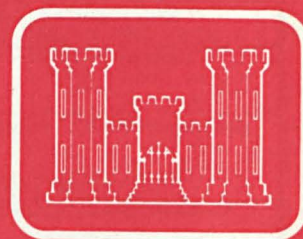


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Terrain analysis procedural guide for geology

James Tazelaar

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report provides the methods and procedures necessary for obtaining information on geology from the most accessible sources, which are topographic maps and aerial photos. The report is written for the U.S. Army Terrain Analyst, and presents the detailed methodology necessary for obtaining approximately 18 Geology Data Elements useful in preparing factor overlays.		

PREFACE

This Terrain Analyst's Procedural Guide for Geology produced under authority contained in Project 4A762707A855, Task T3, entitled "Military Geographic Analysis Technology" is one in a series of Terrain Analyst Guides that will be produced during the next 2 years. It is anticipated that after some modification to both format and content these Guides will be republished as Department of Defense Technical Manuals. In this regard, critical comment and suggestions for improvement are requested by the author.

This work was conducted under the supervision of Mr. Alexander R. Pearson, Chief, Topographic Products Design and Development Group of the MGI Data Processing and Products Division, Geographic Sciences Laboratory.

The use of indicators of terrain conditions on pages 47 through 80 produced by the Center for Remote Sensing of the Research Institute under project 4A161102B52C, Task C, entitled "Research in Geographic Sciences" is gratefully acknowledged. The author also gratefully acknowledges the support and assistance of the late Theodore C. Vogel in preparing this report.

Colonel Daniel L. Lycan, CE, was Commander and Director of ETL during the report preparation.

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ERRATA

Aerial Photo Keys P5 - 29 and P5 - 33 have been deleted.

TERRAIN ANALYSIS PROCEDURES FOR GEOLOGY

INTRODUCTION

PURPOSE: Today's military commanders need terrain information as never before in the history of warfare. They need quick answers to such questions as: Which areas provide the best avenues of approach for armored vehicles? What is the potential for a bomb induced landslide to block an important mountain pass? Where is the best source of crushed stone for construction of an important supply road? Which sites are suitable for helicopter landing zones, field fortifications, or barriers? Answers to these realistic questions rely, in part, on information on the geology and rock types in the area. This report is a procedural guide on the terrain analyst for collecting, recording, and graphically presenting geologic and rock type information from sources such as maps, literature, and aerial imagery.

BACKGROUND: Figure 1 depicts a system for collecting, analyzing, storing, and disseminating terrain data or Military Geographic Information (MGI). This system provides the MGI required by the Army for planning the most effective use of the terrain. This system relies on two methods of data acquisition, field collection and secondary sources such as aerial photographs and existing maps. Efficient storage and use of these data, regardless of the collection method, requires that they be in graphic form called a factor overlay (figure 2). Each factor overlay produced will have one or more supporting data tables (figure 3).

Because of the complex nature of terrain, the data storage effort is divided into a number of data fields that include for example vegetation, soils, geology, and drainage characteristics. For clarity and utility, a map overlay must be produced by the terrain analyst for each of these data fields and registered to a standard 1:50,000 scale topographic map. As these factor overlays are produced, they will be stored in graphic form where they can be withdrawn as needed to produce special map products. Some examples of special map products are Built-up Areas, Air Mobility, and Cross-Country Movement Maps. Producing a special product map often requires the terrain analysis to use several factor overlays. A Cross-Country Movement Map, for instance, would require factor overlays for Slope, Surface Geometry, Vegetation, Geology, and Drainage.

The geologic factor overlay and its supporting data tables will become part of the data base described above. The amount and type of data collected will depend on the analyst's training, the amount of reference materials available, the geographic region, and the type and scale of the aerial imagery available. The source materials vary from area to area. It is often necessary to use incomplete sources, as well as materials prepared by other governments. In many cases, there will

