILE SHEET - DESERT

DUNES

PHOTO: AERIAL (OBLIQUE)

VEGETATION MOUNDS - SPINIFEX

LOCATION: Australia (Western)
Near Fitzroy Crossing

CLIMATE: Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 6 Aug 1981.

IMAGE FILE SHEET - DESERT

DUNES

PHOTOS: GROUND

VEGETATION MOUNDS

LOCATION: Egypt (South-central)

CLIMATE: Hyperarid

Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Maurice J. Grolier, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Feb 1981.

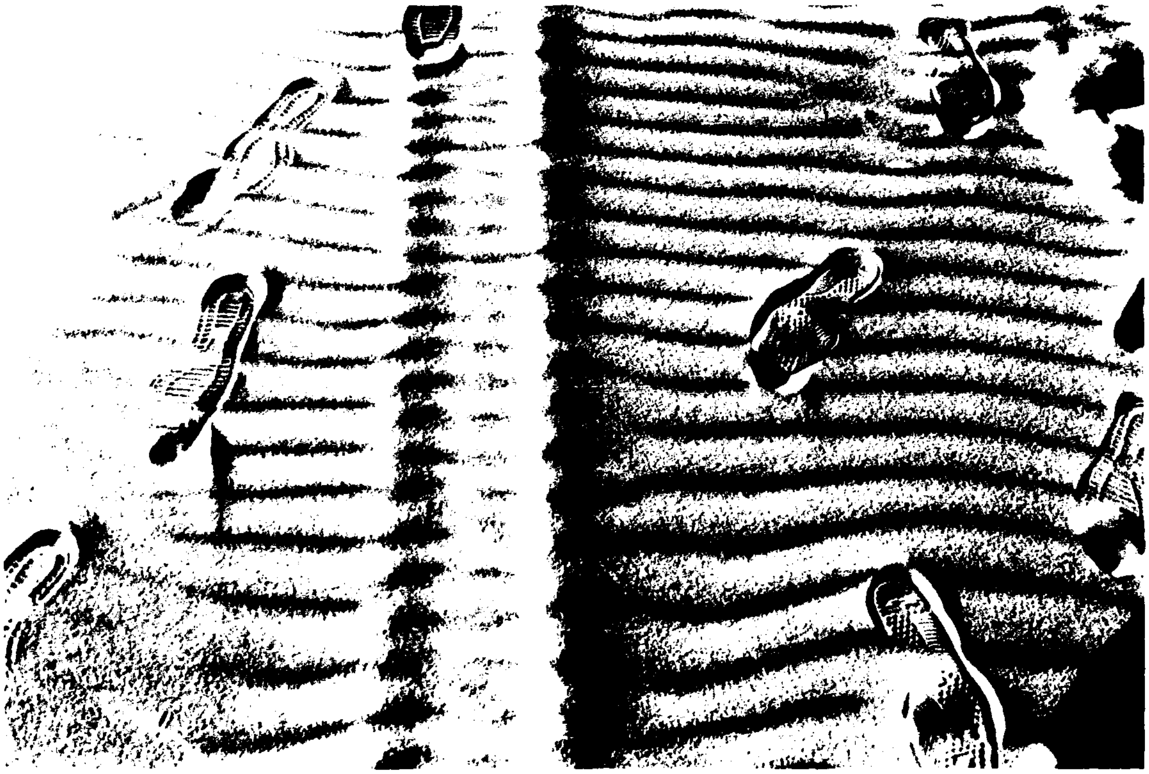
IMAGE FILE SHEET - DESERT RIPPLES

PHOTO: GROUND SAND

LOCATION: Egypt (Southwestern)
Western Desert

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.



LOCATION: Peru (Coastal)
Lower part of Rio Ica Valley

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS:

A. John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

B. G.E. Ericksen, U.S. Geological Survey, Reston, VA, 1971.

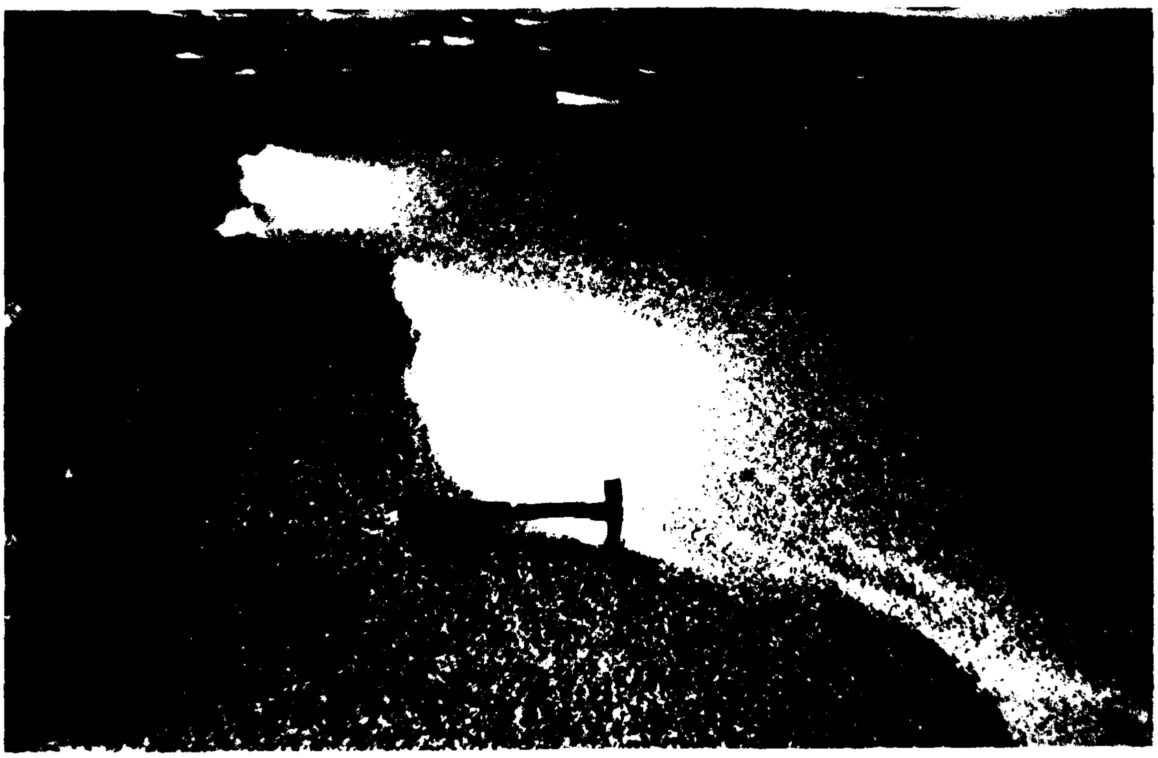


IMAGE FILE SHEET - DESERT | RIPPLES
PHOTOS: GROUND | GRANULE (MEGARIPPLES)

LOCATION: Peru (Coastal)
North of Lima

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

IMAGE FILE SHEET - DESERT

RIPPLES

PHOTOS: GROUND

GRANULE (MEGARIPPLES)

LOCATION: USA, California
Rogers Lake

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1977.

PHOTO: GROUND

LOCATION: Egypt (Southwestern)
Atmur El-Kibeish

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

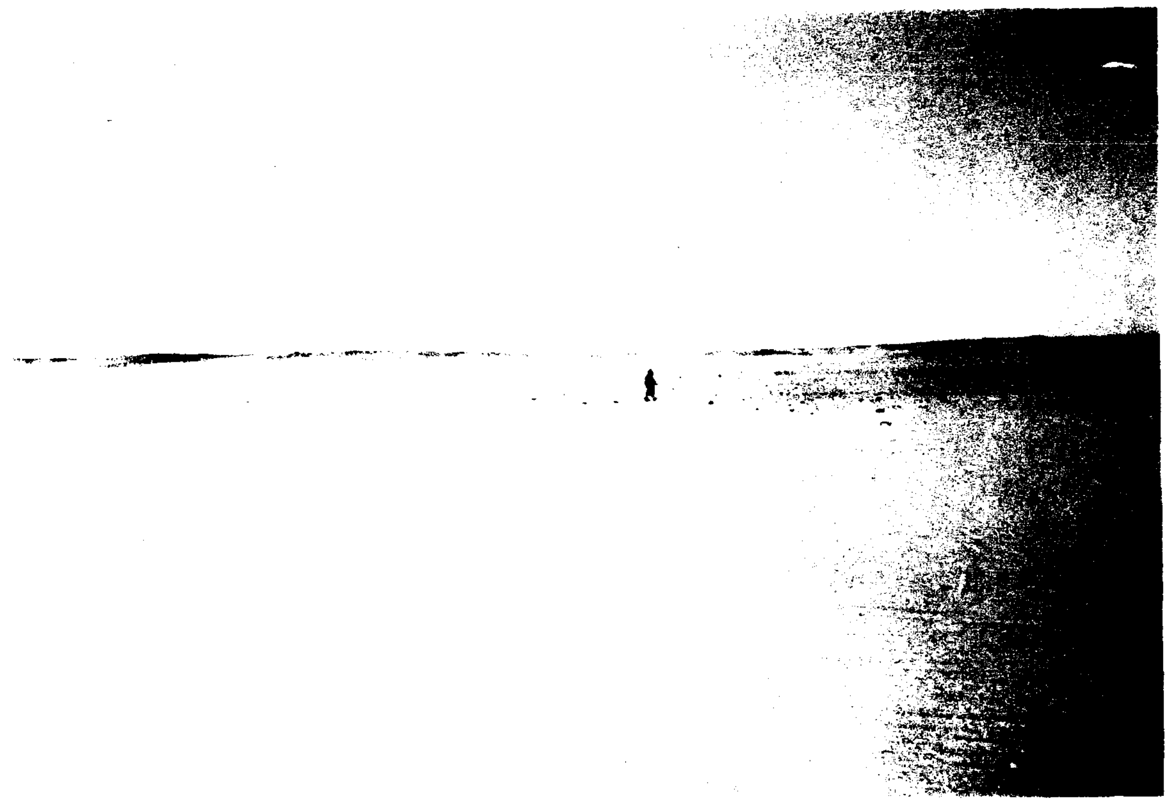


PHOTO: GROUND

LOCATION: Egypt (Southwestern)
Western Desert

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

COMMENTS: The Egyptian coin is about the size of a U.S. quarter.

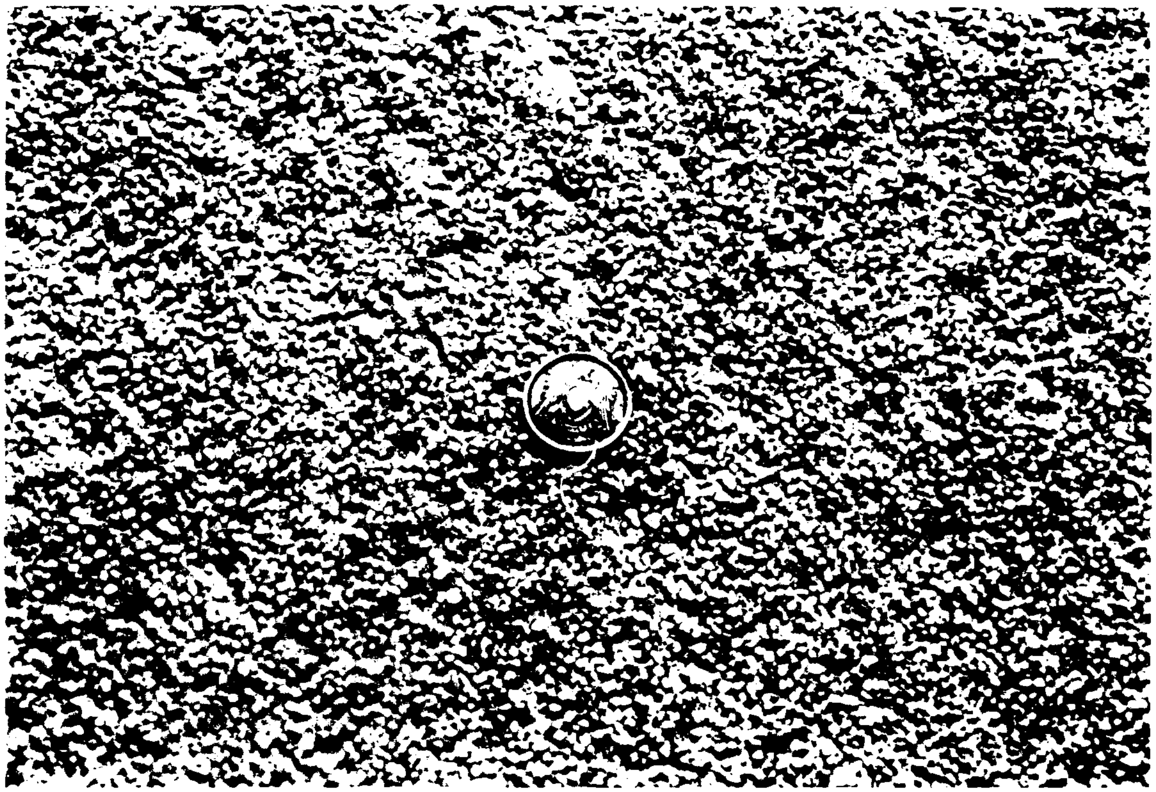


PHOTO: GROUND

LOCATION: Saudi Arabia
North of Khurays, 25°05'N 48°02'E

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

COMMENTS: Near Ad Dahna dune complex. Coppice dunes (dikakah) on many flat areas.

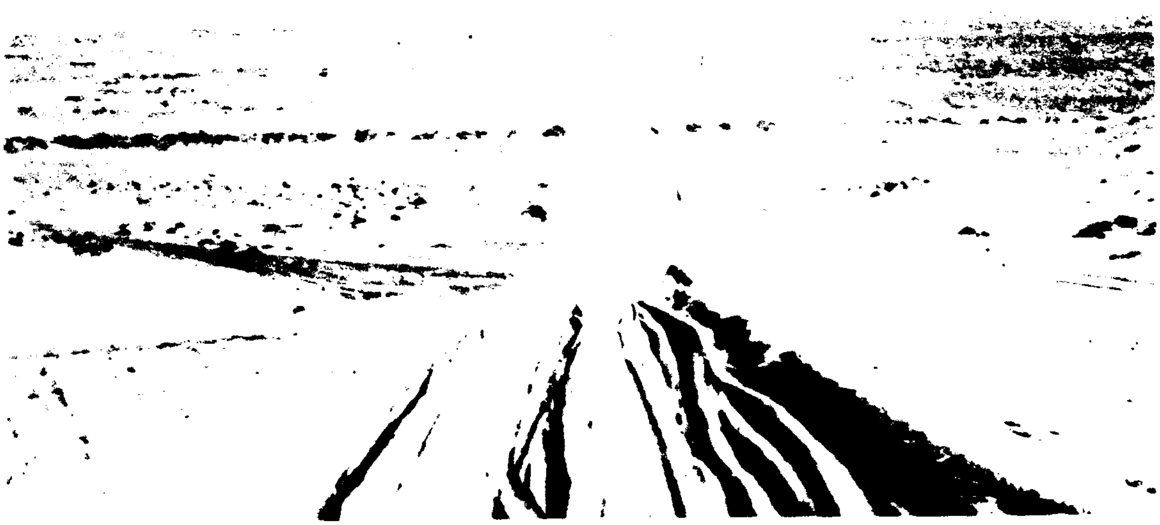


IMAGE FILE SHEET - DESERT | SAND PLAINS/SAND SHEETS

PHOTO: AERIAL (OBLIQUE) | VEGETATED (DIKAKAH)

LOCATION: Saudi Arabia
Between Dhahran and Abqaiq

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: C.A. Kemp (retired ARAMCO), Redwood City, CA, early 1950's.

COMMENTS: In other areas these would be called coppice dunes. Oil well.

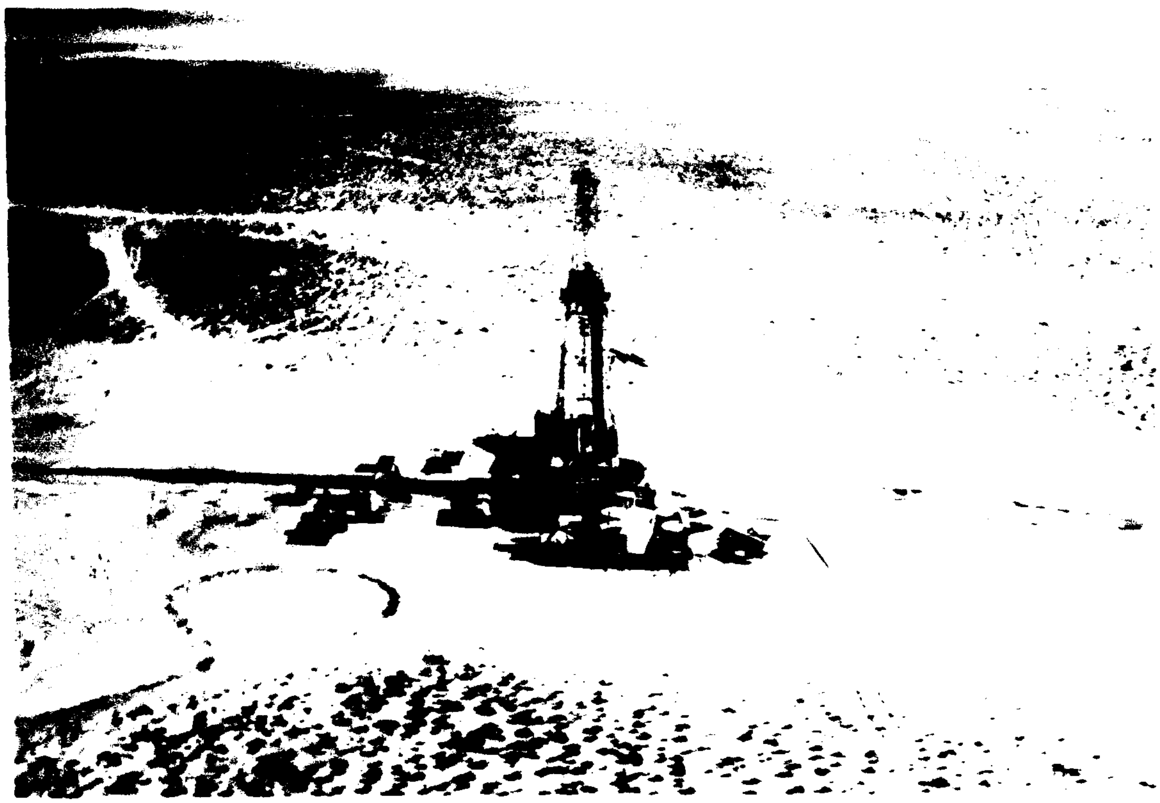


IMAGE FILE SHEET - DESERT

SAND PLAINS/SAND SHEETS

PHOTO: GROUND

LOCATION: Saudi Arabia
Southwest of Sulayyil, 20°40'N 45°40'E

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

COMMENTS: Fine to medium sands.

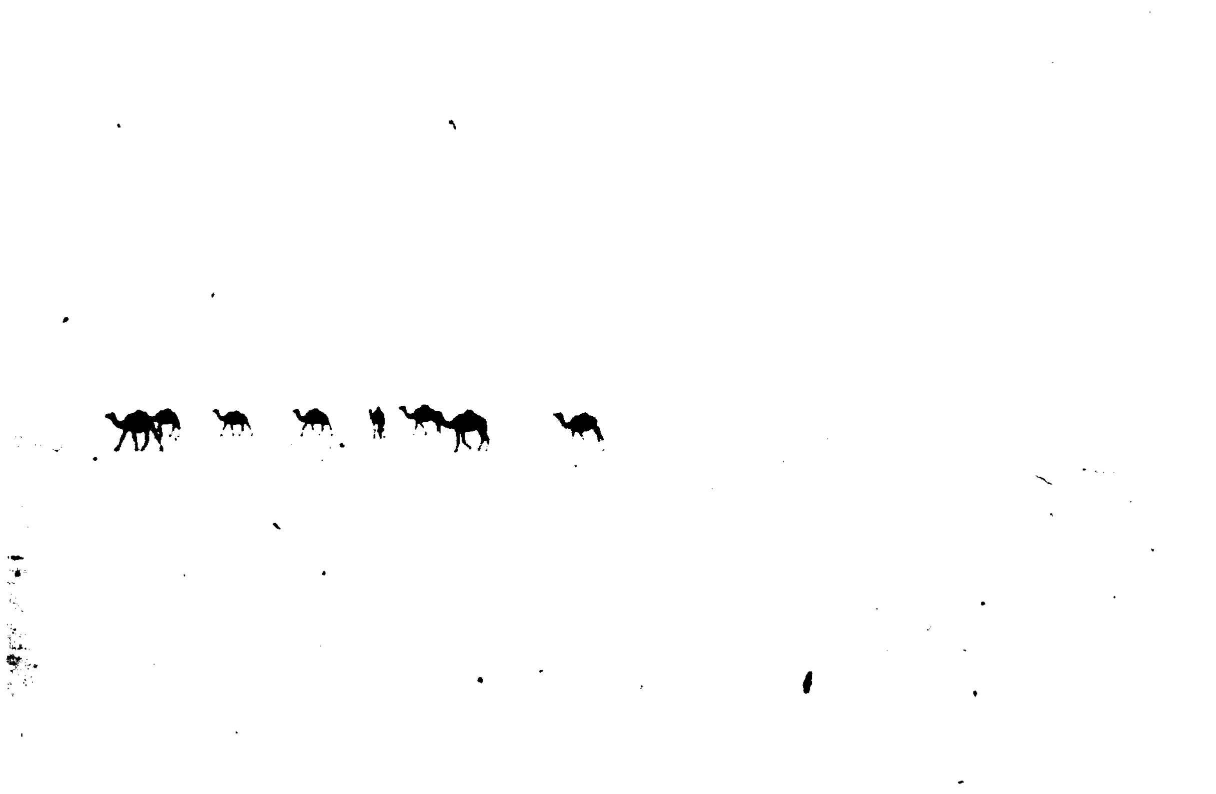


IMAGE FILE SHEET - DESERT

SAND PLAINS/SAND SHEETS

PHOTO: AERIAL (OBLIQUE)

LOCATION: USA, California
Palm Springs, Mojave Desert

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1976.

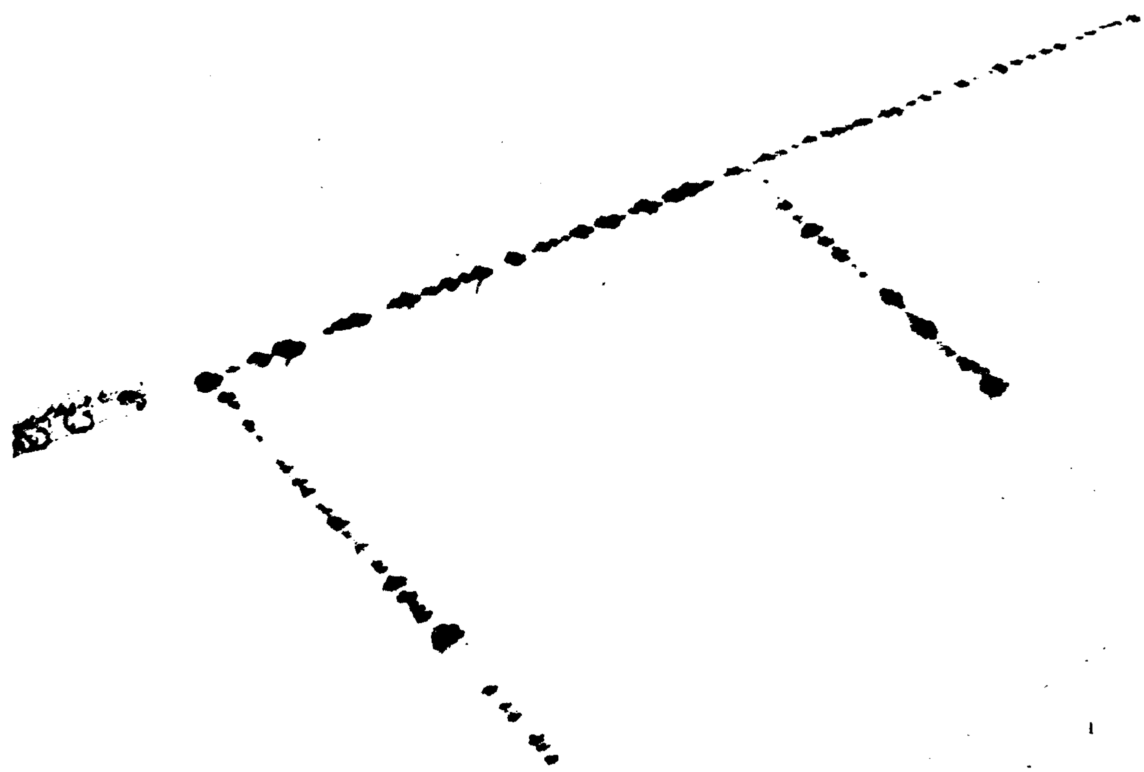


IMAGE FILE SHEET - DESERT | SAND PLAINS/SAND SHEETS

VIKING (SATELLITE) | STREAKS/DRIFTS

LOCATION: Mars, Chryse Planitia, Viking Lander Site 1
22.48°N 47.97°W

CLIMATE: Extremely arid
Trewartha, 1957: Not applicable

IMAGE CREDITS: Lander 1, 1976, panoramic view (2 parts):
A. Image ID 11B097, seg 1/3; B. Image ID 11B097, seg 2/3.

COMMENTS: Arrows indicate area common to both images.

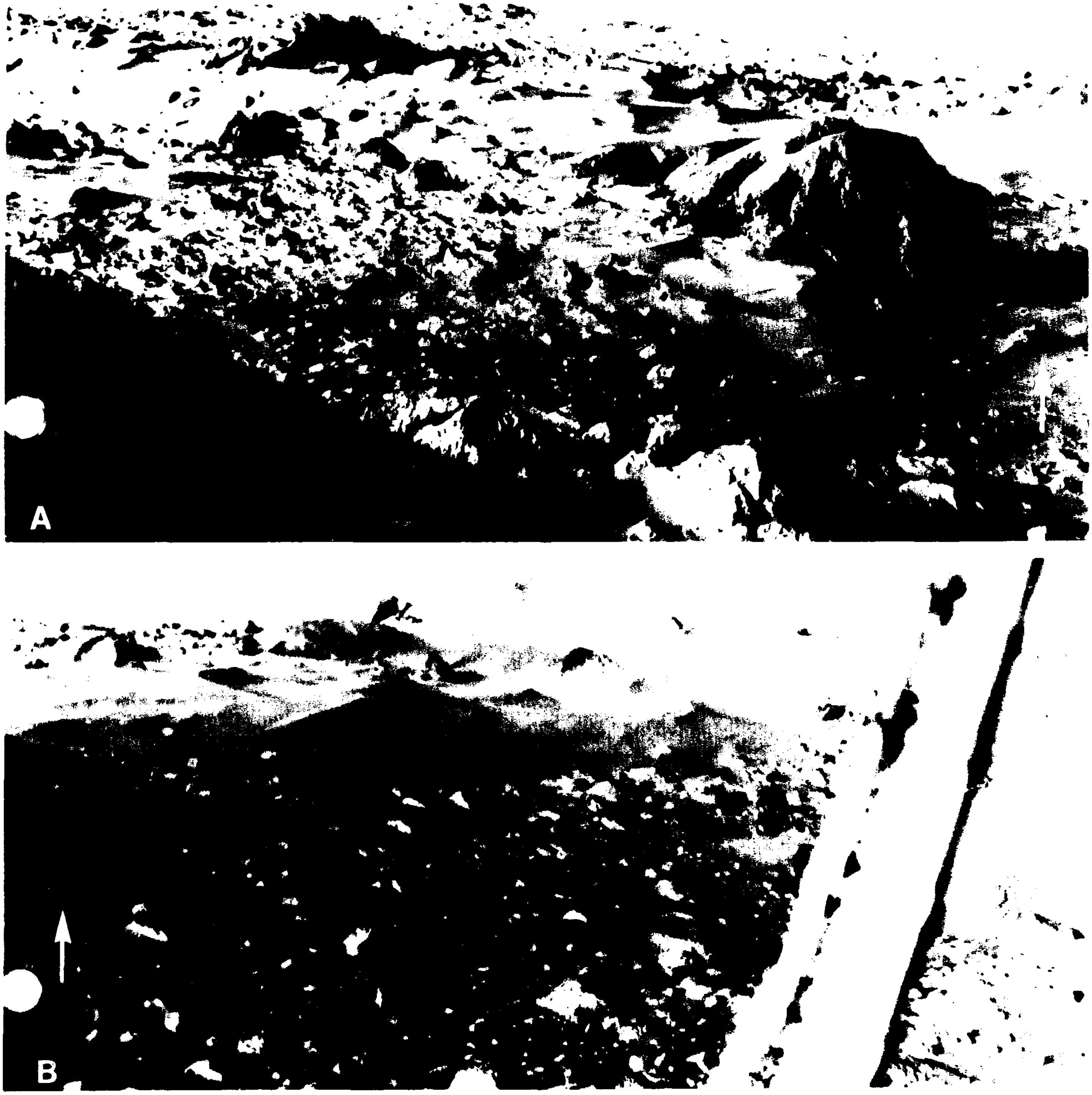


IMAGE FILE SHEET - DESERT

SAND SEAS/ERGS/DUNE FIELDS

LANDSAT: MSS

LOCATION: Oman
18°34'N 53°32'E

CLIMATE: Arid
Trewartha, 1957. BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene E-1111-06204, Band 7, 11 Nov 1972, Scale 1:1,000,000.

