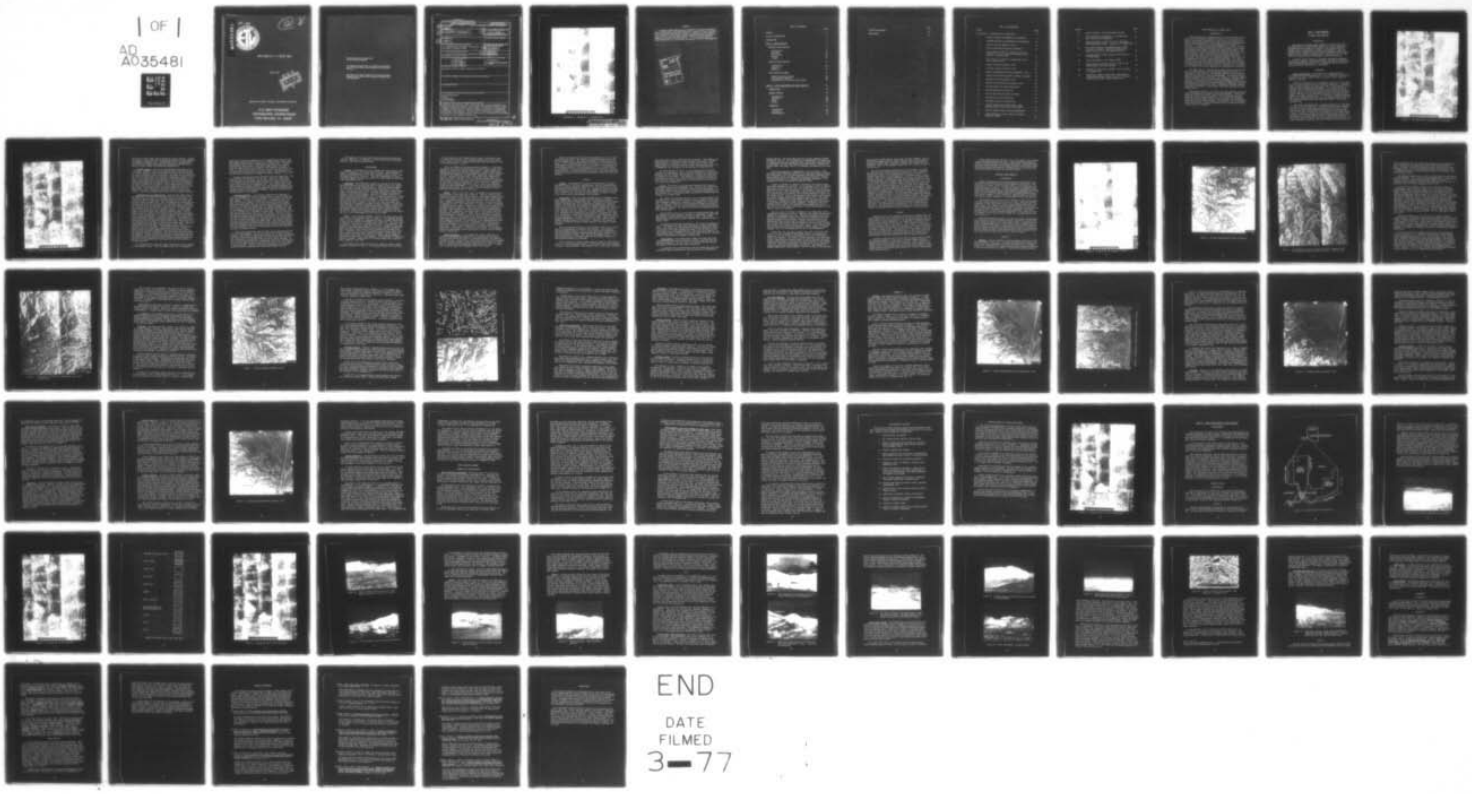
AD-A035 481 ARMY ENGINEER TOPOGRAPHIC LABS FORT BELVOIR VA F/G 8/6
PHOTO ANALYSIS OF A DESERT AREA.(U)
APR 76 J EHLEN

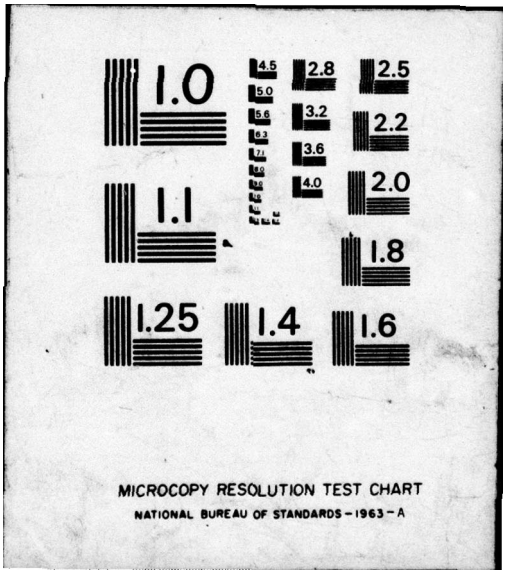
UNCLASSIFIED ETL NL

| OF |
AD
A035481



END

DATE
FILMED
3-77


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.8
1.1
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

ADA035481

ETL - 0068

(12)

PHOTO ANALYSIS OF A DESERT AREA

APRIL 1976

DDC
RECEIVED
FEB 11 1977
C

Approved for public release; distribution unlimited.

U.S. ARMY ENGINEER
TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VA 22060

Destroy this report when no longer needed.
Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The citation in this report of trade names of commercially available products does not constitute official endorsement or approval of the use of such products.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ETL-0068
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): PHOTO ANALYSIS OF A DESERT AREA
5. TYPE OF REPORT & PERIOD COVERED: Technical Report
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Judy Ehlen
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 4A161102B52D
11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060
12. REPORT DATE: April 1976
13. NUMBER OF PAGES: 73
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 72 pgs
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Photo Interpretation
Geology
Geomorphology
Arid Environment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Information derived from 1:9,600 scale stereoscopic aerial photography of a desert area near Yuma, Arizona, is presented. Physiography, geology, climate, landform, drainage, erosional aspects, vegetation, and cultural features are considered in the context of local and regional environmental, engineering, and military considerations. The second part of this report presents a field verification of the general geology, geomorphology, and vegetation in the study area with a list of selected references.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403 192



Frontispiece: Photomosaic of a Desert Area

PRECEDING PAGE BLANK-NOT FILMED

PREFACE

I wish to thank those who have aided in all phases of preparation of this report, but particularly Mr. Robert E. Frost, who provided invaluable step-by-step guidance in preparation and development of Part I of this report (photo analysis) and made valuable comments on content and organization. I also wish to thank Mr. Frank Barnett for his invaluable aid during the field investigation.

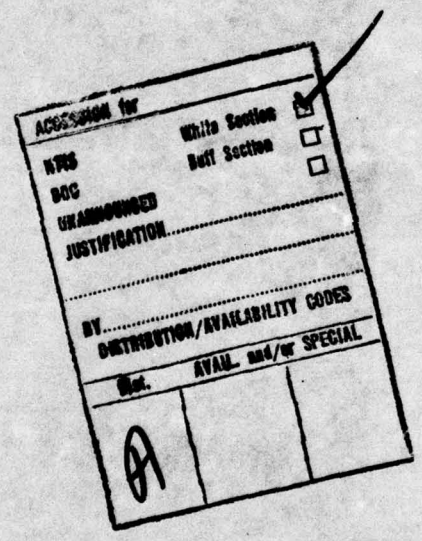


TABLE OF CONTENTS

	Page
PREFACE	2
LIST OF ILLUSTRATIONS	5
INTRODUCTION	7
PART I: PHOTO ANALYSIS	8
REGIONAL PHOTO ANALYSIS	8
Introduction	8
Geography	8
Physiography	13
Geology	15
Climate	18
DETAILED PHOTO ANALYSIS	19
Introduction	19
Example I	19
Example II	32
PHOTO ANALYSIS SUMMARY	42
Summary and Relationships	42
Environmental Problems	46
Selected Areas for Future Field Checks	47
PART II: FIELD VERIFICATION OF PHOTO ANALYSIS	49
INTRODUCTION	49
GENERAL GEOLOGY	49
Introduction	49
Mountains	49
Hills	58
Plains	64
VEGETATION	65
Introduction	65
Occurrence	65
Relationships	66

Page

SELECTED REFERENCES 68

CONCLUSIONS 70

LIST OF ILLUSTRATIONS

Figure		Page
Frontispiece:	Photomosaic of a Desert Area	1
1	Drainage Network Superimposed on Photomosaic	9
2	Landform Boundaries Superimposed on Photomosaic	10
3	Location Map for Examples I and II	20
4	General Landform/Rock Pattern Boundaries	21
5	Stereo Photos of Unit A-1 (gneiss), Unit A-2 (granite), Unit B-1 (dissected granular hills), and Unit C (alluvial fan)	22
6	Stereo Photos of Units B-2 (sedimentary rock) and C (alluvial fan)	24
7	General Drainage Groupings (2-30)	26
8	Detailed Drainage Patterns (2-30)	28
9	General Landform/Rock Pattern Boundaries (1-26)	33
10	Stereo Photo Showing Mountains, Bajada, and Basin	34
11	Drainage Pattern Groupings (1-26)	36
12	General Cultural/Land Use Patterns (1-26)	40
13	Selected Areas for Field Verification	48
14	Location Map of the Study Area	50
15	View of the Study Area from the North	51
16	Geologic Map of the Study Area	52
17	Planimetric Map of the Study Area	54
18	Contact Between Schist and Gneiss. Note Apparent Layering in Schist on the Right	55
19	Contact Between Schist and Red Conglomerate	55
20	Gneiss Outcrops in the Vicinity of the New Tank Hill Course	56

Figure		Page
21	Granite Outcrops. Note Persistent Jointing	57
22	Red Conglomerate Outcropping in the Foreground with Gneiss in the Background	59
23	Gypsum and Light-colored Clay (left) Overlying Red Conglomerate (right). Gneiss in the Background	59
24	The Kinter Formation Overlapping Gneiss (left) and Granite (right). The Road Network on the Gravel is Part of the Old Tank Hill Course	60
25	Youngest Bajada of Photo Analysis with Gneiss in the Background	61
26	Gully Development in the Oldest Bajada	61
27	Bajada Spurs and Erosion Pattern. This is the Oldest Bajada from Photo Analysis	62
28	Surface of Gravel Cap on Bajada. Note Variation in Fragment Size	63
29	Sandy Hills (right), Sandy Plain (foreground), and Gneiss Outcrops (center and left). Concrete Tracks are 40%, 50%, and 60% Slope Course	64

PHOTO ANALYSIS OF A DESERT AREA

INTRODUCTION

Photo interpretation procedures are an excellent method to obtain terrain information needed by the Army to fill military geographic intelligence requirements. Most terrain information pertinent to these requirements is available from readily obtainable (at least of the United States) aerial photography at scales of 1:20,000. On occasion larger scale imagery can be found. However, extracting the required information from the imagery by photo analysis requires some degree of skill and background knowledge. The more detailed the required information, the more skilled the interpreter must be. Many of the Army's requirements depend upon a highly developed skill level to obtain the needed information. In this study, the interpreter is a trained geologist, but a novice in the application of photo interpretation techniques. This report illustrates not only the types of information required by the Army that can be derived from photo interpretation, but also the amount of information that can be derived by an interpreter who is developing the needed skills while applying the interpretation techniques.

The study area is a portion of the Yuma Proving Ground located north of Yuma, Arizona. The information presented in Part I of this report, Photo Analysis, was derived entirely from detailed examination and analysis of aerial photographs. The analysis method applied includes three major parts; (1) analysis of regional aspects of the terrain in terms of physiography, geography, geology, and climate, (2) detailed analysis of selected landscape patterns within the study area in terms of landform, drainage, vegetation, erosion, and cultural characteristics, and (3) analysis of pattern relationships and significance. Questionable areas were selected for field verification.

After photo analysis of the study area was completed, extensive field investigation of selected areas was undertaken. Results are presented in Part II of this report, Field Verification of Photo Analysis, which includes verification of rock type and landform units identified in photo analysis, hand specimen and petrographic analysis of collected rock samples, and detailed study of vegetation types and patterns. A brief literature search for pertinent publications was also undertaken.

PART I. PHOTO ANALYSIS

REGIONAL PHOTO ANALYSIS

Introduction

The purpose of regional photo analysis of an area is to put into perspective the many patterns present in a photo image and to understand how each pattern is related to its adjoining pattern through origin, distribution of events, and materials. This approach allows a synoptic overview of major landscape features and patterns in the study area and provides a basis for selecting small areas for detailed study by developing a working hypothesis.

A regional photo analysis is presented considering geography, physiography, geology, and climate based on 1968 photo coverage at a scale of approximately 1:9,600. All information derived was determined from stereo examination of the photos.

Geography

General description. The study area is approximately 7½ kilometers E-W by 10½ kilometers N-S. It is bounded by mountains on the north and south, a major river on the west, and by plains or basins on the east.

Detailed examination of the photomosaic (figures 1 and 2) suggests the area is located within a military reservation. Indicators noted in photo analysis that define the area as such include: (1) an airfield without commercial development, i.e. no parking area or terminal, (2) a large military aircraft parked beside the runway, (3) what appear to be artillery pieces at the intersection of paved roads on the east, (4) two rockets or missiles at an intersection leading to a small building site, (5) the lack of commercial development in the larger building site, i.e. no shopping centers, and (6) the presence of parked vehicles shaped like tanks in the smaller building site.

The office and housing area of the reservation is in the northwest corner of the study area. A secondary building site composed of large, rectangular buildings and paved lots is located in the east central area. This distinction between major and secondary sites is based on relative size, the presence of two housing areas, a school, a church, a playing field and parade ground, and a large building with a flagpole which could be a headquarters building. The smaller area to the east has none of these characteristics. Besides rectangular buildings, this area contains a settling basin to



Figure 1. Drainage Network Superimposed on Photomosaic

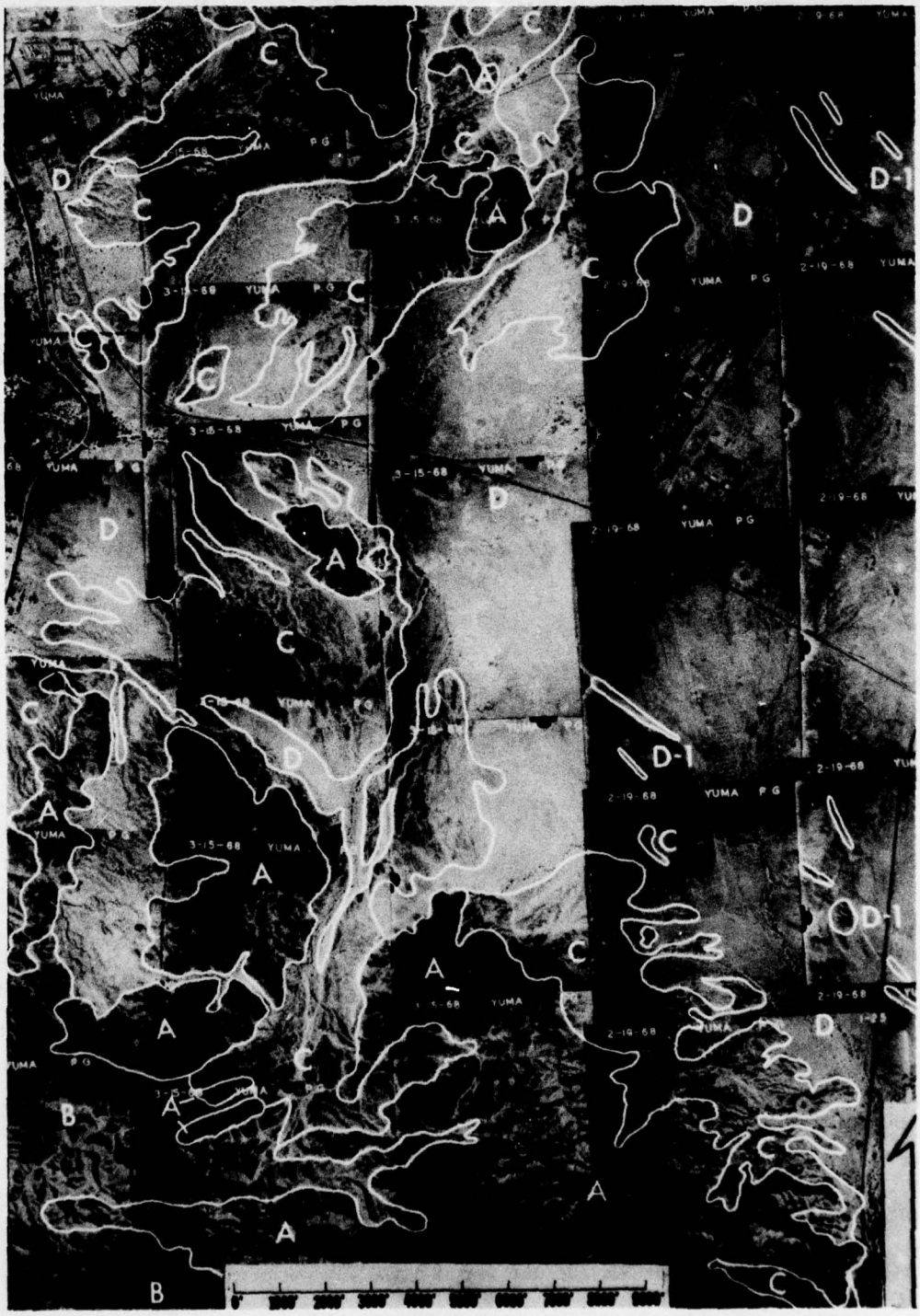


Figure 2. Landform Boundaries Superimposed on Photomosaic

the south, a water tower, and two areas for vehicle storage. Further to the east a large area with a rectangular pattern of lines suggests an abandoned encampment site. Relative age is also suggested by a major wash that crosses the center of the pattern, and the lack of spoil or other evidence of present-day construction.