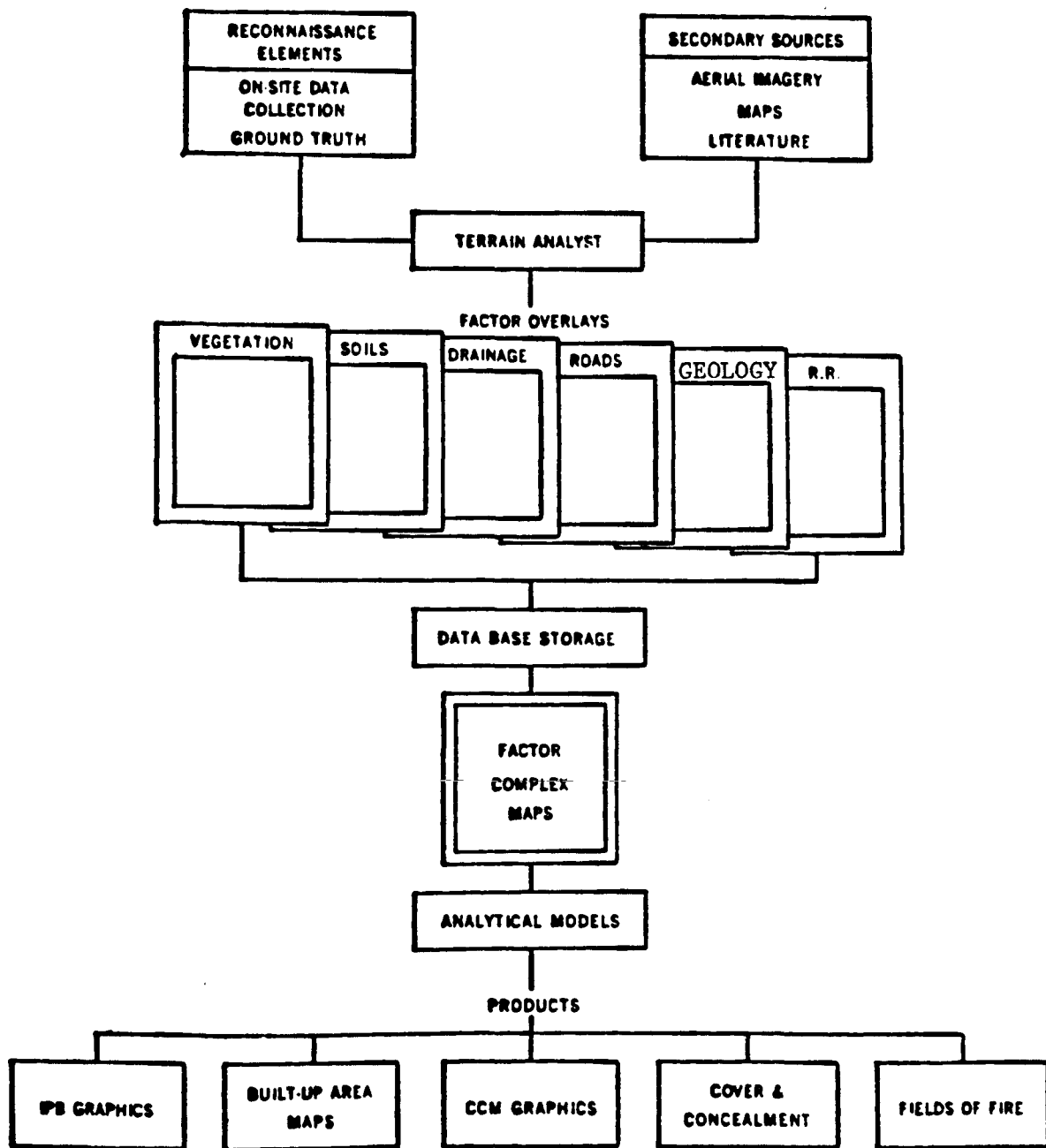
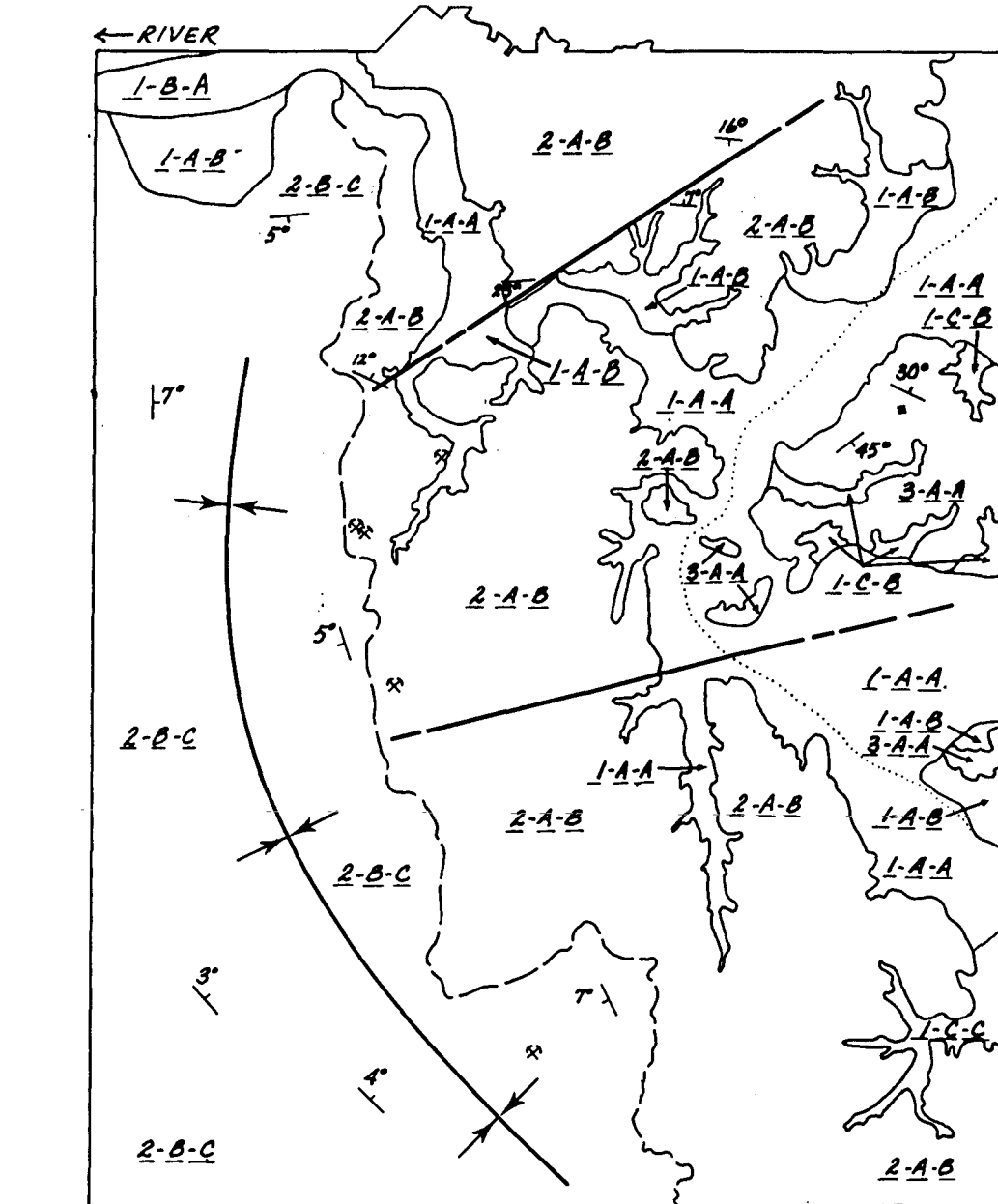