COMMENTS: Shows gradual transition of dune types.

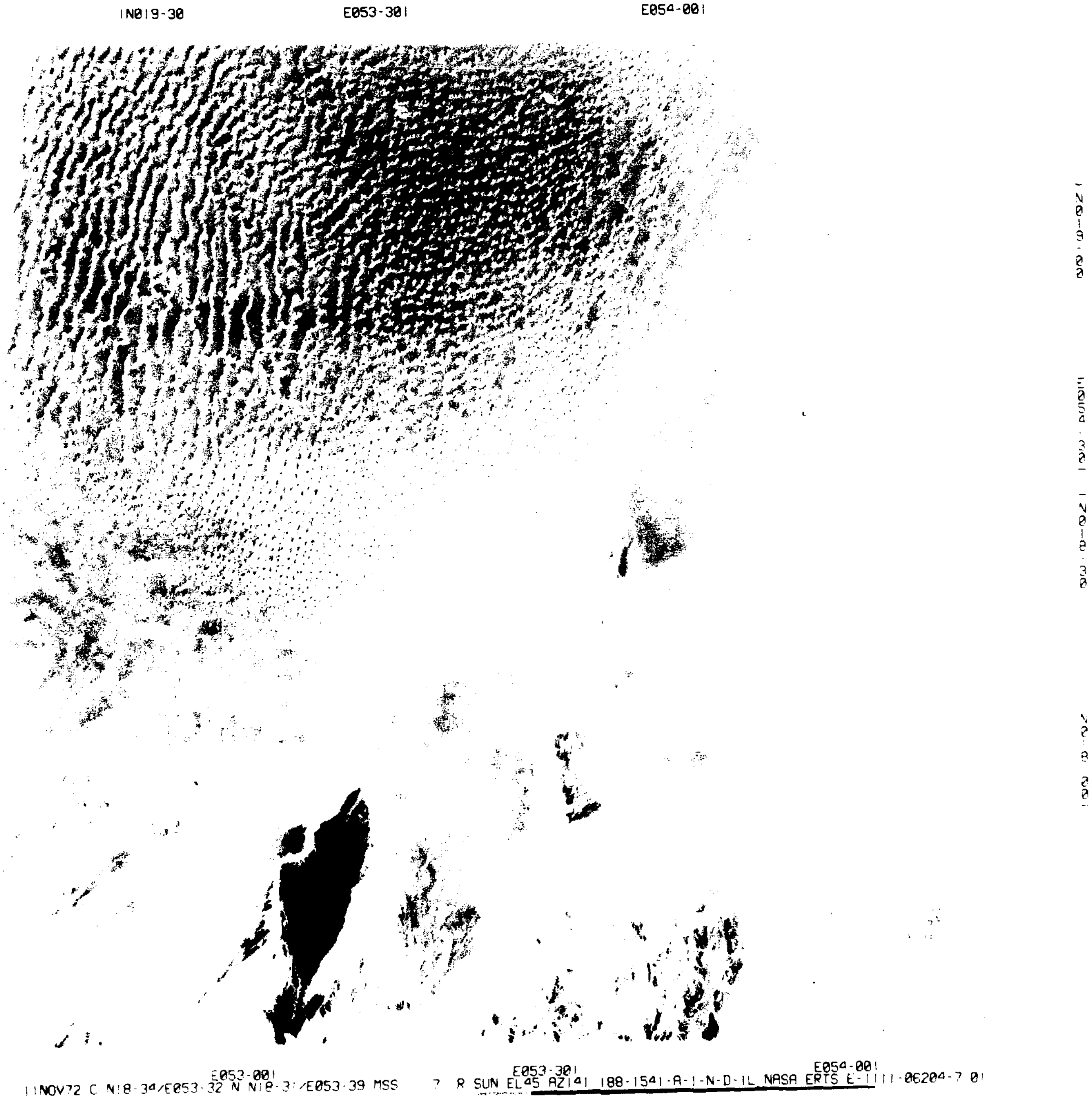


IMAGE FILE SHEET - DESERT | SAND SEAS/ERGS/DUNE FIELDS

LANDSAT: MSS

LOCATION: Saudi Arabia
25°56'N 44°06'E

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

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IMAGE CREDITS: Scene E-1083-07040, Band 7, 14 Oct 1972, Scale 1:1,000,000.

COMMENTS: Arrows point to valley ergs containing dome dunes.

DESERT PROCESSES WORKING GROUP

PHOTO: AERIAL (OBLIQUE)

LOCATION: Australia (Western)
Great Sandy Desert south of Fitzroy River

CLIMATE: Arid to Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geolcgical Survey, Desert Studies Group, Flagstaff, AZ, 25 Aug 1981.

COMMENTS: Located in linear dunes.

IMAGE FILE SHEET - DESERT

PLAYAS

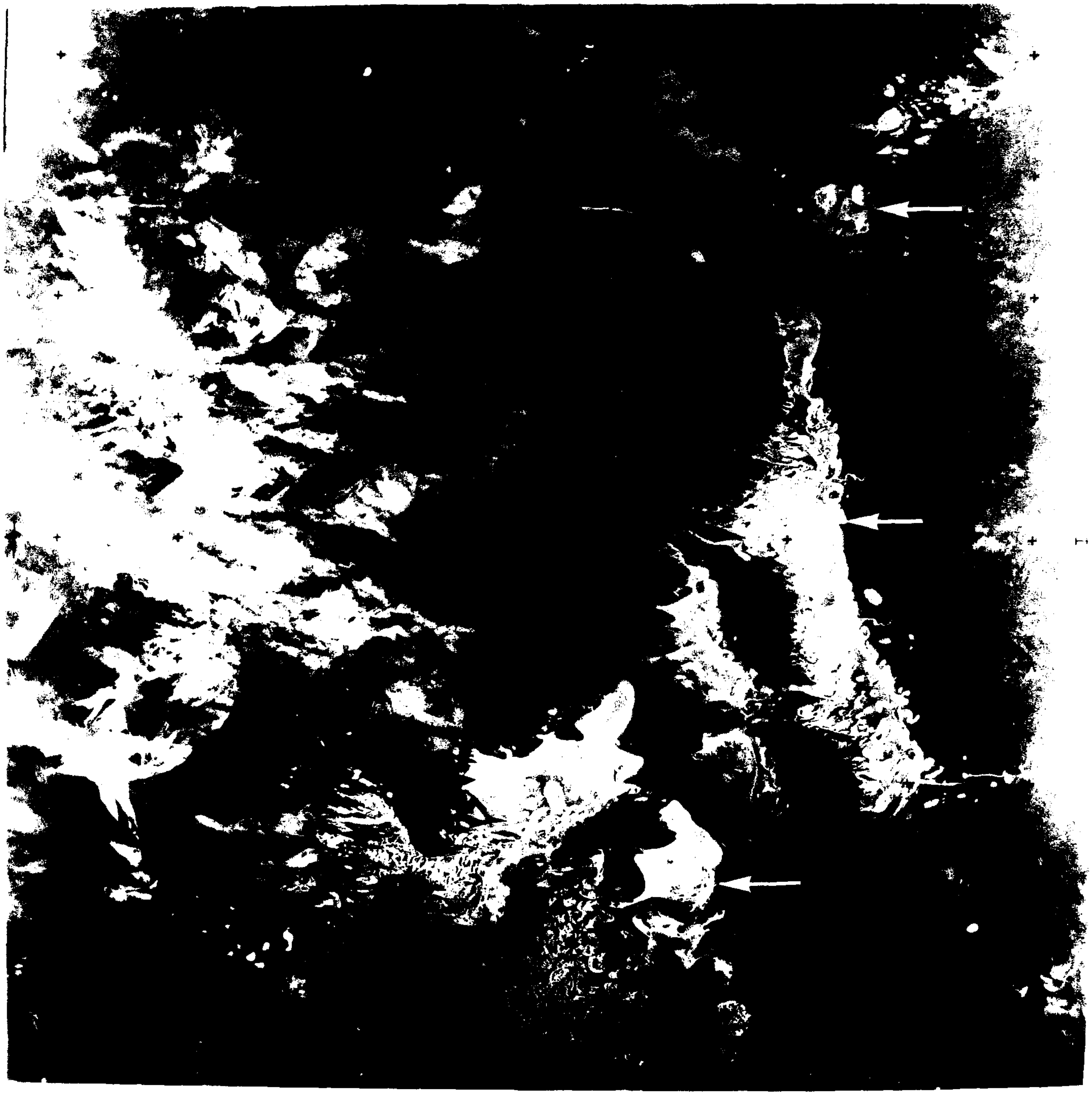
LANDSAT: RBV

LOCATION: Australia (Western), Southwest of Kalgoorlie
West of Lake Johnston, center point 32°06'S 120°29'E

CLIMATE: Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Scene E-31101-00595, Quadrant D, 10 Mar 1981, Scale 1:500,000.

COMMENTS: Arrows point to the feature.



DESERT PROCESSES WORKING GROUP

IMAGE FILE SHEET - DESERT

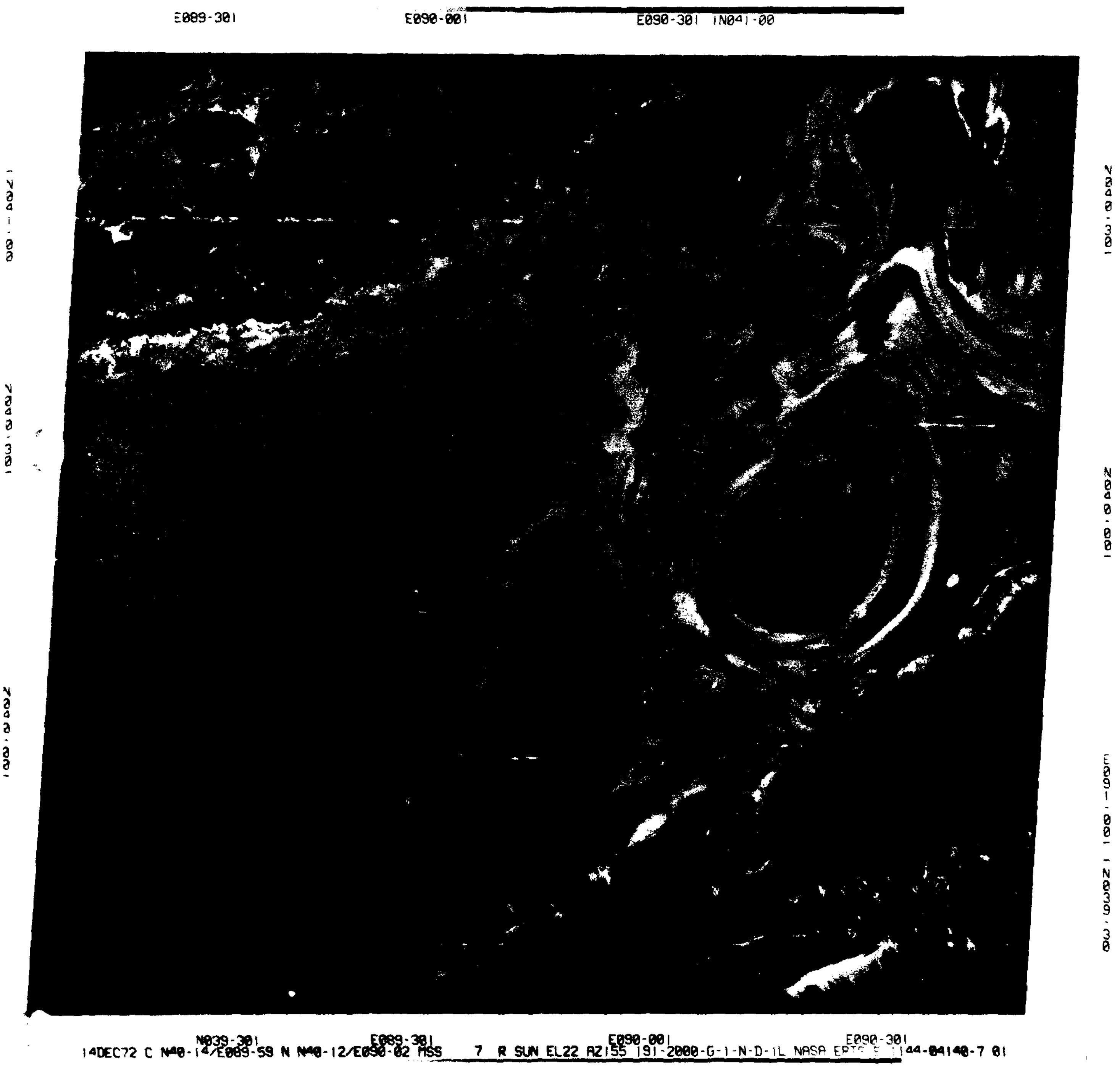
PLAYAS

LANDSAT: MSS

LOCATION: China (Northwestern)
Lop Nur

CLIMATE: Arid
Trewartha, 1957: BWk: Middle Latitude Desert, cold and dry

IMAGE CREDITS: Scene E-1144-04140, Band 7, 14 Dec 1972, Scale 1:1,000,000.



DESERT PROCESSES WORKING GROUP

IMAGE FILE SHEET - DESERT PLAYAS

LANDSAT: MSS

LOCATION: Saudi Arabia (Southeastern) and Oman
Umm as Samim ("Mother of Poisons")

CLIMATE: Extremely Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Scene E-1182-06135, Band 5, 21 Mar 1973, Scale 1:1,000,000.

DESERT PROCESSES WORKING GROUP

PHOTO: GROUND

LOCATION: Saudi Arabia
Southwest of Sulayyil, 20°40'N 40°12'E

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

COMMENTS: Pleistocene lake bed with gypsum evaporite.

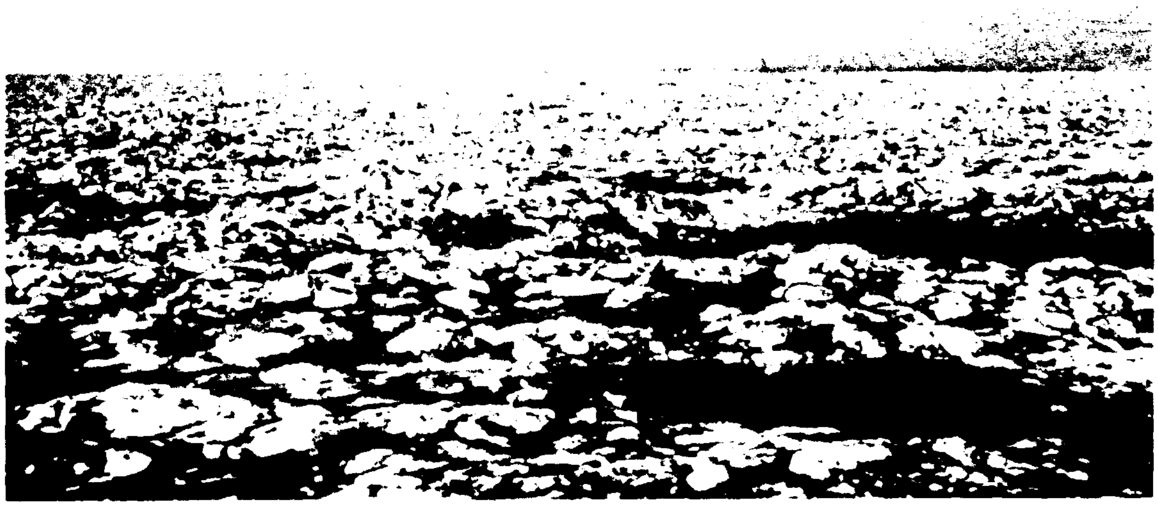


IMAGE FILE SHEET - DESERT

PLAYAS

LANDSAT: MSS

(CLAY PANS)*

LOCATION: South Africa, Botswana, and Namibia
Border region along Molopo River

CLIMATE: Semiarid
Trewartha, 1957: BW: Tropical and Subtropical Desert

IMAGE CREDITS: Scene E-1198-08000, black & white copy of color composite of Bands 4, 5, and 7, 15 Feb 1973, Scale 1:1,000,000.

COMMENTS: *In Australia these would be called billabongs.

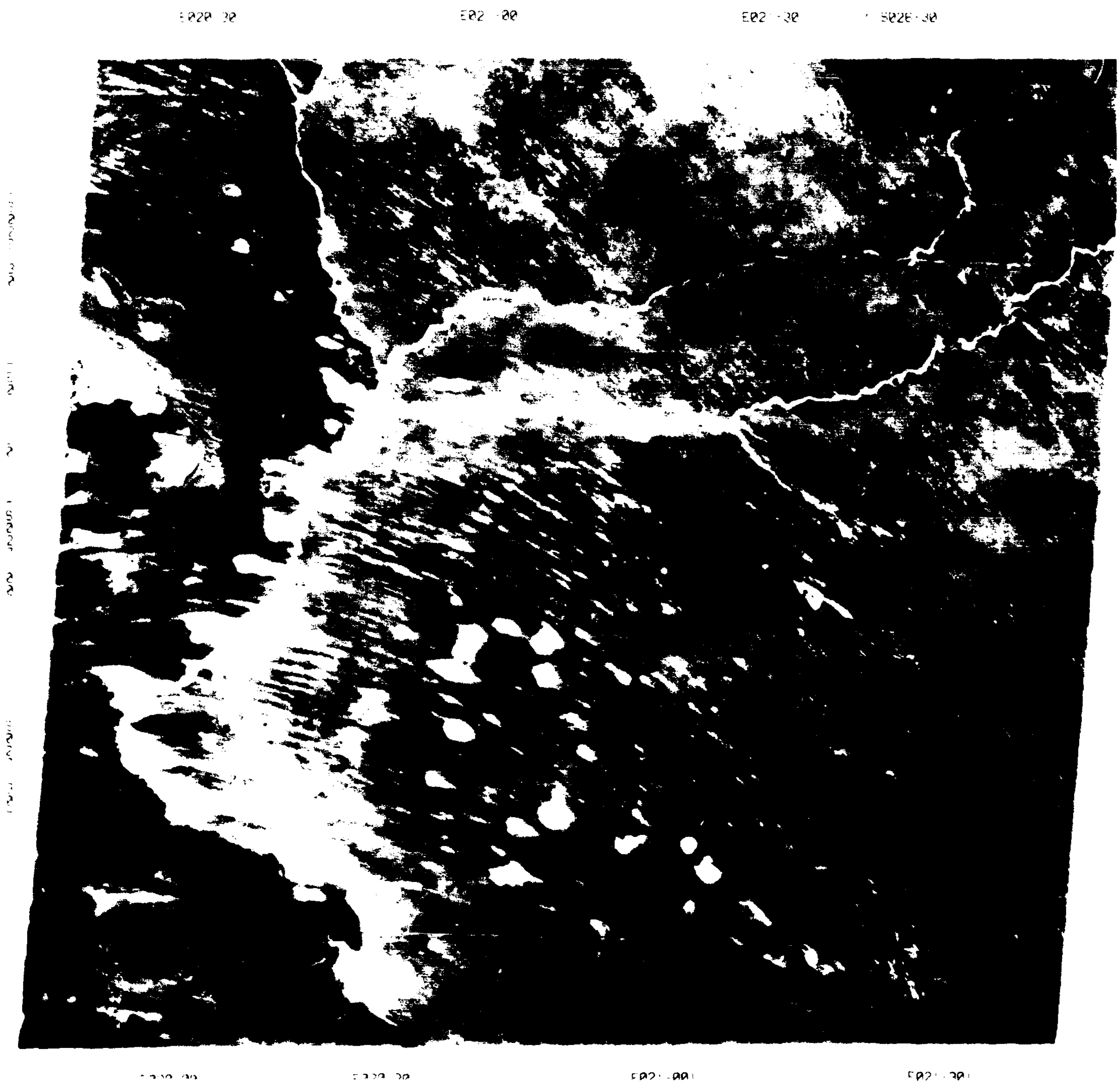


PHOTO: GROUND

LOCATION: USA, California
Death Valley, Badwater

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, May 1980.

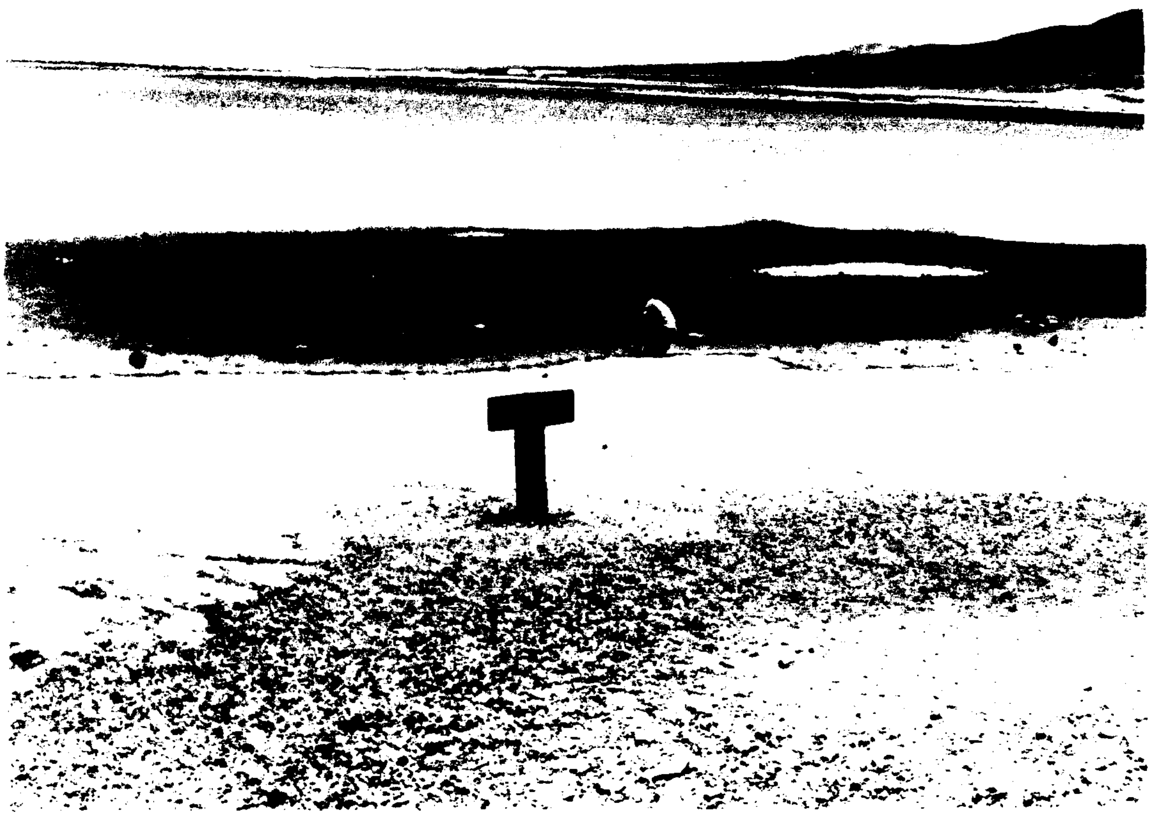


IMAGE FILE SHEET - DESERT PLAYAS

PHOTO: AERIAL (NEAR VERTICAL)

LOCATION: USA, California
Mojave Desert, Danby Lake

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 28 Jun 1983.

COMMENTS: Small (50 m or less in width) flat-topped mesas produced by a combination of sheetwash and deflation of soft playa sediments.

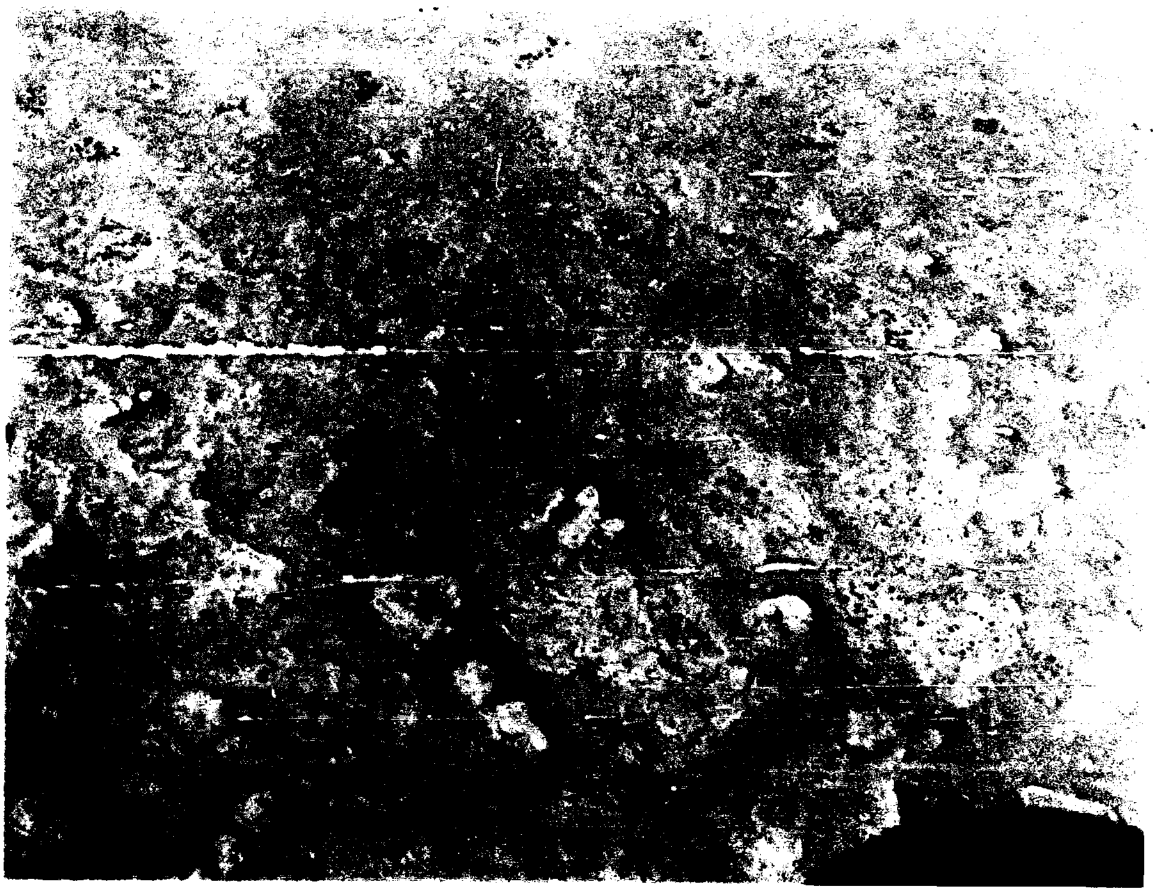


IMAGE FILE SHEET - DESERT

PLAYAS

PHOTO: GROUND

(HIGH CLAY CONTENT)

LOCATION: USA, California
Mojave Desert, Tonopah Dry Lake

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Mar 1973.