Economic aspects. There is no agricultural development in the study area. However, there are strong indications that agriculture is a major interest in areas lying outside of the study area because of a major irrigation canal on the west. The canal is too narrow and the large bend too tight to be used for navigational purposes; therefore, it is assumed to be for irrigation. One water bridge is located on the large bend to move run-off over the canal, keeping the run-off from mixing with irrigation water. This provides sediment-free water suitable for irrigation. The X-shaped structures probably divert water from the basin to the east under the canal for the same reason. Dikes parallel to the canal, extending from the X-shaped structures, are separated from the canal by a broad, flat channel. The dikes probably direct water to the X-shaped structures.

Transportation and communication. There are few paved roads in the study area. The ones that are there are all two laned as evidenced by a dashed center line, clearly visible at this scale. The road on the east is probably the main highway, and all other roads are most likely military roads. This is suggested by the presence of artillery pieces at the intersection on the east, which is probably the entrance to the military base. The main road through the center of the mosaic exits to the west (figures 1 and 2). A right angle bend at the main building area suggests, however, that its primary purpose is to serve that area, and not locations beyond. Dirt or gravel roads are located on both sides of the canal and are probably used for canal maintenance. A tertiary network of dirt roads occurs in the mountainous regions, both north and south. The entrance to these areas comes from the secondary building site, implying that the vehicles that utilize them are stored in this area. The tracks are not through routes, and many of them follow unusual paths. They have steep gradients on hillsides, and there are no cuts, fills, or bridges to even out the grade. These combined characteristics suggest they are not utilized for recreational purposes. However, another series of tracks immediately east of the primary building site could be used for recreation. The tracks here, which are probably motorcycle tracks, are narrower and exit to the housing area of the compound. As the two major occurrences of tracks associate only with the secondary building site where vehicles including tanks are located, it is suggested that these areas are used for testing or training purposes.

An airfield with at least one runway and possibly two is located in the northeast corner. The one runway is ENE, is 2.1 kilometers

long, and is paved with asphalt, which is suggested by the dark tone. The possible second runway is NNE, is of unknown length, and is paved with crushed stone, which is suggested by a lighter tone. Several buildings are located next to the latter (NNE) runway, but none of them are large enough to be a terminal, and there are no parking areas. A military aircraft with the U. S. Air Force star on its wing is parked near the west end of the paved runway. The structure of the tail and the placement and number of engines indicate it is a B-52.

Several utility lines can be observed within the study area. Two lines parallel the paved road on the east. One has a double pole structure with a cross piece, and the other has only a single pole. It is assumed that the double pole structure is a power line and the single pole structure is a telephone line. Other single pole structures connect the primary building site, the secondary building site, and the airfield, but they are not connected to those paralleling the highway within the area of photo coverage. There are no double pole structures west of the highway.

Analysis/summation. If the entire study area is observed in terms of geographic or cultural characteristics, there are three primary types of activity; (1) the military, (2) the canal, and (3) the main highway. In terms of interest and in the amount of area covered, the military aspects of the study area are of prime concern. The paved roads within the area connect three spheres of activity, that is, the northwest building site, the smaller building site, and the airfield. The roads center upon the largest building site, and it is considered the living area for the military reservation. The smaller building site is probably the work area. The two networks of dirt tracks substantiate this idea; both networks lead only to the secondary area and cross paved roads to get there. It is also probable that the primary purpose for the airfield does not exist within the area of photo coverage as it seems unusual to have an airfield of this size serving only these two small areas. This implies that the military reservation extends beyond the area covered by these photos. These two building sites, then, supply both living and working space for the inhabitants, and the airfield suggests additional operations occurring in adjacent areas.

There are no indicators that the canal and the military activities are interdependent. The living area in the northwest corner is assumed to be related to the military rather than to the canal because the roads connect the building site to military activities and the canal continues north and south off the area of photo coverage. If the two units were connected, it would seem likely that the beginning of the canal would be near the building area, and within the limits of photo coverage. However, there are no buildings or structures along the canal to indicate any relationship between the two.

The highway on the east links the important centers lying outside the study area. In addition, a short connecting link provides access to and from the military area.

Physiography

General. The study area can be divided into three general landforms; (1) mountains, (2) hills, and (3) basins. The mountainous region is designated Unit A, the hilly regions as Units B and C, and the basins as Unit D (figure 2). The form, arrangement, and relationships suggest that the area is part of a more extensive basin and range physiographic unit.

Mountains. The mountainous regions are located at the extreme north and south of the study area and in a small area in the center. All areas have the same characteristics. They are generally medium in tone, and of higher elevation than any other unit in the study area. The mountain areas consist of long, steep-sided, sharp-crested ridges with perpendicular spurs. Northwest-trending lineations are present, which could be bedding, jointing, or perhaps foliation or banding as found in metamorphic rocks. Veining also occurs on a large scale trending parallel to the lineations. This pattern consists of narrow white lines that are discontinuous, unlike the lineations. The drainage density (figure 1) in Unit A is less than other units, which implies the material is harder and more resistant. Streams are long with short, straight tributaries and have a barbed pattern indicating stream piracy has occurred, which strongly suggests uplift. Low-growing, sparse vegetation is present only in the dry gullies. The lack of vegetation is probably due to the steepness of the slopes, the lack of soil development, and the lack of water.

Hills. In the extreme southwest corner of the study area is the first of two hilly patterns (Unit B, figure 2). The boundary between Units A and B is marked by a change from blocky to smooth texture and a change in the direction and pattern of stream flow. Unit B is lower in elevation than Unit A, is medium toned, and is fine textured. The vegetation is sparse but denser than in Unit A. A dendritic drainage pattern is well developed (figure 1) with long, straight streams and many tributaries, which implies uniform composition throughout the area. Direction of flow is both northwest and southeast, which indicates a small drainage divide trending northeast. Gully slopes are more gentle than in the more rugged Unit A and become box-shaped in cross section downstream. This suggests a more resistant or impervious material at depth. Straightness of the main stream over a long distance suggests a fault zone.

The second of the hilly areas (Unit C, figure 2) forms an apron around all exposures of Unit A. The boundary between Unit A and Unit

C is very similar to that between Units A and B. The slope of Unit C is much less than Unit A and the break between the two is easily noted. There is also a textural change from rough and blocky in Unit A to smooth and even in Unit C.

Unit C has different drainage densities (figure 1). The drainage pattern is better developed than in the mountainous areas, which suggests a softer, more easily eroded material. Small streams and tributaries are shorter and form a dendritic, almost pinnate, pattern. The basin-side boundaries are scalloped, suggesting a row or series of fans. Gullies are steep sided, indicating coarse composition. There is a vertical change in tone in some areas where there is the least dissection. The top layer is quite dark and thin in comparison to the lower, lighter toned material. Unit C varies in width along the base of the southern exposure of Unit A, and in the southeast corner is almost nonexistent. It is widest on the north slope where streams drain directly into the basin. The unit generally slopes away from the mountain mass it surrounds.

Basins. Unit D, the basin area, is located in the central and eastern parts of the study area (figure 2). This is a broad, flat, low-lying area with little surface relief. The boundary between Units C and D is similar to that between Units A and C, but is more moderate. A noticeable change in tone from medium to light occurs along with a change in topographic expression as Unit C is hilly and Unit D is essentially flat. The central part is unusual in that no drainage is apparent on the surface, suggesting an area of porous material with internal drainage (figure 1). There are two major gully systems in the basin, one trending north and west and the other trending south and east. This indicates a drainage divide in the central area and therefore two separate basins. Light tone is suggestive of coarse-grained material. Elongate, cresentic hills that suggest sand dunes (Unit D-1, figure 2) are located in the eastern basin. The terrain surrounding the hills appears to consist of the same material as that which composes the dunes. No differences can be detected between materials composing the two basins. Vegetation in the gullies is an excellent indicator of soil moisture and is useful in delineating gully paths. There is more vegetation in the basins than in any other unit in the photos. It consists of two types; (1) low-growing, regularly spaced shrubs outside the gullies, and (2) taller, bushier trees in the gullies.

Analysis/summation. If we observe the entire study area, it consists of mountains surrounded by hills separated by two basins. The two basins divide the area on a northeast trending line from the southwest corner. A major river and an associated flood plain probably exist to the west because of heavy vegetation and of bodies of water that are located on the extreme west side beyond the canal. In addition, a second large river probably exists to the south.

There is a possibility that several escarpments or scarps occur within the study area. The change in elevation between Unit A and any surrounding unit is very sharp and exhibits a striking break in slope. It was suggested above that a fault occurs in Unit B on the south because of the straight path of the stream. This suggests the southernmost boundary of this exposure of Unit A is a fault scarp. The straightness of the northern boundary of this exposure also suggests faulting. If these boundaries are scarps, the hilly areas surrounding the mountain masses could be pediments covered with alluvial material.

Geology

General. The geology of an area can be discussed at several different levels. The first and most basic level is the identification of the various material compositions. The second level is the determination of immediate origin, i.e. whether the units are residual or transported. The final and most complicated level is the geologic history of the area and the relationships, in terms of formation, of the various physiographic units present.

Composition. Unit A has been described above as medium-to-dark-toned, steep-sided, sharp-crested, and very hard and resistant. These characteristics suggest bare rock. The origin of the northeast-trending lineations may aid in defining the composition of the material. The lineations are probably not bedding planes (implying sedimentary origin) because the material appears homogenous, and there is no suggestion of dip. They could be a joint pattern (any rock type), but more than one direction is usually apparent. Since there is no indication of flowlayering, the material is probably not igneous. In addition, it would be difficult for a coarse-grained, intrusive igneous mass to form these knife-edged ridges. The rock type is probably metamorphic. Neither schistose nor slaty textures would produce apparent banding on this scale. Therefore, the texture of the rock is probably gneissic, which implies a high degree of metamorphism.

The fine-textured material in the southwest corner of the study area is not suggestive of residual rock surfaces. The dendritic drainage pattern indicates it is at least surficially homogeneous, and the box-shaped gullies downstream suggest a more resistant or impervious material at depth. This implies sedimentary origin. The impervious material is probably shale and the surficial material, a fine grained sandstone or limestone.

Unit C consists of easily eroded material, which is sufficiently coarse to form steep-sided gullies. A thin, dark-toned layer overlies a thicker, lighter material. The areas of Unit C where most dissection

occurs are where no dark-toned material is present. This implies the dark material is a protective layer, probably consisting of gravel-sized particles, overlaying a finer material such as sand. The higher degree of dissection implies a loose, unindurated material, not a sedimentary rock as implied by the presence of layering alone.

In the discussion of Unit D, it was suggested that the hilly landforms are sand dunes. This, along with homogeneity, uniform composition, and the braided drainage pattern, suggests the basin area is composed of loose sand. The similarity of vegetation patterns in both basins and the lack of tonal differences between the dunes and basin material further substantiate the conclusion that both basins are of the same composition.

Origin. The origin of the material comprising Unit A has already been identified as metamorphic rock. The rock was formed from previously existing rock subjected to extreme heat and pressure. It was either formed in place and eroded to its present configuration or was uplifted (or is continuously being uplifted) by faulting and then eroded to its present form.

The texture and drainage pattern of Unit B strongly suggest sedimentary origin, which in turn implies original deposition from water with subsequent cementation, induration, or compaction to form solid rock. If the unit consists of two sedimentary formations covered by surficial material, the two rock units would have been formed from a body of water; whereas, the surficial material was probably deposited from running water.

The location of Unit C at the base of the mountainous mass, and the presence of stream channels crossing it immediately suggest that the material has been deposited by running water. The thinner, darker gravel layer may have been formed by the winnowing process of wind or water.

The material comprising the basins in Unit D has two primary origins. The presence of sand dunes immediately suggests wind deposition as one origin, but the presence of vegetation apparently stabilizing most of the dunes implies that wind is not the major factor. Since almost all the streams present in the study area originate in the mountain areas, cross Unit C, and then enter the basins, the major origin of the material is probably running water.

Relationships. The various units within the study area have been described as separate, unrelated entities. This was done for discussion purposes. At this time, the interrelationships between the various units can be more easily understood.

As mentioned above, metamorphic rocks are formed when rock deep within the earth is subjected to extreme pressure and temperature

without melting. The rock bodies are then usually exposed by uplift followed by erosion. In the discussion of escarpments, the occurrence of faulting was strongly suggested, which implies this particular body of metamorphic rock has been uplifted and then eroded. Because this process takes many years, Unit A is considered the oldest in the study area.

Three major exposures of metamorphic rock are present. They could have been faulted and uplifted as one mass and eroded to present day configuration, or they could have been uplifted as separate units along parallel faults and then eroded along the fractures. Because of the parallelism of all northeast and southwest boundaries, it is suggested all three are bounded by parallel faults.

A fault is defined as a break or fracture in the earth's crust along which movement has occurred. It is therefore a zone of weakness along which erosion can occur at a more rapid rate than in an area where there are no zones of weakness. For instance, it may be assumed that the outcrop in the central part of the basin was much larger and was separated from both northern and southern exposures of Unit A by one or more faults. Over a long period of time, erosion would enlarge the cracks, perhaps producing a situation such as this. The linear trend of the boundaries of these masses would then be called fault line scarps. Between the actual break and the uneroded rock would be a planed bedrock surface called a pediment. Sediments would be deposited on this surface, and eventually would completely cover it. The rock left in the center would have an island like appearance, and would be called an inselberg.

The only other occurrence of bedrock in the study area is the sedimentary formations in Unit B. Sediments were deposited from water, compacted, and cemented into rock. They were originally horizontal, and when the metamorphic masses were lifted from beneath them, they were bent upwards over this mass. Erosion has removed all of the sedimentary layers except from the southern side of the mountains. Unit B slopes gently away from the mountains, and the slope is probably caused by the degree of bend in these units. As it requires more time to form solid rock than to deposit, lightly compact, or cement sediment, Unit B is considered next in age to the metamorphics.

Uplift does not take place rapidly, but over a very long time. There is no way to determine from photos whether the process has stopped or not, but there are indications that it has continued at least until recently. As a body is slowly uplifted, it is also being eroded. Gradients of streams increase as uplift proceeds, and they erode rapidly headward, carrying more and more debris as the gradient increases. When the streams reach the flat basin floor, they can no longer carry the same large amount of sediment. The sediment is dropped immediately, which produces a fan at the base of the mountains.

When parallel streams deposit their fans, the fans coalesce. The individual fan-shaped units are called alluvial fans, and a series of coalescing alluvial fans is called a "bajada," the Spanish word for downslope. This is the suggested origin for Unit C, which is next in age to Unit B.

The zones of weakness between blocks of metamorphic rock were described as being filled with alluvial material. This is probably the geologic origin for the majority of the material in Unit D. Streams cross Unit A, flow through Unit C, and enter Unit D. Consequently, some of the alluvial material in the basin is derived from the mountain mass. In addition, since some streams originate in Unit C, this would then be a secondary area of source material. It is not known how far beyond the limits of photo coverage any of these units extend, so only visible sources in the study area can be mentioned. Wind contributes to the accumulation of material in the basins. Windblown material could have come from outside the area of photo coverage, and most of it probably did. Some areas in the photos, however, are suggestive of source material for wind deposition. Wind velocity is a major contributing factor. The fine-grained materials are removed from dry surfaces and only the coarser particles remain. This results in a desert pavement, which could be the source of the thin gravel layer in Unit C. The winnowing process would remove fine particles and leave the coarser gravel, which would protect underlying fine particles. The finer particles removed from Unit C would then be carried to, and deposited in, nearby basins. As a result, the material in this basin would then be the youngest in the study area.

Climate

There are three major indicators that this is a desert area; (1) sparse vegetation, (2) a canal used for irrigation purposes, and (3) flash flood, or scour type erosion. Of the three indicators, the most obvious one is sparse vegetation. No vegetation is visible in the mountain areas, except in the gullies. Most vegetation occurs at lower elevations and is quite low in height. Only in stream channels are trees visible, which indicates soil moisture content is too low elsewhere to support them. The spacing of the low shrubs in the basins is wide, indicating a lack of moisture. Palm trees (which may have been planted by man) surrounding the artillery pieces at the intersection on the main highway also indicate lack of moisture.

A large irrigation canal and the lack of surface water in numerous drainage channels in late winter (the photography is dated February and March) are indicators of aridity. Other indicators include the knife-edged ridges in the mountains and the presence of a bajada, which is a landform found only in dry, arid climates. Sharp ridges and sand dunes suggest that mechanical erosion is predominant over chemical erosion.

These characteristics indicate a dry, arid climate, which implies a very low annual precipitation rate. Most precipitation probably occurs as violent deluges followed by flash floods. The dikes along the canal associated with the X-shaped structures could direct floodwater to locations where man has provided access to the flood plain to the west without contaminating irrigation water.

DETAILED PHOTO ANALYSIS

Introduction

Based on information derived from regional photo analysis, two areas were chosen for detailed stereo examination (figure 3). The first area is located in the southwest corner of the study area and includes Units A, B, and C. It consists primarily of mountains and hills with some fan remnants. It was selected to determine in greater detail the relationships between these three physiographic units. The nature of the interface between them will be closely examined along with closer inspection of the network of nonpaved roads in the area. This stereo triplet, Example I, includes photos 2-29, 2-30, and 2-31.