FIGURE 1. Production and Use of Factor Overlays

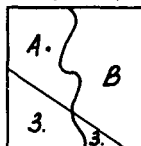
ROCK TYPES



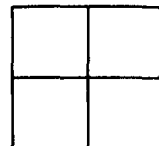
MAP-UNIT IDENTIFICATION → 1-C-A ← ENGINEERING CHARACTERISTICS
STRUCTURAL CHARACTERISTICS

STRIKE and DIP OF UNIT (IN VICINITY OF SYMBOL)
FAULT (DASHED WHERE SUSPECTED)
MINE SHAFT OR ADIT
QUARRY (ROCK) OR PIT (SAND, GRAVEL)
SYNCLINE
LINE SEPARATING PROMINENT SINKHOLE REGION
(MOSTLY IN WESTERN PART OF AREA).

COVERAGE
DIAGRAM



INDEX
OF PARTS



SOURCES:

1. TOPOGRAPHIC MAP - VINE GARD, KY. 1:50,000
2. DRAINAGE AND RELIEF OVERLAYS THEREOF -
3. AERIAL PHOTOGRAPHY - 1:20,000 (1956).

Figure 2. Example of a Factor Over

**TABLE
SAMPLE DATA TABLES**

A

DATA TABLE I

Map Unit	ROCK			TYPE	
	Classification	Composition	Grain Size	Color	Variations, including dissection, in area
1	Sedimentary	Shale	Fine to very fine.		Forms round hills; steeper slopes on north side; avg. relief 500 m. above flood plains. Drainage is dense on east slopes, with deep gulleys.

B

DATA TABLE II

STRUCTURAL			CHARACTERISTICS		
Types of Layering	Thickness	Strike/Dip	Joints/Faults	Seismic Aspects	Water Potential
[?] Beds common in shale.	[?]	? Contours suggest shale beds are dipping south.	Drainage bends suggest E-W joints in shale beds.	Good along N. slopes where rock is not deeply weathered.	Poor except along south base of shale hills where soil is deep.

C

DATA TABLE III

ENGINEERING			CHARACTERISTICS		
Weathering Aspects	Swelling Data	Abrasion Data	Aggregate Suitability	Drill/Blast Aspects	Siting Suitability
Deep soil (clay) everywhere except on north slopes.	? (shale usually swells)	High losses are probable	Poor (no quarries on map). Forms platy aggregate.	Only deeply weathered shale along south slopes are rippable. Light blasting.	Good except base of slopes where high water table and low percolation rates in shale create foundation (water, slopes) problems.