IMAGE FILE SHEET - DESERT

SABKHAHS

PHOTO: GROUND

LOCATION: Saudi Arabia
Dammam area

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: C.A. Kemp (ARAMCO retired), Redwood City, CA, early 1950's.

COMMENTS: Oasis in background. Dark area in middle ground is a sabkhah - can see water to the right - stay off dark area as well.

PHOTO: GROUND

LOCATION: Saudi Arabia
Eastern Province, east of Abqaiq

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: Photograph courtesy of S.G. Fryberger, Desert Engineering, Golden, CO, early 1980's.

COMMENTS: Salt ridges of this type typically have relief on the order of 5 to 10 cm. The flat areas between the ridges can be 10 to 20 cm across. Arenaceous - evaporite dominant.

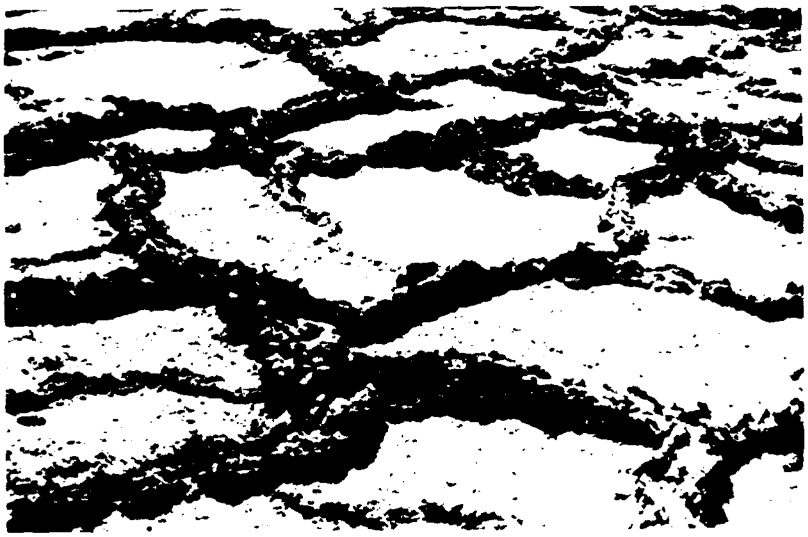


IMAGE FILE SHEET - DESERT

SABKHAHS

PHOTO: GROUND

LOCATION: Saudi Arabia
East of Abqaiq, on coast

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

COMMENTS: Salt drying beds - harvesting salt.

IMAGE FILE SHEET - DESERT

SABKHAHS

PHOTO: GROUND

LOCATION: Saudi Arabia, Eastern Province, about 10 km south of Dhahran, off west side of highway between Dhahran and Abqaiq

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: Photograph courtesy of S.G. Fryberger, Desert Engineering, Golden, CO, early 1980's.

COMMENTS: Wind deposited quartz sand on surface, and water-saturated sand a short distance below (1 m). Surface will be dry during heat of day, but can be damp at night due to the hygroscopic effect of the salt, and the presence of fog and dew. Arenaceous - detrital dominant (from proximity to dune field--sand source).

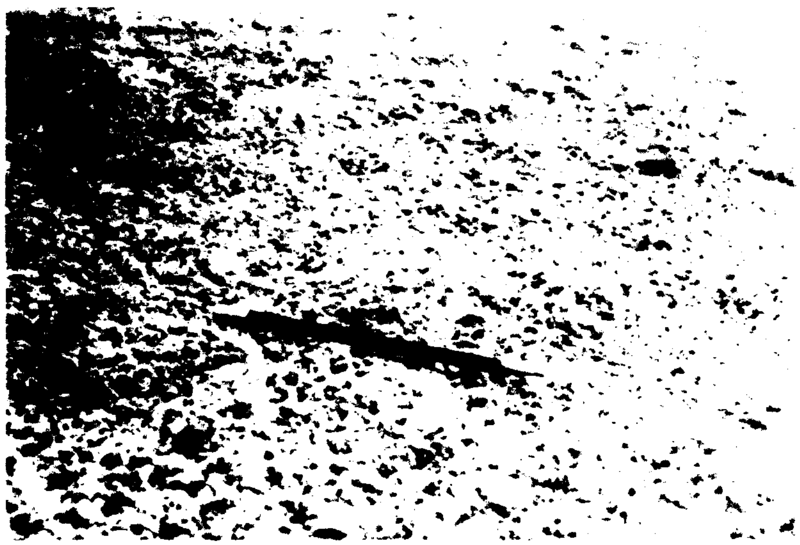


IMAGE FILE SHEET - DESERT

ALLUVIAL FEATURES

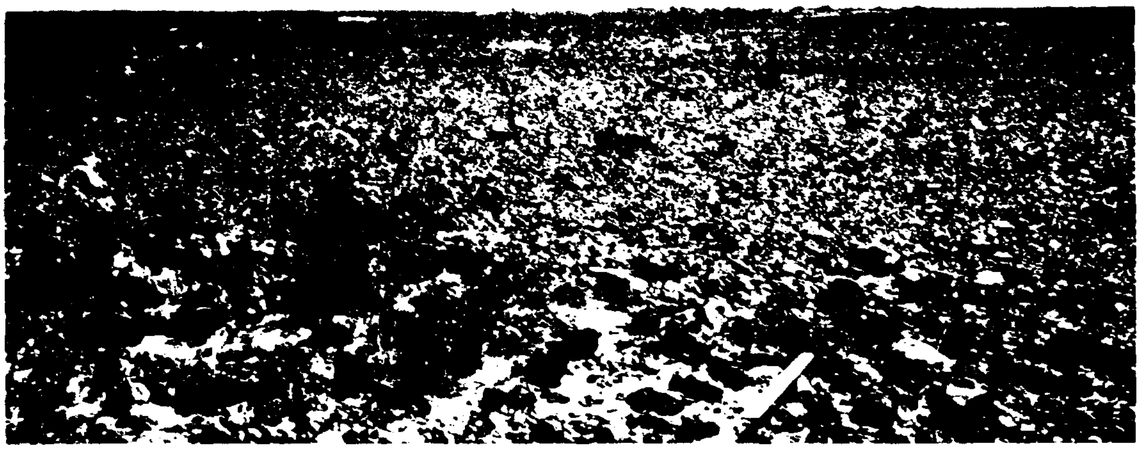
PHOTO: GROUND

GRAVEL PLAINS

LOCATION: Australia
Simpson Desert

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1976.



LOCATION: Egypt (South-central)
Western Desert

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1980.

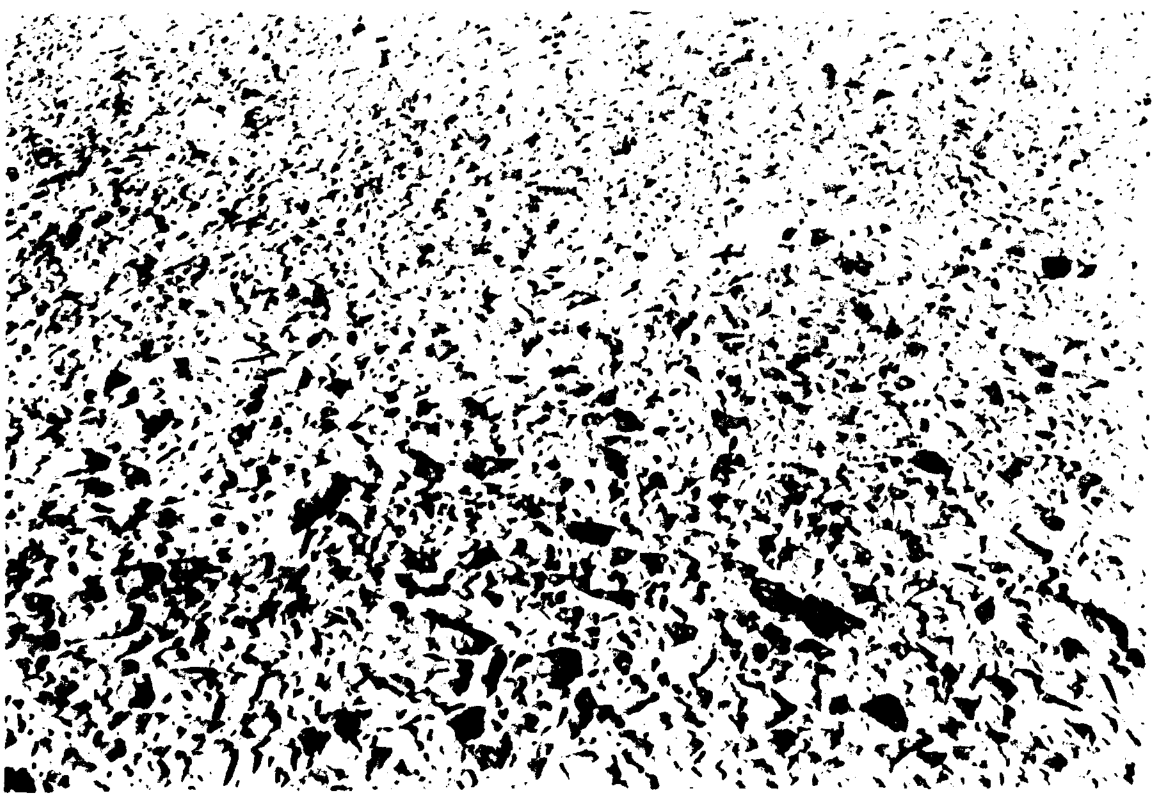


IMAGE FILE SHEET - DESERT

ALLUVIAL FEATURES

PHOTOS: GROUND

GRAVEL PLAINS

LOCATION: Egypt (South-central)
Western Desert

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

COMMENTS: Maurice J. Grolier, U.S. Geological Survey, Desert Studies Group, in photo.

IMAGE FILE SHEET - DESERT | ALLUVIAL FEATURES

PHOTOS: GROUND | GRAVEL PLAINS

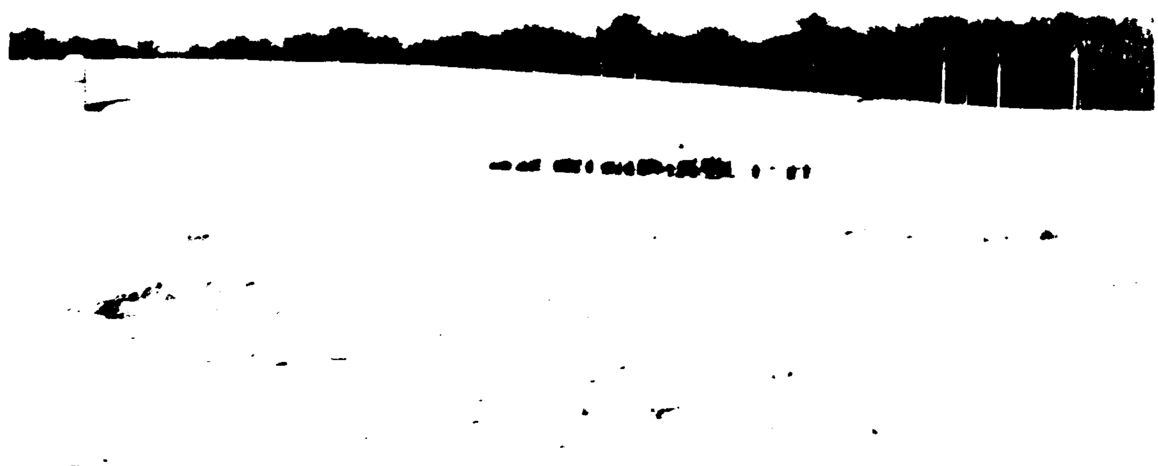
LOCATION: Saudi Arabia
Al Qatif area, halfway between Dhahran and Ras Tanura

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: C.A. Kemp (retired ARAMCO), Redwood City, CA, early 1950's

COMMENTS: A. Sand dunes in background. The cylindrical object is an old well, now exposed by loss of surrounding material. B. Oasis in background, herd of sheep, old water well exposed by loss of surrounding material.

A



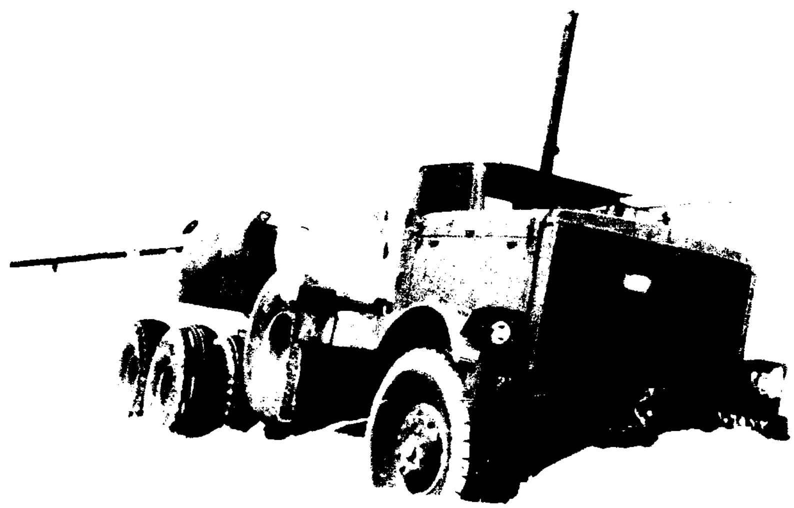
B

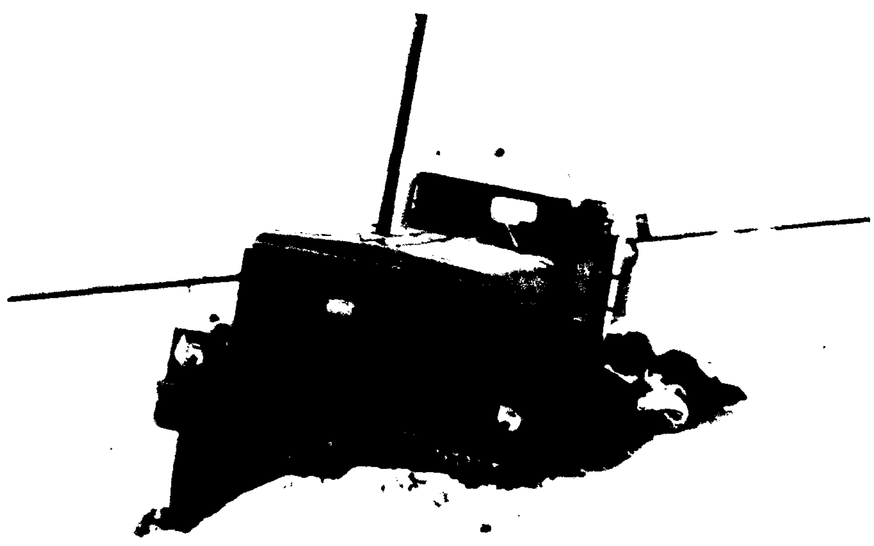
LOCATION: Saudi Arabia
Near Nariya

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: C.A. Kemp (retired ARAMCO), Redwood City, CA, early 1950's

COMMENTS: Truck stuck in a soft spot--probably a sand-covered solution pit in the underlying gypsum hardpan.





LOCATION: Saudi Arabia
Nariya An Nu'ayriyah

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: C.A. Kemp (retired ARAMCO), Redwood City, CA, early 1950's

COMMENTS: Gravel plain typical of the area. Oil well in background.

IMAGE FILE SHEET - DESERT

ALLUVIAL FEATURES

PHOTO: GROUND

GRAVEL PLAINS

LOCATION: Saudi Arabia
West of Riyadh

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

COMMENTS: Gravel surface of a sedimentary basin. Tuwayq escarpment in the background.

IMAGE FILE SHEET - DESERT

ALLUVIAL FEATURES

PHOTO: GROUND

GRAVEL PLAINS

LOCATION: Saudi Arabia
West of Sakakah, 29°59'N 40°12'E

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

COMMENTS: This lag surface covers deep loamy soils.

IMAGE FILE SHEET - DESERT

ALLUVIAL FEATURES

PHOTO: GROUND

GRAVEL PLAINS

LOCATION: USA, Arizona
South of Quartzsite

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1983.

IMAGE FILE SHEET - DESERT

PHOTO: AERIAL (OBLIQUE)

DEPRESSIONS

BLOWOUTS

LOCATION: USA, Arizona (Northeastern)
Moenkopi Plateau, South of Tuba City

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1979.

IMAGE FILE SHEET - DESERT | DEPRESSIONS

PHOTO: AERIAL (VERTICAL) | BLOWOUTS

LOCATION: USA, Nebraska
Custer Co.

CLIMATE: Subhumid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Stereo, U.S. Geological Survey, GS-JW, 7-196, 197, 22 Oct 1949, Scale 1:19,615.

COMMENTS: Arrows point to examples.

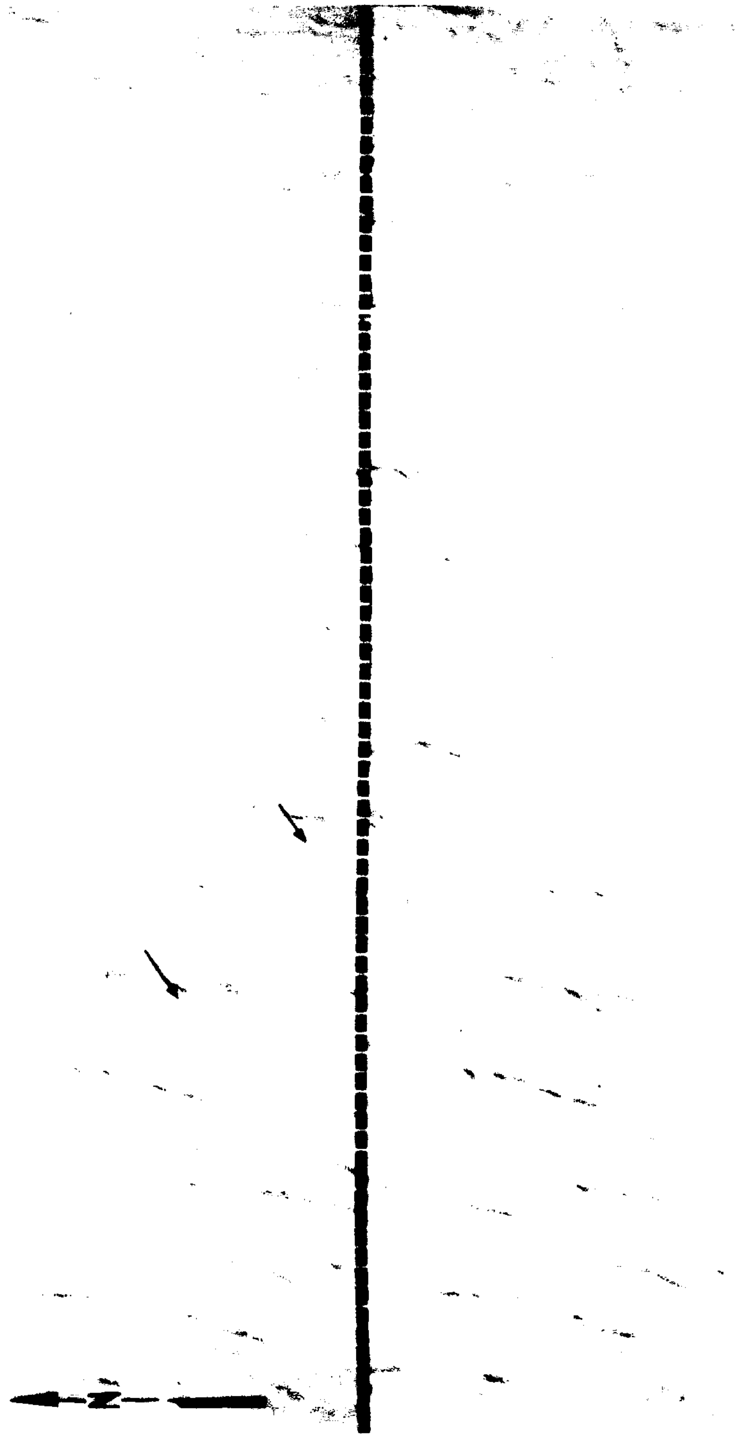


IMAGE FILE SHEET - DESERT

DEPRESSIONS

PHOTO: AERIAL (OBLIQUE)

DEFLATION HOLLOWS

LOCATION: USA, Arizona (Northeastern)
Moenkopi Plateau, Big Hollow

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1979.

COMMENTS: Hollow is bisected by a highway (middle ground of photo).

IMAGE FILE SHEET - DESERT

GROOVED TERRAIN

PHOTO: AERIAL (LOW ALTITUDE OBLIQUE)

(JOINTED LIMESTONE)

LOCATION: Australia (Western)
East of Fitzroy Crossing

CLIMATE: Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 6 Aug 1981.

COMMENTS: Structural control of erosion. Relief is 1 to 5 m. Note tree for scale (arrow).

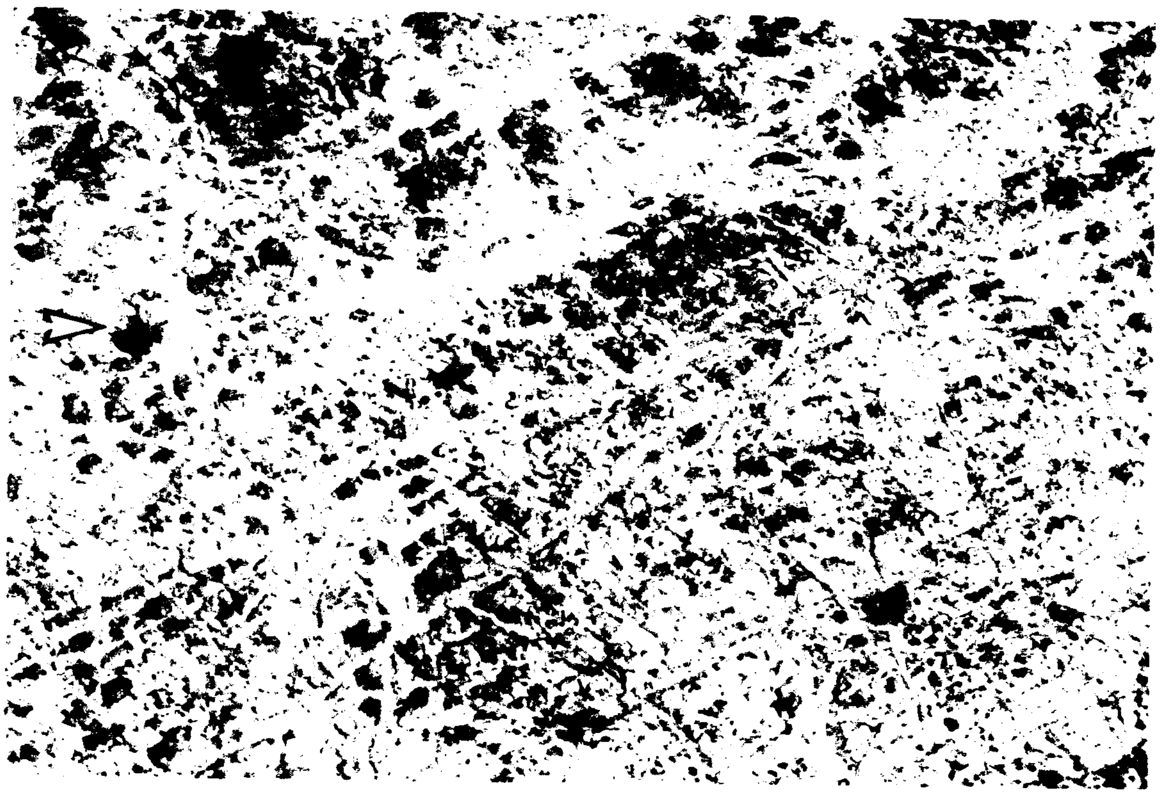


IMAGE FILE SHEET - DESERT

GROOVED TERRAIN

PHOTO: AERIAL (LOW ALTITUDE OBLIQUE)

(LIMESTONE - TILTED)

LOCATION: Australia (Western)
Mt. Anderson, West of Fitzroy Crossing

CLIMATE: Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 6 Aug 1981.

COMMENTS: Mesozoic sediments, mostly limestone. Structural control of erosion. Relief is 5 to 15 m. For scale, note trees in upper right corner of image.

IMAGE FILE SHEET - DESERT | GROOVED TERRAIN

PHOTO: AERIAL (OBLIQUE) | (LIMESTONE)

LOCATION: Egypt (South-central)
Northeast of Kharga, Limestone Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

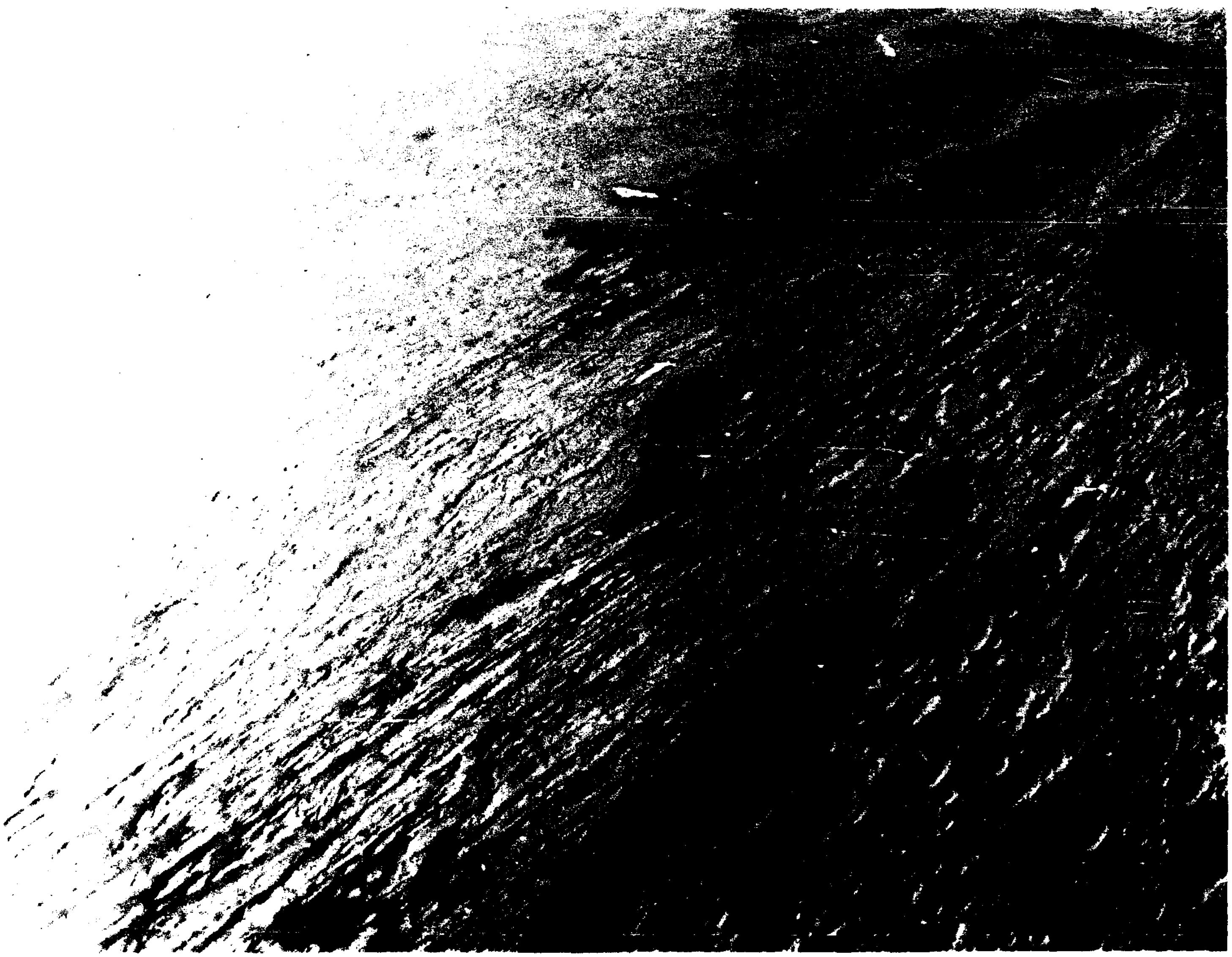


IMAGE FILE SHEET - DESERT | GROOVED TERRAIN

PHOTO: GROUND

LOCATION: Iran
Lut Desert

CLIMATE: Arid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1977.