The second area is located in the southeast corner of the study area and includes exposures of Units A, C, and D. The area consists primarily of hills with small areas of both mountains and flat, low-lying areas. Here, again, the relationships between the units and their boundaries will be studied in detail, and special attention will be given to Unit C because of its varying appearance. The faint, regular pattern of lines mentioned previously in the basin will also be examined. This stereo triplet, Example II, includes photos 1-25, 1-26, and 1-27.

Detailed stereoscopic analysis of these two areas will determine such characteristics as landform, drainage, vegetation, cultural features, erosional aspects, and varying photo tones. Designations applied to physiographic units in the stereo triplet analysis will conform as closely as possible to regional photo analysis, but because of new information derived from more detailed study, the designations may not always coincide. Physiographic units will be referred to as Unit, and drainage subdivisions will be called Patterns.

Example I

Landform. Unit A-1 (figure 4) has the highest elevation and the greatest relief in this area. A series of medium-toned, blocky, parallel ridges trend east-west across the central part of the photos (figure 5). The ridges are steep sided and sharp crested as indicated by the size and spacing of shadows. A northeast-trending lineation

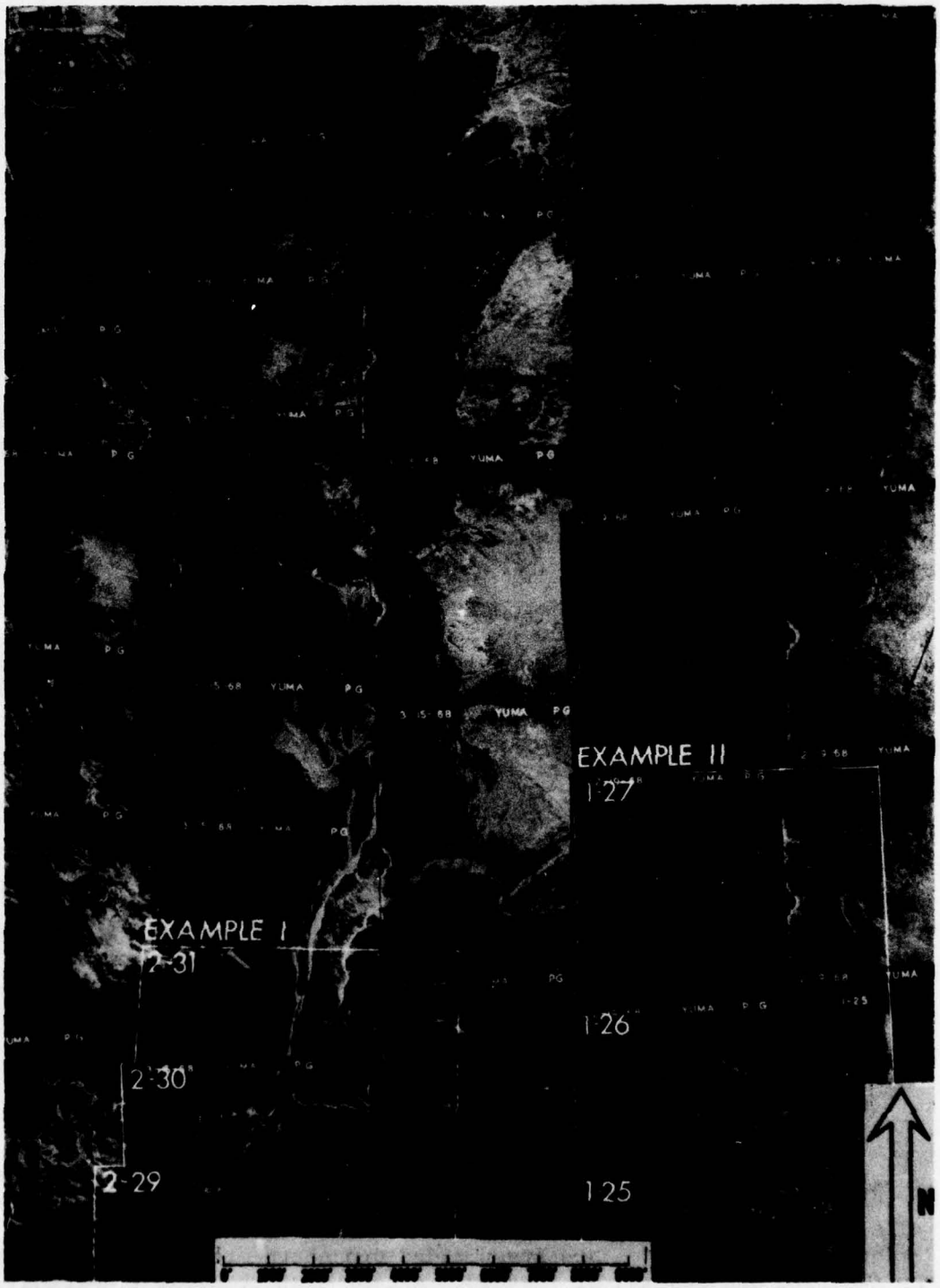


Figure 3. Location Map for Examples I and II



Figure 4. General Landform/Rock Pattern Boundaries

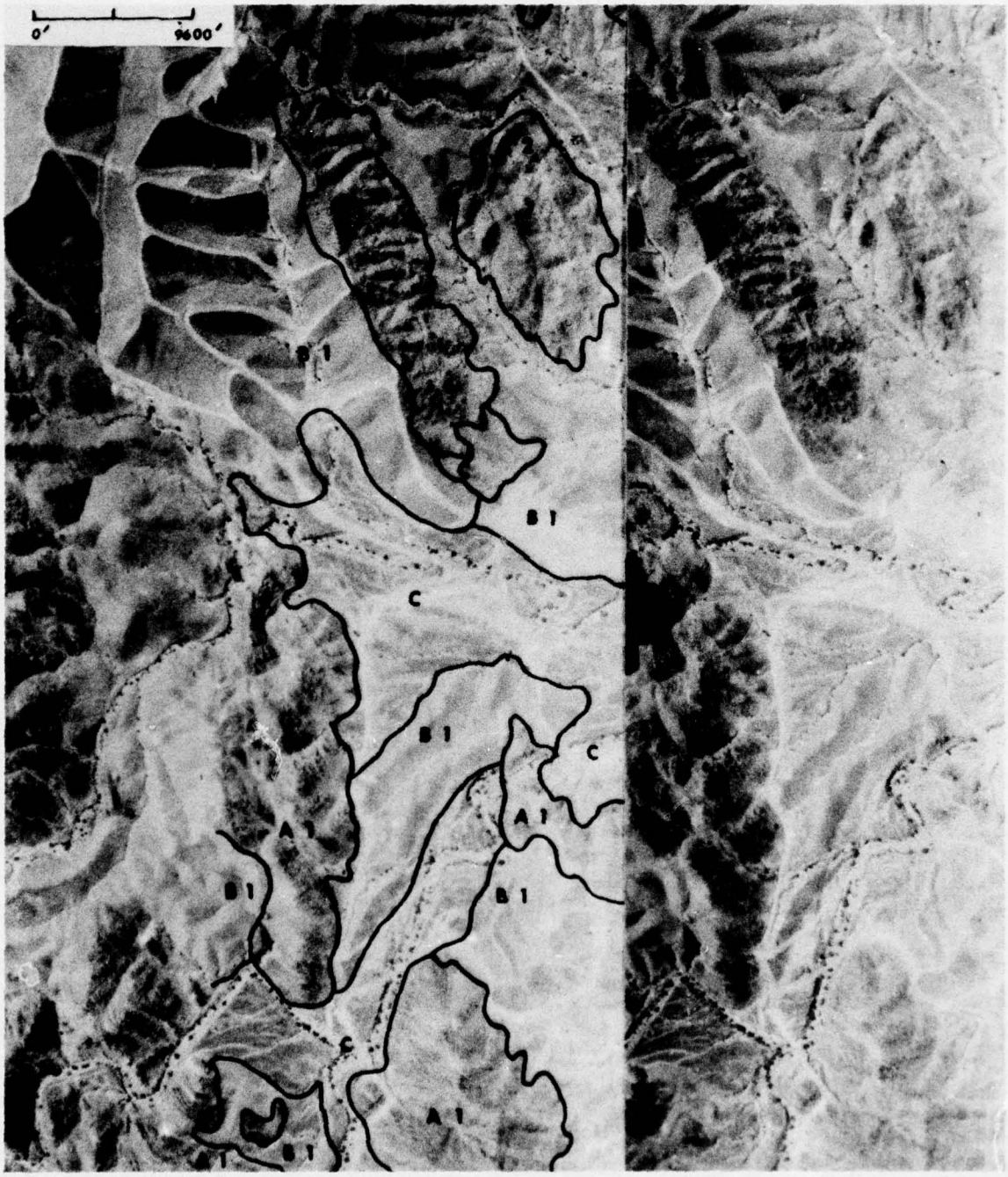


Figure 5. Stereo photo of Unit A-1 (gneiss), Unit A-2 (granite), Unit B-1 (dissected granular hills), and Unit C (alluvial fan)

occurs throughout the unit, but is most obvious in the northeast corner. The area has the appearance of bare rock without surficial cover. The lack of visible vegetation, except in the gullies, substantiates this. All of these characteristics identify Unit A-1 as the same unit defined in regional photo analysis as metamorphic rock with gneissic texture.

The boundary between Unit A-1 and all other areas of these photos is quite distinct. It is marked by the disappearance of rough, blocky texture, and by a change in the drainage pattern and trend. As streams reach the textural boundary, they often parallel this interface for a while and then change direction of flow.

An area in the northwest corner of the study area suggests a second bedrock unit (Unit A-2, figure 4). It is lower in elevation than Unit A-1, and the shadows indicate that the slopes are not as steep. Although the texture is blocky, the unit does not have as angular an appearance, and the ridge lines are more rounded. At least two sets of lineations occur in this unit, unlike Unit A-1, which only has one set. One set in Unit A-2 trends northwest, and the other, east-west. Northeast-trending lineations have the appearance of faulting; whereas, other lineations are shorter and more discontinuous like joints. All these characteristics suggest Unit A-2 is of different composition than Unit A-1 (figure 5). The texture and the joint pattern suggest it is igneous rock. The comparatively light tone suggests it is siliceous rather than basic, and the "lumpiness" suggests it is coarse, rather than fine, grained. This in turn implies intrusive rock.

East-west trending Unit B-1 (figure 4) is even but slightly rough-textured, has prominent ridges, and has shadows indicating steep slopes. Surface roughness is much less than Units A-1 and A-2 and is not suggestive of bare rock. Grain size of the material must be fairly coarse because of the steep slopes and the rough surfaces (figure 5). Tone is even, except in shadowed areas. Sparse drainage implies porous material. No banding or layering is visible, and composition appears homogeneous.

Unit B-2 (figure 4) is smaller than Unit B-1 and the general trend is northwest. It is located in the southwest corner parallel to the southern border of Unit A-1. It is an area of low, rolling hills, moderately dissected by south-flowing streams. The southern part of the unit is darker in tone than the northern, but no vertical tone change is evident, suggesting two parallel layers. It appears that this unit dips south, since slopes are steeper to the north and drainage occurs primarily on the southern slope perpendicular to strike (figure 6). The rolling hills and the well-developed drainage pattern suggest Unit B-2 is comparatively fine grained.

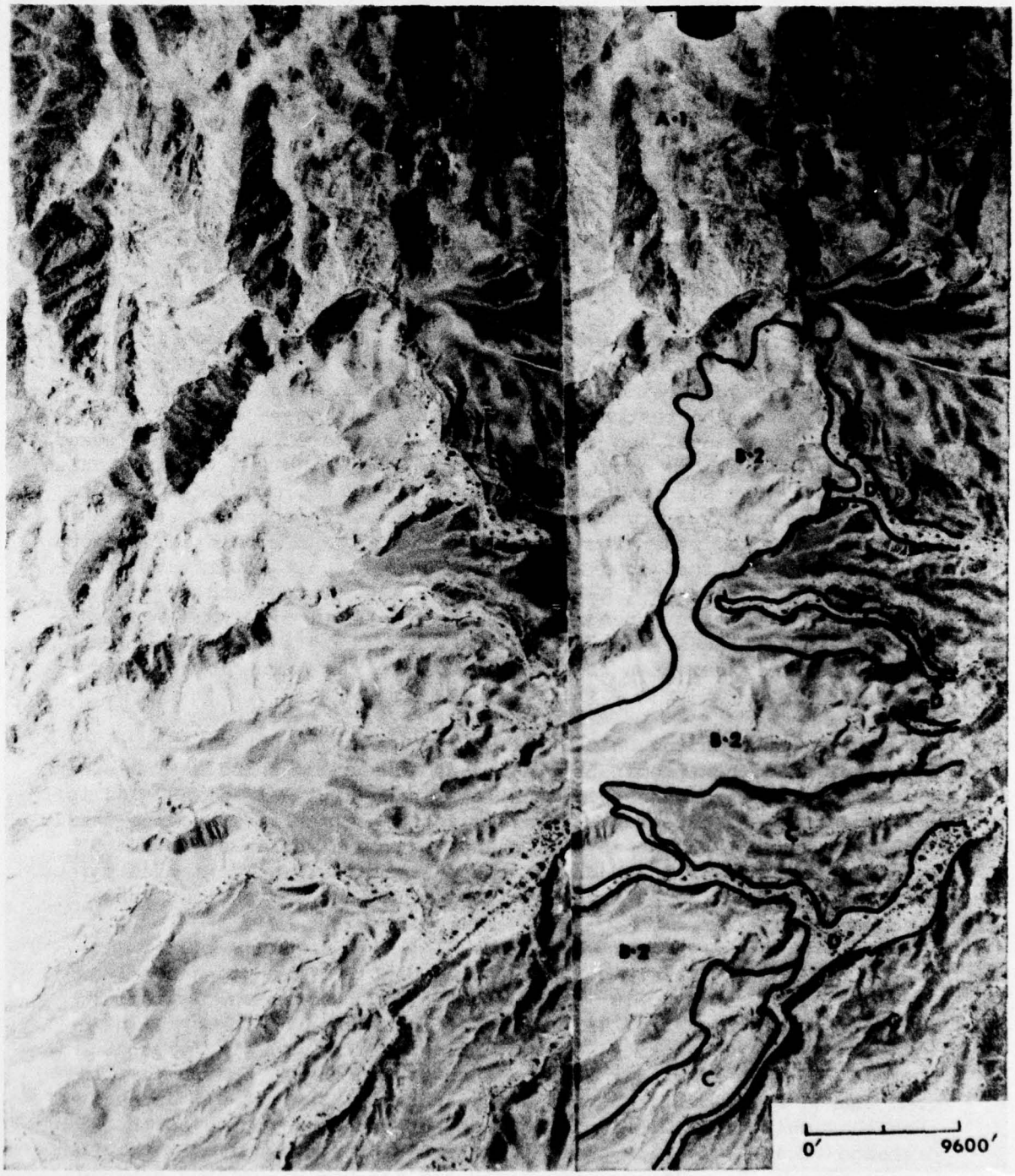


Figure 6. Stereo Photo of Units B-2 (sedimentary rock) and C (alluvial fan)

Unit C occurs in two locations, one south of Unit B-2 and the other north of Unit B-2 (figure 4). It appears to have homogeneous composition, the greatest stream density, and most of the visible vegetation. In the northern section, the unit slopes north, and in the southern section, it slopes gently southeast. The material is dark toned on the surface and lighter toned in gully walls (figures 5 and 6). It is darker in tone and finer in texture than any other unit on the photos.

The boundary between Units C and B-2 is subtle in comparison to that between Unit A-1 and any other unit. There is a slight tonal change, with B-1 the darker. There is a textural difference with Unit C the smoother. A slight break in slope also occurs along the interface.

To summarize, five different units occur on these photos; (1) rugged, mountainous terrain identified as metamorphic rock with gneissic texture, (2) intrusive igneous hills, (3) unconsolidated, coarse-grained massive material, (4) two parallel rock units dipping south, and (5) fine-grained, easily eroded material that is composed of two distinct layers.

Drainage. The central portion of photo 2-30 (Pattern 1, figure 7) has few streams or gullies. Most gullies trend east or west and then become tributary to streams outside the area. Angular stream paths suggest stream piracy and barbed drainage pattern. A line dividing the central area from other units can be drawn based on a change in drainage trend from east-west to north-south, which strongly suggests composition change across this interface. Streams are long with only one short set of tributaries, and those on the edge of the pattern flow in all directions, giving a radial appearance to the overall pattern (figure 7). It appears that the unit defined by this drainage pattern does not exist to the west because the pattern narrows. Conversely, the pattern widens to the east, implying similar material in this direction. Comparison of drainage and landform overlays shows that Pattern 1 and Unit A-1 coincide.

In the northwest corner (figure 7), drainage density is similar to Pattern 1, but streams flow north in parallel courses. The pattern is that of trellis drainage. Tributaries are longer and occur only to the south of main streams. Stream paths are diverted to the east by the igneous masses. Little alluvium is seen along the stream courses, but more vegetation occurs in these gullies than in Pattern 1. This pattern is designated Pattern 2 and coincides with Unit B-1. It was suggested above that Unit B-1 is porous, so drainage could be internal.

Drainage in the northeast corner (Pattern 3) has characteristics of both Patterns 1 and 4, discussed below (figure 7). Long streams with few tributaries are present except in one area. Angular bends



Figure 7. General Drainage Groupings (2-30)

here suggest stream piracy as in Pattern 1. In the central area, streams have a dendritic pattern, which implies a different composition. When drainage and landform overlays are compared, Pattern 3 contains exposures of both Unit A-1 and Unit C, and each pattern indicates the respective compositions.