* Analyst note: Rate a unit as follows. A is given only when all input is of the highest quality. Where input is less, rate the unit B. Where all or most of the input for a unit is poor, rate the unit C. The example shows that Unit 1 is sedimentary, shale, forms round hills that are densely dissected on the east slopes. Structural characteristics for unit 1 are not particularly poor; this explains the rating, B. But the Engineering Characteristics are poor; the rating is C. This unit would appear on the factor map as 1-A-C.

Figure 3. Format of Supporting Data Tables

be areas for which no geologic source materials are readily available. This situation requires initiation of a collection effort by reconnaissance elements.

Since the Army operates on a worldwide basis, detailed information on geology, vegetation, slope, and so forth, and how these terrain parameters relate to each other are needed on a worldwide basis. To obtain this information, the analyst must have at least a limited knowledge of the major rock classifications (igneous, etc.) and some idea of their engineering characteristics. Additionally, the analyst is also required to have a working knowledge of the methods used to obtain information from geologic maps, the scientific literature, and various types of aerial imagery. Therefore, the analyst should review the following texts that have been provided to the terrain analysis teams:

1. FM 30-10, Military Geographic Intelligence (Terrain)
2. FM 21-26, Map Reading
3. TM 5-545, Geology
4. TM 5-818-2, Soils and Geology
5. TM 5-818-4, Soils and Geology
6. EM 1110-2-1906, Laboratory Soils Testing
7. TM 5-330, Planning and Design of Roads, Airbases, and Heliports in the Theatre of Operations
8. FM 21-33, Terrain Analysis

This guide, including the appendixes, provides a procedure whereby the terrain analyst can map those geologic data elements required for field operations.

SOURCE MATERIALS

To locate source materials dealing with the geology of the area of interest, review the data base holdings as well as information found in Appendix B. Useful materials include current topographic maps, existing geologic maps and studies, various reconnaissance or route reports, and aerial photography. The latter, if available at different scales, provides a regional overview of the terrain as well as geologic details needed in analysis.

Review the materials and determine whether they are adequate to make a geologic factor overlay. If they provide insufficient detail or, in the case of aerial imagery, insufficient area coverage, initiate action to collect additional materials. Start the analysis with the materials on hand. In general, any book, report, text, or material that provides information on the geology of the area of interest is considered source material. Locating these source materials will often require a tenacious and comprehensive search of libraries, government agency files, and university research centers.

In this guide, source materials have been divided into three major categories: maps, literature, and aerial imagery.

MAPS. In general, four major map types are available to the terrain analyst that can provide the geologic data required for the factor overlay. These map types are characterized as follows.

1. Topographic Maps. Topographic maps are available at scales of 1:1,000,000; 1:250,000; 1:125,000; 1:50,000; and 1:12,500. Since all of these maps contain relief information in the form of contour lines, they also provide indicators of slope and landform. With the additional information supplied by the drainage pattern they can be used to determine broad classes of surface materials (soils) and the underlying bedrock. As would be expected, the larger the map scale (small contour interval), the greater the amount of information obtainable. Large scale topographic maps also contain symbols that indicate the location of gravel pits, quarries, mines, sand dunes, etc. that can be used to confirm the rock type identifications made from both the map and other sources.

2. Special Purpose Military Maps. Special Military Engineering Geology maps are available at a number of scales, which may vary in completeness of information according to the scale and/or country of origin. These maps can provide many of the Geology Data Elements needed for factor map preparation. Their chief value (assuming they are not otherwise complete respecting the needed geologic data) is that they provide descriptions of the major rock types common to the area of interest. For this reason, they should be examined when available by the terrain analyst.

The boundaries of the geological units (rock types) shown on these maps can be adjusted for scale and transferred to the map overlay. Descriptive data found in the map legend can be analyzed and recorded on the Data Tables in accordance with the specifications presented in Appendix A.

3. Small Scale Geology Maps (1:1,000,000). This type map is common to most general geography texts and usually provides a very broad description of the rock units found in an area of interest. In general, these maps and associated descriptions will not provide the detailed information desired by the terrain analyst to prepare factor overlays. Often, however, such maps are the only source available for a large region. Their value then is to acquaint the analyst with the general geology of the area.

Many world atlases contain geology maps for most countries. The best source for geology maps for any region in the world, however, is the map library of the United States Geological Survey (Appendix B).