IMAGE FILE SHEET - DESERT | GROOVED TERRAIN

PHOTO: AERIAL (OBLIQUE) | (SILTSTONE)

LOCATION: Iran
Lut Desert (view to North), About 30°28'N 58°16'E

CLIMATE: Arid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Daniel B. Krinsley, U.S. Geological Survey, Washington, DC, 22 Sep 1965.

COMMENTS: Photographed from an altitude of 300 m. The yardangs, oriented in the direction of the prevailing wind (333° true), are approximately 60 m high. Generally, no flat or rounded summits are still preserved; the ridges are narrow and sharply gullied. Some ridge valleys have no outlets as in the left foreground, and are drained by subsurface channels which connect with the furrows. The slopes are mantled with clay or gypsum which moves slowly downslope. Note the steep angle at the base of the slope; the result of periodic erosion from floodwaters reaching into the furrows.[1]

[1]Krinsley, D.B. 1970. A geomorphological and paleoclimatological study of the playas of Iran, Part II, p. 398. Geological Survey, U.S. Department of Interior, Washington, D.C., Final Scientific Report - Contract No. PRO CF 70-800, prepared for U.S. Air Force Cambridge Research Laboratories, Hanscom Field, Bedford, MA.

B

DESERT PROCESSES WORKING GROUP

IMAGE FILE SHEET - DESERT

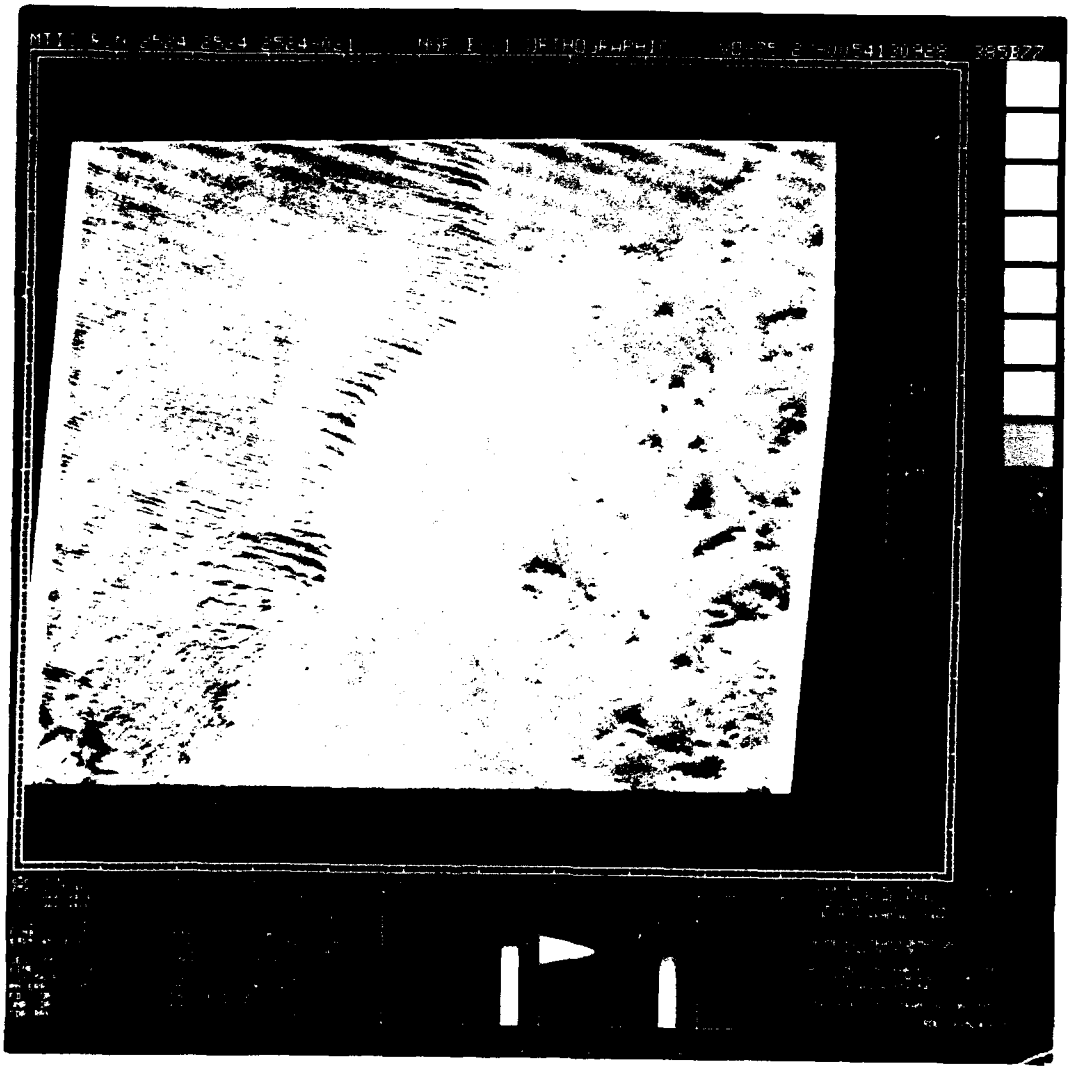
GROOVED TERRAIN

VIKING (SATELLITE)

LOCATION: Mars, Equatorial Region
12°S 183°W, Slopes of Apollineris Patera

CLIMATE: Extremely arid
Trewartha, 1957: Not applicable

IMAGE CREDITS: Orbiter 2 (Aug 1976 to Jul 1978), Image ID 385B77 and 385B79



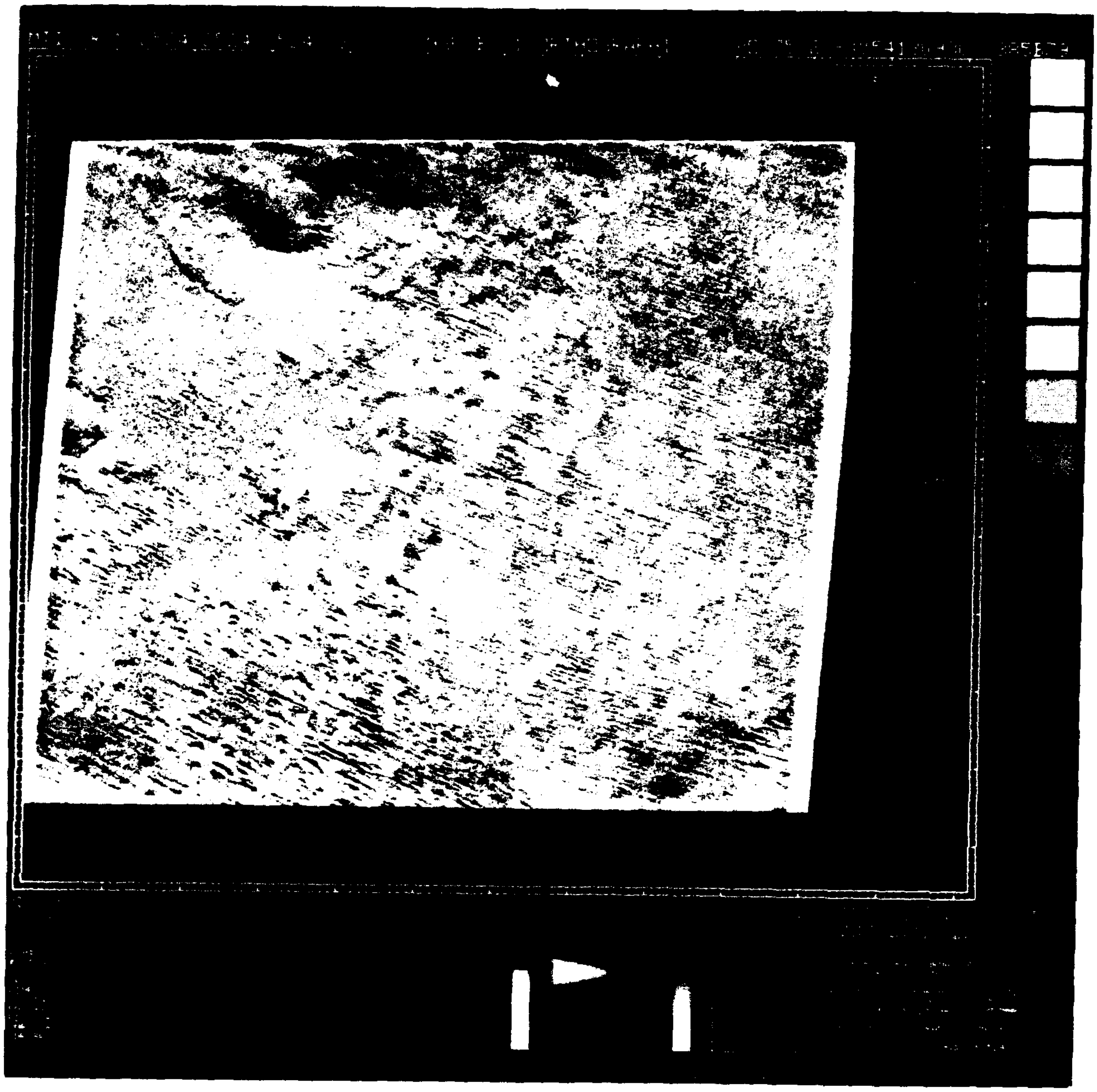


IMAGE FILE SHEET - DESERT

YARDANGS

PHOTO: GROUND

LOCATION: China (Northwestern)

CLIMATE: Arid
Trewartha, 1957: BWk: Middle Latitude Desert, cold and dry

IMAGE CREDITS: T. Donovan, U.S. Geological Survey, Flagstaff, AZ, 1982.

COMMENTS: This is part of a grooved terrain area.

IMAGE FILE SHEET - DESERT | YARDANGS

PHOTO: AERIAL (OBLIQUE) | (SANDSTONE)

LOCATION: Egypt
East of Kharga

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1980.

IMAGE FILE SHEET - DESERT

YARDANGS

PHOTO: AERIAL (OBLIQUE)

(LIMESTONE)

LOCATION: Egypt
Northeast of Kharga, Limestone Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

IMAGE FILE SHEET - DESERT YARDANGS

PHOTO: GROUND (SANDSTONE)

LOCATION: Egypt
Northwest of Bir Tarfawi, Western Desert

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

COMMENTS: This isolated yardang is about 2 m high.

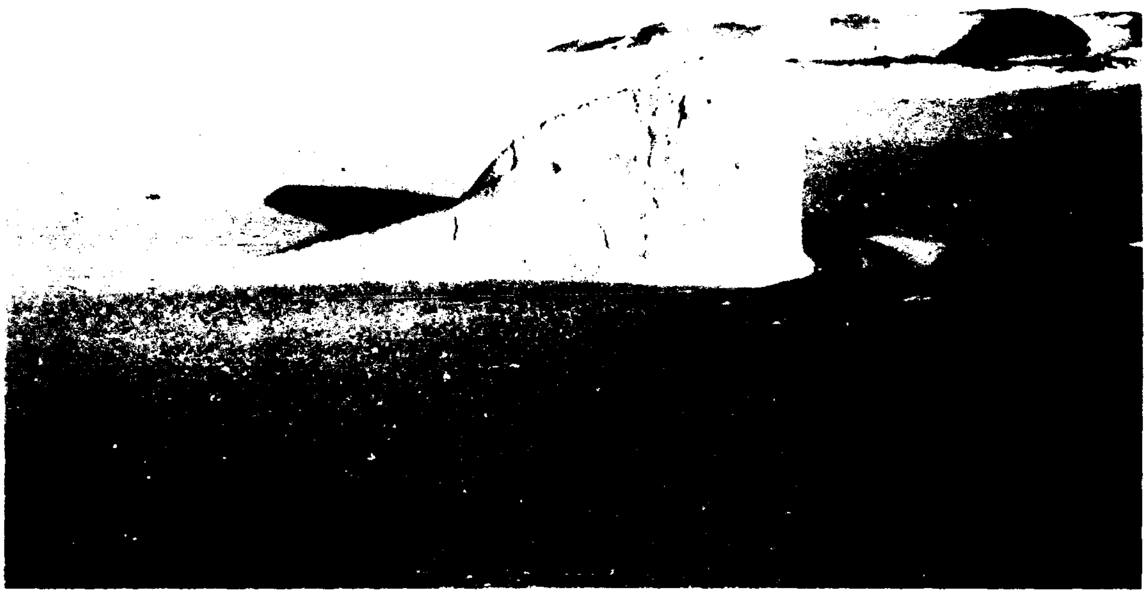


IMAGE FILE SHEET - DESERT YARDANGS

PHOTO: GROUND (LAKE BED - CLAYSTONE)

LOCATION: Egypt (West-central)
Farafra Depression

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

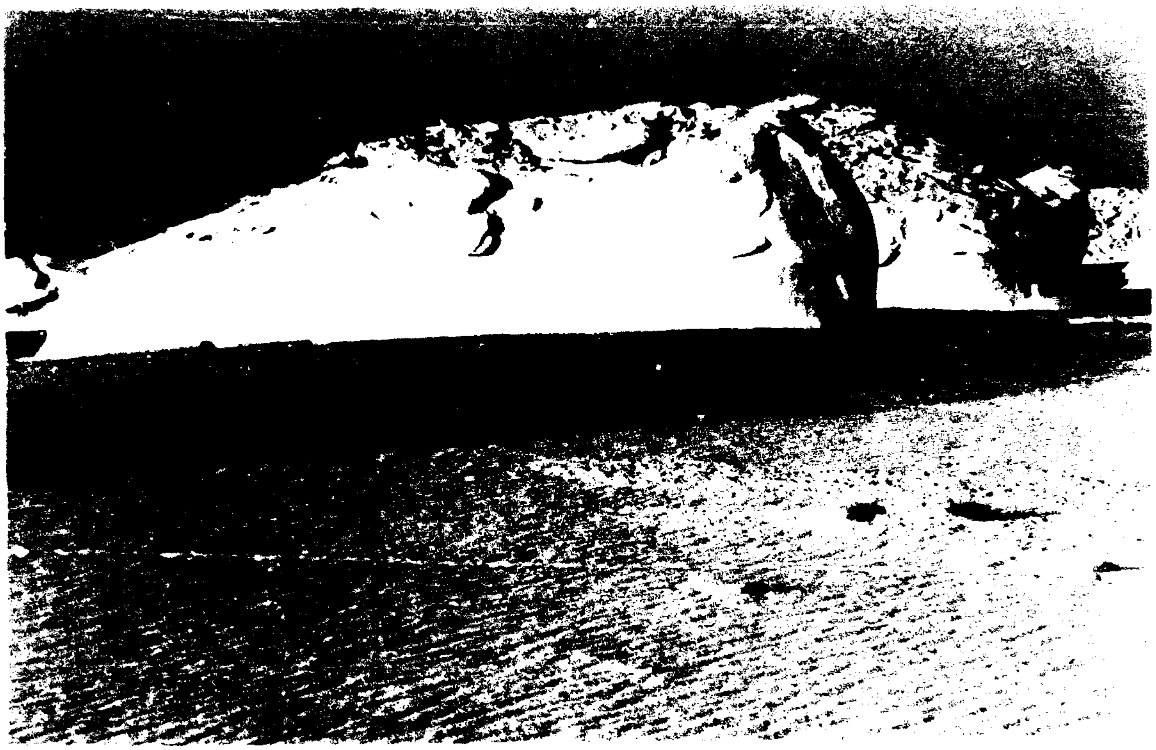
IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1979.

COMMENTS: These isolated yardangs are 2 to 3 m high.

LOCATION: Egypt (West-central)
Western Desert, Farafra Depression

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1979.



PHOTOS: GROUND

LOCATION: Iran
Lut Desert

CLIMATE: Hyperarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1977.

IMAGE FILE SHEET - DESERT

YARDANGS

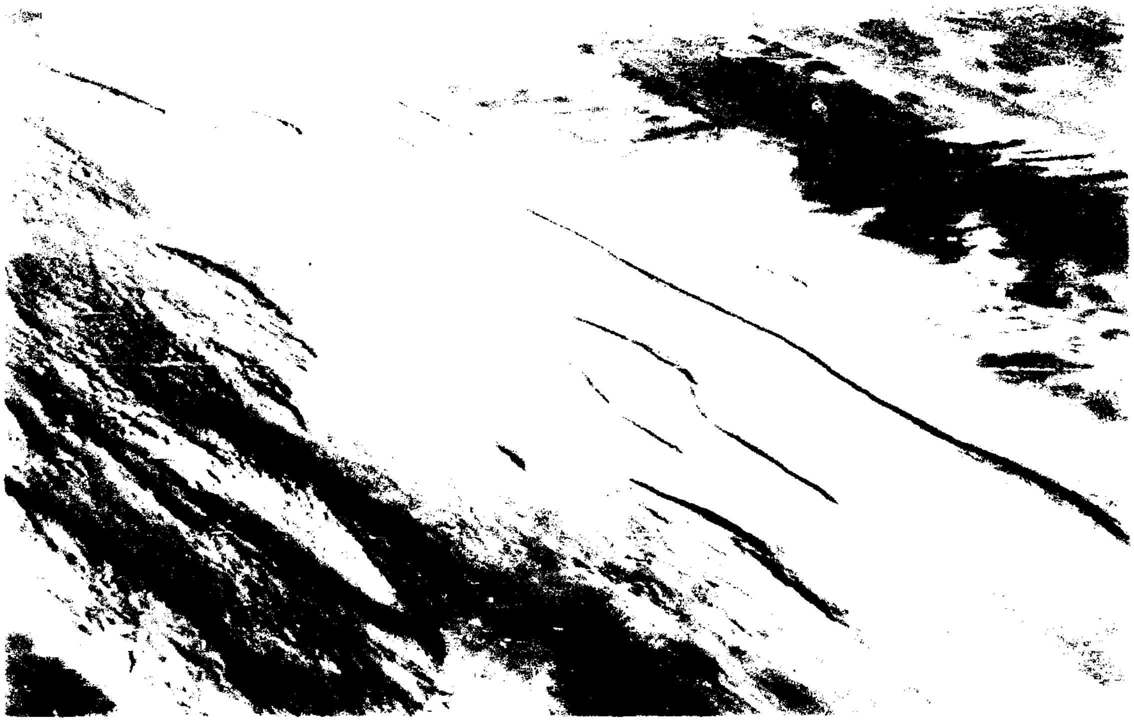
PHOTOS: AERIAL (OBLIQUE)

(SILTSTONE)

LOCATION: Peru (Coastal)

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

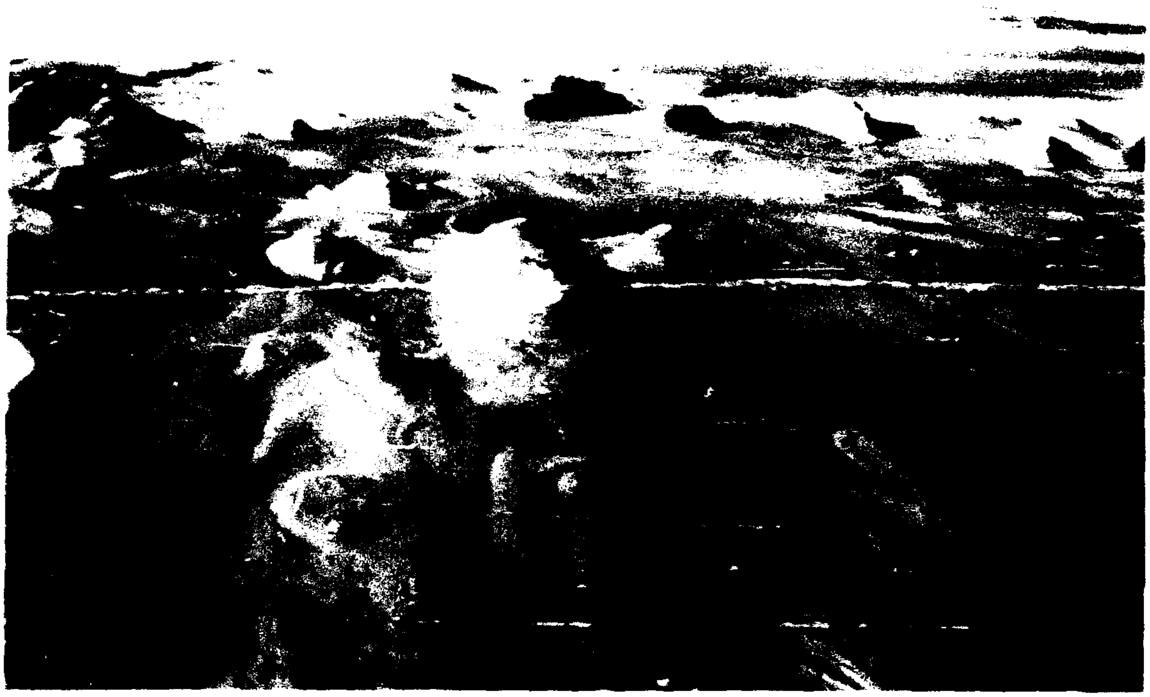


PHOTOS: AERIAL (OBLIQUE) (SILTSTONE)

LOCATION: Peru (Coastal)
Ica Valley

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.



PHOTOS: GROUND

LOCATION: Saudi Arabia
South of Al Hufuf in direction of Harad

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: C.A. Kemp (retired ARAMCO), Redwood City, CA, early 1950's

PHOTO: GROUND

LOCATION: Saudi Arabia
Dhahran

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: C.A. Kemp (retired ARAMCO), Redwood City, CA, Dec 1950

COMMENTS: Jebyl Dhahran in background, inselbergs, and elongated ridges (yardangs).

LOCATION: USA, Arizona
East of Cameron, Little Colorado River Valley

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1976.

PHOTO: AERIAL (OBLIQUE) (SANDSTONE)

LOCATION: USA, Arizona (Northeastern)
Edge of Moenkopi Plateau

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1980.

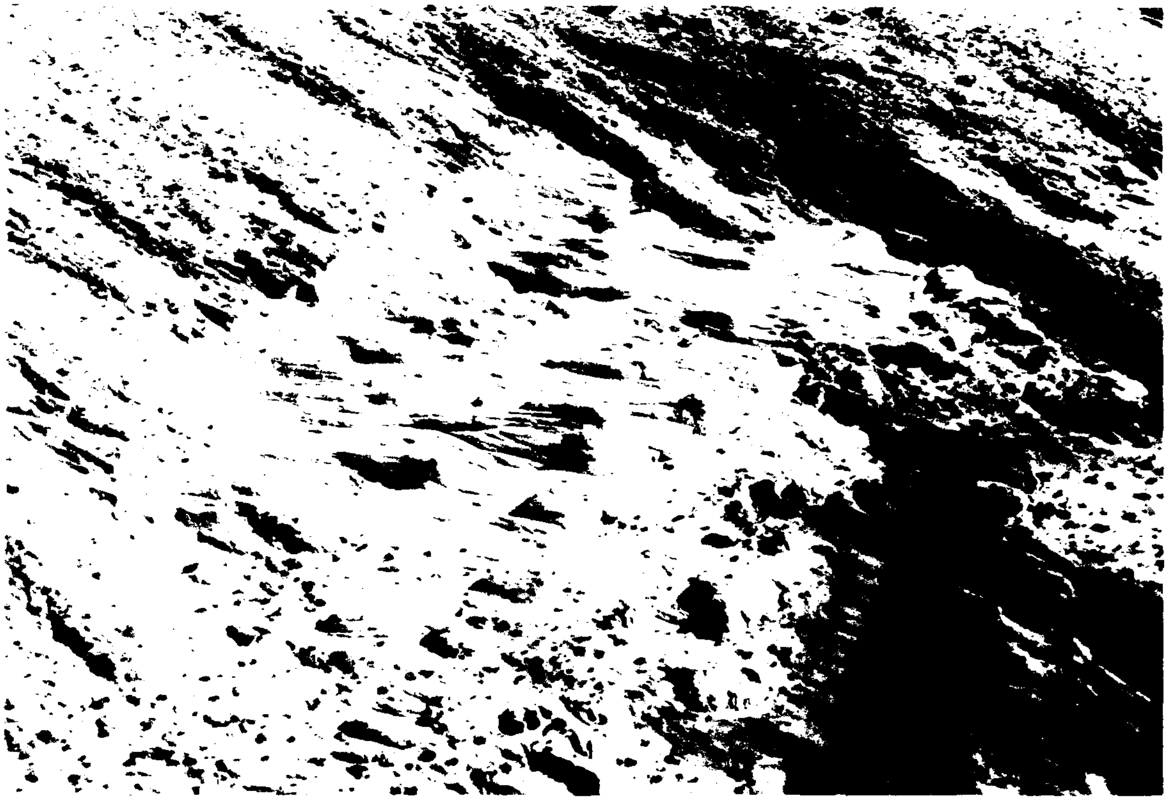


IMAGE FILE SHEET - DESERT | YARDANGS

PHOTO: AERIAL (OBLIQUE) | (CLAYSTONE)

LOCATION: USA, Arizona (North-central)
Little Colorado River Valley

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1976.