Pattern 4, located in the southwest corner (figure 7), is a fine-textured, dendritic pattern. The main stream flows southeast and tributaries flow into it in a leafy manner. A tertiary set of tributaries produces an almost pinnate drainage pattern, nonexistent in either Patterns 1 or 2. The small, short streams occur with greater density than either the main streams or the secondary tributaries. Only the primary stream and its main tributaries have any valley development. Box-shaped gullies with flat bottoms contain small, alluvial terraces. The main stream is straight compared to the tributaries, which suggests structural control. Pattern 4 coincides with Units B-2 and C on the landform overlay. The pinnate drainage, however, occurs only in Unit C.

In the above discussion, the overall drainage patterns in this area were segregated based on overall appearance in broad areas. However, when each major drainage pattern is examined in detail, each is seen to be composed of separate parts. For instance, in Pattern 1 (figure 8), a definite angular, barbed pattern is evident in overall appearance. Tributaries to the barbed main stream, however, have a trellis appearance. Along the northern border between Pattern 1 and Patterns 2 and 3, many streams have a dendritic pattern. In the west, where the overall pattern narrows, the streams have a radial pattern. The inclusion of these various patterns into one major unit (Pattern 1) is justifiable, however, because of even more obvious differences with patterns in other areas.

Erosional aspects. Numerous V-shaped stream valleys in Units A-1 and A-2 indicate running water has been predominant in sculpturing the land surface. Extreme temperature variations could explain the blocky, shattered appearance of these units. High daytime temperatures followed by much cooler nighttime temperatures could cause the rock to expand and contract so rapidly that it eventually shatters. Gravity and running water would then combine to move debris downslope.

In Unit B-1, the V-shaped gullies indicate that erosion has occurred by running water. Shadows indicate slopes are fairly steep, so gravity helps move material downslope to be carried away by streams. The loose, uncompacted material in Unit B-1 suggests it was originally deposited from water; therefore, deposition has also played a part in the formation of this landform unit.

In Unit B-2, the V-shaped stream valleys indicate that erosion has occurred by running water. Valleys are wider here, though,



Figure 8. Detailed Drainage Patterns (2-30)

suggesting deposition is also occurring. As the unit has been identified as sedimentary rock, deposition, probably from water, explains its presence.

Streams have cut the gullies across Unit C and have deposited small terraces along gully sides. Deposition by running water is responsible for the origin of the bajada as explained in the section in regional photo analysis. If the veneer described in regional photo analysis and evident here is desert pavement, wind has also aided in bajada formation. Smaller particles would be winnowed out to be deposited elsewhere by either wind or water, leaving bajada surfaces covered with gravel.

The erosional agents with the greatest effect in the study area are mechanical, i.e. running water, wind, and gravity. The arid climate is the primary factor allowing mechanical erosion to predominate over chemical erosion. Although some aspects of chemical erosion must be taking place, it cannot be detected on aerial photographs of this scale.

Photo tone and texture. Both texture and tone are of primary importance in distinguishing Unit A-1 from other units. The effect of shadow, which gives a darker tone, indicates steepness of slope for a given sun angle. The identification of bare rock in Units A-1 and A-2 is based primarily on the rough, blocky shattered texture of the central portion of the photos. The change in tone and texture from this unit to any other unit indicates that changes are occurring.

The pattern of light and dark seen in Unit B-1 is due to shadow. The lighter tone of the tracks indicates their surfaces are different in composition from the land they traverse. This suggests a coated surficial material. If the material was not coated, there would be no striking tone change so close to the surface. Surface roughness can be used to determine composition by estimating grain size. For instance, grain size in Unit B-1 is thought to be smaller than that in Units A-1 and A-2 because the surface is not as rough.

The identity of Unit B-2 as a separate, distinct unit is based on tone alone; the surrounding areas are of slightly lighter tone. The subtle tone change down dip was of prime importance in identifying Unit B-2 as a sedimentary rock, indicating the presence of two layers.

Identification of Unit C as bajada covered with a thin gravel layer depends on tonal change created by tracks breaking through the thin gravel pavement into finer, lighter toned material. The surficial layer is probably coated in a manner similar to that in Unit B-1. There are also textural differences between Unit C and the units surrounding it, but the tonal difference is the key in the interpretation. Texture is used to distinguish this unit from those which surround it.

Vegetation. All vegetation visible on the photos is located in stream valleys and gullies. No vegetation can be discerned in either Unit A-1 or Unit A-2 except in small gullies. In Units B-1 and B-2, low-growing shrubs occur, and the smaller the gully, the smaller and more scattered the plants are. Gullies in Unit C contain round, bushy, short trees. Low-growing plants are also present, along with low, scattered shrubs on gully slopes. Even here, though, most vegetation is in gully bottoms, and not on the sides.

Widely scattered plants suggest several things. One, there probably is not much soil development in the rocky areas, which helps explain the lack of vegetation there. Two, most plants grow in lower elevations along gullies and streams which indicates a general lack of water in the area. Three, the occurrence of vegetation only in the gullies provides an easy method to trace gully paths and each gully appears as a line of small, dark spots.

Special features. One of the more intriguing features of this stereo triplet is the pattern of tracks in Unit B-1 (figure 2). The tracks are about 9 meters wide and appear to be vehicle tracks. The light tone indicates they are not paved. They do not follow valleys, but climb straight up the sides of hills and proceed along the crests, which suggests these tracks are for off-road or special purpose vehicles. The network of tracks is a closed circuit; there is only one route leading into or out of the area. There is no evidence of commercial or recreational development, and there is also no evidence of either mining or construction. Since the study area is part of a military reservation, it is possible this area is used for vehicle testing or training.

Another interesting feature occurring in Unit C is the pattern of circles described in regional photo analysis. The arcs cut through the veneered surface exposing lighter toned material and consist of equally spaced, parallel lines about 2.4 to 3.0 meters apart. They are located along the tracks, which suggests they are vehicle tracks formed by trucks or other large vehicles.

Cultural aspects. The only cultural features in the study area are the tracks in Unit B-1, a square building in Unit C, and narrow tracks in Units B-1 and C. The reason for the lack of cultural features is that the study area is located in a military reservation.

The building in Unit C (figure 2) is located in the extreme northern part of the photo. Since half the roof is in shadow, the building has a peaked roof. There is a small rectangular feature with rounded ends immediately west of the building, which may be a water tank or a tank truck. The building could be a water stop for vehicles and personnel working in the area. The narrow tracks are most obvious in Unit C on the extreme southern border of the photo (figure 2).

They are about 1.5 meters wide, which suggests they are jeep trails. They have no relationship to the network of tracks to the north and could be used for hunting or some other recreational purpose.

Analysis/summation. The area has been divided into units of texture, tone, drainage, and composition differences. The central rugged portion of the photos (Unit A-1) has been identified as metamorphic rock with gneissic texture in regional photo analysis. Sharp-crested ridges, indicating hard resistant material, prominent northeast-trending lineations, and veins substantiate this conclusion. Inhomogeneity is suggested by different drainage patterns within the overall Pattern 1. Perhaps small areas within the large body of metamorphics are of slightly different composition and resistance.

Rocky hills identified in the northwest corner of the photo (Unit A-2) are different in texture, form, and elevation. The lack of bedding, foliation, or banding, the presence of a well-developed joint system, and the existence of a rounded, lumpy texture suggest that it is an intrusive igneous body. Light tone indicates it is siliceous, rather than basic, in composition and probably granite or granodiorite.

Units B-1 and B-2 were identified in regional photo analysis as shale, and either limestone or sandstone. However, extensive examination shows Unit B-1 could be none of these. It is too coarse textured and too loosely compacted. No vertical tone change is evident, so desert pavement over finer grained material is not likely. Because Unit B-1 is porous, homogeneous, and rough, it is considered to be massive, loosely compacted granular material.

Unit B-2 was described in regional photo analysis as a layered unit consisting of two parts along with Unit B-1. The suggestion of dip slope to the south-southwest, indicated by drainage pattern, and a change in tone in the dip direction imply that the description in regional photo analysis is valid for this unit. The trend of the formations parallel to the southern boundary of Unit A-1 is northwest. Tone differences within the unit suggest an upper layer of dark shale, partially removed closer to the mountains and a lower unit of sandstone rather than limestone because of the lack of a well-developed joint system, which is very common in limestone.

Unit C is also composed of two layers of material; a thin, coarse, dark layer overlying a thicker, lighter toned layer. Because of the vertical change in tone, of the gentle slopes, and of the smooth, even texture, Unit C is assumed to be part of a bajada covered with desert pavement, as suggested in regional photo analysis.

Example II

Landform. The mountainous region (Unit A-1) consists of sharp-crested, dark-toned ridges trending northeast (figure 9). A linear pattern trending north-northeast is probably the metamorphic banding identified in regional photo analysis in this same unit. Some white veins are also visible. Few gullies occur in this unit in comparison to areas to the north and northeast. The streams are comparatively long, with long, straight tributaries. The texture of this region is very rough and coarse, suggesting it is composed of shattered, bare rock. Rubble occurs in the small gullies, often obscured by vegetation.

The boundary between Units A-1 and C is marked by a striking change in slope, a change in tone from dark in Unit A-1 to medium in Unit C (figure 10), an increase in the number of streams in Unit C, and a change in overall drainage pattern.

Unit C, located between mountains and basins, slopes generally to the northeast away from the mountains (figure 9). It occurs as an apron along the base of the mountains, and scalloped edges on the northeast side indicate it is a bajada as identified in regional photo analysis. Within Unit C, a gradual tone change to the northeast from dark to light occurs, along with an increase in drainage density (figure 10). Looking at this fan in detail, three separate units can be identified. One occurs in the northwest section of the unit (Unit C-1), a second in the central area running the full length of the photo (Unit C-2), and a third in a terracelike manner along the valley sides in the mountainous region (Unit C-3). Distinctions are based on breaks in slope, degree of dissection, and difference in texture and tone.

Unit C-1, next to the mountains, is not continuous from northwest to southeast, and has been either removed in the southeast or covered by subsequent deposition. The northeast boundary between Units C-1 and C-2 has a fan shape. The few streams crossing Unit C-1 are semi-parallel in pattern. Larger stream valleys divide it into several parts. Wide areas of dark-toned material occur between gullies, which are marked both by the presence of vegetation and by a vertical change in tone.

Unit C-2 is lighter in tone, has a feathery appearance, and is more heavily dissected that in Unit C-1 (figure 10). It is essentially continuous from northwest to southeast, except where it is cut by streams also crossing Unit C-1. The vertical tone change noted in Unit C-1 also occurs here, but it is found in fewer localities. The higher stream density suggests it has been removed. The northeast border of this unit is scalloped like Unit C-1.



Figure 9. General Landform/Rock Pattern Boundaries (1-26)

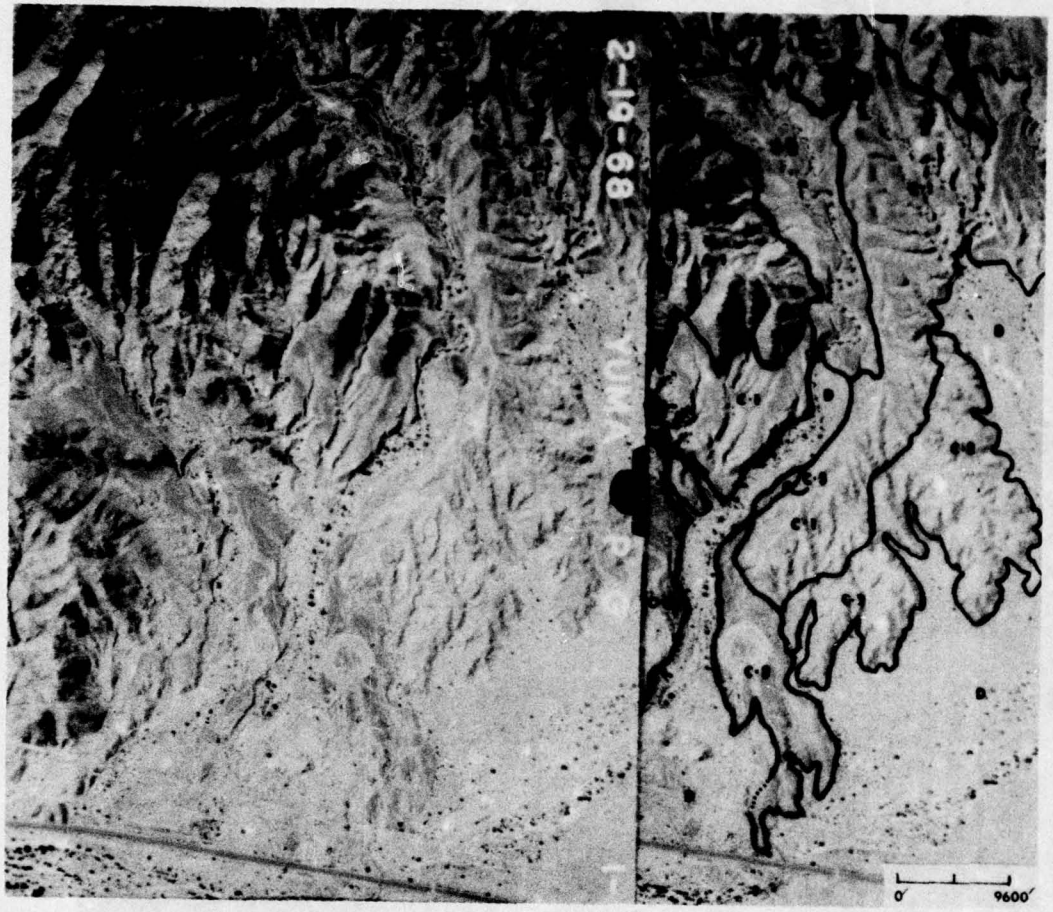


Figure 10. Stereo Photo Showing Mountains, Bajada, and Basin

Unit C-3 occurs along valleys in the mountains and is dissected very little. It forms terraces sloping gently downstream. The appearance of this surface is soft, very fine, and dark in tone. The sides of the small streams and gullies are lighter in tone than the surficial material. The streams are not as deeply incised as in the other two units, which suggests that the unit is younger (figure 10). The streams do cross Unit C-3; therefore, it is also undergoing active erosion.

The boundaries between Units C and D are similar to those between Units A-1 and C, but the characteristics are not as marked (figure 10). An obvious break in slope occurs between bajada and basin along with a change in topographic expression from hilly to flat. A decrease in the number of streams also occurs along with a change in drainage pattern. A tone change from medium to light and the occurrence of more vegetation in the area to the northeast also suggest change.

The third major subdivision on these photos (figure 9) is the low-lying, flat area in the northeast corner (Unit D). Low elevation and location indicate a basin probably filled with debris from the mountains. There are fairly large gullies crossing it, suggesting it is now actively eroding. Texture and tone throughout the area are uniform indicating homogeneous composition. The basin surface is light toned, which suggests fairly coarse, porous material. Steep gully walls also imply coarse material. Elongate, cresent-shaped parallel forms are suggestive of sand dunes. The sand dunes, the light tone, the probable porosity, and the steep gully slopes suggest that the material in the basin is sand and that wind has contributed to the present topographic form.

In summary, these photos are composed of three distinct landform units, (1) mountains, (2) a bajada, and (3) a basin. The mountains are generally homogeneous in composition, consisting of dark-toned resistant rock identified as metamorphic in origin and as gneissic in texture. The bajada occurs in three different units delineated on the basis of tone, of degree of dissection, of location, and of relative elevation. It is covered with dark-toned, coarse material overlying finer, lighter toned material. The amount of dark material decreases outward from the mountains. The basin area is homogeneous in composition, has steep gully sides, has a light tone, and is probably quite porous.

Drainage. Pattern 1 in the southwest corner consists of streams flowing north or northeast with fewer, longer tributaries than elsewhere in the photo. Streams flow north to the boundary between Units A-1 and C (figure 11), and then turn and flow east. This implies either composition change or structural control, or both, along the northern boundary of the mountain. The streams are nearly parallel,



Figure 11. Drainage Pattern Groupings (1-26)

with only some of the angular characteristics of drainage patterns found in other photos. This, however, could be because only a small area of this material occurs here. When this drainage pattern is compared to the landform overlay, it coincides with Unit A-1.

Although drainage Pattern 2 is similar to Pattern 1 in that it consists of long parallel streams, the tributaries are much shorter and Pattern 2 has greater density than Pattern 1. Stream courses are much more irregular, and the pattern is subdendritic (figure 11). This pattern coincides with Unit C-1 on the landform overlay.

Pattern 3, which is located in the center of the photos, and extends from the northwest to the southeast corner, is the most prominent. It consists of short streams with numerous, very short tributaries, giving it a feathery appearance. The pattern is essentially dendritic, but in certain areas, it approaches pinnate. When this drainage pattern is compared with the landform overlay, it occurs in Unit C-2.

Pattern 4 (figure 11) consists of long, straight streams that form a braided pattern. The pattern is linear, and all other streams in the photos flow into these east-southeast flowing streams. These streams are the only ones to continue across the triplet, and they appear to enter a large wash in the extreme southeast corner. Before the southeast flowing network of streams enters this large wash, it crosses beneath a small bridge on the highway. The highway also has a short drainage ditch on the east side that feeds into Pattern 4 drainage before it enters the large wash. When compared to the landform overlay, Pattern 4 is seen to correspond to Unit D.

Erosional aspects. In Unit A-1, erosion by running water is evidenced by numerous stream paths. The gullies are steep sided, show no valley development, and are probably eroding rapdily headward. The broken, blocky appearance of the land surface is probably caused by drastic temperature changes. Gravity and running water combine to move debris downslope. Even though no vegetation or requisite soil development is obvious at this scale, root wedging is probably also occurring.

The bajada area (Unit C) is probably the most diverse in terms of erosion. It is formed by deposition from running water. However, it is now in the process of eroding by this same agent as evidenced by the many streams. Wind is also involved in desert pavement formation. Water is the primary agent responsible for the present landform configuration.