4. Large Scale Geology Maps. These maps are commonly produced by the various geological surveys or agencies of most countries. The chief U.S. agency holding these maps is the map library of the U.S. Geological Survey. In other countries, the colleges and universities often are repositories for their geologic maps. Each country has (or had) a geological survey responsible for producing geologic maps at various scales. Often these large-scale maps provided much of the required input for the Geology Data Tables of this guide. When it is lacking on such maps, the specific information must be inferred from the data shown, interpreted from aerial photos of the area, or obtained from geology studies or reports.

As a rule of thumb, the larger the scale of a map, the more useful the data presented in the legend. On the other hand, the larger scale reduces the size of the geographic area. The chief benefit of the larger scales is that the data on the map legend will be more detailed than that found on smaller scale maps. For instance, most geologic maps at small scales emphasize the geological ages, but provide inadequate descriptions of the rock types. This type of information is essentially useless to the military terrain analyst. The same area shown on a larger scale map will have a more detailed description of the rock types common to the region, as well as the geological ages.

LITERATURE. Within the United States, the federal, state, and county governmental agencies hold coverage of the geology of various regions of the entire world. The information available from these sources is often adequate to supplement the topographic maps, geologic maps, or aerial photos used by the analyst.

Even if the available literature provides only an introduction to the general range of geologic maps or reports available for particular areas, the analyst should review them. The range of literature includes reports, articles, studies, economic papers, text books, etc.; all have, or can have, some specific geological information that the terrain analyst can use in the preparation of factor overlays. For instance, suppose the only

document for an area, other than a generalized geologic map, is an economic study of the region's minerals. Examining this paper might reveal brief references to the broad categories of rock and geological structures of the area in which the ore minerals occur.

In other countries, libraries of government agencies, universities, public libraries, scientific societies, or offices of various international organizations ought to be contacted regarding holdings of geological studies.

AERIAL IMAGERY. As used in this guide, aerial imagery includes imagery obtained with any of the following remote sensor systems: aerial cameras, thermal infrared scanners, multispectral scanners, and radar. Imagery obtained from each of these systems can provide much of the information required for the geology factor overlays. The accuracy and amount of detail obtainable will depend on type of system, scale, and availability of the imagery, as well as the analyst's background in image interpretation.

PROCEDURE OUTLINE

DATA ELEMENTS: Data elements are the specific pieces of information that must be extracted from the source materials and recorded for each map area. It may not always be possible or practical to determine all data elements for all areas, but even partial information can be useful. The data elements required for completion of the geology factor overlay and data tables are listed below:

DATA ELEMENT	
1. Map area identification:	Identification number of map areas composed of the same type of rock.
2. Rock classification:	Identification of major rock type, i.e., Igneous, Sedimentary, or Unconsolidated.
3. Rock composition:	A more precise identification of rock type, i.e., shale, limestone, granite, basalt. All areas of the same composition will carry the same identification number.
4. Rock grain size:	Qualitative description of rock matrix.
5. Rock color:	Identification of rock color.
6. Rock type variations:	Identification of regional changes in terrain relief underlain by a rock type.

- | | |
|----------------------------|--|
| 7. Type of rock layering: | Qualitative description of rock type change with depth. |
| 8. Thickness: | Qualitative description of rock type with depth. |
| 9. Strike and dip: | Direction and slope of rock formations, (see Appendix D). |
| 10. Joints and faults: | Location of "cracks" in map area and identification of type and direction of movement. |
| 11. Seismic aspects: | Qualitative measure of rock unit density. |
| 12. Water potential: | Water bearing capacity of the rock type. |
| 13. Weathering aspects: | Qualitative description of amount and depth of degradation of rock unit. |
| 14. Swelling data: | Measure of volumetric change in rock type with absorption of water. |
| 15. Abrasion data: | Qualitative description of the loss of volume of rock in laboratory testing. |
| 16. Aggregate suitability: | Measure of the suitability of aggregate produced from rock type. |
| 17. Drilling and Blasting: | Response of rock type to this type of excavation. |
| 18. Siting suitability: | Measure of the building foundation support provided by rock type. |

SEQUENCE OF ANALYSES: Figure 4 (page18) presents a graphic outline of the normal sequence followed when performing an analysis of the geology of an area. Variations in the type and quality of source materials may require deviations from this normal sequence. Figure 5 (in pocket) provides a step-by-step example of the procedure for performing an analysis using only the topographic map; analysis of imagery will follow much the same approach.

Tables 1, 2, and 3 (pages 23, 27, 31) give the approximate characteristics of the three major rock classes considered in this guide: igneous, sedimentary, and unconsolidated. Once the rock classification has been established, the Approximate Characteristic Tables (ACT) will help in the determination of the rock composition, variations, and the engineering and structural characteristics.