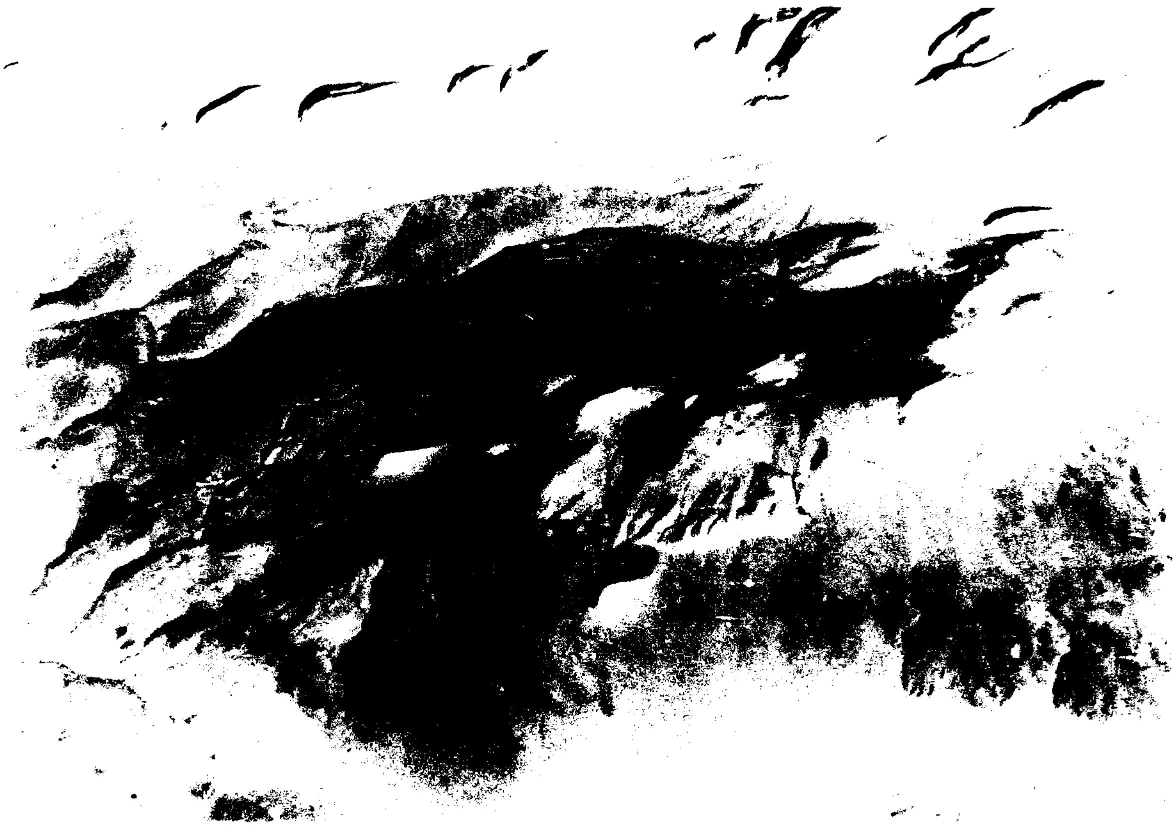
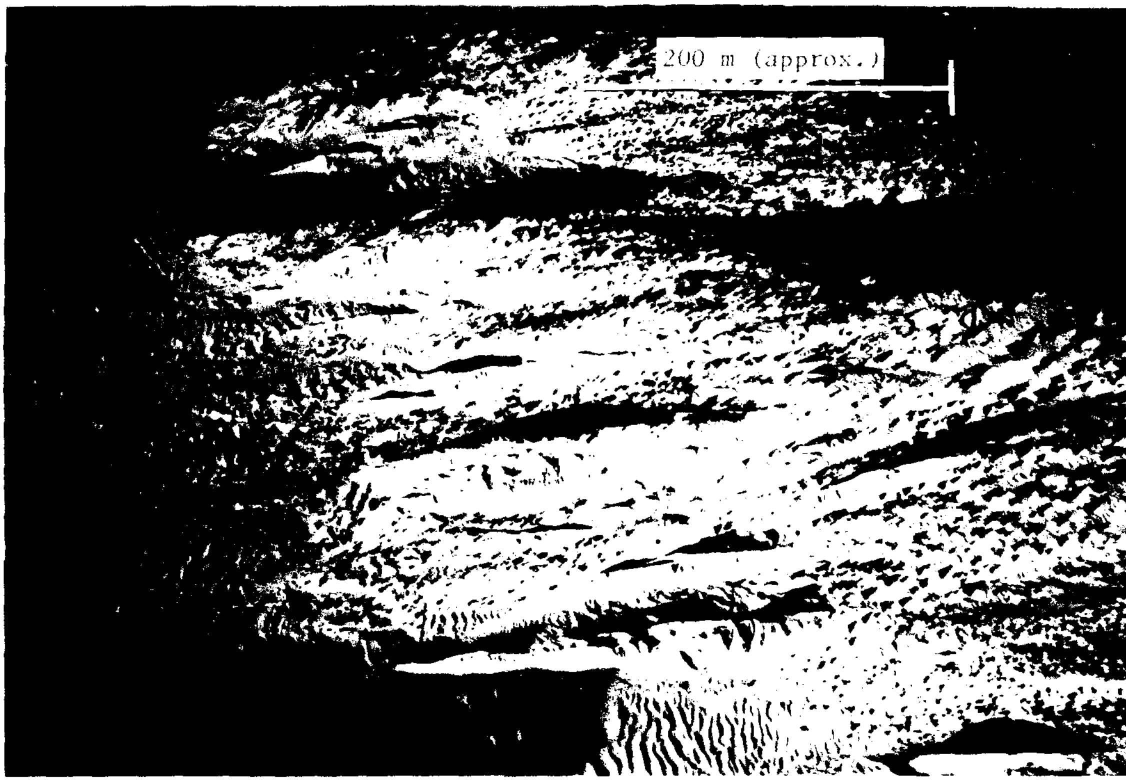


PHOTO: AERIAL (OBLIQUE)

LOCATION: USA, California
Rogers Lake

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1977.



PHOTOS: GROUND

LOCATION: USA, California
Rogers Lake

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1977.

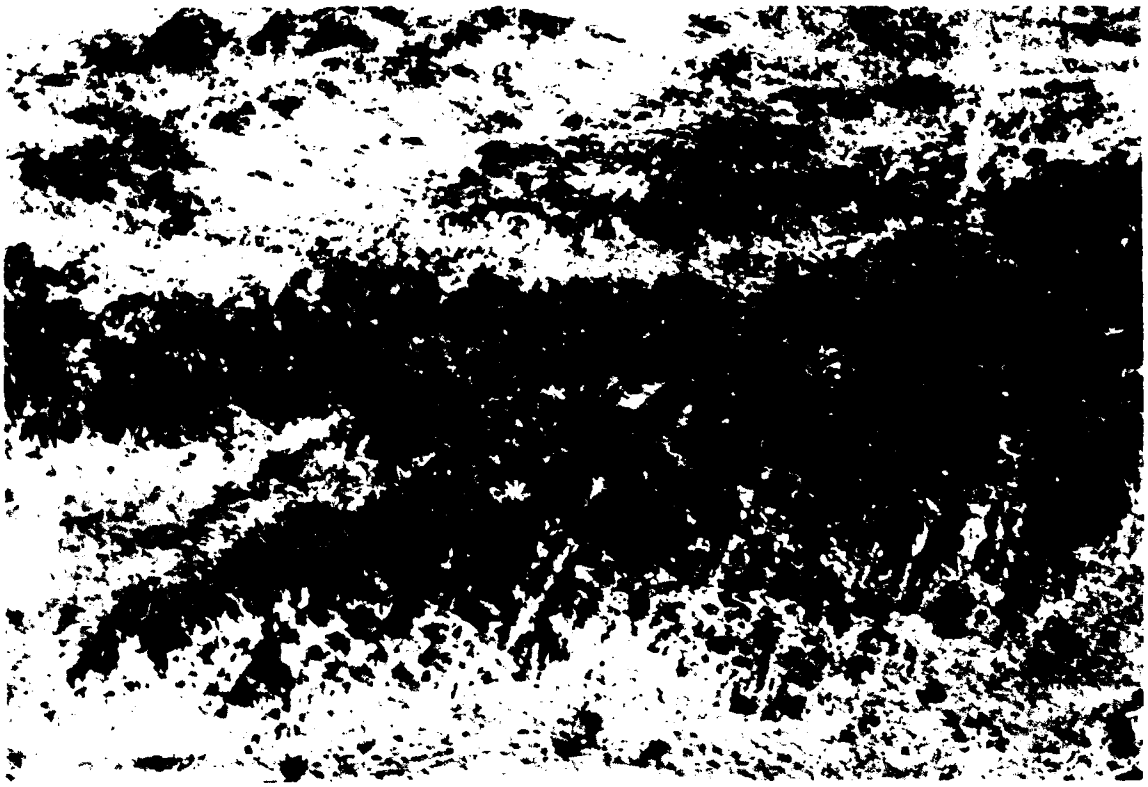
PHOTO: AERIAL (OBLIQUE) (LIMESTONE)

LOCATION: Australia (Western)
East of Fitzroy Crossing near Geikie Gorge

CLIMATE: Subhumid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 6 Aug 1981.

COMMENTS: The pinnacles are approximately 10 m high.



PHOTOS: GROUND

(CROSS-BEDDED SANDSTONE)

LOCATION: USA, Arizona, Coconino Co.
Five miles north of Tuba City

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Jack N. Rinker, U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, Nov 1988.

IMAGE FILE SHEET - DESERT

HOODOOS

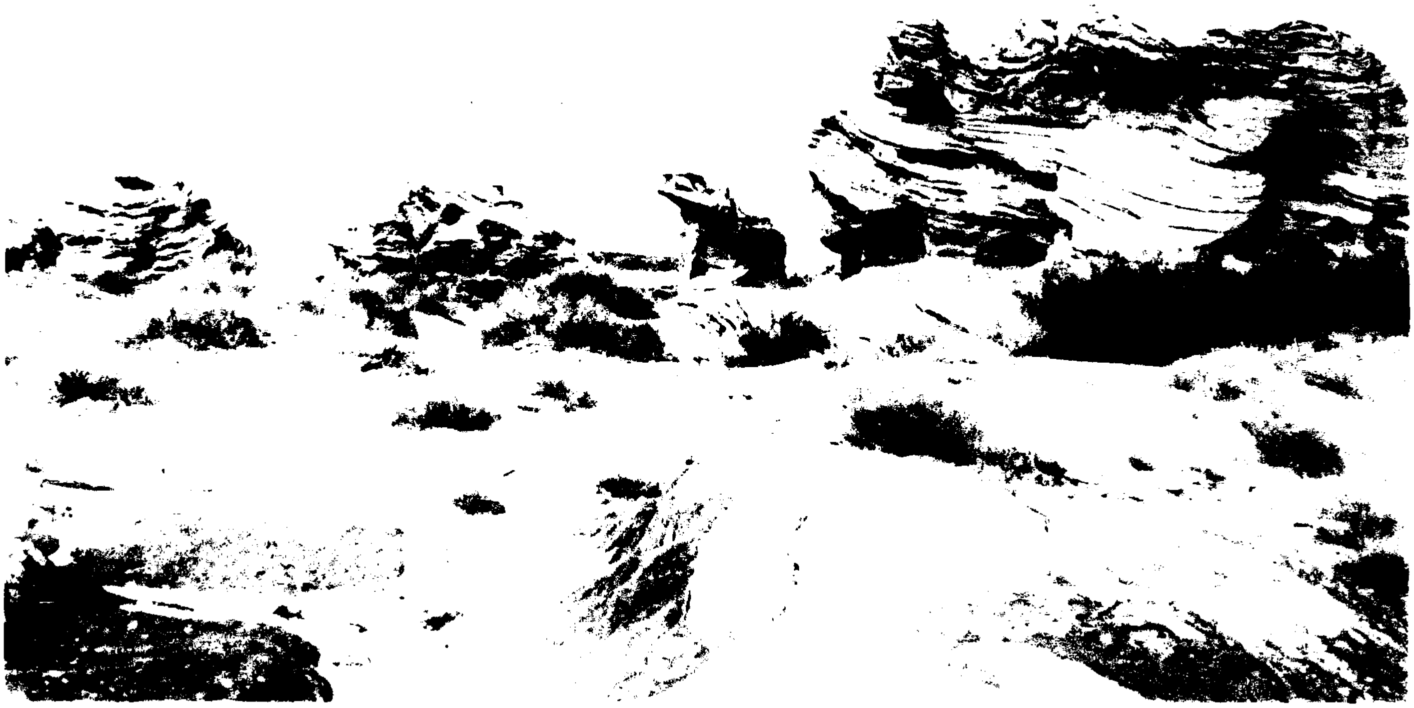
PHOTOS: GROUND

(CROSS-BEDDED SANDSTONE)

LOCATION: USA, Arizona, Coconino Co.
Five miles north of Tuba City

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Phyllis A. Corl, U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, Nov 1988.



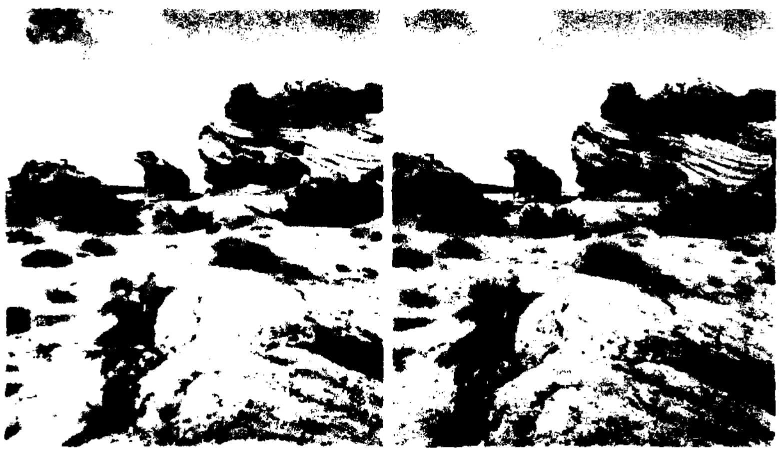


IMAGE FILE SHEET - DESERT

HOODOOS

PHOTOS: GROUND

(CROSS-BEDDED SANDSTONE)

LOCATION: USA, Arizona, Coconino Co.
Five miles north ot Tuba City

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Jack N. Rinker, U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, Nov 1988.

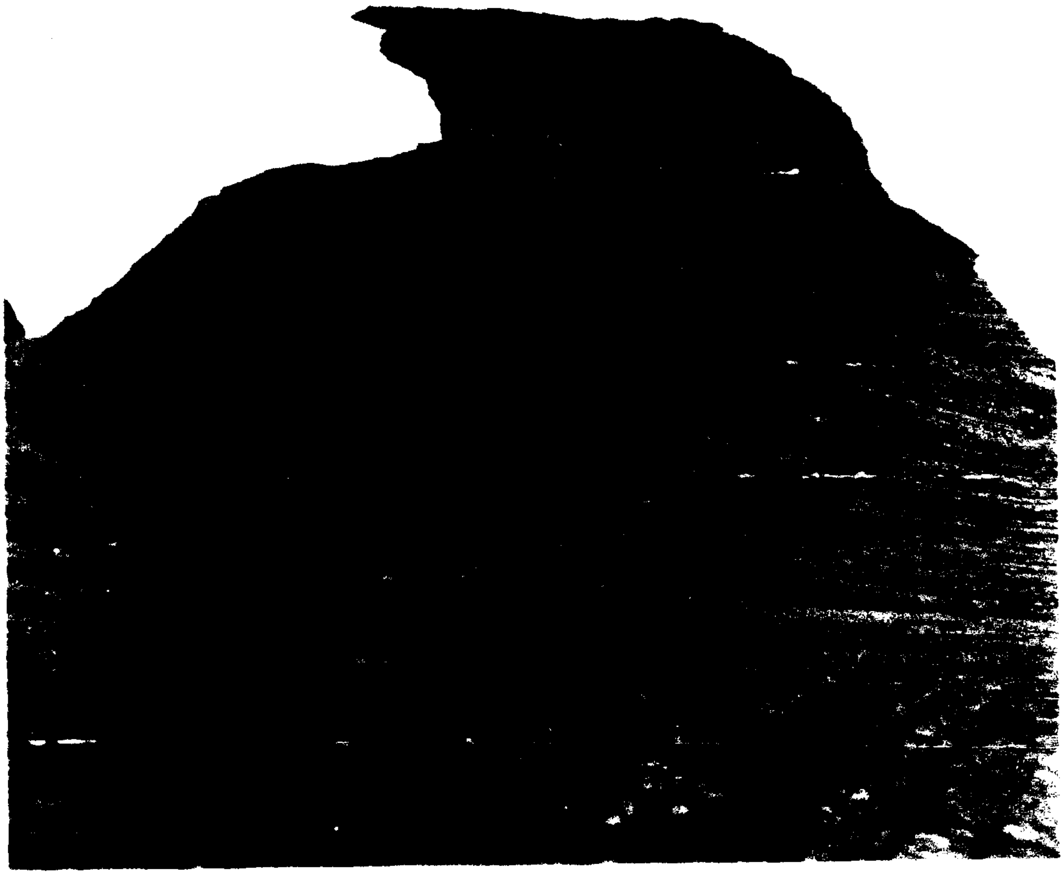


IMAGE FILE SHEET - DESERT

HOODOOS

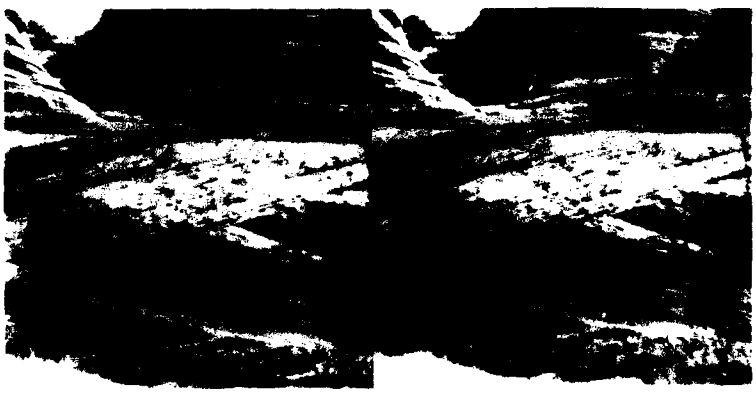
PHOTOS: GROUND

(CROSS-BEDDED SANDSTONE)

LOCATION: USA, Arizona, Coconino Co.
Five miles north of Tuba City

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

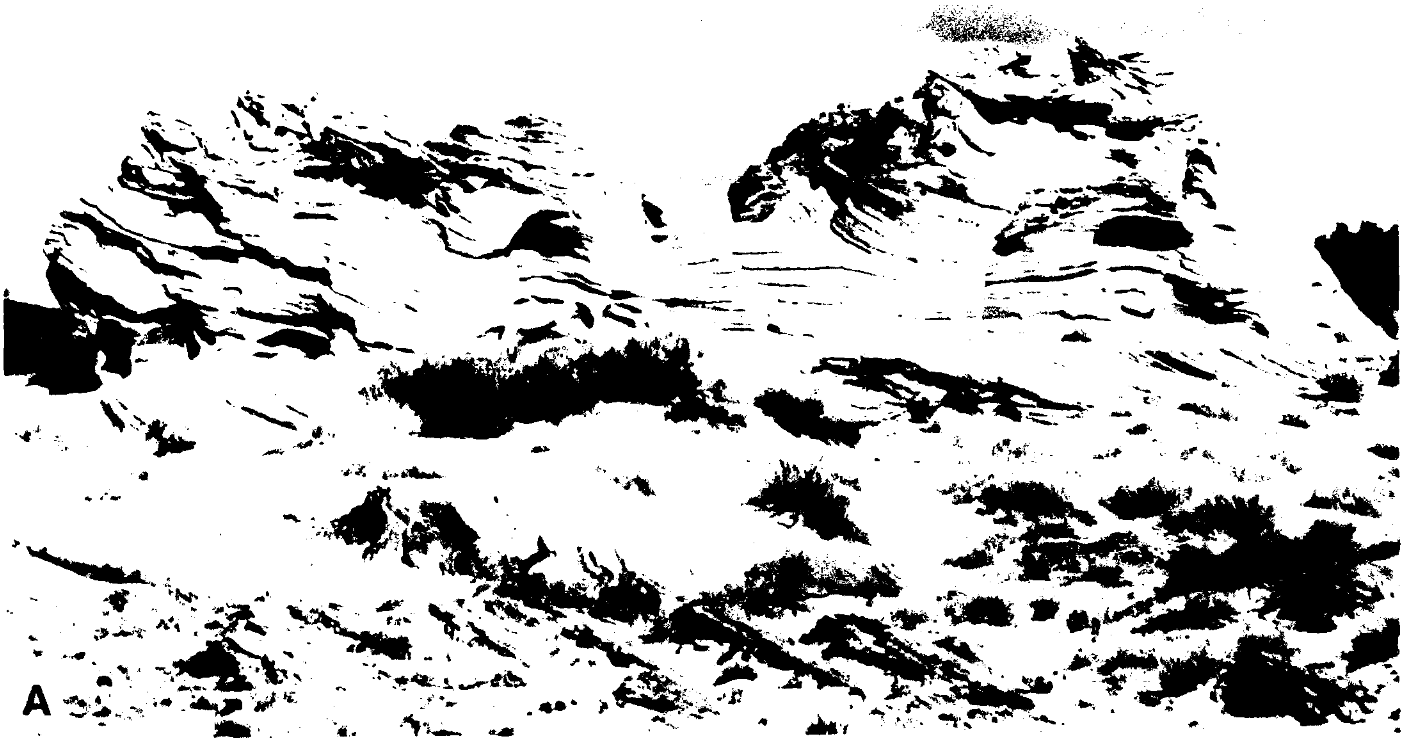
IMAGE CREDITS: Jack N. Rinker, U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, Nov 1980.



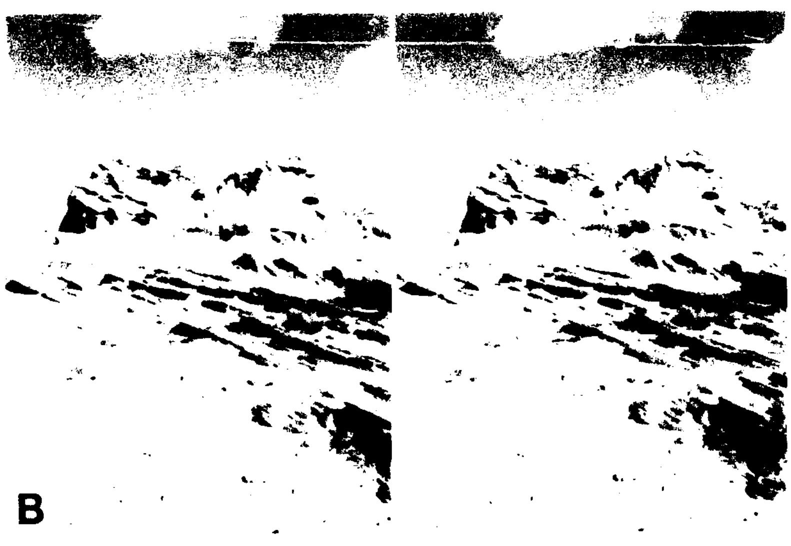
LOCATION: USA, Arizona, Coconino Co.
Five miles north of Tuba City

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, Nov 1988:
A. Phyllis A. Corl
B. Jack N. Rinker



A



B

IMAGE FILE SHEET - DESERT | HOODOOS

PHOTOS: GROUND | (CROSS-BEDDED SANDSTONE WITH CONCRETIONS)

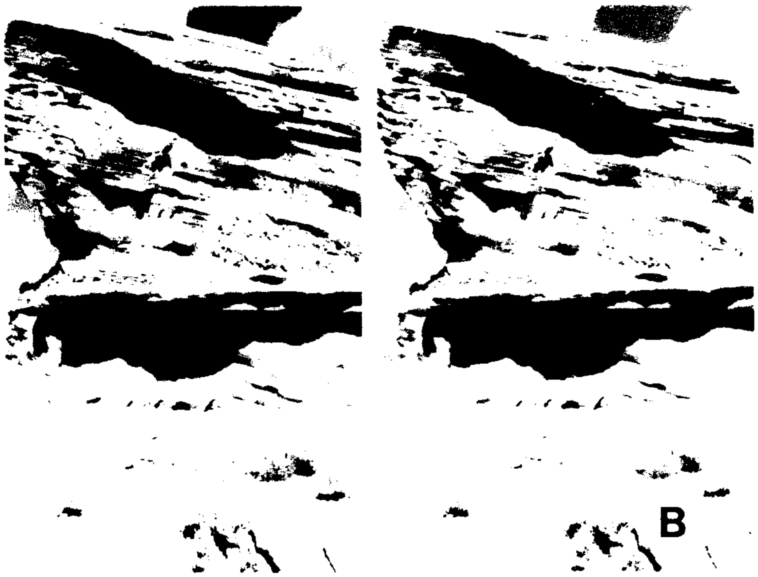
LOCATION: USA, Arizona, Coconino Co.
Five miles north of Tuba City

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

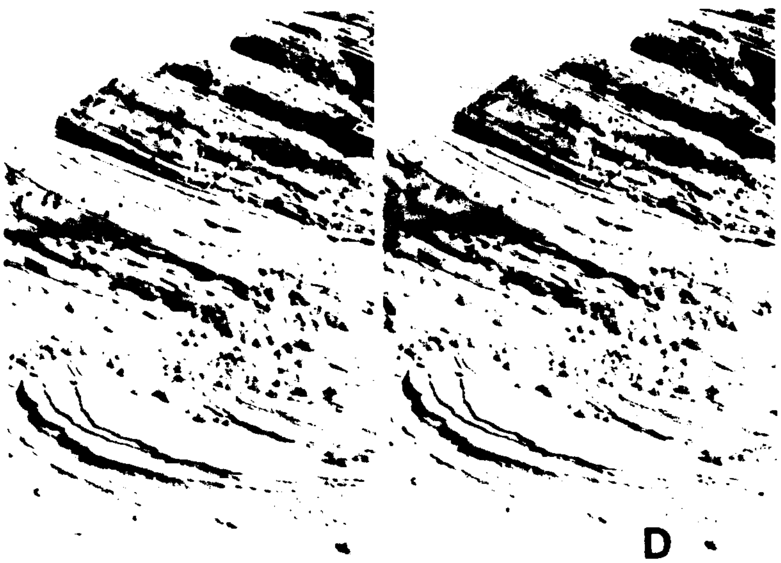
IMAGE CREDITS: Jack N. Rinker, U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, Nov 1988.

COMMENTS: Photos B, D, and G are stereo views. Arrows on Photos E, F, and G point to the same feature.

A



B



D

C


E
F
G

PHOTO: AERIAL (OBLIQUE)

LOCATION: USA, Nevada
North of Las Vegas

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Jul 1972.

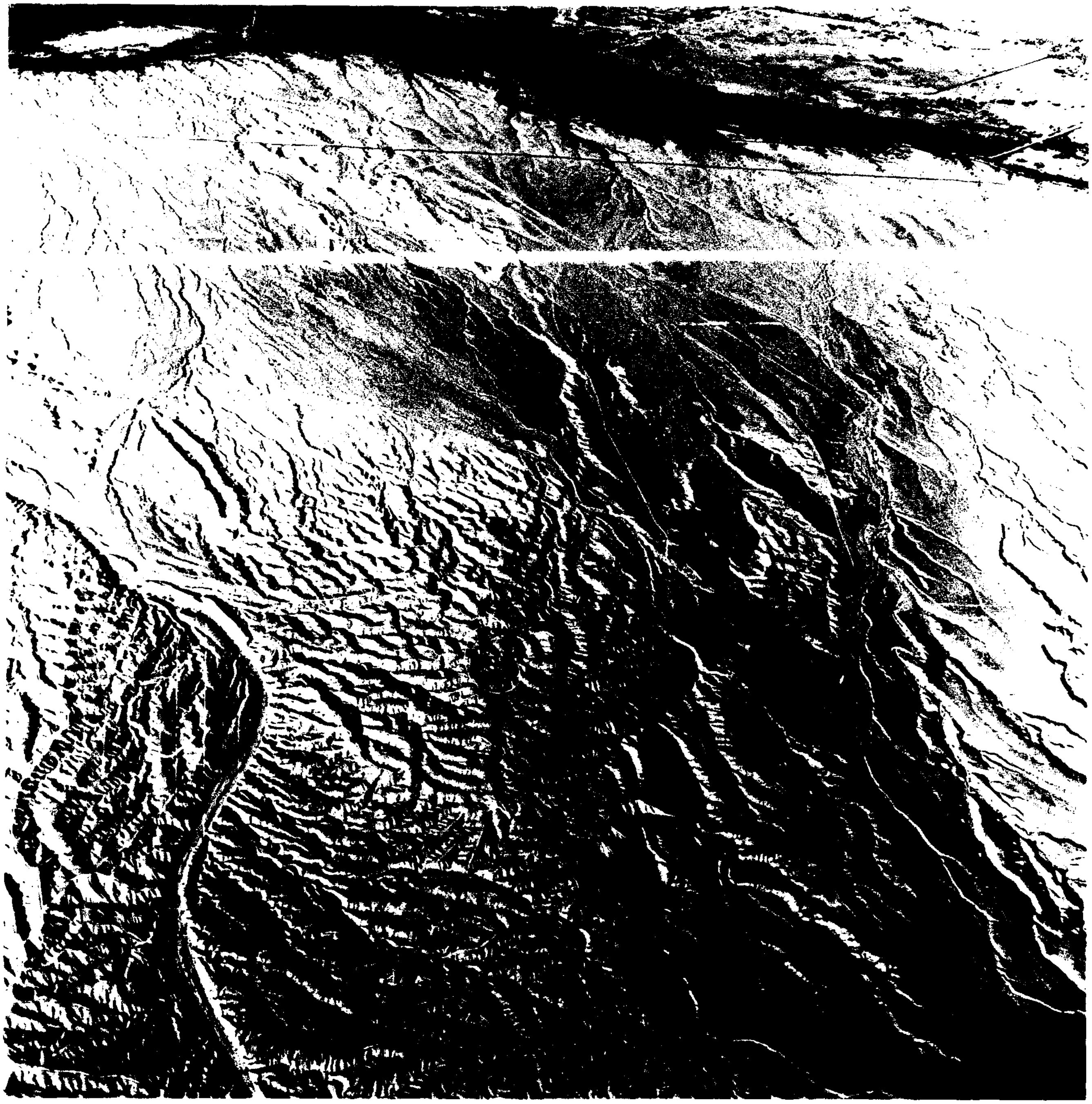


PHOTO: GROUND

LOCATION: Egypt (South-central)
Western Desert, near Bir Kiseiba

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

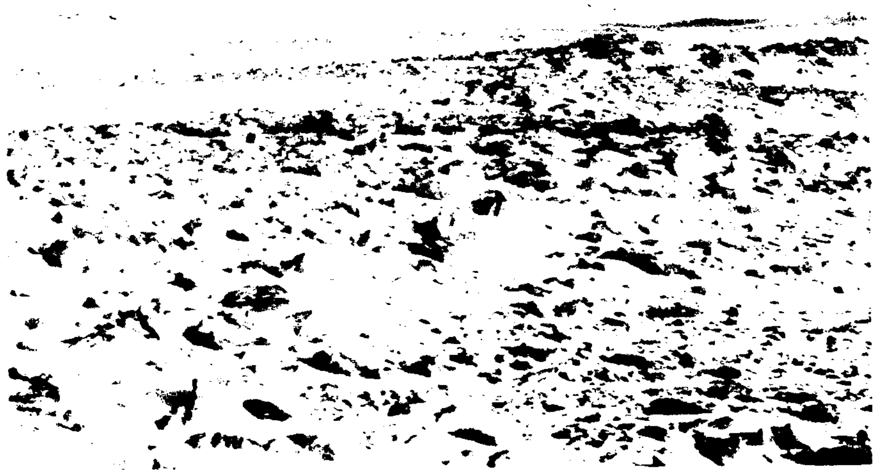


PHOTO: GROUND

LOCATION: Peru
South of Lima

CLIMATE: Hyperarid
Trewartha, 1957: BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1973.