Like the bajada, the basin area (Unit D) is the product of both wind and water, which were responsible for depositing material originally. However, because of vegetation on the dunes indicating they

are stabilized, water is the primary agent now. Wind is probably doing no more in the area at this time than moving material around.

Photo tone and texture. In Unit A-1, the tone is quite dark, and only the high steep ridges have shadows. This is unlike the occurrences in other parts of the study area and could be due to either the photo reproduction process or the low sun angle at the time the film was exposed. The texture of Unit A-1 is very rough and blocky. Because of the rough texture and dark tone, vegetation cannot be distinguished in the gullies so that stream courses can be followed. Even though tone is unlike that observed before, the similarities in texture allow this unit to be identified as the same as Unit A of regional photo analysis and Unit A-1 of Example I.

The texture of the bajada, Unit C, is the same throughout the photo. It is finer and smoother in appearance than any other part of the photo. However, on close inspection, the difference between coarse surficial material and fine underlying material can be made. One of the striking characteristics of this unit is its varying tone. The tone is darkest near the mountains, and it gradually lightens to the northeast. The boundary between the basin and the bajada is located where the tone becomes constant. Tone is also important, along with other characteristics, in delineating the different fan surfaces because of the dark surficial material, which is probably a coating of desert pavement.

The area of lightest tone is the basin, Unit D. Two types of tone occur here - a very even, light grey on the basin floor and a white in the gullies. Along with vegetation, the light tone of the gullies is important in delineating drainage. Just as streams do, tracks and trails cut swaths in the vegetation. Therefore without the tonal difference, the tracks would be difficult to locate or to follow.

Vegetation. The only vegetation visible at this scale in Unit A-1 occurs in the gullies. However, the dark tone of the photos makes it difficult to distinguish it. The vegetation here appears to be very low-growing shrubs. Other low plants probably grow on the bare, rocky slopes, but they cannot be seen. More vegetation does occur in the bajada, Unit C. It is primarily in gullies and stream valleys, but some shrubs do grow on gully sides. Where major valleys cross the bajada, larger shrubs and low, bushy trees grow. The taller vegetation increases downstream. In Unit D, the vegetation pattern changes strikingly. Instead of occurring only in gullies, it is found regularly spaced on the surface. Concentrations of larger vegetation are in the large wash in the southeast corner. Trees are present in clumps here differing from the scattered occurrence in smaller gullies.

Special features. In Unit D, several features of particular interest occur. The first feature is the striped pattern (figure 12) in the northeast corner of the photo. It consists of northeast-trending, narrow, light stripes about 13.7 meters wide edged by darker toned stripes about 20.7 meters wide. There are tracks or roads paralleling the east-west boundaries perpendicular to the stripes, and one lighter track crosses parallel to the stripes. Fainter traces similar to these occur south of this area, and the entire pattern trends northwest. Because a stream crosses the pattern, the fact that it is within a military reservation, and the relationship to nearby tracks, it is suggested that this area is the location of old barracks or tents as mentioned in regional photo analysis.

A small area marked by an "X" on the cultural overlay (figure 12) is also of interest. It is 248 meters long and 98 meters wide, and consists of irregularly spaced, small oval holes about 3 meters long and narrower in width. The area around them is covered with faint vehicle tracks, which suggests that they might be shell holes and that this small area is used for target practice.

In the southeast corner, west of the main highway in Unit D, are two rosette-shaped features (figure 12). One feature is a depression, located on the bajada, that cuts through the pavement surface. The other feature, located between two noses of the bajada, has bands that go up a small, pointed hill, as if material is being or has been removed. A similar pattern occurs on one of the sand dunes, but the bands are wider here. These could be areas for vehicle testing and/or training with different band widths due to different size vehicles or material composition, or for extraction purposes.

Cultural aspects. The only cultural features occurring in Unit C are tracks consisting of parallel lines roughly 1 to 2 meters apart and a circular depression about 131 meters in diameter (figure 12). The tracks proceed up one of the major bajada spurs, with several shorter tracks traversing smaller spurs. They do not appear to have any specific destination and terminate near the mountains. The circular depression, which has a raised center covered with desert pavement, is located in the southeast corner of the photo west of the highway near the rosette-shaped features. Roads lead from the rosette area to the depression, and another set of tracks connects it directly to the main highway. The design suggests an extractive process and the material removed is probably used for construction purposes outside the area of photo coverage. The occurrence of this feature near the rosettes suggests they might also be extractive in nature.

More diverse cultural features occur in Unit D (figure 12). These features include a paved road, the pattern of stripes and small holes, and some lines of communication. The dark tone and center line of the highway indicate it is paved, probably with bituminous



Figure 12. General Cultural/Land Use Patterns (1-26)

bituminous material. It is the same highway identified as the major transportation route in the area in regional photo analysis. A large truck (tractor and semitrailer) and a smaller vehicle (a car with a travel trailer behind it) suggest that the road is a main highway and not part of the military road network.

Several light-toned strips are parallel to the highway, and when observed closely, these strips are also parallel to two types of communication lines. One type, as described in regional photo analysis, is a telephone line, and the other type is a power line. The light-toned strips are probably for maintenance purposes.

Unit D is also crisscrossed with a pattern of tracks or trails. In general, they are parallel or are perpendicular to the striped pattern, trending northeast or northwest ranging in width from approximately 3 to 12 meters. Most of them have been well used as they make broad swaths in the vegetation cover. They are obviously vehicle tracks, but their purpose is unknown.

Analysis/summation. The mountainous section (Unit A-1) has been described previously as metamorphic rock with gneissic texture. Since the characteristics of this unit are the same as in other areas except for tone, this sharp-crested, banded unit is assumed to be the same metamorphic rock found elsewhere in the study area.

On close inspection of the bajada, Unit C, three distinct units can be identified, and relative ages can be determined. As a fan is built, material nearest to the mountains would be the oldest; thus, the fan becomes progressively younger away from the mountains. When a second fan is formed, it would partially cover the first fan, be built further out toward the basin, or occur along valleys cutting the first fan. This process can occur many times, and it appears to have occurred at least once in this area.

The oldest of the three fans (Unit C-1) is located closest to the mountains. It is noncontinuous, it is moderately dissected, and it is covered with desert pavement. In addition, it is crossed by streams which traverse both the middle-aged fan (Unit C-2) and the youngest fan (Unit C-3). The material on all the fans appears to be coated with desert varnish, which produces the dark tone. There still remain, however, large expanses of undisturbed desert pavement. The middle-aged fan unit, Unit C-2, is located farther out toward the basin than Unit C-1 and is continuous from northwest to southeast. It is distinguished from other fan units by being intermediate in elevation, by being more heavily dissected than either of the other units, and by having the smallest amount of undisturbed desert pavement. Streams crossing the older unit (C-1) also cross Unit C-2. The youngest fan, lowest in elevation (Unit C-3), occurs along the sides of valleys crossing both of the older units. It is comparatively

undissected, is quite flat, and could be covering parts of the older units in certain areas. Because of this and because it follows streams through older units, it is considered the youngest fan.

The causes for the cycle of erosion and deposition in the bajada are interesting. One more obvious cause is faulting along the base of the mountains, resulting in uplift of the entire area and subsequent rejuvenation of streams. Another possible cause is that the base level of the main stream into which the streams flow has been lowered; therefore these streams are able to deepen their valleys and subsequently lower themselves. It is also easier for a stream to erode faster once it has broken through the protective desert pavement. This explains the similarity between Patterns 2 and 3 on the drainage overlay, where pavement has been mostly removed from Pattern 3.

The basin area (Unit D) is essentially as described in regional photo analysis. It is a low-lying area, with sparse, low-growing vegetation covering most of its surface and with a major stream flowing east. This is the east basin described in regional photo analysis. Many features, possibly owing to vehicle testing occur here, along with the majority of other cultural features. Dune-shaped features, tone, and slope of gully walls indicate the basin is composed of sand.

PHOTO ANALYSIS SUMMARY

Summary and Relationships

Area covered by photography. The study area is in an arid environment and consists of two major landscape units - mountains and basins. The mountains comprise about 25 percent, and the basins, or low-lying areas, comprise about 50 percent of the area. In addition, there are many lesser geomorphic units, such as alluvial fans, stream flood plains, terraces, sand dunes, and rugged, sharply dissected hills.

The mountainous areas are composed of 20 percent igneous and 80 percent metamorphic rock. Only the western part of the southern range contains mountains that are not metamorphic. The mountains also contain the highest elevation in the area, which occurs in the southeast corner. All of the mountain areas trend northwest, and they are bounded by northwest-trending faults. Most of the drainage in the study area originiates in the mountains. The mountains contain gullies that are deep and steep sided with some rubble found in them along with very sparse, low-growing vegetation. The mountains have little cultural activity occurring there, except that of a military nature.

The bajada areas surround the individual mountainous regions in all but the southwest corner of the study area. At least three

different age fans have been identified, and age relationships have been determined from detailed stereo photo analysis. It appears likely that a fourth fan may also exist in some parts of the study area. The bajadas consist of two layers of material; (1) a dark-toned, thin layer of coated gravel on top, and (2) a light-toned, fine, thick layer of material on the bottom. Dissection in the bajada increases away from the mountains, and some drainage originates in the bajada. All vegetation grows to greater heights in the bajada than in the mountains. Some cultural activity occurs in this area, including tracks and trails for testing and a borrow pit. Many of the tracks merely cross through the bajada areas indicating most of the testing occurs elsewhere.

Although the basin area is the least diverse in terms of topographic expression, it contains almost all the cultural activity, about half the drainage channels, and most of the vegetation. The basin area has a drainage divide that trends northeast through it, dividing it into two separate, smaller basins. The western basin drains to the west, and the eastern basin drains to the south. The basin surface is dotted with low-growing plants, and the gullies contain taller trees and shrubs. The shrubs grow to about the same heights as in the bajada, but are much more numerous. The basin has trees that are much higher than elsewhere, and they grow in clumps rather than as single plants. Competition for water is evidenced by the spacing, height, and density relationships; on the basin floor plants are widely separated, but in the gullies which have higher soil moisture content, vegetation is taller and more dense. The kinds of vegetation are different in the two occurrences, which suggests that moisture requirements are critical.

Cultural activity in the basin is primarily of a military nature as evidenced by the living and working areas, the tracks leading to the testing areas, the paved roads connecting spheres of human activity, and the airfield. A major highway occurs on the east, and a large irrigation canal occurs on the west. These will be discussed later in terms of what they indicate about the area surrounding the study area. Beyond the canal is the flood plain of a large river.

In the southwest corner are topographic forms and material compositions that do not fit into the above categories. The area consists of low, rolling hills composed of granular material. The dissected granular hills are traversed by a network of tracks used for vehicle testing, and some jeep trails probably used for recreational purposes occur south of here.

The above are distinct units based on photo tone and texture, drainage pattern, elevation, and vegetation density and type. Each unit has been designated by a letter, and the same letter has been used for the same unit in both regional and detailed studies. All

rock units in the mountains are designated A, all material in the southwest corner as B, all bajada units as C, and all basin areas as D. Subdivisions of these major units are indicated by 1, 2, etc.

Relationships to the area outside the study area. This report consists of three separate photo studies, which have been analyzed and interpreted on their own merits. A regional photo study allows general conclusions to be formed, and a detailed photo study gives substantiation and a better understanding of patterns identified in regional analysis. A summation of information derived in the combined studies is presented above, and up to this point, only features that occur within the area of photo coverage have been included. It is possible from the information presented here to derive further information about the region surrounding this small study area which would give a greater understanding in terms of processes, relationships, and formation in a desert environment.

The suggestion has been made previously that the mountains and basin areas are separated by faults. Both these physiographic units continue outside the study area and it is therefore logical to assume that the pattern of faulted mountain blocks and basins does also. This overall pattern is called basin and range, and this small area is probably part of a much larger basin and range province. The complex formation processes described previously in regional photo analysis and the diversity of material composition within the study area must be associated with a larger desert environment. The sizes of the topographic features in the study area are too large to be considered in terms of an isolated occurrence.

It was suggested in regional photo analysis that the military reservation includes a larger area than that shown on the photos. This assumption was based on the presence of a large airstrip. An approximate house count in the living area of the reservation indicates that over 100 families live here. In addition, barracks-type buildings are visible in the same area, and these house more personnel. This indicates more personnel than required to man the facilities present in the photos. The reservation probably does not extend to the west because of the river. It probably does extend to the north because both roads and the airstrip continue off the edge of the photos. Since no roads continue to the south, the southern limits of the reservation are probably within the area of coverage. There is nothing to indicate whether the reservation extends to the east, but a guess is that it probably does.

Military posts usually have support facilities, such as commissaries, exchange stores, etc., for military families. However, these facilities are not entirely satisfactory for the needs of the military family, and commercial establishments are in demand. In addition, military posts usually have many civilians associated with them.

Since this reservation has been discussed in terms of testing and training, the civilian personnel are probably conducting applied research. For these and other reasons, military reservations are usually located close to previously established commercial centers. The location of this center in relation to the reservation can be deduced from other criteria on the photos.

The canal and the river were discussed in regional photo analysis. The river was assumed to be a major river because of the presence of water bodies in the area of photo coverage and the presence of dense vegetation. The canal was assumed to be for irrigation rather than transportation purposes because of its size, alignment, and location in an arid environment. The canal also provides clues as to the surrounding area and the direction of flow of both river and canal which was thought impossible to determine from photos.

To produce an environment such as that evidenced west of the canal in a desert environment, water must be impounded downstream. This strongly suggests the presence of a dam downstream. It is suggested that the canal flows in the same direction as the river and that the canal must associate with a dam. This suggests that a second dam, possibly larger than the southern dam, exists upstream. The presence of two dams and an irrigation canal indicates extensive agricultural activity must be occurring in the downstream direction. Since the agricultural activity is occurring downstream, the major commercial center serving the personnel of the military reservation is probably located downstream also. The large wash in the southeast corner of the study area flows to the south as indicated by the angle of tributary entry. As this wash is approximately 2 kilometers wide, it probably indicates the general slope of the land, i.e. to the south. Since the river and canal would therefore also flow south, the commercial center is probably located to the south.

It is possible to describe the general characteristics beyond the study area. The following statements, based only on information extracted for the area of photo coverage, could indicate the location of the study area. These criteria are (1) the arid climate, (2) the characteristics defining climate (which indicate the area is in the middle latitudes), (3) the basin and range geometry, (4) the design and layout suggestive of an American military test reservation, (5) the type of activity inferred to be occurring on the reservation, i.e. testing and training, (6) the high level of technology required to produce the canal and dam system, (7) the direction of flow of the river and its apparent large size, and (8) the fact that the river is through-flowing in an arid climate. All these criteria combined indicate that the most probable locality for the study area is in the southwestern United States, east of the Colorado River, in the state of Arizona. When this information is compared to maps, it appears that the northern dam is Imperial Dam, the southern dam is Laguna Dam, and the commercial center is Yuma, Arizona.

Environmental Problems

The results of photo analysis suggest certain problems, which will influence both military and engineering activities in the study area. Some of these problems are listed below:

1. Excessive heat and dryness
2. Hot surfaces during the day, cold at night
3. Effect of dark and light surfaces on the use of optical instruments in making distant observations (shimmer effect)
4. Mirages (sighting and ranging)
5. High evaporation rate resulting in increased surface alkalai and loss of water in curing concrete
6. Shortage of water for construction purposes
7. Shortage of water for domestic, military, and commercial uses
8. Flash flood dangers resulting in rapid rise of water in gullies and low areas, protection of structures from washouts, and rapid accumulation of sediment in low areas
9. Use of water separation structures to separate silt-laden runoff from irrigation water
10. Blowing sand affecting engine intakes, bearings, housekeeping, etc.
11. Cannot travel across varnished surfaces without leaving tracks
12. Difficulty of movement without raising dust
13. Lack of vegetation for cover and concealment except in gullies and washes
14. Scarcity of edible plants
15. Effect of thermal current and air density differences on aircraft performance

Selected Areas for Future Field Checks

One of the prime advantages of a photo study such as this is that the amount of required field checking is drastically decreased. Instead of requiring the entire area to be traversed on foot, problem areas can be determined from the photo study, and only these need to be visited in the field. Certain areas have been chosen in the study area where it was felt that field checking would yield more information about the relationships identified in photo analysis (figure 13). Selection was also based on accessibility.

Area A is located in the southwest corner of the study area and includes exposures of Units B and C, Example 1. Composition determinations for each unit can be validated, and their boundaries checked. The required route to this area passes near outcrops identified as granite in Example I, and this identification can also be verified.

Area B can be reached by the same road network as that leading to Area A, and is located in the south-central part of the study area. It will allow verification of Unit A in terms of composition and location, and it will also allow actual identification of characteristics used in identifying this unit as gneissic metamorphic rock. Part of the sample area is located in Example I.

Since Area C is located along the main highway in the southeast corner, access will be no problem. The area will allow further verification of Unit A as gneissic metamorphic rock, and the absence of bajada in this area can also be investigated.

Area D is also located in the southeast corner of the study area, but is within Example II. A visit here will allow verification of the three bajadas; their composition, their location, and vegetation. It will also be possible in this locality to investigate composition and vegetation of the basin area, both on the surface and in the gullies, and a slight side trip will allow observation of the striped pattern discussed in both regional analysis and Example II.

Area E will give verification of the material compositions located in the northern outcrop of gneissic metamorphic rock. It is located along the paved road in the north-central part of the study area, and reconnaissance can be made on foot from the road.