MAJOR STEPS:

1. Collect and review sources.
2. Prepare topo map overlay and data table work sheets.
3. Analyze literature and plot results on map overlay.
4. Extract data from geologic map and record on map overlay and in data tables.
5. Outline drainage patterns and landforms of the topo map on the map overlay.
6. Estimate rock classification (igneous, sedimentary, unconsolidated) based on drainage patterns and landforms.
7. Use Approximate Characteristics Tables (ACT) to estimate rock composition (sandstone, limestone, shale, granite, basalt, alluvium).
8. Refer to the ACT and estimate variations and engineering and structural characteristics. Record results on the map overlay and in data tables.
9. Prepare air photo mosaic and overlay.
10. Repeat steps 5 and 9 using the air photos instead of the topo map.
11. Compare map and mosaic overlays and resolve differences. Transfer additional data from mosaic to the map overlay and data tables. The map overlay is now the geology factor overlay.

SEQUENCE OF ANALYSIS

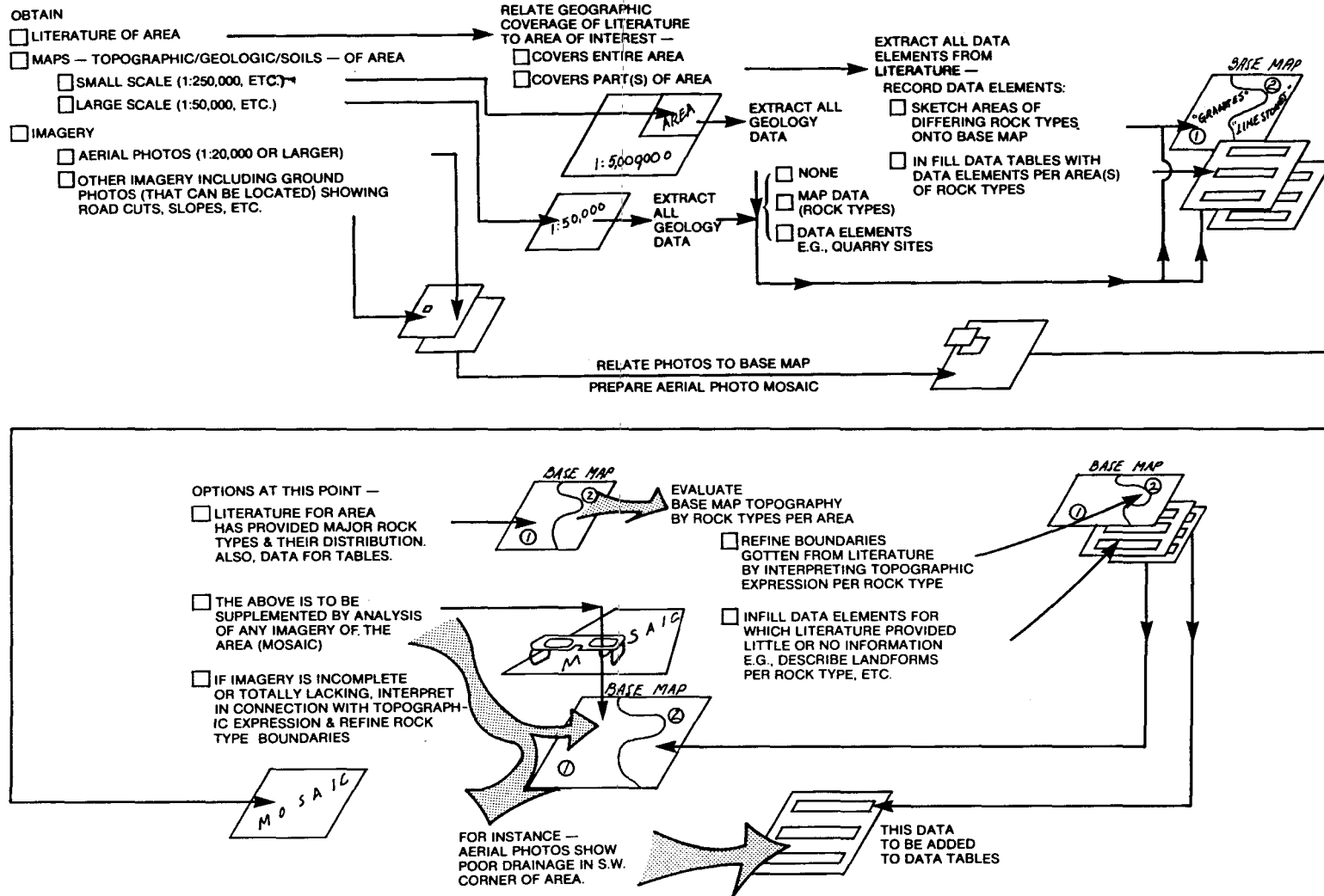


Figure 4. Sequence of Analysis

ANALYSIS METHODS

TOPOGRAPHIC MAP ANALYSIS. The Data Elements required to prepare a geologic factor overlay are usually derived from a variety of map, aerial photo, and literature sources without direct field acquisition. When geologic maps are not available, the terrain analyst must rely on other sources. For instance, a country or state soils map will usually provide many of the geologic Data Elements required. As a rule, the analyst should use all of the source materials available to produce the factor overlay, realizing that some information is better than no information as long as the information is dependable.

The following example assumes that the only information sources available to the Terrain Analyst are a military topographic map and a generalized geologic textbook for the region in which the map sheet to be analyzed is located.

Step 1. Fasten a clean, translucent sheet of Mylar or other transparent material (preferably stable-base) to a printed copy of the 1:50,000 scale map. Place registration ticks at each of the four corners of the map sheet. It may be helpful to trace the map sheet neatlines and the 10,000-meter grid lines lightly in pencil onto the overlay.

Step 2. Add the map sheet name, number, and other marginal information as shown in Appendix A.

Step 3. Refer to Annex A and construct Data Tables I, II, and III.

Step 4. Locate and trace the boundaries of all water bodies including ponds, lakes, and major two-line rivers and streams onto the overlay.

Step 5. Locate and trace the boundaries of swamps, bogs, and marshes onto the overlay.

Step 6. Using the contour lines as a guide, locate and trace on the overlay all major floodplains, sand beaches, and sand dune areas whose longest dimensions are greater than 2 millimeters.