IMAGE FILE SHEET - DESERT | DRAINAGE COURSES

PHOTOS: GROUND | WADIS

LOCATION: Egypt (Southwestern)
Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Sep 1978.

Upper wadi Ard el Akhdar

Wadi Mashi, near mouth

IMAGE FILE SHEET - DESERT

DRAINAGE COURSES

PHOTO: GROUND

WADIS - WASHES

LOCATION: Egypt (Southwestern)
Wadi Ard El Akhdar, Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

IMAGE FILE SHEET - DESERT

DRAINAGE COURSES

PHOTO: GROUND

WADIS - WASHES

LOCATION: Egypt (Southwestern)
Lower Wadi Bakht, Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

IMAGE FILE SHEET - DESERT

DRAINAGE COURSES

PHOTO: GROUND

WADIS - WASHES

LOCATION: Egypt (Southwestern)
Mouth of Wadi Maftuh, East side of Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

PHOTO: AERIAL (OBLIQUE)

WADIS - ARROYOS

LOCATION: USA, Arizona (Northeastern)
Navajo Reservation

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 26 Jun 1983.

LOCATION: USA, California
Mojave Desert

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1982.

PHOTO: AERIAL (OBLIQUE)

WADIS - ARROYOS

LOCATION: USA, California
Mojave Desert, Rice Valley

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Jun 1983.

IMAGE FILE SHEET - DESERT

DRAINAGE COURSES

PHOTO: AERIAL (OBLIQUE)

WADIS - RAVINES/CANYONS

LOCATION: Egypt
Limestone Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Mar 1983.

IMAGE FILE SHEET - DESERT

DRAINAGE COURSES

PHOTO: AERIAL (OBLIQUE)

WADIS - RAVINES/CANYONS

LOCATION: USA, Arizona (Northeastern)
Tsegi Canyon

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Jun 1983.

IMAGE FILE SHEET - DESERT | DRAINAGE COURSES

PHOTO: AERIAL (OBLIQUE) | WADIS - INVERTED

LOCATION: Egypt (Northeast)
Between Cairo and Asyut

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

COMMENTS: The coarse materials on the surfaces of the dendritic pattern of ridges once lined the bottoms of channels (wadis) of the old drainage system. The less resistant surrounding matrix has been eroded away, leaving a capped ridge system.

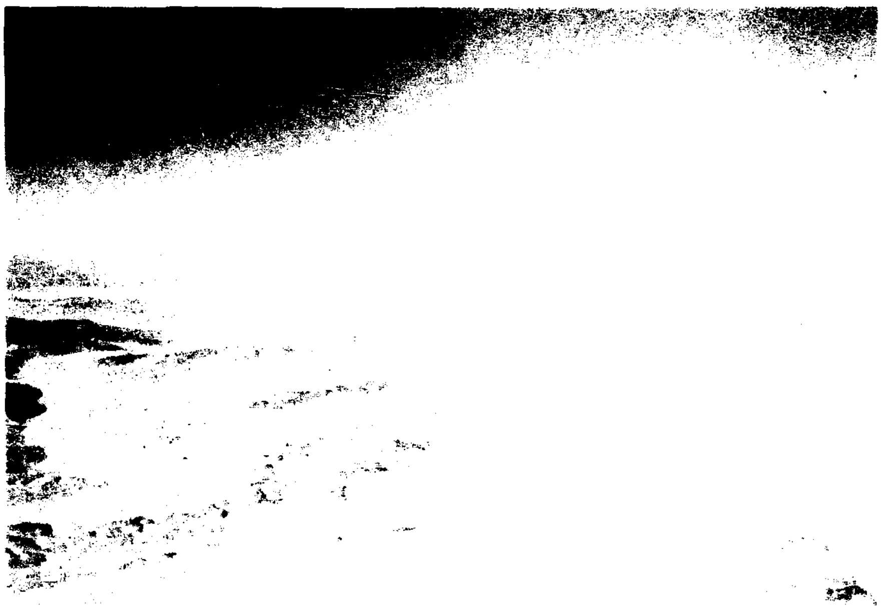


IMAGE FILE SHEET - DESERT

DRAINAGE COURSES

PHOTOS: AERIAL (OBLIQUE)

WADIS - INVERTED

LOCATION: Peru
Rio Casajal

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

COMMENTS: These ridges developed from the accumulation of sand around the denser vegetal cover in an old wadi.

IMAGE FILE SHEET - DESERT | DRAINAGE COURSES

LANDSAT: TM; PHOTO: GROUND | WADIS - INVERTED

LOCATION: Saudi Arabia, Western Shield
Landsat center 27°25'N 46°36'E; center of area C 26°43'48.2"N 47°00'05.2"E

CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:

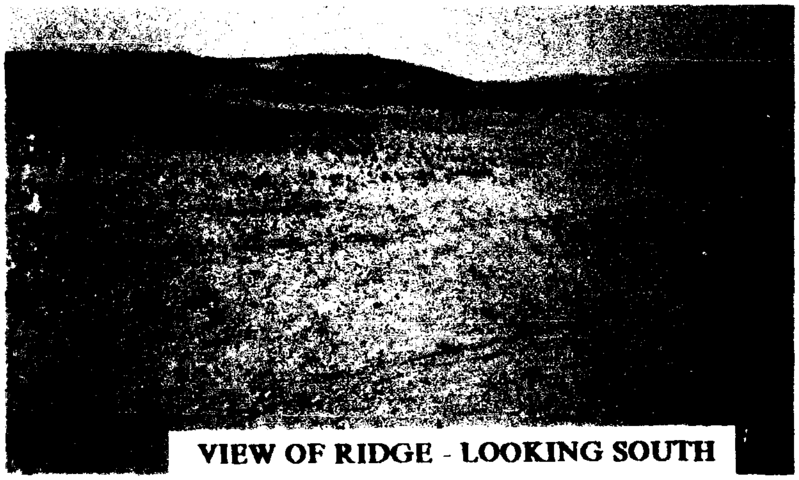
A. Path/Row 166-041, 30 Aug 1990, Bands 2, 4, 7 (blue, green, red), Scale 1:1,000,000.

B. Scale 1:250,000 of area outlined as B on TM image A. The arrows on A and the right hand portion of B mark a feature common to both images.

C. Three ground photographs of the site indicated by the arrow and letter C on image B. These photographs were taken by Jack N. Rinker, U.S. Army Engineer Topographic Laboratories, Remote Sensing Division, Fort Belvoir, VA, on 4 Apr 1991.

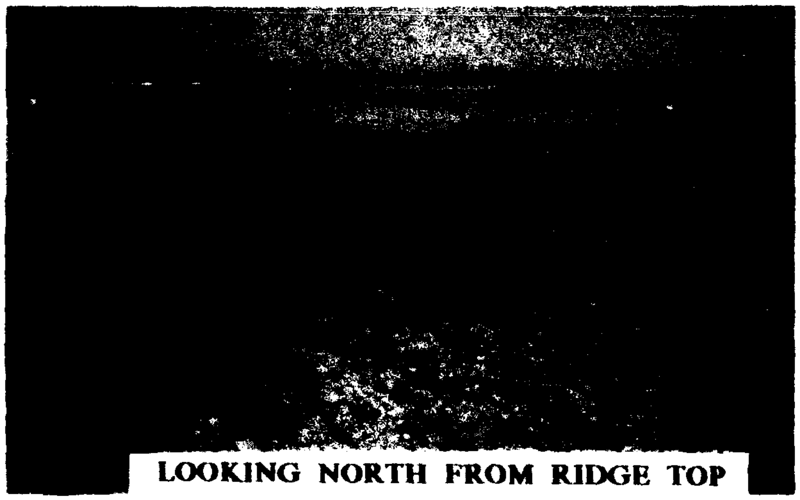
A TM 166-041 08/30/90 2,4,7 (B,G,R)

SITE C 26°43'48.2"N, 47°00.0'05.2"E



VIEW OF RIDGE - LOOKING SOUTH

CAP EDGE



LOOKING NORTH FROM RIDGE TOP

IMAGE FILE SHEET - DESERT

INSELBERGS/HILLS/KNOBS

PHOTOS: GROUND

(SANDSTONE)

LOCATION: Egypt (Southwestern)
Gilf Kebir Plateau

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

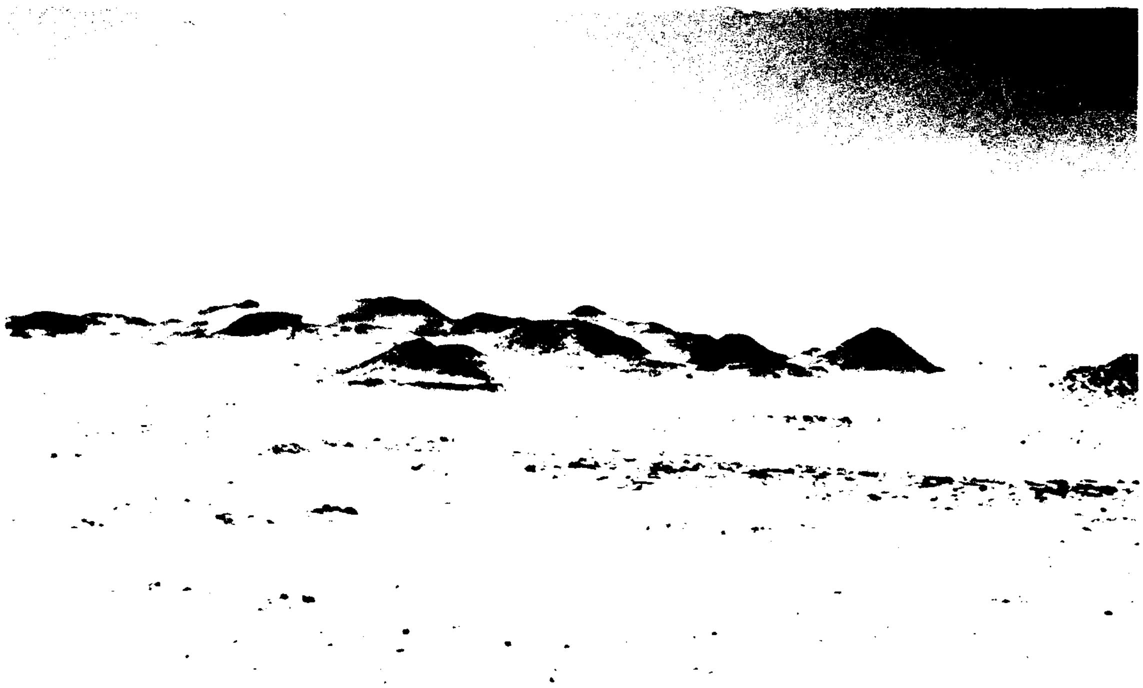


IMAGE FILE SHEET - DESERT

INSELBERGS/HILLS/KNOBS

PHOTO: GROUND

(GRANITE)

LOCATION: Egypt (South-central)
Qaret El Maiyet

CLIMATE: Hyperarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1978.

PHOTO: AERIAL (OBLIQUE)

LOCATION: USA, California
Mojave Desert near Baker

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: John F. McCauley, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Jul 1972.

PHOTO: AERIAL (OBLIQUE)

LOCATION: USA, Arizona (Northeastern)
Ha Ho No Geh Canyon, east of Tuba City

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

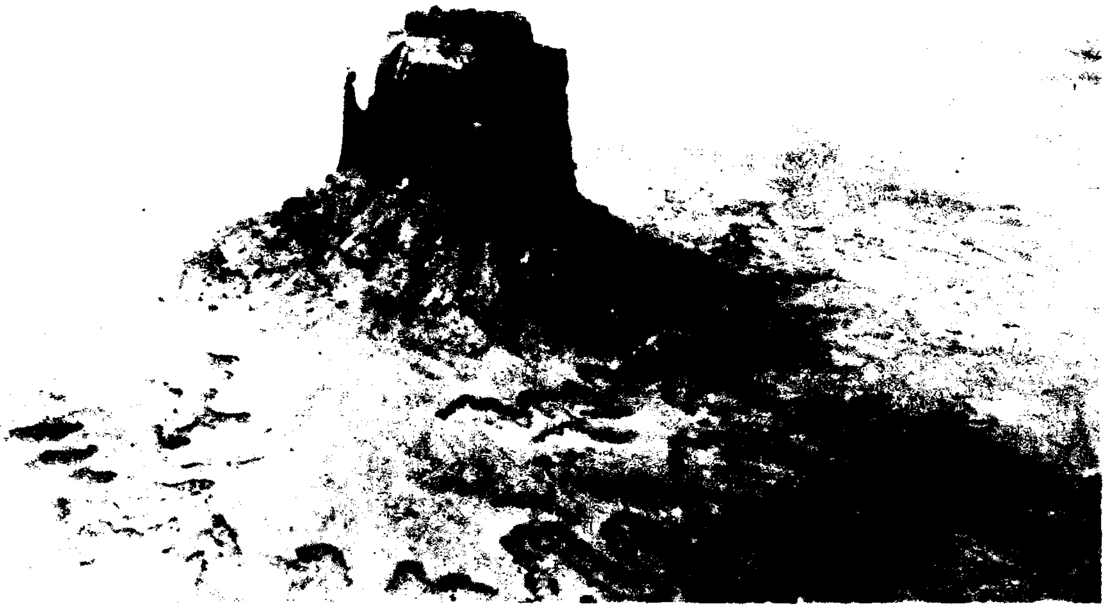
IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Dec 1979.

PHOTOS: GROUND AND AERIAL (OBLIQUE)

LOCATION: USA, Arizona (Northeastern)
Monument Valley

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Jun 1980 (top photo); Jun 1983 (bottom photo).

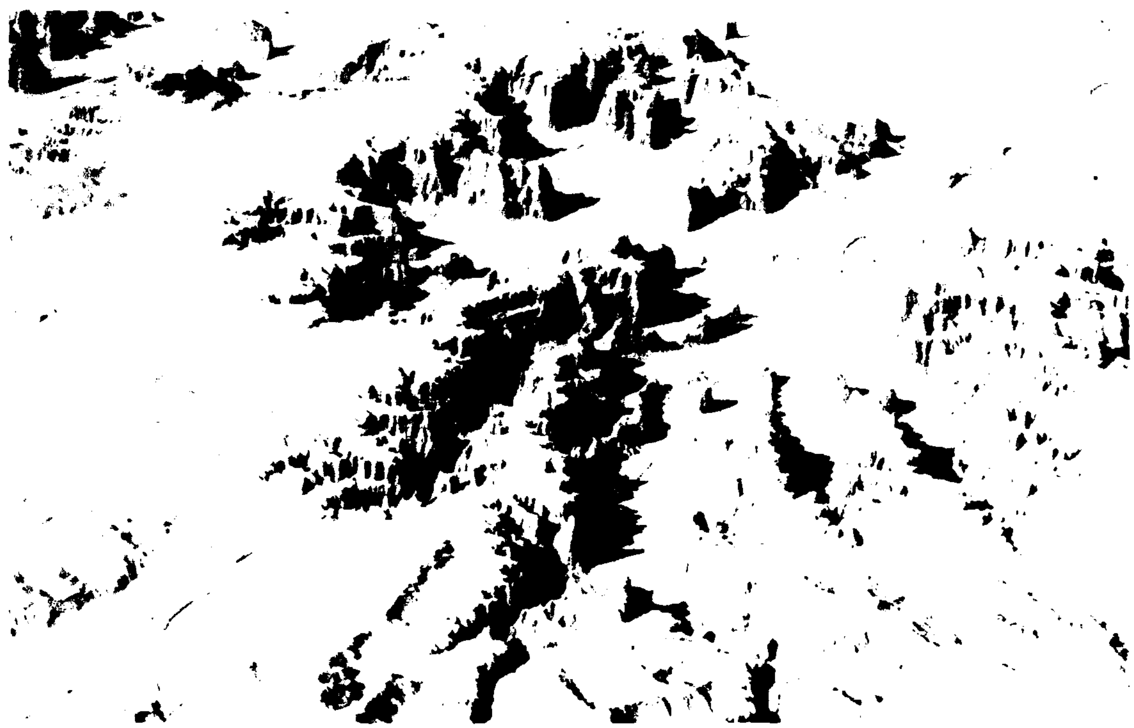


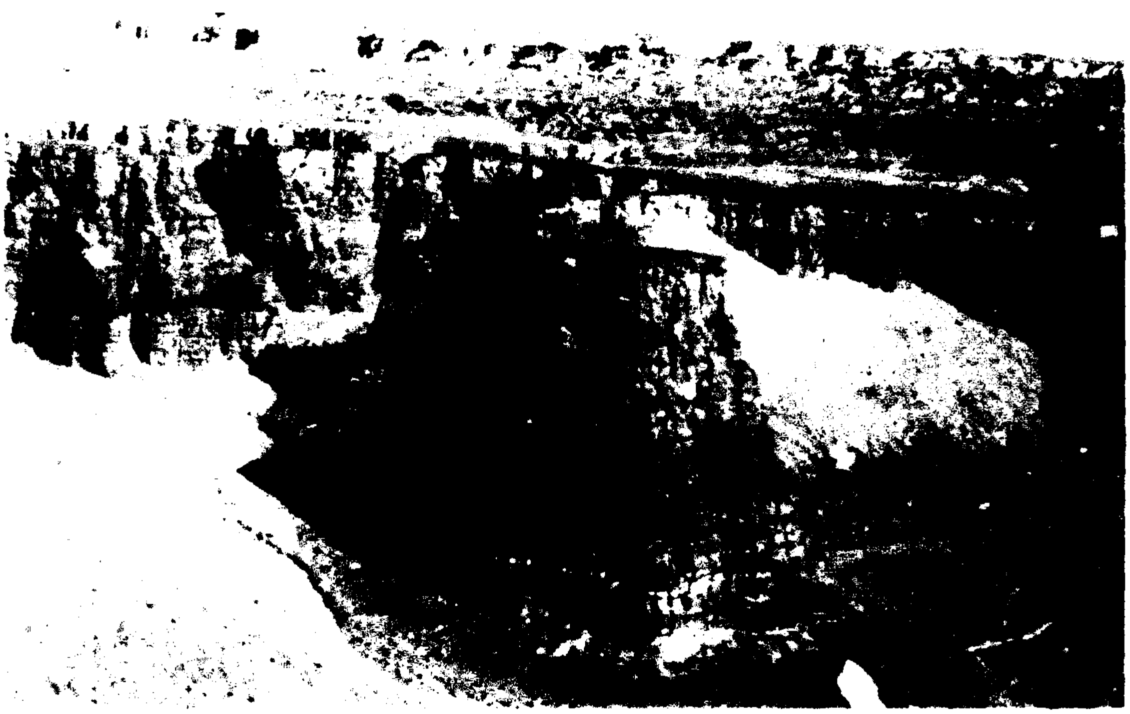
PHOTOS: AERIAL (OBLIQUE)

LOCATION: USA, Arizona (Northeastern)
Red Rock Cliffs

CLIMATE: Semiarid
Trewartha, 1957: BSk: Middle Latitude Steppe, cold and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 1980(?) (top photo); 1979 (bottom photo).





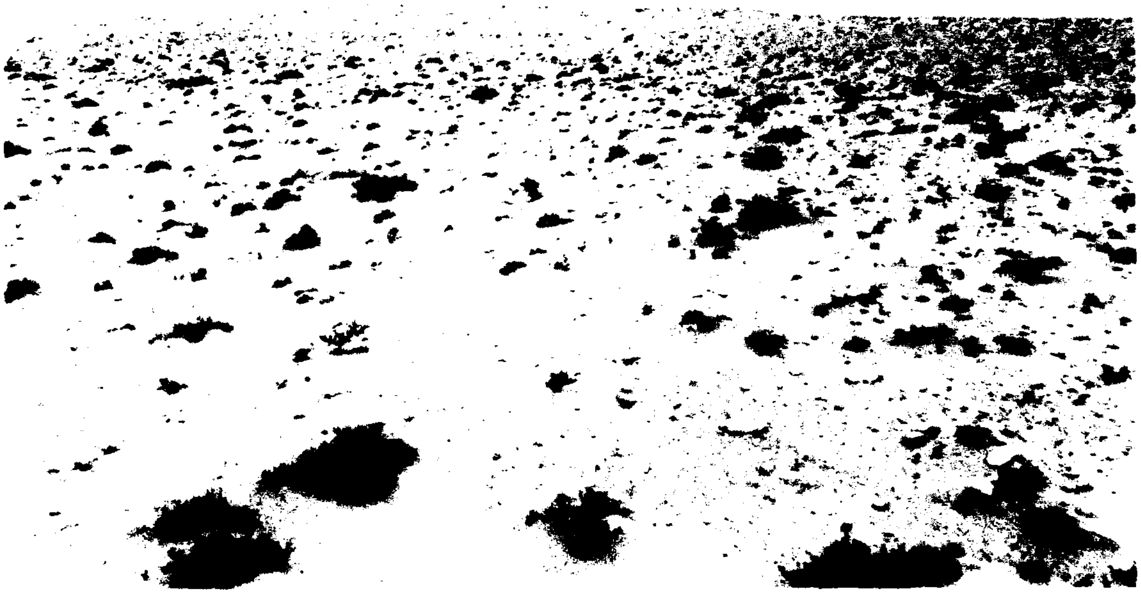
PHOTOS: GROUND

LOCATION: Morocco (Coastal)
Near Tarfaya

CLIMATE: Arid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 10 Jan 1988.

COMMENTS: This beach ridge is one in a series now standing abut 40 m above sea level. Cobbles are from wadi gravels redistributed by wave and current action and consolidated in beach deposits.



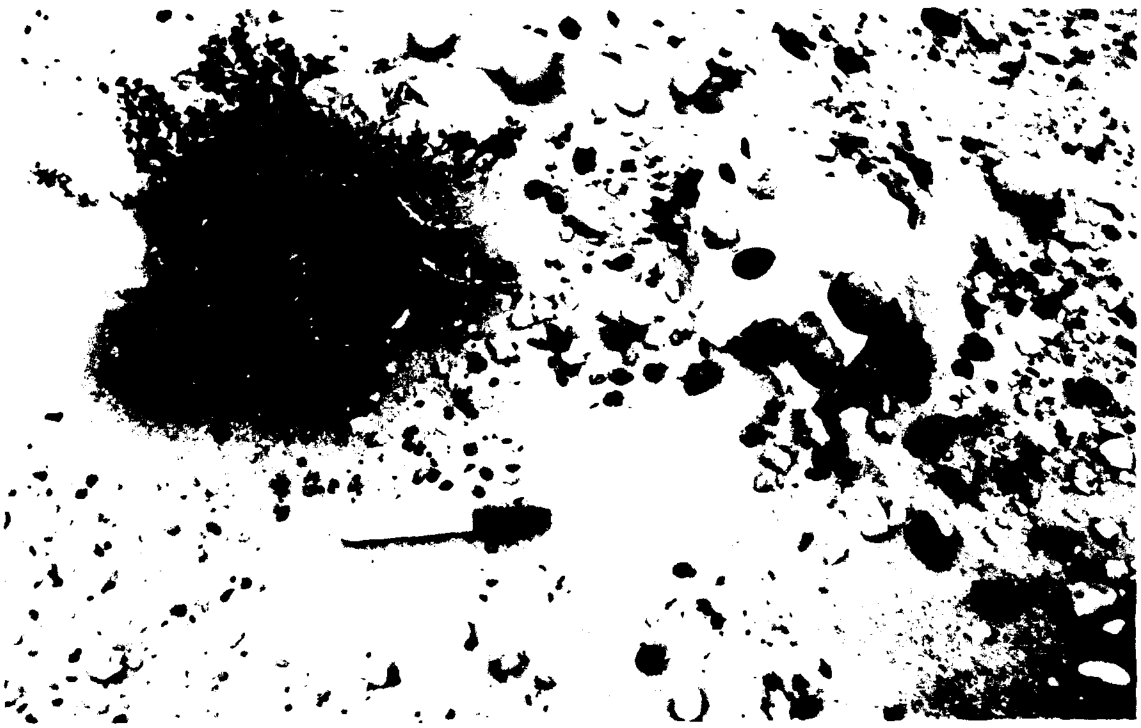


IMAGE FILE SHEET - DESERT

BURN SCARS

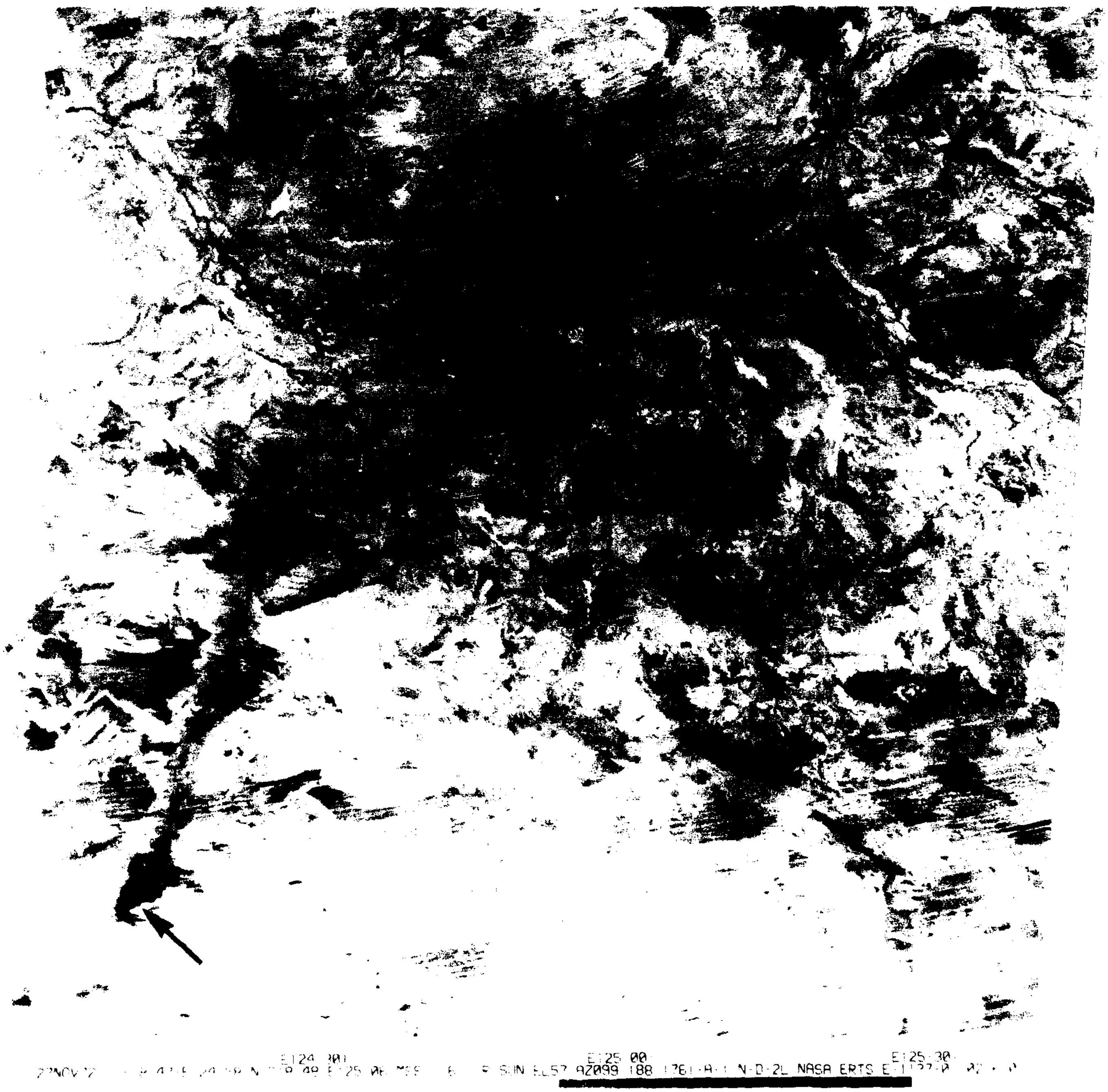
LANDSAT: MSS

LOCATION: Australia (Western)
Center point 18°47'S 124°58'E

CLIMATE: Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Scene E-1127-01102, Band 6, 27 Nov 1972, Scale 1:1,000,000.