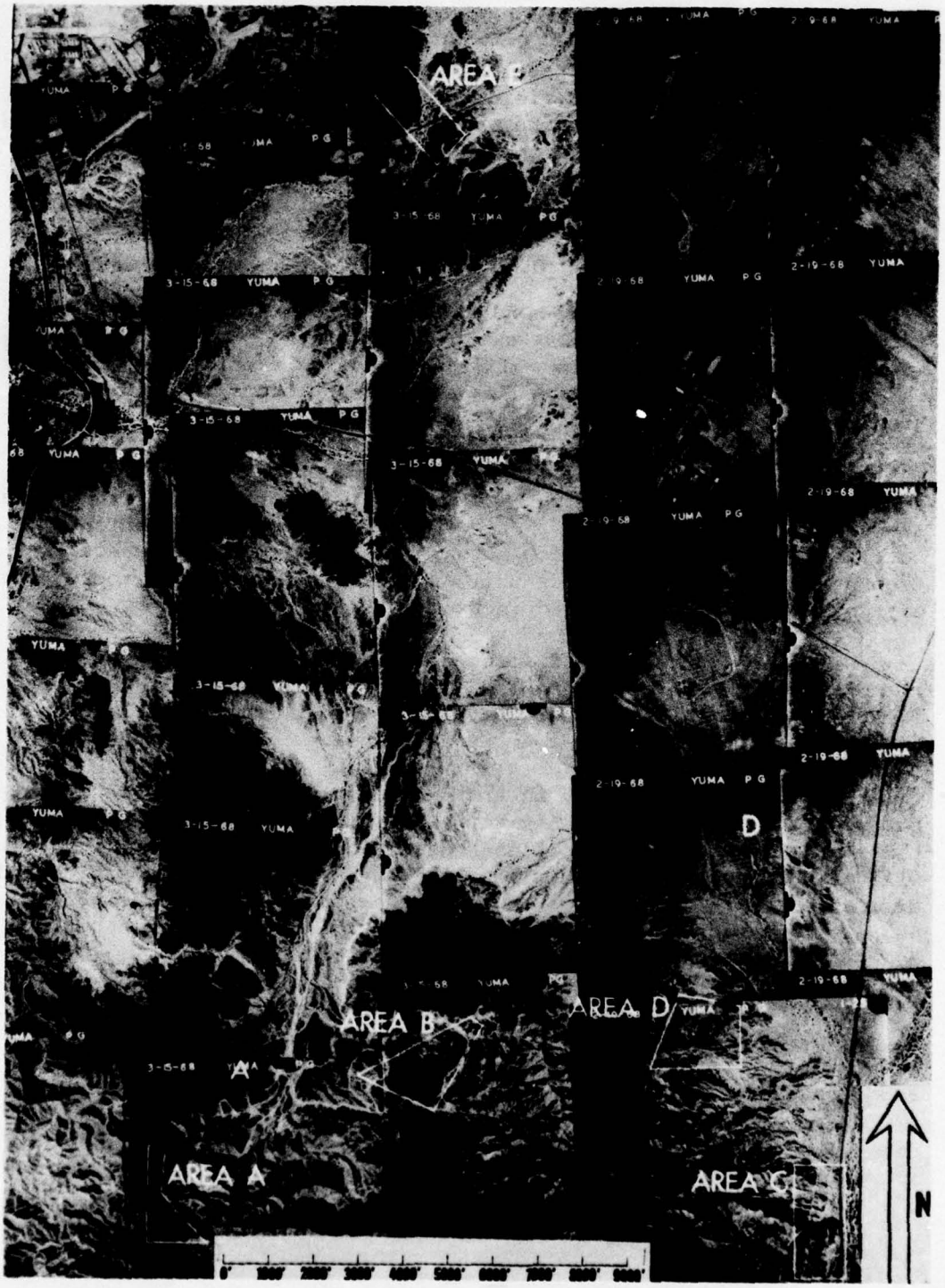


Figure 13. Selected Areas for Field Verification

PART II. FIELD VERIFICATION OF PHOTO ANALYSIS

INTRODUCTION

The study area is located in the Sonoran Desert approximately 40 kilometers northeast of Yuma, Arizona. Located near the Colorado River on the California-Arizona state boundary, the area is within the U. S. Army Yuma Proving Ground (figure 14). It includes most of the Laguna Dam 1:24,000 7½ minute quadrangle.

A trip was made to Yuma Proving Ground in the spring of 1973 following completion of the photo analysis section (Part I). Ground field checks of areas designated in photo analysis as requiring field verification were completed along with low-level helicopter observation of the entire quadrangle.

Most geologic information derived from photo analysis is valid with only a few discrepancies, such as exact location of contacts between rock units and exact identification of rock types. Therefore, three types of information relating to geology and landforms are included here; (1) a detailed description of natural features, (2) an attempted explanation of erroneous and incomplete interpretations in the photo analysis phase, and (3) information derived from sources other than photo analysis and field verification, such as petrographic analysis and the literature. Most information on vegetation was unrecognized in photo analysis, even though vegetation was briefly discussed. All information presented in this field-oriented section is based on field observation and on lab investigation. If comparisons are made to information derived in photo analysis, this is so stated; otherwise, all data were determined in the field.

GENERAL GEOLOGY

Introduction

The study area can be divided into three general topographic classes; (1) mountains, (2) hills, and (3) plains or basins (figure 15). These classes will be discussed by material type and/or grain size. In general, the mountains are composed of hard rock, the hills of moderate-to-coarse sediments of varying compaction and induration, and the plains, of finer, less indurated material (figure 16).

Mountains

The mountainous regions are composed of three distinct rock types; schist, black-and-white-banded gneiss, and coarse-grained granite. In some areas, the gneiss and schist are distinct rock types;

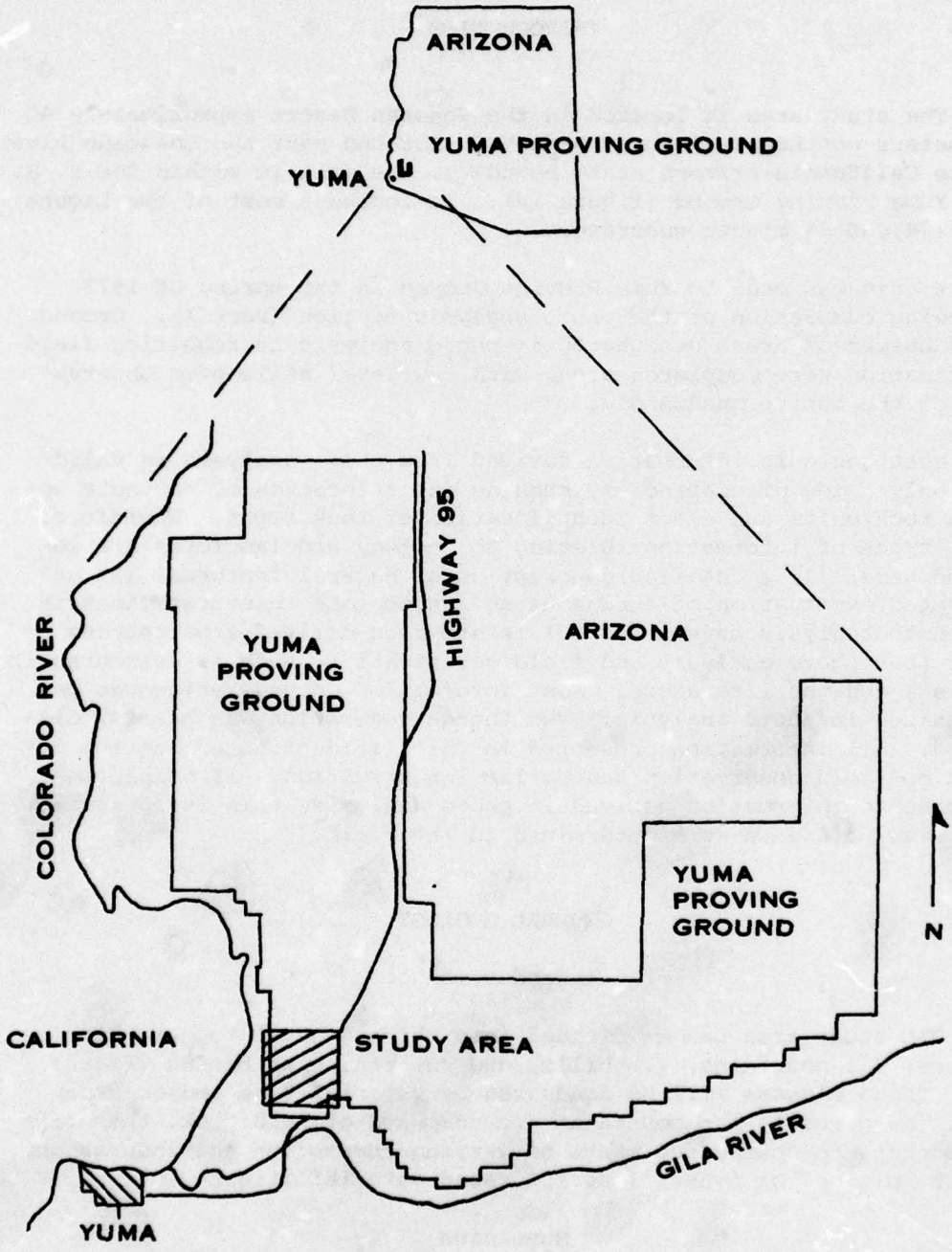


Figure 14. Location Map of the Study Area

however, in contact zones, they grade into each other. The differences in the amount of visible mica and the degree of foliation determined the boundaries shown in figure 16. Distinctions in foliation were also found in the aerial photos, along with tonal variations.

Schist. Schist outcrops occur in the eastern part of the study area along Highway 95 (figures 16 and 17) and are lower in elevation than the gneiss outcrops to the west. The schist occurs as wide, alternating bands of light and dark; whereas, the gneiss is uniformly dark in color (figure 18). In the photo analysis, the rocks of this area were identified as metamorphic, but misinterpreted as gneiss rather than correctly identified as schist. A general difference in elevation between subsequently identified schist and gneiss areas was noted in the photos, but this was not thought to be significant, so more detailed observations of the lower area were not undertaken. Besides being in contact with gneissic rock, the schist also comes in contact with conglomerate in the extreme south (figure 19).

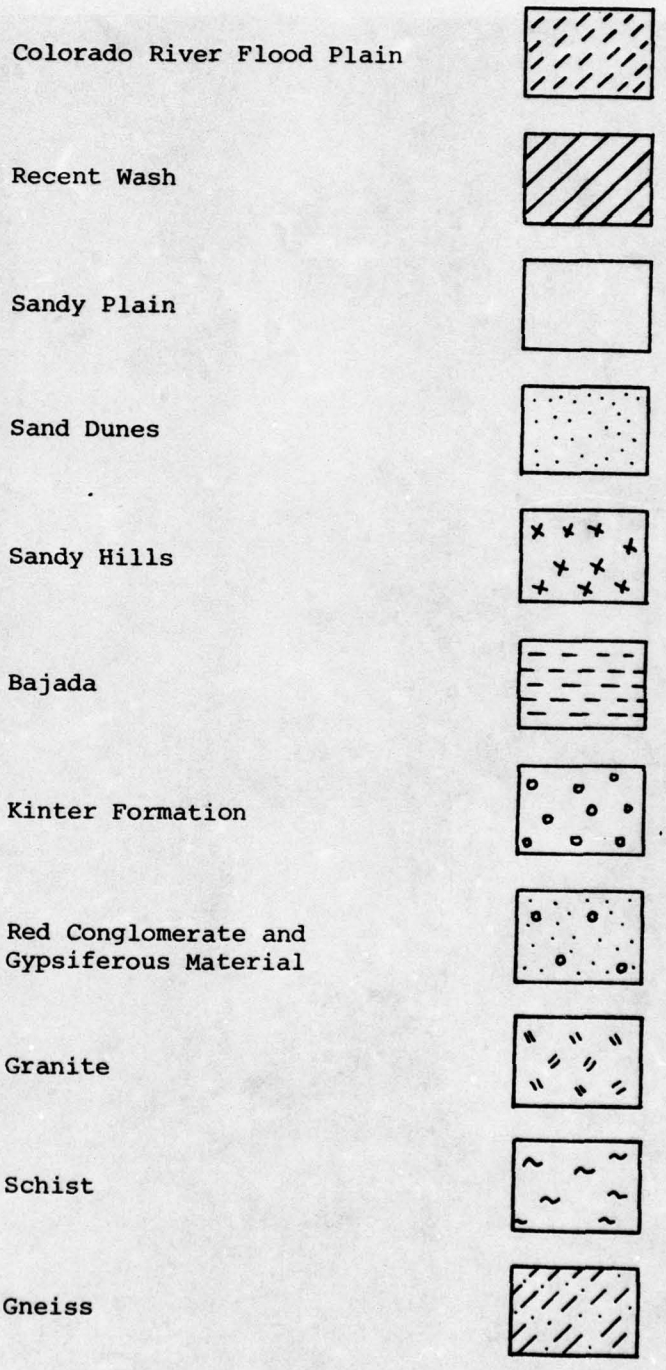
Hand specimens of the schist have varying appearances related to nearness of the schist-gneiss contact. Closer to the contact, schist samples are more foliated and consist of thin bands of quartz and dark minerals with intervening layers of light-colored mica. Farther from the contact, the schist is blue or slightly red, is only slightly foliated, and is very micaceous.



Figure 15. View of the Study Area from the North



Figure 16. Geologic Map of the Study Area



LEGEND FOR GEOLOGIC MAP OF THE STUDY AREA

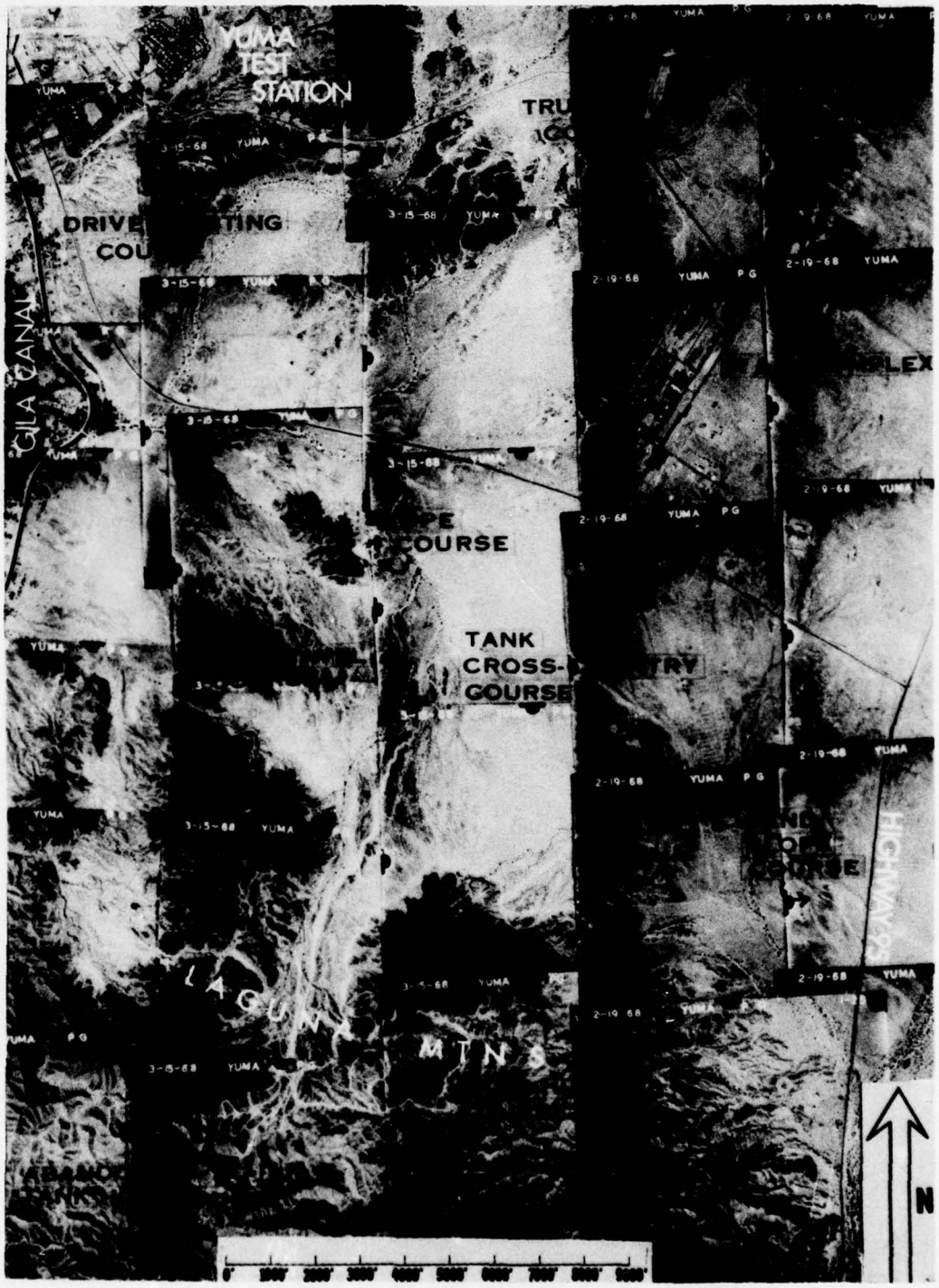


Figure 17. Planimetric Map of the Study Area

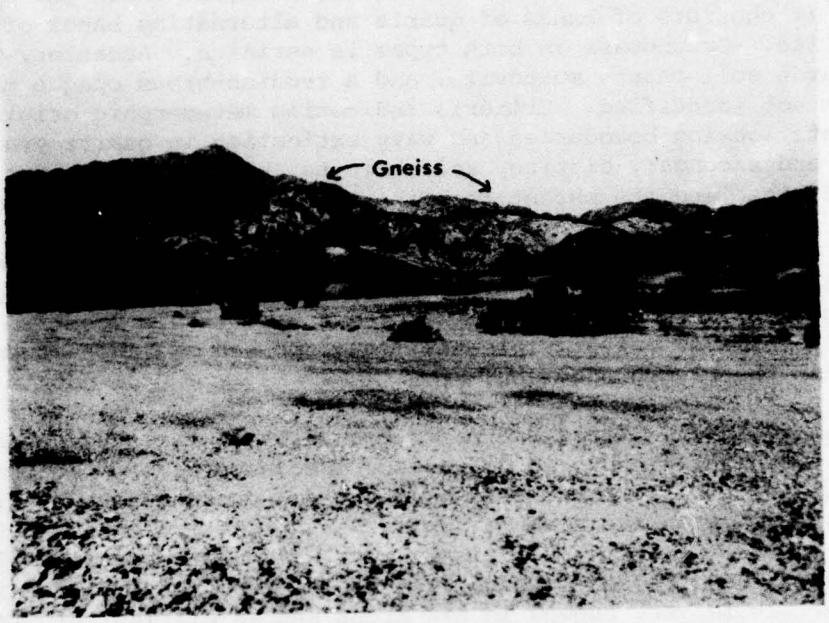


Figure 18. Contact Between Schist and Gneiss. Note Apparent Layering in Schist on the Right