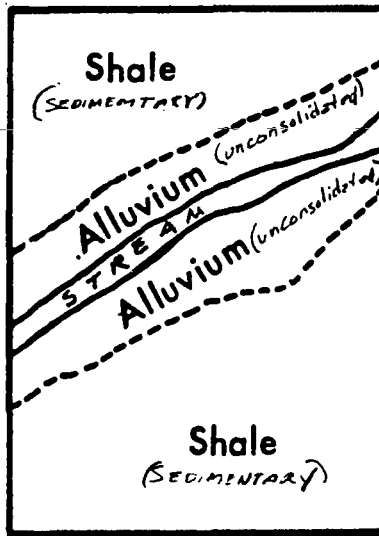
Step 7. If you have not already done so, review the materials that you have located in the data base file. Pay particular attention to the bibliography or list of reference texts, reports, etc., that are provided for the geographic region in which your map is located. Attempt to obtain any texts or reports listed from a local library.

Step 8. Study the overlay, step back from the map and look at the pattern formed by the streams and rivers. In general, is the pattern formed by the rivers and streams constant throughout the map sheet or does the pattern change in different parts of the map sheet?

Step 9. Study the map once more, and note the patterns formed by the contour lines. Is the relief pattern constant throughout the map sheet, or does it change at locations similar to the drainage pattern? Are the various types of recognizable landforms, i.e., floodplains, hills, and valley floors more or less at a common elevation?

Step 10. Read through Procedure 1, Topographic Map Analysis on page 37 for information and examples on how to study the topographic map in detail.

Step 11. With a soft lead pencil, carefully trace or delineate the patterns indicated on the map sheet by the differences in the density of the contour lines, height of the hills, and drainage channels onto the overlay.



Step 12. Using Procedure 1, Topographic Map Analysis on page and other data sources that are available, you should be able to, at least, estimate the class of rock that underlay the terrain represented on the map sheet. In the illustration in Step 11, the analyst has shown that the map sheet has two types of materials, shale and alluvium. In many cases it may be possible to identify the rock class but not the rock type (composition).

Step 13. Based on the class or type or rock you have identified, refer to either Tables 1, 2, or 3 (pages 23, 27, 31). In the example, you would refer to Table 2 for shale since it is a sedimentary rock, and to Table 3 for the alluvium because this material is considered to be unconsolidated. Use the tables to complete or confirm your estimates of the rock class and composition.

Step 14. Assign an area identification number to each area outlined on the overlay based on the type or composition of the rocks within the area. Areas with the same type of rock are given the same identification number. Record the area numbers in column 1 of the data tables.

A

DATA TABLE I

Map Unit	R O C K				T Y P E
	Classification	Composition	Grain Size	Color	Variations, including dissection, in area
1	Sedimentary	Shale	Fine to very fine.		Forms round hills; steeper slopes on north side; avg. relief 500 m. above flood plains. Drainage is dense on east slopes, with deep gulleys.