COMMENTS: Arrow marks an active burn.



DESERT PROCESSES WORKING GROUP

IMAGE FILE SHEET - DESERT BURN SCARS

LANDSAT: RBV

LOCATION: Australia (Western), Southwest of Kalgoorlie
West of Lake Johnston, center point 32°06'S 120°29'E

CLIMATE: Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Scene E-31101-00595, Quadrant D, 10 Mar 1981, Scale 1:500,000.

COMMENTS: Arrows point to the feature.

DESERT PROCESSES WORKING GROUP

IMAGE FILE SHEET - DESERT

BURN SCARS

PHOTO: AERIAL (OBLIQUE)

(ACTIVE)

LOCATION: Australia (Northern Territory)
Simpson Desert

CLIMATE: Semiarid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Sep 1976.

COMMENTS: Black areas are burn scars; note smoke from one in foreground.

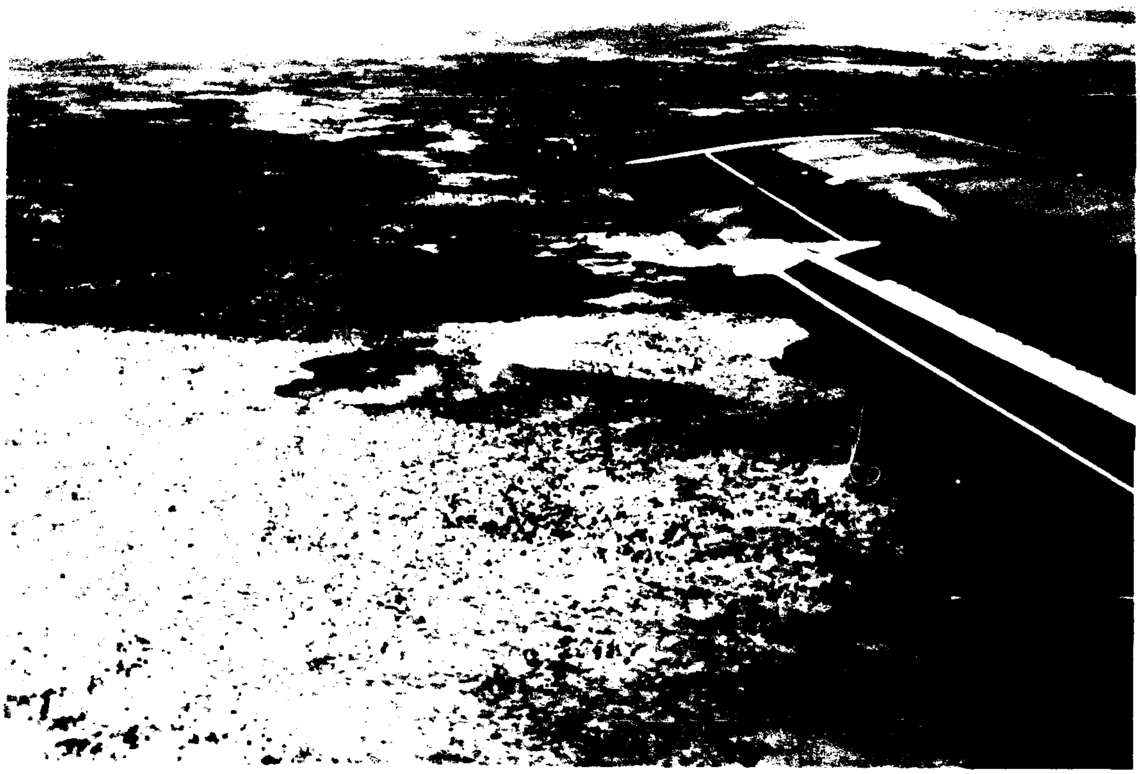


IMAGE FILE SHEET - DESERT

DURICRUSTS

PHOTO: GROUND

LOCATION: Saudi Arabia
West of Riyadh

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's

COMMENTS: This deflated duricrust, and rubbly surface on top of the Tuwayq escarpment, presents obvious problems to cross-country movement.

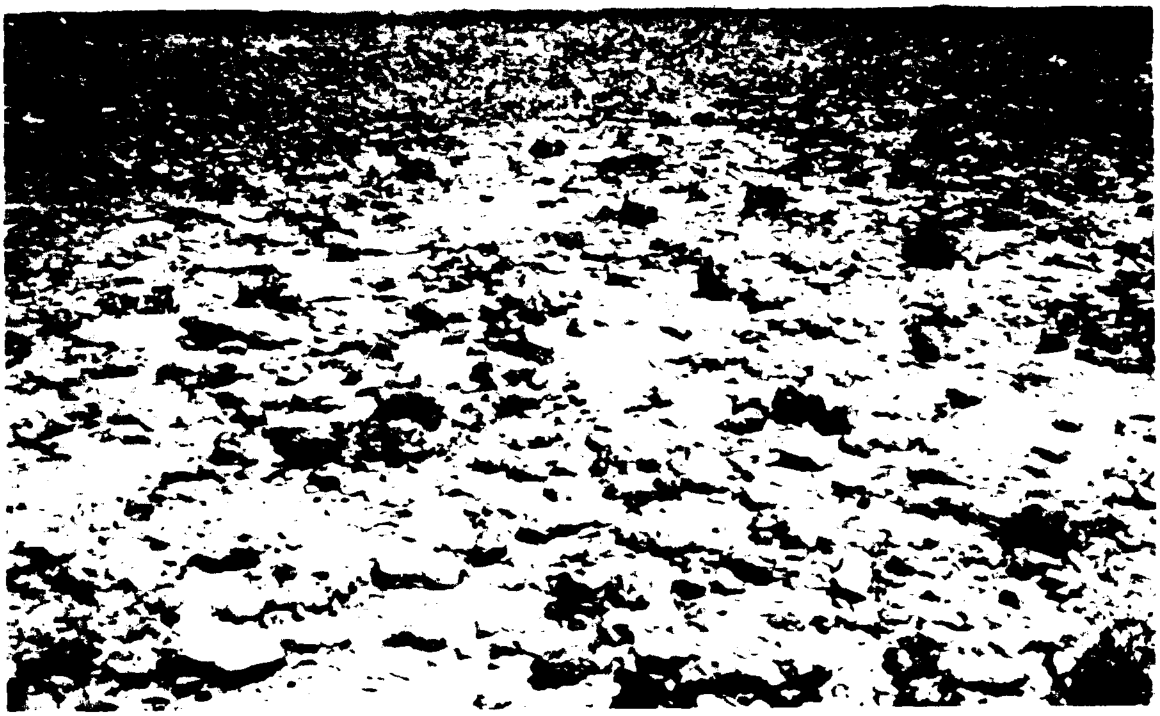


IMAGE FILE SHEET - DESERT

DURICRUSTS

PHOTO: AERIAL (OBLIQUE)

LATERITE/FERRICRETE

LOCATION: Australia (Western)
South of Fitzroy Crossing

CLIMATE: Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 6 Aug 1981.

COMMENTS: Irregularly shaped dark-toned patches are laterite (see arrow).

IMAGE FILE SHEET - DESERT

DURICRUSTS

PHOTO: GROUND

SILCRETE

LOCATION: Australia (Southern)
Sturt Stony Desert, Near Innamincka

CLIMATE: Semiarid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe, hot and dry

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, Sep 1976.

COMMENTS: Silcrete-capped mesa or "breakaway."

IMAGE FILE SHEET - DESERT TAFONI

PHOTOS: GROUND

LOCATION: A. USA, Arizona (Northeastern), near Holbrook
B. Mexico, Baja California, near Cabo San Lucas, 23°N 110°W

CLIMATE: A. & B. Semiarid
Trewartha, 1957: A. BSk: Middle Latitude Steppe, cold and dry
B. BWn: Tropical and Subtropical Desert, cool coastal, frequent fog

IMAGE CREDITS: U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ:
A. Carol S. Breed, Mar 1978.
B. John F. McCauley, Apr 1979.

A

B

IMAGE FILE SHEET - DESERT

CULTURAL FEATURES

LANDSAT: TM

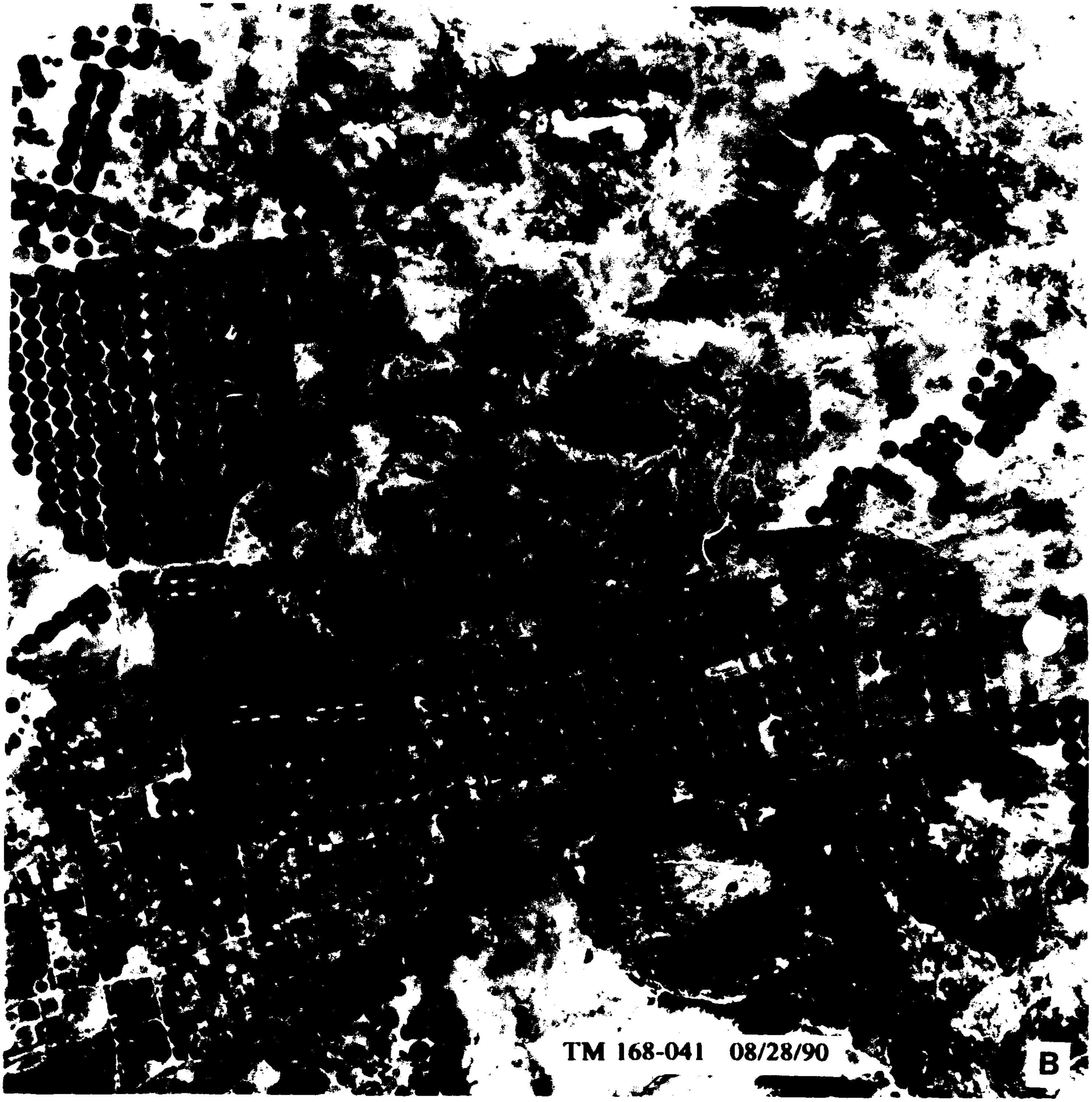
AGRICULTURE (IRRIGATION)

LOCATION: Saudi Arabia
Center point of image A: 27°27.8'N 45°30.2'E

CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. Path/Row 168-041, 28 Aug 1990, Bands 2, 4, 7 (blue, green, red), Scale 1:1,000,000.
B. A 1:250,000 scale image of the area denoted as B in image A.

COMMENTS: Center pivot irrigation systems. The larger circular fields are about 1 km in diameter.

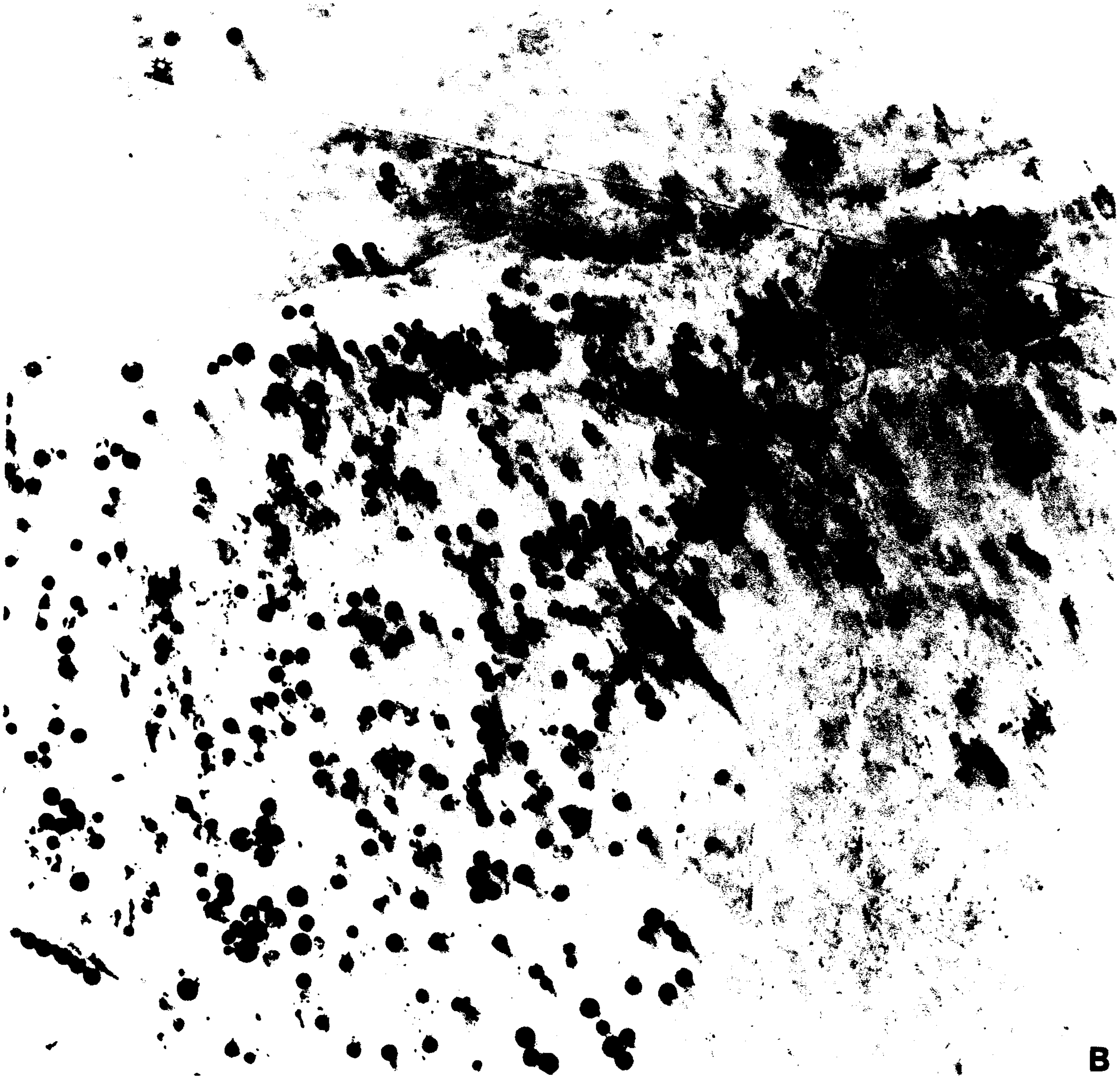

TM 168-041 08/28/90
B

LOCATION: Saudi Arabia
Center point of image A: 27°26.2'N 48°07.8'E

CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS:
A. Path/Row 165-041, 31 Aug 1990, Bands 2, 4, 7 (blue, green, red), Scale 1:1,000,000.
B. A 1:250,000 scale image of the area denoted as B in image A.

COMMENTS: Center pivot irrigation systems. The circular fields range from 0.5 to 1.0 km in diameter. The Trans-Arabian Pipeline road angles across the upper part of the image, and the village of Qaryat al Ulya is in the blue streaked area near the center of image B.



B

PHOTO: GROUND FENCELINES (SAND CONTROL)

LOCATION: North Africa (Western Sahara), Tunisia, near Tozeur

CLIMATE: Arid
Trewartha, 1957: BSh: Tropical and Subtropical Steppe

IMAGE CREDITS: Carol S. Breed, U.S. Geological Survey, Desert Studies Group, Flagstaff, AZ, 28 Oct 1989, 1400 hrs.

COMMENTS: View from top of jebel. Dunes with sand-control fences. Bedrock is late Tertiary (Mio-Pliocene) sandstone.

LANDSAT: TM

FENCELINES

LOCATION: Saudi Arabia
Center point of image 27°27.8'N 45°03.2'E

CLIMATE: Extremely arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: Path/Row 167-041, 29 Aug 1990, Bands 2, 4, 7 (blue, green, red), Scale 1:1,000,000.

COMMENTS: Two of the large fenced-in areas are indicated by arrows. These fences serve for control of sand and grazing cattle.

IMAGE FILE SHEET - DESERT

CULTURAL FEATURES

PHOTO: GROUND

INDUSTRIAL (OIL FIELD)

LOCATION: Saudi Arabia
Between Hufuf and Haradh

CLIMATE: Arid
Trewartha, 1957: BWh: Tropical and Subtropical Desert, hot and dry

IMAGE CREDITS: U.S. Department of Agriculture, mid 1980's.

COMMENTS: Oil field gas flares.

IMAGE FILE SHEET - DESERT | CULTURAL FEATURES

PHOTO: AERIAL (OBLIQUE) | INDUSTRIAL (PIPELINES)

LOCATION: Saudi Arabia
Eastern Province, Dhahran area

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: Photograph courtesy of S.G. Fryberger, Desert Engineering, Golden, CO, early 1980's.

COMMENTS: View south along pipeline carrying oil from Berri to Abqaiq.

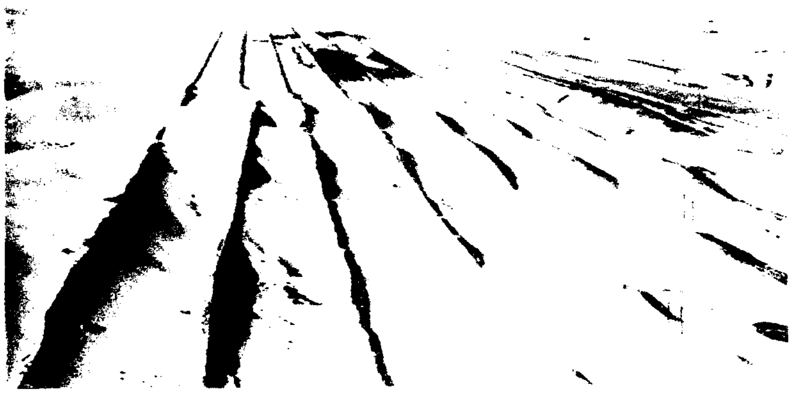


IMAGE FILE SHEET - DESERT

CULTURAL FEATURES

PHOTOS: GROUND

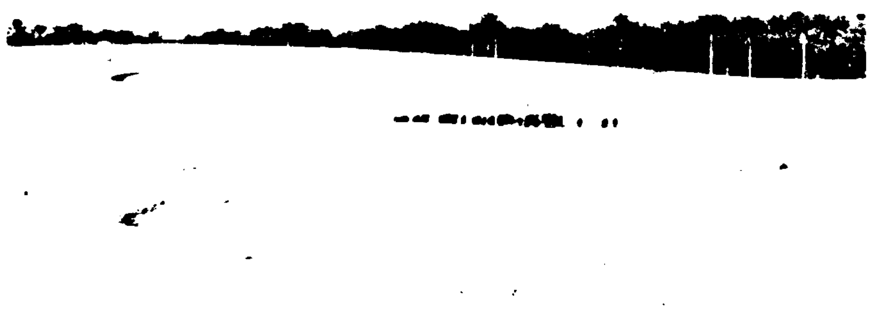
WATER

LOCATION: Saudi Arabia
Al Qatif area, halfway between Dhahran and Ras Tanura

CLIMATE: Arid
Trewartha, 1957: BWhn: Tropical and Subtropical Desert, hot and dry, coastal fog

IMAGE CREDITS: C.A. Kemp (retired ARAMCO), Redwood City, CA, early 1950's.

COMMENTS: The cylindrical objects on the left side of the sand plain are old well walls, now exposed by erosion of surrounding material.



When driving downwind in a dune field, even at slow to moderate speeds, care must be taken not to drive off the slip faces of small dunes superposed on larger, more obvious features. These faces can be many meters high and, in the desert glare, can come upon the unwary driver without warning. The consequences of becoming airborne are not pleasant, and tales of wrecked vehicles and serious injury abound among field workers in dune areas--including military groups, oil exploration teams, and scientific parties.

General trafficability is partly a function of the time of day. Early morning is the best time to traverse dune fields because nighttime condensation makes the upper layers of sand slightly cohesive. Sand tracks, or some equivalent aid, are a bother to carry, and cumbersome to use; but, they are a necessity for wheeled vehicles if continuous mobility is to be maintained in areas of loose, deep sand. Avoid traveling in the tracks of preceding vehicles. If tracks must be crossed, cross them at a fairly large angle, but not so close to perpendicular that unnecessary bouncing takes place. When crossing recently destabilized areas where there are many criss-crossing tracks, such as convoy routes, oil field roads and work areas, care must be taken to avoid loss of traction and induced swerving sufficient to cause roll over. Dust generation is not a problem when traveling on active dunes or on most sand plains.

In very arid regions there is little or no vegetation, and concealment from the air is practically nil, except down the sun line where backscattered sun glare makes visual detection difficult. Horizontal visibility is controlled by the wave pattern of the dunes, and lines of sight can be very short. The highest parts of a dune field do not allow for a view of all the low parts of the field, but assure the detectability of the observer.

Digging in dry active dunes is futile, because of the lack of cohesion. In damp sand areas, excavations can be made to a meter or more, but these rapidly collapse as the exposed sand dries. Even when a cohesive substrate is present, and excavation is practical, the void fills in rapidly with loose sand that moves with every windstorm.

Surface operations in the hyperarid regions of the world, particularly in the Sahara, present a distinctive set of problems. The landscape looks totally alien. At certain times of the year, extreme temperatures, low humidity, and episodic regional dust storms (Khamsins) make any type of sustained effort away from a base camp very hazardous. There is a six month period (October-March) however, when operations are more feasible if certain cautions are exercised.

Navigation can be a problem because the extensive, gently undulating sand sheets with their isolated patches of large dunes present a vista somewhat like that of the open ocean. The horizon is featureless, and there are few landmarks to steer by--no mountains in the distance--no easily recognized water courses --no trees--only scattered bedrock nubbins and isolated small vegetation mounds that can be tens of kilometers apart. A dead reckoning plot (compass and odometer) must be kept for all traverses as a backup for any electronic locating devices being used. All of the techniques of coastal piloting become applicacable with the few reliable scattered landmarks serving as navigational aids. Landsat TM imagery co-registered with whatever topographic data are available, is probably the best overall type of chart for use in these areas.

GETTING AROUND

WHEN YOU AND YOUR VEHICLE MEET THE EAST SAUDI DESERT

Draft by

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1 March 1991

Well, here you are. Eastern Saudi Arabia. Unless you come from certain parts of Australia or a few spots in the American Southwest, it looks pretty weird. Being plunked down in the middle of our dune fields or gravel plains can in fact be something like a moon landing. You will soon discover that your vehicle also feels a bit strange here and may not behave in its accustomed manner.

The ideas collected here are the distillation of one Westerner's 30 years' experience in local desert travel and are intended to help newcomers short-circuit some scratch learning.

One of the greatest highway hazards is hitting livestock after dark. A camel has enough bulk to demolish a car and kill its occupants when hit at highway speeds. Even where freeways are fenced, there may be gaps allowing camels to get out on the road. The danger is greatly increased on non-fenced, narrower roads. The only defense is never to "overdrive" your headlights. Use high beams and keep your speed low enough to enable you to stop in the short time available after that first glimpse of an animal.

A word should also be said about tire care in hot summer weather. Contrary to what some might expect, the harder a tire is inflated on a hot highway, the cooler it runs. Heat build-up is caused by underinflation and excessive flexing. Standard and some fleet-grade passenger car tires, if underinflated, can get hot enough here in summer to peel off their treads and blow out. The best prevention is to keep tire pressure high in hot weather --preferably 40 pounds--despite what the owner's manual says. That's best for the tires and the car. You'll only feel the bumps a bit more.

Off-Road Equipment

You probably have little choice about what vehicle you drive, but a few remarks about desert equipment might be worthwhile. Many standard military vehicles are near-ideal for desert use. They have good ground clearance, multi-wheel drive, and tough suspensions. The standard military tires are good for our rocky areas and northern plains. They may not, however, be ideal for sand. Experts will argue for hours over the merits of different sand tires, but there is general agreement on the following points.

* Radial tires are better than bias plys, even though their sidewalls are more liable to damage on rock.

* A broad tire with rounded profile is better than one that is narrower and square, with sharper corners.

* A thin, flexible tread with shallow pattern is better than a thick one with a deep "mud-cutter" pattern.

If you are spending much of your time in heavy sands, it would be worthwhile looking into a way to get more sand-worthy tires. Remember, though, that broad tires lose much of their advantage if they are "pinched" onto narrow rims. The ideal solution, perhaps not attainable, is to keep on hand a set of sand tires, ready-mounted for use in sand and a standard set on standard rims for moving out into rock and gravel country.

Keep in mind that changing tire diameter can effect the calibration of your car's speedometer and odometer by up to about 13 percent. Increasing tire diameter will result in your speedometer reading <u>lower</u> than actual speed and distance. And vice versa. This can be important in dead-reckoning navigation and must be compensated for in calculations of distance. Changing tire diameter will also affect general vehicle performance by effectively changing your rear-end ratio. In most cases, the improvement of sand tires will more than offset the change in overall gear ratio.