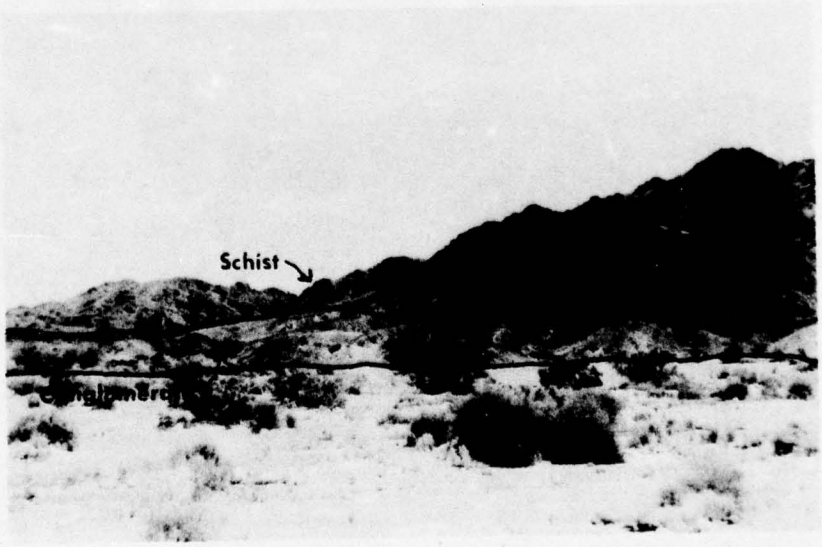


Figure 19. Contact Between Schist and Red Conglomerate

One specimen of the bluish schist was analyzed under the microscope. It consists of bands of quartz and alternating bands of quartz and biotite. Groundmass in both types is sericite. Accessory minerals include collophane, muscovite, and a reddish-brown opaque mineral that was not identified. Criteria indicating metamorphic origin include interlocking boundaries and wavy extinction in quartz grains, primary and secondary biotite, and sericite. The specimen is greenschist facies, and the parent rock is probably a quartz-rich mud.

In one area near the contact, one of the light bands was sampled. It was thin sectioned and consists primarily of microcline and quartz. Minor amounts of sericite, orthoclase, and biotite also occur. The rock is considered only incipiently metamorphosed and much lower in grade than the bluish specimen.

Gneiss. Gneiss forms the major mountains in the study area, an example of which is shown in figure 20. Because the area composed of schist was originally identified as gneiss in photo analysis, figure 16 shows less extensive areas of gneiss than were indicated in Part I of this report (figure 4). Gneissic rock was observed and sampled on the ground along the contact and also viewed from a helicopter in its entirety. It is very rugged in all areas and is difficult to traverse. The rock is composed of black and white bands of varying thickness and is covered with desert varnish. Close to the schist/gneiss contacts, the bands become less distinct and somewhat discontinuous. The rock, however, is distinctly gneissic and nonfoliated.



Figure 20. Gneiss Outcrops in the Vicinity of the New Tank Hill Course

After gneiss samples were collected from all parts of the study area, one was selected for petrographic analysis. The analysis revealed that the sample is composed of white bands of quartz and sericite and black bands of biotite, sericite, and an unidentified black opaque mineral. In parts of the sample consisting primarily of sericite, ghost plagioclase twins could be seen; so sericite is assumed to have almost completely replaced plagioclase. Small amounts of hornblende and white mica also occur. The sample is greenschist facies, quartz-albite-epidote-almandine subfacies; the parent rock was probably igneous.

Granite. Granite outcrops (figure 21) occur west of the gneiss exposures in the southern mountain area and also around the northern mountain area. The general appearance of the outcrops is brown, heavily jointed, and lumpy and rounded in texture. In most areas, outcrops are badly weathered. The hand specimen is coarse grained, with crystals three centimeters or so long. Intense weathering has allowed large plagioclase crystals to separate from the rock matrix, and the crystals may be picked up off the ground. The loose crystals make granite slopes more treacherous than slopes developed on other rock types, even though the granite slopes are not as steep. Granite outcrops are usually lower in elevation than either schist or gneiss outcrops.

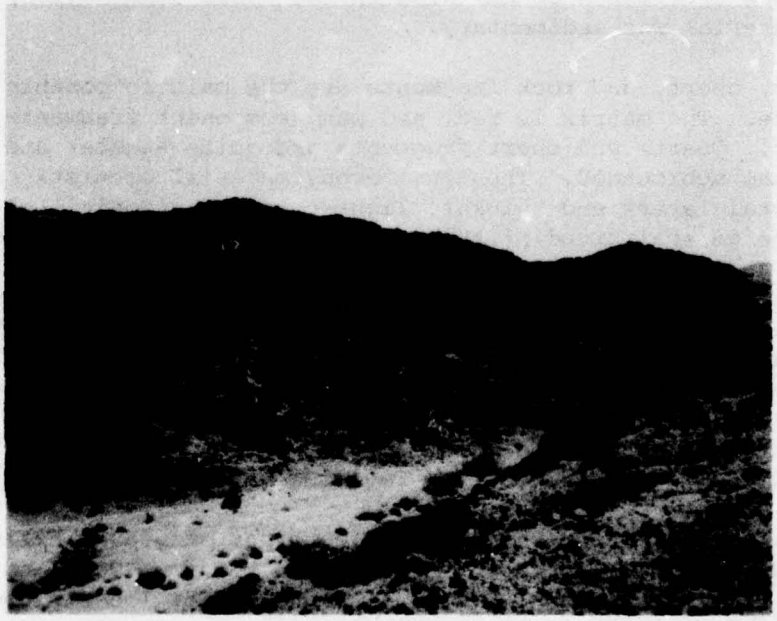


Figure 21. Granite Outcrops. Note Persistent Jointing.

Petrographic analysis indicates the granite consists primarily of quartz, potassium and plagioclase feldspar, and minor mica. Accessory minerals include chlorite, pyroxene, epidote, and black opaque minerals. The composition was consistent wherever the unit was sampled with the only variations occurring in the component percentages. All samples collected had a greenish alteration product, visible in both hand specimen and thin section. The rock is actually slightly metamorphosed and is not truly igneous as suggested from the hand specimen analysis. Samples are of the greenschist facies, varying subfacies.

Hills

The term "hill" is used here in an intermediate sense, i.e. all areas so designated are intermediate in elevation between mountains and plains. These areas have been subdivided on the basis of composition, (1) sedimentary rock, (2) gravel, and (3) sand.

Sedimentary hills. On the southwest side of the southern mountain range is an area of hills of very coarse-grained red conglomerate (figure 22) overlain by thinner layers of white, gypsiferous material (figure 23). A thin layer of varnished gravel covers the conglomerate near the mountains. In detailed photo analysis these materials were identified as shale (the varnished gravel) overlying sandstone or limestone (conglomerate and gypsiferous material). These are the greatest differences found between field verification and photo analysis. All criteria used for identification in photo analysis were determined to be false in the field examination, except that the material was sedimentary.

Quartz, chert, and rock fragments are the main components of the conglomerate. The matrix is red, and many component fragments are stained red. Quartz and chert fragments are quite angular and rock fragments are subrounded. The gypsiferous material consists of pure gypsum crystal layers and thicker, light-colored bentonitic clay layers. The general trend of this sedimentary unit is northeast, and the dip is about 20° NW. In photo analysis, it was suggested that this material dipped to the south. This was based on the assumption that the general slope of the land in this area was to the south (which it is) and that what is now known to be a gravel cap follows this slope. It was therefore incorrectly assumed that this south-trending slope was a true dip slope. The sedimentary sequence is in contact with both schist and gneiss and appears to lap up against them, as if it were deposited by a receding water body.

Gravel hills: Kinter Formation. Two types of gravel hills occur in the study area. The first type occurs in the southwest and is called the Kinter Formation. This unit consists of loosely consolidated, layered gravels and it reaches a thickness of 245 meters further to the soutwest. The gravel is varnished, but to a lesser degree than the bajada gravels. The hills are very steep sided and abrupt,

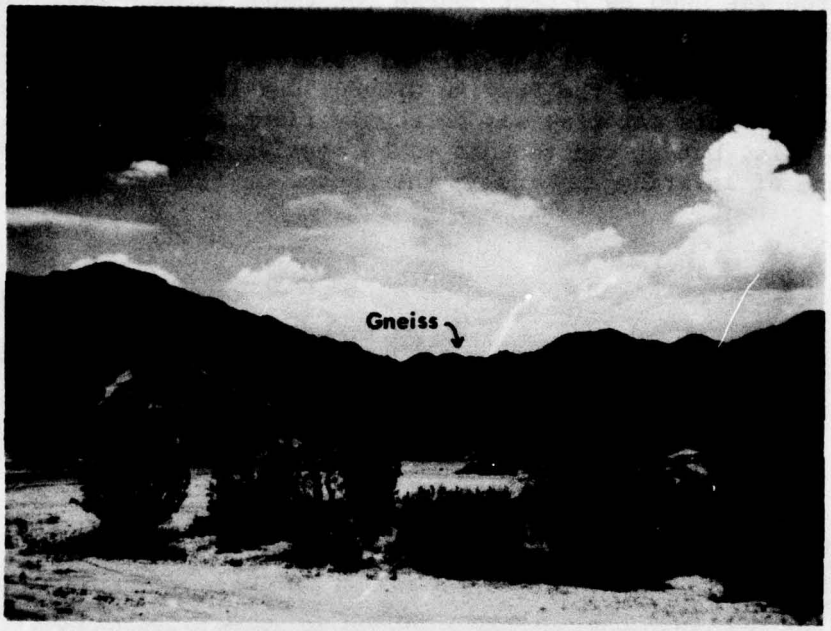


Figure 22. Red Conglomerate Outcropping in the Foreground with Gneiss in the Background

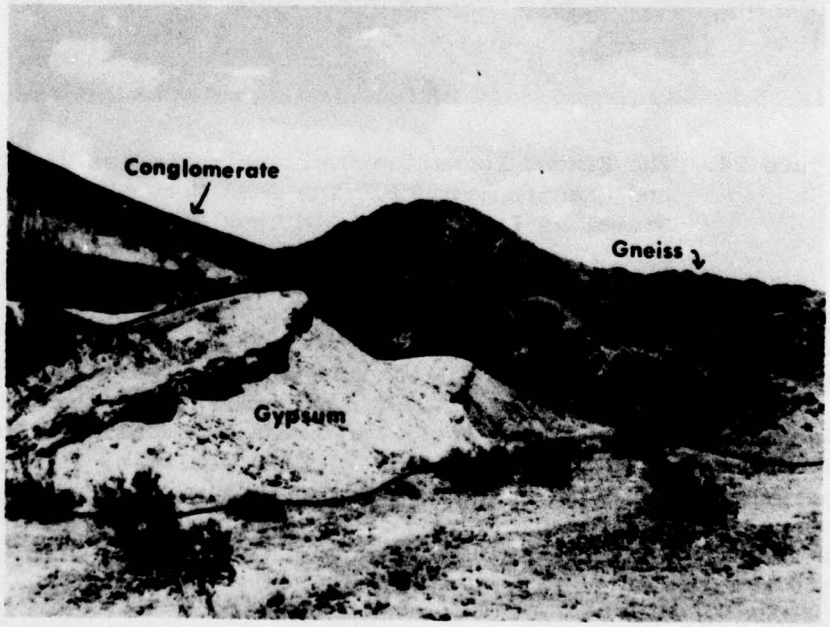


Figure 23. Gypsum and Light-colored Clay (left) Overlying Red Conglomerate (right). Gneiss in the Background

and one area was used as a test course for tanks (figure 24). The gravel comprising these hills is of different compositions, sizes, and degrees of roundness or angularity. Similar units occur further north in other parts of the Proving Ground, but little is known of their origin. This material was correctly identified as gravel in photo analysis, but it was thought to be massive rather than layered. No evidence of layering appears in the photos on further inspection.

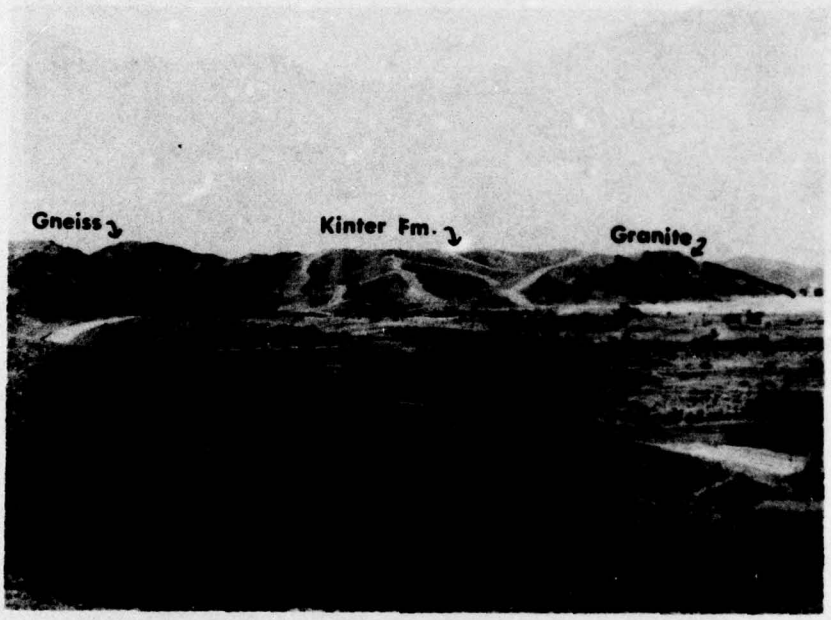


Figure 24. The Kinter Formation Overlapping Gneiss (left) and Granite (right). The Road Network on the Gravel is Part of the Old Tank Hill Course

Gravel hills: bajada. The second type of gravel hills was designated as bajada in photo analysis (figures 25, 26, and 27). Discussions with various people while at Yuma and observations made in the field suggest that this particular landform is more than simple, coalescing alluvial fans. The outer fan shape, or scalloped edge, indicative of alluvial fans was noted in photo analysis, as was the flat upper surface (figure 26). Since this flat surface is too flat to be entirely the result of local runoff and erosion, s small inland sea or a lake must have been present at one time in this area, which planed off this upper surface.

The bajada areas have a very specific and continuous stratigraphy wherever they are found. The top layer is a zone of touching



Figure 25. Youngest Bajada of Photo Analysis with Gneiss in the Background



Figure 26. Gully Development in Oldest Bajada

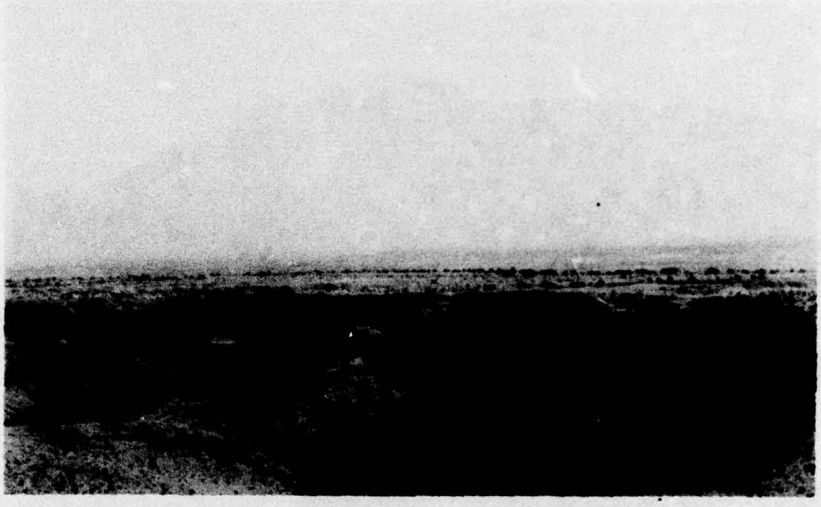


Figure 27. Bajada Spurs and Erosion Pattern. This is the Oldest Bajada from Photo Analysis

rock fragments (figure 28), which may be up to a meter thick. This layer is a desert pavement, consisting of rock fragments up to 25 to 30 centimeters long covered with dark, purplish-brown or black varnish. Most fragments range from 2 to 10 centimeters. When viewed from a distance and in aerial photography, the bajada is in striking contrast to surrounding material because of the varnish. An orange or light-colored spot is often found on the underside of pebbles. The spot varies in size with the fragments. It is not known how this spot is formed or how it is related to the varnish formation process, if indeed it is. Composition of the fragments is varied, and appears to have little relationship to rock bodies nearby. Most rock fragments are angular, but some such as chert are well rounded.

Below the gravel layer is a very thin layer of fine silt, measurable in milimeters. This layer allows vehicle tracks to remain for long periods of time because by traversing such an area the gravel layer is broken and fragments are pushed down into the silt. As a result, the lighter colored silt stands out strikingly in comparison to the varnished gravel on either side of the track. Below the silt layer is what is called the ped layer. It is of varying thickness, usually less than a meter. It is a very cohesive, hard layer, which gives the bajada surfaces their high bearing strengths. It has a columnar structure. Below the ped layer is a thick layer of very loose, fine soft material. When the ped layer is broken down and this lowest layer becomes visible, it is very difficult for wheeled vehicles to traverse that particular area.

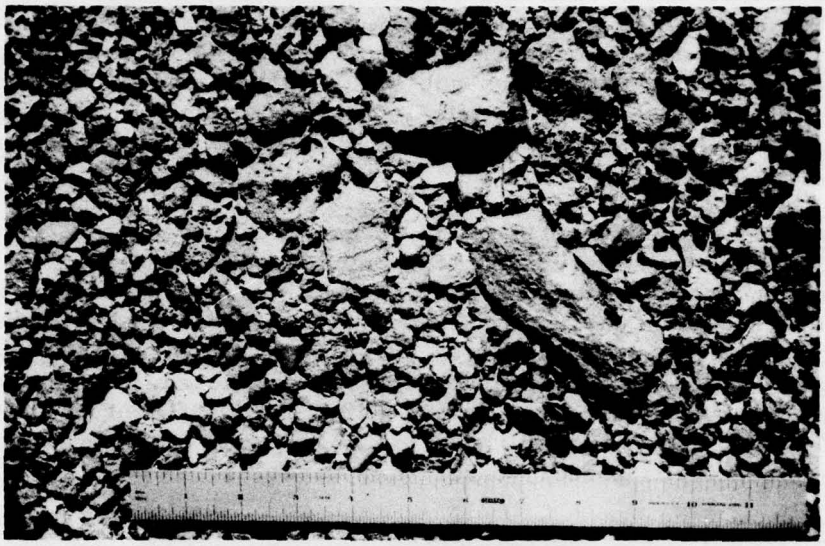


Figure 28. Surface of Gravel Cap on Bajada. Note Variation in Fragment Size

The uniqueness and continuity of this bajada stratigraphy causes speculation on its origin. The following is one plausible origin that has been developed. A true desert pavement such as that described above must be formed in place from water-laid gravels. Several examples of old gravel washes were seen in various parts of the Proving Ground that are similar to the older gravel caps on the bajadas. This strongly suggests that the gravels are originally deposited in large washes. Wind and rain-splash may be most important in the leveling and spreading process, which must occur after initial deposition. When the gravel cap is flattened, varnished, and stabilized, the development of a true soil profile can begin below the surface, which is accomplished by chemical means. Sheet wash (laminar flow) produces the moisture to allow this, even though sheet wash does not exceed 5 to 7 centimeters in depth. Over long periods of time, a profile such as that described above would be the result of these processes.[1]

A hand specimen of rock covered with desert varnish was selected for thin sectioning. The varnish is black and waxy. This sample has a quartz and sericite groundmass with alternated plagioclase phenocrysts. A difference in color between the rim and central

[1]This theory was developed by Mr. H. Frank Barnett, ETL geologist working at Yuma Proving Ground, Arizona.

portion was noted, but it was the reverse of that observed in the hand specimen, i.e. the central area is darker under the microscope than the rim. The darker central area contains a very fine, unidentified purple mineral, which does not occur in the rim. This mineral is too fine grained to identify, but it could be either cordierite or manganese-rich muscovite. The sample is considered an incipiently metamorphosed chert.

Sand dunes and sand hills. Sand dunes were noted in stereo photo analysis and correctly identified as barchans and longitudinal dunes. However, the presence of low, sandy hills and rises, upon which the dunes occur, was not observed (figure 29). Much of the flat, featureless plain of Part I is actually composed of very low hills. In most roadcuts, a layer of loosely compacted, slightly cemented sand is underlain by a fairly thick layer of bentonitic material. The main component in these hills is sand, which seems to cap and to protect the softer, underlying material.

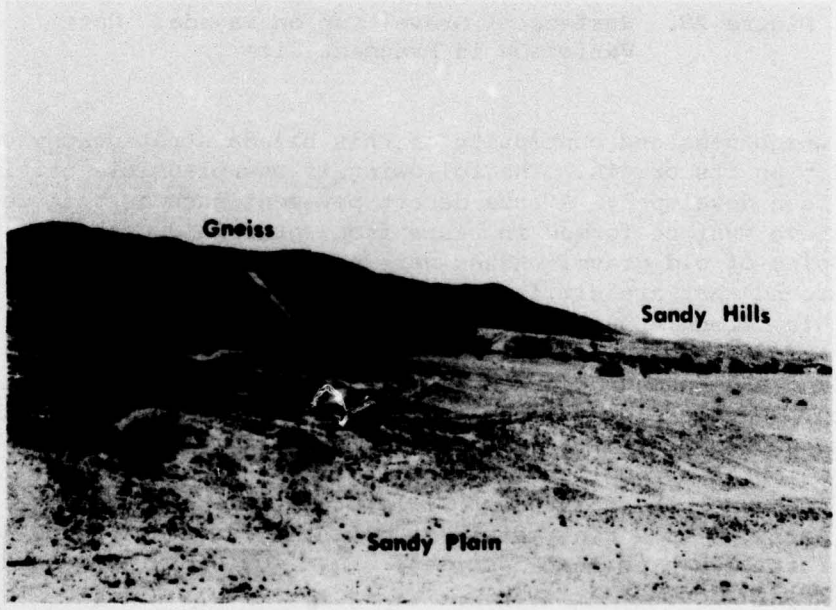


Figure 29. Sandy Hills (right), Sandy Plain (foreground), and Gneiss Outcrops (center and left). Concrete Tracks are 40%, 50%, and 60% Slope Course

Plains

The low-lying, essentially flat portions of the study area form broad plains or basins, consisting of two landforms; (1) flat, sandy

areas, and (2) recent washes. Detail about these areas is not presented other than their names indicate. More information probably could have been obtained from the photos, but owing to scale and tonal quality of the imagery used, it would have been difficult.

Sandy plains. In photo analysis, it was suggested that the basin areas (figures 14 and 29) were composed of fine light-colored silt and sand. Based on field observations the primary component is sand, probably about 80 percent in most areas. In some parts of the basin, the sand is covered with a thin layer of very sparse gravel. Some of the gravel is slightly varnished, but on close inspection, it is obviously different from the desert pavement on the bajada. It is probably a lag gravel positioned primarily by deflation.

Recent washes. The alluvial washes are fairly large with flat-bottomed channels. The channels range from 6 to 8 centimeters to 3 to 4 meters deep and up to 250 to 300 meters wide. They consist of fine sand or gravel, but sand predominates. The material is of very recent origin.

VEGETATION

Introduction

Far more vegetation occurs in the study area than was determined from stereo photo analysis. This is true for both areas known to be vegetated and for those thought to be barren. The lack of identification was probably caused by masking by photo tone and by the small size of most of the plants in relation to imagery scale.

Occurrence

The bare rock mountainous units were considered barren except in the gullies in photo analysis. However, several granite outcrops were visited in the field, and beavertail (Opuntia basilaris), staghorn cholla (Opuntia versicolor), and barrel cacti (Ferocactus covillei) were observed, along with ocotillo (Fouqueria splendens) and low grasses (figure 21). Beavertail cacti grow to about 30 centimeters, staghorn cholla to about 60 centimeters, barrel cacti to about 45 centimeters, and ocotillo to about 4 meters. Numerous small shrubs and cacti were observed at a distance on gneiss and schist outcrops (figures 9 and 14).

In hilly areas, ocotillo was often the only large plant, growing to 5 meters high. On rocky or gravel slopes, small staghorn cholla, beavertail, barrel (Ferocactus wislizenii), fishhook (Mammilaria microcarpa), hedgehog (Echinocereus engelmannii) and teddy bear cholla (Opuntia bigelovii) cacti were prominent vegetation types along with low, sparse grasses. The cacti vary in size from 5 to 45

centimeters. On the sandy hills, large clumps of ocotillo occur, along with several types of sage, creosote (Larrea tridentata), brittle bush (Encelia farinosa), and other small shrubs. The huge saguaro cacti (Cereus giganteus), not found at higher elevations in this area, is first seen here in gullies and small washes. Many very small shrubs, such as sand verbena, form a dense ground cover on sand dune slopes.

The basins, as noted in photo analysis, are covered primarily with low shrubs, predominantly creosote, brittle bush, and types of sage. Mesquite (Prosopis juliflora), desert ironwood (Olneya tesota), kidneywood (Eisenhardtia sp.), and desert mallow (Sphaeralea ambigua) also occur. In basin washes, saguaro cacti reach 12 meters in height and 1 to 2 meters in diameter, much larger than in the hilly areas. Paloverde (Cercidium sp.) grow at the base to protect the young saguaro from damage. Saguaro were not identified during photo analysis prior to field checking, but on closer inspection of the imagery, they were discerned.

On the west side of the large canal, additional vegetation types were found. The feathery tamarisk (salt cedar; Tamarix pentandra), in association with arrowweed (Pluchea sericea) in alkaline soils, were in bloom with pale pink-lavender blossoms. Paloverde, Fremont screwbean (Prosopis pubescens), desert ironwood, desert willow (Chilopsis linearis), mesquite, and a few cottonwoods (Populus fremontii) were also found. The shrubs include various types of sage, creosote, and brittle bush. In the immediate vicinity of water, cat tails (Typha latifolia) and reeds (Phragmites sp.) were observed. Low grasses along the canal banks occur slightly above water level.

Relationships

Several different types of relations between vegetation, elevation, and material compositions were noted in the study area. Perhaps one of the more striking is the size difference from small gullies to large washes: plants increase in size downstream. The smallest vegetation in incipient gullies (figure 26) is sage about 30 centimeters in height and 40 centimeters in diameter. Downstream, creosote up to 1 meter tall occurs with small paloverde trees about 3 meters tall. Further downstream, these plants increase in both height and diameter. Creosote can be up to 2 meters in height and 3 meters in diameter, for instance. In the larger gullies, trees such as mesquite, desert ironwood, desert mallow, and kidneywood occur along with the larger shrubs. In the largest washes, primarily near their mouths, the trees reach 6 to 8 meters in height, and the shrubs reach 2 to 3 meters.

Vegetation types also appear to be somewhat segregated in relation to soil types. The cacti, for instance, are predominant on

rocky or gravelly, well drained slopes. The ocotillo also occurs in this type of area, but the slopes are usually less, and there are fewer plants. Ocotillo also seems to prefer sandy, hilly areas of the basin where they occur in great profusion. Saguaro cacti are most common in the sandy bottoms of washes, either in hilly or basin areas. Shrubs like creosote and brittle bush appear to be indicative of areas where the material is mainly sand, and sand verbena occurs only in the very sandy areas where the above mentioned shrubs and ocotillo are not found.

A relationship to soil moisture is also apparent, and was noted in the photo analysis. Certain types of trees, such as tamarisk, desert willow, and cottonwood occur only where large quantities of water are found. On the other hand, the smaller cacti and ocotillo seem to require less water as they are found the farthest from water and in higher elevations. Shrubs and saguaro cacti seem to require intermediate amounts of moisture to flourish.

SELECTED REFERENCES

The references listed below were chosen to enable readers interested in literature of a desert area to begin their own literature search. Also included in this list are publications concerning the area covered in this report. The following reports and books were located after the photo analyses were completed and are presented only for correlation and verification purposes. They are not referred to in the text and were not used in any way during preparation of this report. Each is briefly described for the reader's benefit. This list is by no means complete, and includes only those references obtained on a limited search.

Arizona Bureau of Mines, Geologic map of Yuma County, Arizona: Arizona Bureau of Mines, Tucson, Arizona, Map No. 3-11, 1960.

This map includes the area covered in this report. The scale is too small in comparison to the study area to allow satisfactory use. However, the majority of the information on the study area is questionable in light of this report and other more recent publications.

Barnett, H. Frank, Jr., Surface Materials and Terrain Features of Yuma Proving Ground, Part I, Summary description: U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, ETL-0021, AD A018175, May 1975.

This report summarizes geologic and terrain information as related to materiel testing at the Proving Ground. Emphasis is placed on the low-lying alluvial areas rather than on the bedrock mountains because of this fact. More detailed descriptions of landform and geology are to follow in a second report. Data presented here are based in part on the maps discussed in the next entry.

Barnett, H. Frank, Jr., Judy Ehlen, Jerry Gilbert, and Janet Sanderson, Surface Materials and Terrain Features of Yuma Proving Ground, Arizona (maps): U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, 1973.

Geology and landform features of the entire Proving Ground are presented on five sheets comprised of all or parts of ten topographic maps at a scale of 1:62,500. Classification of materials is in terms of application to the Proving Ground rather than in strict geologic terms (alluvial material is broken down into eight categories and bedrock materials are combined). This is the most complete and detailed report to date on Yuma Proving Ground.

Benson, Lyman, The Cacti of Arizona, 3rd edition. Tucson: University of Arizona Press, 1969.

This publication is probably the best available of recent date for cacti identification in this area. Rose and Britain, however, is the definitive work on cacti in general. Most cacti identifications determined in this report were based on Benson.

Earle, W. Hubert, "Cacti of the Southwest: Desert Botanical Garden of Arizona," Science Bulletin, No. 4, 1972.

A very general work and not as definitive as Benson above. Used here very little for cacti identification.

Leighty, Robert D., Operation Hotdeck (Preliminary Report): USACRREL Hanover, New Hampshire, Special Report 48, 1962.

This report is concerned with the thermal aspects of terrain, "hot" surfaces in particular. It does not cover the area included in this report, but as it does include nearby areas, it could be of interest.

MacDonald, Charles C. and Gilbert H. Hughes, Studies of Consumptive Water use by Phreatophytes and Hydrophytes near Yuma, Arizona. USGS Professional Paper 486-F, Washington, DC, 1968.

This report is concerned with transpiration of several species of flood plain vegetation and evaporation from water surfaces and bare soil. The area covered is the flood plain just visible on the west side of the study area. The species involved were found within the study area. MacDonald and Hughes determined that use of water decreases with plant maturity.

McGinnies, William G., Bram J. Goldman and Patricia Paylore (Eds.). Deserts of the World. Tucson: University of Arizona Press, 1968.

This book contains excellent bibliographies of arid environments throughout the world. One section is involved with deserts in North America and is quite extensive.

Millett, John A. and H. Frank Barnett, Jr., Surface Materials and Terrain Features of Yuma Proving Ground, Arizona (Laguna Ariz-Calif, 1:62,500 Quadrangle): USA Natick Laboratories, Earth Science Laboratory, Technical Report, 71-14-ES, 1970.

Contains a good geologic map of the area of photo coverage. Units are identified in geomorphic terms, such as gravelly, undissected piedmont and sandy hills, and rock types are identified as in this report. Oral communication with Mr. Barnett indicates that gneissic zones on the map also include minor schistose zones.

Millett, John A. and H. Frank Barnett, Jr., Surface Materials and Terrain Features of Yuma Proving Ground, Arizona (Red Hill, Red Bluff Mt., and Roll, Arizona 1:62,500 Quadrangles): USA Natick Laboratories, Earth Science Laboratory, Technical Report 71-56-ES, 1971.

This report is very similar to the above publication by the same authors except that it covers a different part of Yuma Proving Ground that is not included in this report.

Olmstead, F. H., O. J. Loeltz, and Burdge Irelan, Geohydrology of the Yuma Area, Arizona and California. USGS Open File Report, Washington, DC, 1970.

This report includes fairly detailed geologic information such as stratigraphic and structural descriptions of the study area and surrounding areas. Identification of units and landforms substantiates information derived from photo analysis in this report. Also included is a brief geologic history of the area.

Wilson, Eldred D., Geology and Mineral Deposits of Southern Yuma County, Arizona. University of Arizona, Arizona Bureau of Mines Geological Series No. 7, Bull. No. 34, 1933.

Wilson summarizes general and mining geology of southern Yuma County, including the study area. He includes good descriptions of rock types in the area, plus attitudes of schistosity and gneissic banding. The geologic map is the same as that put out by the Arizona Bureau of Mines (at least for the study area), and is questionable in light of this study and more recent geological investigations as to location of specific rock types.

Shepard, James R., James G. Johnstone, Alton A. Lindsay, Robert D. Miles, and Robert E. Frost, Terrain Study of the Yuma Test Station Area, Arizona. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Contract Report 3-14, March 1955, AD 626500.

This is a very comprehensive study of the Yuma Test Station area (now Yuma Proving Ground), including the area of this report. Much detailed and valuable information on vegetation, landform, material composition, drainage, and military relevance and activities is included here. Much of the information presented is based on aerial photography.

CONCLUSIONS

This report successfully illustrates that at least some of the Army's requirements for terrain information can be met by using photo interpretation techniques and that these techniques can be applied by a novice in the process of developing the required photo analysis skills. Although this study was not specifically oriented to solving a military problem, basic terrain information required to solve a tactical problem such as cross-country movement or available cover and concealment has been developed.

The information derived from photo analysis was sufficiently complete so that only a short time was needed in the field to investigate questionable areas; as the interpreter's skills increase, a shorter amount of field time would be required. A similar effort conducted entirely in the field without the aid of previous detailed photo analysis would have involved a period of at least several months. As shown in this report, the results obtained in the photo analysis procedure generally agreed with the observations made in the field. Any erroneous interpretations from the photos were readily corrected in the field.