The following equipment is also very useful or required:

* A tire gauge for accurate tire inflation (and deflation--more on that later).

* A reasonably high-volume air pump for tires (this is not primarily for repairing tire punctures--again, see ahead).

* At least one shovel for digging out.

* Sand tracks, if one spends much time in slipface dune country or if your tires do poorly in any sand terrain (described below).

* A pair of binoculars for checking out the route ahead (even a small, fairly cheap pair will do the job in our desert light).

The above does not cover navigation aids, to be discussed later.

O.K., it's time to get off the road. You will most probably start off on one of those ...

Desert Tracks

By "track" we mean here anything from paired ruts made by more than one vehicle to the improved routes sometimes graded and built up with marl (a pale, chalky, clay-like material).

The main problem with desert tracks is that there are too many of them. Maps are usually based on aerial photographs several years old and therefore out of date. Photo-interpreters can't possibly show all the tracks on their maps anyway; they have to pick and choose from the photos. They usually do a pretty good job, but they can't help you on the ground when you are confused by all the old or new tracks they haven't put on the map. And the desert is criss-crossed with them.

You will probably get to your unit location from the highway on a well-marked and easy-to-learn track. You can put a few markers along it to help remember any turns. But what about using tracks farther afield? Let's look at some common types and what they're good for:

* Well used tracks leading to villages that aren't yet served by paved roads: these can be very useful for getting to important landmark locations.

* Bedouin tracks that lead all over the desert with many turns, heading for desert wells and Bedouin campsites: Very confusing and not of much use unless they happen to lead in roughly your desired direction.

* Oil company exploration tracks: These may be old seismic exploration lines, often running straight as an arrow for a hundred kilometers or more, sometimes oriented due north-south or east-west, sometimes on other bearings. At intervals you'll see iron pipe markers with welded code numbers. Problem: these tracks often lead to no place of interest and become sanded over, and the code numbers won't help you find where you are unless you have a difficult-to-obtain seismic line map. When these lines do lead somewhere useful they are sometimes heavily used by local Bedouins and become good routes.

* Oil company work tracks: These may be improved by grading or marl surfacing. But they usually lead only to remote and long-abandoned drilling locations. They can still be useful if they happen to pass near your assigned or desired patrol area. Another kind of work road, usually found in barren gravel plains and not marled, are old truck routes used for pipeline construction hauls. These may be 40 years old but still clear with their original washboarding. They are often marked by a grader berm along one or both sides and thus make useful reference lines in open country.

The thing to remember about tracks is that it's almost always better to use any kind of one than to go straight cross-country in raw desert. When the terrain includes rocky hills, bush hummock areas or other rough going, time will always be saved using tracks rather than virgin desert. This can be true even if the track distance is a lot longer than as the crow flies.

Whenever you know what direction to go, try and find a track that leads generally that way. Don't be overly concerned about each little twist and turn; take a long view from a high point and check the track out to the horizon. If it averages roughly the right direction, it will save you time.

Track surfaces are very variable. Some provide very fast and smooth going, particularly when the ground is fairly hard but covered with a thin, cushioning layer of sand. Others are rough and become "washboarded." This happens when a track on hard ground is used by heavy traffic. The pounding produces close-spaced cross ridges that make for a very rough ride. Washboarded tracks tend to get wider and wider as drivers take to the edges where going is smoother. They may end up as multiple, parallel tracks with a total width of several kilometers. Vehicles with coil springs generally do better on washboard than those with leaf springs.

Washboard can be very tiring and even damaging at medium speed. The worst of it can be avoided by driving along the track edges rather than the older middle section. One can slow down to a crawl to reduce the pounding, but a better technique is to <u>increase</u> speed. Each type of vehicle on each type of washboard will have an optimum higher speed at which the suspension will "float" over the tops of the ridges with much less vertical motion. It's partly a matter of system resonance. Keep in mind that such "floating" involves reduced ground contact and traction. It then becomes easier to skid or lose control, so drive with extra care. One may be tempted to leave the track entirely and parallel it in the raw desert. This may help for a while, but it can leave you exposed to dangerous bigger bumps and runnels and usually takes more driving time in the long run.

But don't be a slave to any track. Go <u>around</u> the bad stuff. A typical example is where a fairly good track passes through some deep, loose sand where loose channels show that previous vehicles had trouble. In cases like this build up some speed and go off the track to one side where you see sand with bushes and <u>no car tracks</u>. It will be firmer there and you won't have to waste time churning out from a stall.

So you just <u>have</u> to go off cross-country? In our coastal and southern parts the first thing you may see is lots of ...

Sand

Sand is strange stuff. It's unexpectedly hard under your back and unexpectedly soft under your tires. Successful driving in sand is 75 percent skill and 25 percent equipment. You'll believe that when you see a Bedouin Arab take a two-wheel drive mini-pickup with street tires across a field of slipface dunes, without a pause, leaving nothing behind but neat, clean tread prints. He can do that because he's learned to read the sands since he first started to walk. For most of us it's not so easy. But it helps to learn a bit about how sand behaves.

Sand, for those who care, is defined by the geologist as loose particles ranging in size from 2 mm to 1/16 mm. When its smaller it's silt. Smaller still and it's clay. Sand, because of its relatively large particle size, moves with the wind quite close to the ground, each grain in multiple bounces. It takes exceptional winds to lift sand much above waist high. The great majority of what many people call "sandstorms" are actually dust storms, consisting of the desert's finer silt particles.

On open ground sand is laid down by the wind in neat layers that are invisible when dry but which can be seen when a dune is wet from rain and cut with a shovel. The thickness and direction of these layers is all-important. They are normally laid down horizontally or with only gentle slopes, and the surface then takes on a compact, tight structure that provides a relatively firm surface.

You will soon discover that many kinds of sand terrain show a sort of "crust effect": it behaves as if it had a firmer, invisible layer on the surface, with softer stuff below. This is apparent both when walking and driving; if you work much in sand country you'll soon find yourself starting to walk like a Bedouin --taking short quick steps and putting your feet down very flat. It's easier because you don't break through that crust. In a car you'll find that as long as you keep moving and keep your wheel turn rate in synch with your horizontal speed, you will float along nicely and not break through. But if you brake suddenly or spin your tires by gunning the engine, you will break through and sink down, and often stall in place.

All of this means that you will soon be forming new sand "walking habits" in your vehicle. Never brake hard except in an emergency. Always slow down very slowly and release your brakes those last few inches, <u>coasting</u> to a stop. This gives you the best chance of staying on top for an easy start later. Whenever you have a choice--and you usually do--stop your car on higher, firmer ground not cut up by other vehicles, and pointing downhill. Starting out again will then be easier. When you do start up again, engage the clutch very slowly and be tender with the gas pedal. If you break through, you'll have to go through that annoying, low-gear churn routine.

Here are some other important facts about sand driving in any kind of terrain:

Rain can be a problem in some kinds of desert terrain, but in sand, <u>rain is always your best friend</u>. Forget anything you may have heard about heavy rain turning sand into quicksand. It doesn't happen. The heavier and longer-lasting the rain, the better. When wetted thoroughly sand becomes magically firm and friendly, and you can go places you would never dream of trying when it's dry. The "crust effect" disappears and the surface stays firm all the way down. Even when the top layer dries out and looks loose, the firm moist ground below will give you added days or weeks of easy going. The only danger is that this speedy traveling will make it all too easy to take flight over a slip face or hit one head-on. More about that ahead.

Even more than in other desert terrain, dune driving requires taking a long view. Don't become so engrossed with what's just in front of you that you forget to keep an eye on the kind of general terrain you're getting into. Stop often on high points, look all around, and pick the best general direction and route.

Dunes

When sand gets piled up enough so that its downwind slope is somewhat protected from wind effects, this downwind face gets steeper and steeper until the sand starts to slip downwards in little avalanches. Wherever this happens, the layered structure changes abruptly. It is no longer compact, and it is angled steeply downwards at an angle of about 34 degrees, forming a slipface. This slipface sand is loose and "airy," just like flour is after it's been sifted.

Under some conditions this may lead to the formation of one classic and common dune form, the barchan. This, when standing alone, is the familiar crescent-shaped dune with the relatively long backslope on the upwind side, and the abruptly falling, concave slipface on the downwind side. The sides are elongated and slope forward, forming two "horns."

Barchan dunes tend to move, always downwind, at speeds ranging from about 2 to 60 feet per year. They do this because sand is continually blown up the backslope and keeps tumbling down the front slipface. The slipface, and the whole dune behind it, thus keeps moving forward.

Incidentally, just in front of the slipface of a big crescent dune may look like a great place to camp for the night. Wind protection, right? Only if the wind is guaranteed not to exceed about 10 miles an hour. If it does blow a bit harder, all night long you will enjoy a continual, overhead sifting of the finest grit, settling into your hair, food, and sleeping bag.

Desert scientists have studied and named more than a dozen different shapes and kinds of dunes. These different forms are often mixed together and attached to each other. But in sand driving the only things that really matter are the following questions:

* Are there any slipfaces here, or not?
* How big are the ripples?
* If there are bushes, how close together are they?

The first question is by far the most important.

In our area, if you don't see any slipfaces you will be dealing with sand sheets or bush hummock country, or the gently rounded, smooth clean whalebacks called zabayir by the local Bedouins (a single one is called a zibaarah). Sand sheets and whalebacks are safe, fast going, and about the only problem are the ripples found between them and on their upwind slopes. These ripples (which are also found in slipface country), may range in height from one to 12 inches. Don't underestimate their hardness. The larger ripples hit head on at speed feel like rock and can damage your suspension or make you lose control.

The good news is that they always mark firm ground, enabling you to go slow and thread your way through. It is best to avoid these patches of big ripples entirely by skirting them on either side. If you do have to cross them, it is easier working parallel to their ridges, or at least diagonally across them, rather than at a right angle.

Bushes become a problem when they are so close together that it's hard to work between them. Bushes gather windborne sand at their bases to form hummocks, and sand collects in elongated humps on their downwind sides. When you have to pass a bush closely crosswind it's therefore usually better to do so on the upwind side; otherwise you will have to skirt the hump that can give you a sharp jolt at any speed. Unless a patch of prominent, close-spaced hummocks has a well used track through it, it always saves time to go around, rather than through, it. This is true even if the detour is much longer. Working through hummocks can be very slow and especially tiring, as it requires incessant wheelwork and a lot of jouncing.

Remember, though, that sand with any vegetation is usually well stabilized and firmer than bare dunes. It can provide a haven if you're continually getting bogged down in nearby soft terrain.

But what if we do see slipfaces ahead... even a few of them?

Slip faces have two unpleasant effects: (1) they form dangerous sand cliffs that can turn your car into a wingless airplane if you go over them at speed from their backslopes. (2) their presence means slipface movement has occurred in the area, and this leaves patches of loose, vehicle-grabbing sand wherever they have passed and wherever these patches have not received enough subsequent wind treatment to form supportive top layers.

IMPORTANT: Before driving into any slipface area, consider a better alternative. GO AROUND IT, NOT THROUGH IT. Experienced desert drivers with a job to get done will always choose to avoid a heavy dune field if possible. Even if this means making a long detour. For some vehicles this may be the only choice. The longer route will provide faster going and save time in the long run. You also avoid the risk of getting badly stuck and failing your mission. So you really have no choice? If you insist .....

One thing about slipfaces is predictable. All of them in a given area face the same direction. This will be downwind, as established by the generally prevailing wind in that area. (This of course may not be downwind of the particular wind blowing the day you happen to be there!) But once you spot one you know which way the others will be facing. In northeastern Saudi

Arabia, the prevailing wind direction is from the north-northwest, and virtually all slipfaces thus face south-southeast. Wind changes may cause a temporary, small-scale slipface reversal at the very top of dunes, but this will be short-lived and easily recognized.

This alignment of slipfaces makes traveling with the prevailing wind the most dangerous direction of travel in slipface dune fields. You can't see the slipface until you are right on top of it, and without constant concentration, it is all too easy to find yourself flying over the edge. Highly experienced drivers can take a car down a big slipface, easing over the lip very slowly, taking care to maintain traction control and always pointing straight down. Not recommended unless you're willing to risk a rollover. Find a way down to the side, instead.

Traveling in a direction directly against the slipfaces is much safer but not without hazard. You won't try going up a slipface, but you may encounter rounded banks that look quite passable when seen in the light of the overhead sun. They may in fact be steep enough to cause a serious impact when you hit them. Any sand driving is more dangerous around noon when there are few shadows to show terrain shapes. Experienced sand drivers tackle dune fields (when they can't be avoided) at an angle, moving crab-like along a zig-zag route to maintain their general intended direction.

A wind much above 12 knots also makes driving more dangerous, reducing visibility and leading to a "white-out" effect that can lead to a loss of terrain feel.

The back of a slipface dune is usually quite firm until one approaches the summit. Old slipface layers may still be exposed there, and a car will often bog down at some point below the top. Working out downhill to one side usually provides an easy out.

Low patches of former slipface sand that lie between dunes are often unpredictable and are the most common cause of getting seriously stuck. The general rule is thus to always choose a higher route rather than one lower, and maintain speed and thus momentum to carry you through such unexpected soft patches. One of the greatest problems of dune driving is the contradictory need to be cautious around slipfaces and yet maintain speed and momentum. Slipface country is never high-gear country. Keep in four-wheel drive and use a middle gear range with good engine rpm, being prepared to downshift fast.

The only way to learn dune driving is to do it. But don't learn alone. When you practice have two vehicles and keep them well apart. Carrying three or four extra men will make pushing and digging out much faster and easier. That leads us to an important topic:

When You Get Stuck

If someone tells you he never gets stuck in sand he is either a liar or hasn't really gone into the stuff. Even the pros get bogged down at times, and getting out has been reduced to a pretty well established drill. The steps are as follows. Experienced drivers may omit or combine some of these steps, depending on their assessment of the situation, but all have to be kept in mind:

1. If you are fairly sure that firm ground is not far ahead or to the rear, shift into lowest gear, lowest range (four-wheel drive, of course, if available), keep the front wheels straight, and try going back or forward--whichever seems better. Trying to go up any slope will generally be a waste of time. Build up engine speed before engaging the clutch (or you will stall), but as soon as the wheels are turning reduce engine rpm to not far above stalling speed and turn the wheels <u>slowly</u>. If there is no vehicle movement and the wheels just spin in place, stop immediately.

2. Get out and look under the car to see if the differentials are hanging up in the sand. If so, dig them free, leaving a channel ahead in the intended direction of travel. Dig out any humps of sand building up in front of the tires. Reduce pressure in the tires if you have not already done so. Take them down to 12-20 pounds, depending on your load (heavier loads require higher pressure).

3. Reconnoitre by walking around the area, feeling the supporting qualities of the sand under your feet. This will be readily apparent, and you can search that way for the shortest route to harder ground. This route should be downhill, or at least level, if at all possible, even if it is longer. Going uphill from a stuck position is <u>very</u> difficult and can only be accomplished in many, very short stages. But make sure that your downhill route does not lead into a soft low spot where the only way out is up!

4. With everyone except the driver out of the car and pushing hard, use the same driving technique as in step 1 and try to establish movement, even if very slowly. Any turning should be very gradual and attempted only after the vehicle is in motion.

5. If you cannot get moving at all, you will have to add support under the wheels. If you have sand tracks* with you, use them now. If not, use anything at hand, such as pulled up bushes, sacking, cardboard, lumber or sheet metal. These should be placed by digging down in front of at least the two rear tires, and placing the material low, just starting under the tire, and inclining gently in the direction of travel, so that the wheels will have a ramp to climb up on. When you try again this will probably get you started, but you may have to repeat the process several times before reaching firm ground.

* SAND TRACKS: These are dune-country unsticking aids carried by most experienced drivers who have to travel much in slip-face country. Everyone has his personal favorite. The basic requirement is a piece of stiff, unbending material about 3-6 feet long, a bit wider than the tire, strong enough not to break up under

the car's weight but not too heavy to handle. A current favorite of oil company fieldmen are pieces of the thick fiberglass grating used to surface oil rig floors. This has a gritty, non-slip surface that helps the tires to get a purchase. Other possibilities are metal channels, or pieces of thick plywood. Flexible material, such as canvas or machine belting, is much less effective, as these bend under the tire and provide little support. (The author's dream tracks, yet to be manufactured and probably unaffordable, would be 8-foot-long carbon-fiber composite channels with a grit-impregnated inner surface.) When using sand tracks, take enough time to dig well ahead so that the tracks are inclined forward at only a moderate angle. If the rise is too steep the car can't climb out.

Once you get a stuck car moving, some experience is required to know when to shift into a higher gear. If you try to shift too soon, while you are still churning your way along instead of surface floating, you will usually stall and have to start over. But when you do feel you have regained some flotation it usually pays to shift immediately to the next higher gear to build up speed and momentum. The ability to shift up or down fast and smoothly is an important ability in desert driving and well worth practicing. It often means the difference between keeping moving and stalling.

In some cases, getting unstuck may require removing all the load from the car. In extreme cases (usually as the result of an inexperienced driver spinning the wheels in place and thus sinking straight down) jacks may have to be used to raise the car and clear its underparts from the ground.

All this can be very hard work, especially in summer. A good reason to avoid slipface country when possible.

It is important to reinflate your soft tires as soon as you get back to hard, especially rocky, ground. When soft, they are more liable to damage from sharp stones. And when you get back to the highway you must reinflate to highway pressure immediately or be content with driving at 50 kph. Otherwise you risk serious heat damage and blowouts.

Sabkhahs

"Sabkhah" is a good Arabic topographic term that has found its way into the everyday vocabulary of English-speaking residents and explorers of Arabia and North Africa. Its proper Arabic plural form is sibakh (pronounced si-bahkh). The sabkhah is a very important terrain type in eastern Saudi Arabia, and it is essential to know about them; they can give you more serious problems than slip-face sand.

Perhaps the most common translation for "sabkhah" is "salt flat," but that is deceptively simple. They are easy to recognize: They look like absolutely flat, brownish stretches, usually completely free of any vegetation, shaped like ponds, lakes, or even seas when really big (but holding water only after rain), surrounded at slightly higher elevation by normal sandy or bushy desert. Their surface has a characteristic crunchy texture with a puffy look; a close look and a taste will tell you that it is mostly salt. Take a walk on one and your feet will immediately break through the surface crust. How much farther you sink will depend on many things and is not always predictable. When a sabkhah dries after rain, the salt leached from the crust may form a snow-white covering--or even cracked, white, solid sheets--that leave the flat looking like a lake of ice.

Sabkhahs are formed when the local land surface intersects the local water table. Sediments above the water table are blown away by the wind; those below are held together by moisture and salt concretion and thus form a level surface. Near-surface ground water is nearly always salty in our parts, and this accounts for the sabkhah's salt crust, which forms from the evaporation of rising brine. It is this association with the local water table that makes sabkhahs so dangerous for vehicles: the earth below the surface crust is usually saturated with salty water and has the consistency (and supportive characteristics) of mud.

Sabkhahs are especially common at or near the coast, but they may also be found well inland, as far as the edge of the Summan plateau, or about 125 kilometers from the sea. Some of them may be enormous, stretching out of sight to the horizon; others may be only 50 feet in diameter. Their margins are usually quite distinct; one doesn't wander onto one accidently, except perhaps through non-attention at night.

Sabkhahs are wonderful places for getting stuck--seriously stuck--in motor vehicles. Even with tracked vehicles their raw surfaces should normally be avoided even at the cost of longer and rougher routes. An important exception are situations where repeated traffic, even several years past, has compacted a track through the flat. Most large sabkhahs have one or more such track crossings, and if one is careful to stay <u>precisely</u> on them, they are safe, smooth routes at least for lighter vehicles. This may be true even when the track is wet after rain, although one must be very careful then in using brakes on the slick surface. But after heavy rains they may turn into shallow lakes that last for weeks. In such cases do not think they are fordable because the water is shallow. They most definitely are not.

A sabkhah without tracks, in the dry season and if it is pale in color, can often be attempted by a light, four-wheel-drive vehicle in a lower gear. One must stop and back out immediately, however, if there is any tendency to sink toward one's differentials. This is not safe in a heavy truck, and no attempt should be made on any raw sabkhah that has that menacing dark color indicating abundant moisture near the surface. Extrication of deeply-stuck vehicles from a sabkhah can be slow, tiring and messy work involving the use of jacks, and bushes, boards, or sheet metal to support the vehicle at slowly gained, progressively higher levels. After you succeed in such an encounter, remember to wash your car's undersides soon with fresh water. The salts are corrosive. This is in fact good practice even after traveling a well-packed sabkhah track.

One occasionally hears stories about cars completely swallowed up in sabkhahs. A vehicle, in fact, will not sink farther than its chassis members. But anytime you have a car down so far you cannot reach underneath it, you have a serious problem!

Sabkhahs, of course, in quite opposite fashion to sands, become softer, not firmer after rain. Stay quite away from them under such conditions, except perhaps in a light vehicle and using a track already used successfully after the rain by other vehicles, and that does not show ruts.

When extensive sabkhahs occur in rough, hummocky, trackless terrain, advantage can often be made of them by driving just inside their edge, where sand has drifted down from higher ground. This edge will be firmer and provide a nearby escape if flotation is lost.

Inland Silt Flats

Some military maps incorrectly label another terrain type, salt-free silt flats, as "sabkhah." These are found well inland from the coastal plain and not formed by the local water table. Desert Arabs never apply the term sabkhah to one of these; they will call it a "faydah," a "qaa'," or (if it carries vegetation), a "rawdah." These are simply natural basins floored with washed-in silts and clays from surrounding higher terrain. They may lie over rock or over deep alluvial deposits; most important, they are not fed by underground water.

Such basins may be the sites of long-lasting pools after rain. The pools remain quite sweet and are often frequented by Bedouins to collect drinking water, water livestock (or to wash cars!). When they dry they are floored by a smooth, level layer of hard silt and clay, often with a characteristic whitish color and often with cracks in geometric patterns.

Basins of this type are always safe to cross when dry because they provide a wonderfully smooth, pavement-like driving surface. When wet, however, they can be very treacherous, losing their bearing strength and becoming as sticky and slippery as grease.

Other Terrain of the Northeast

Apart from some sabkhahs and a few dunes in near-coastal tracts, much of the northeastern plains up to and beyond the Kuwait and Iraq borders is some of the finest off-road vehicle terrain in Arabia. These are gently undulating to very flat plains, sometimes with a firm sand or grit surface, grading further inland to firm silts with a thin layer of gravel or cobbles. Some of this country is quite barren, without any perennial vegetation, and called in Arabic qara'ah, or "bald lands." Other stretches are sprinkled with saltbushes or other shrublets up to about 2 1/2 feet high. All of this area is criss-crossed by old and new vehicle tracks, and the lack of good landmarks makes it important to keep track of direction and distance to avoid going astray.

Light vehicles can maintain speeds of over 50 mph over some parts of these plains, particularly in the "qara'ah," and in the gravel sheets to the west, called the Dibdibah. One must be careful at high speeds, however, about encountering unexpected rare runnels or deeply rutted vehicle tracks at right angles. These can badly shake up passengers and loads, or even endanger the running gear of the car.

One of the few significant relief features in these parts is the great linear depression called the "Batin" or "Wadi al-Batin," which runs in a southwest-northeast direction through the town of Hafar al-Batin and runs on to form Kuwait's western boundary with Iraq. The walls of the Batin are in many parts gentle and rounded, and easily crossed by vehicles. In a few stretches, particularly around ar-Ruq'i southwest of the Saudi-Kuwait-Iraq boundary corner, the walls are highly dissected into deep ravines and can be negotiated only along certain tracks.

SURFACE CONDITIONS IN RELATION TO LANDFORMS

General characteristics. For details, refer to Summary Sheets.

SOFT - DRY:

Dunes - lee slopes
Nafash
Playas - dry, silty, salty, materials
Ripples - sand
Sand streaks and drifts

SOFT - WHEN WET:

Playas
Sabkhahs
Wadis

QUICK CONDITIONS - WHEN WET:

Arroyos/wadis - residual wet spots
Sabkhahs

STICKY/SLIPPERY - WHEN WET:

Interdune surfaces - enclosed
Playas
Sabkhahs
Washes

FIRM, SEMI-FIRM, STABLE:

Dunes - upwind slope
Dunes - vegetated surfaces
Interdune surfaces - enclosed, dry
Sand sheets/sand plains
Washes - dry

HARD:

Alluvial fans
Bajadas
Duricrusts
Gravel plains
Interdune surfaces - open, dry
Pediments
Playas - dry, high clay content

ROUGH:

Alluvial fans - coarse, high arched
Duricrust surfaces
Playas - dry, high clay content, desiccation cracks
Playas - dry, salt ridge polygons
Ripples - granule and truncated
Rock outcrops
Sand plains - areas where rock outcrops graze the surface

DUST PRODUCERS:

NOTE: Dust is ubiquitous to deserts - it is a question of more or less, not absence or presence.

Gravel plains with desert pavements - if crust is broken, or with high speeds
Interdune surfaces
Nafash
Playas - dry, silty, salty
Sabkhahs - if dry
Sand plains - some, if lag surface is disturbed
Washes - dry

SURFACES/LANDFORMS IN RELATION TO OPERATIONS

NOTES:

1. Do not track vehicles - this will disrupt the surface and generate more dust. Travel in echelon formation.
2. The greater the speed, the more the dust.

FOOT TRAFFIC:

All surfaces except lee dune slopes, wet playas and sabkhahs.

DUNE-BUGGY AND LIGHT 4-WHEEL-DRIVE VEHICLES:

Alluvial fans
Dunes - upwind slopes
Gravel plains - do not track vehicles on desert pavements
Pediments
Playas - dry, high clay content; be careful not to break crust
Ripples
Sabkhahs - on defined, old, compacted tracks
Sand plains
Washes - except boulders and large cobbles

HEAVY 4-WHEEL-DRIVE AND TRACKED VEHICLES:

Alluvial fans
Gravel plains
Pediments
Ripples
Sand plains

FIXED-WING AIRCRAFT:

Gravel plains - except areas of large sharp rocks; dust probable
Interdune surfaces - dry
Pediments (some)
Playas - dry, high clay content
Ripples - granule - restriction on landing/takeoff direction
Ripples - pebble
Ripples - giant - usually dust because wheels break up surface
Ripples - sand - except on dunes
Sand plains - usually dust because wheels break up surface

SPEED RESTRICTIONS FOR SURFACE VEHICLES - ROUGHNESS:

Alluvial fans - coarse, highly arched
Bedrock outcrops
Dunes - coppice and vegetation clumps
Duricrust - rough, broken
Playas - dry, high clay content, desiccation cracks
Playas - dry, silty/salty, salt ridges and polygons
Ripples - granule and truncated
Sand plains - areas where bedrock grazes the surface
Yardang fields - sharp ridges

OBSTACLES TO TRAFFIC:

Alluvial fans - coarse, highly arched, large sharp rocks, gullies
Dunes - coppice
Hoodoos
Playas - dry, high clay content, deep desiccation cracks
Playas - high salt content - polygonal ridges
Sabkhahs
Vegetation mounds
Yardangs

OBSTACLES TO CROSS-COUNTRY MOVEMENT:

Arroyos
Dune fields
Grooved terrain
Ravines/Canyons

COVER AND CONCEALMENT AND OBSCURATION BY PATTERN CLUTTER:

Alluvial fans (large)
Basins and other topographic lows
Burn scars
Dune fields - coppice
Hoodoos
Inverted wadis
Knobs and ridges
Tafoni
Yardangs

OBSERVATION POINTS:

Dunes - isolated
Inselbergs
Vegetation mounds
Yardangs

NAVIGATION AIDS:

Inselbergs - show on maps, radar, and Landsat
Vegetation mounds - larger ones show on maps, radar, and Landsat
Ventifacts, yardangs, lee dunes - prevailing wind direction

TERRAIN TO AVOID:

Badlands
Dune fields - no interdunal areas
Grooved terrain
Sabkhahs

BIVOUAC, STOPPING, AND ASSEMBLY SITES:

Dunes - lee of isolated large barchan or star dunes
Gravel plains
Sand plains