Step 15. Record "Rock Classification" in Column 2 of Data Table I for each map area identified. This data element is obtained from either Table 1, 2, or 3, depending on the type of rock identified for each map area.

Step 16. Record "Rock Composition" or rock type in Column 3 of Data Table I for each map unit. As in the example, Step 14, you would record the word "Shale" in this column.

Step 17. The data elements of Tables 1, 2, and 3 are organized so that they correspond to the column headings of Data Tables I, II, and III. Once either Tables 1, 2, or 3 have been entered, the analyst should continue down each table until each of the three Data Tables have been completed. Where the information cannot be obtained from either Tables 1, 2, or 3 or from literature sources, simply leave the column blank.

DATA TABLE II

STRUCTURAL			CHARACTERISTICS		
Types of Layering	Thickness	Strike/Dip	Joints/Faults	Seismic Aspects	Water Potential
[?] Beds common in shale.	[?]	? Contours suggest shale beds are dipping south.	Drainage bends suggest E-W joints in shale beds.	Good along N. slopes where rock is not deeply weathered.	Poor except along south base of shale hills where soil is deep.

DATA TABLE III

ENGINEERING			CHARACTERISTICS		
Weathering Aspects	Swelling Data	Abrasion Data	Aggregate Suitability	Drill/Blast Aspects	Siting Suitability
Deep soil [clay] everywhere except on north slopes.	? [shale usually swells]	High losses are probable	Poor [no quarries on map]. Forms peaty aggregate.	Only deeply weathered shale along south slopes are rippable. Light blasting.	Good except base of slopes where high water table and low percolation rates in shale create foundation [water, slopes] problems.

Step 18. Rate each of the map units according to Step 16, check each map unit to make sure it is properly labeled, clean up overlay and data tables, and redraft if necessary.

Step 19. Return all source data to data base file.

*Analyst note: Rate an area as follows: A is given only when all input is of the highest quality. Where input is less, rate the unit B. Where all or most of the input for a unit is poor, rate the unit C. The example shows that Unit 1 is sedimentary; shale, forms round hills that are densely dissected on the east slopes. Structural characteristics for area 1 are not particularly poor; this explains the rating, B. But the Engineering Characteristics are poor; the rating is C. This area would appear on the factor map as 1 - B - C.

TABLE 1. APPROXIMATE CHARACTERISTICS OF IGNEOUS ROCK

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
ROCK CLASSIFICATION	
Igneous	
ROCK COMPOSITION	
Intrusive	For military purposes <u>all</u> coarse-to medium-grained igneous rocks, regardless of their chemical composition will be grouped under "Intrusive". Granite is the most common example; diorite and gabbro are less common.
Extrusive	For military purposes <u>all</u> fine-grained igneous rocks, regardless of their chemical composition or occurrence, will be grouped under "Extrusive". The most common example is Basalt; andesite and rhyolite are less common.
ROCK GRAIN SIZE	Use descriptive terms, <u>fine</u> , <u>medium</u> , or <u>coarse-grained</u> . Generally, Intrusives will be coarse to medium-grained. Extrusives are usually fine-grained.
ROCK COLOR	Use the simplest terms unless complex terms, e.g., bluish-gray, are needed.
ROCK TYPE VARIATIONS, INCLUDING DISSECTION CHARACTER	<p>"Variations" means that a rock type underlies an extensive area but has significant chemical, physical, or topographic differences locally. These differences will be described. A granite, for instance, could underlie a large area; locally, it may form hills and elsewhere (in the same area) form plains. Thus, the rock unit would be described as, "Granite" but with varying topography, <u>Plains</u> and <u>Hills</u>.</p> <p>"Dissection Character" means the overall general topographic expression of a rock composition. If the unit commonly contains deep valleys, for example, describe it as forming deep valleys. Stream valleys in granite (Intrusive) terrain are often broad and rounded except in desert areas; there, the valleys are usually sharp, angular and steep. Basalt forms broad, rolling</p>

TABLE 1. CONTINUED

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
TYPE OF ROCK LAYERING	<p>to hilly topography with steep valleys.</p> <p>Use simplest terms such as layered flow, massive, thick, thin, etc. Intrusive (Granite) rock is usually massive. Extrusive rock is commonly layered but highly variable in thickness.</p>
THICKNESS OF UNIT	<p>Use terms like thick or thin except where precise figures are available; use averages if possible. Seldom used for igneous rocks except for flows such as Basalts.</p>
STRIKE AND DIP OF UNIT	<p>Intrusive rocks have no strike and dip. Extrusive rocks, basalts in particular, can have strike and dip. Where precise data is not available but it is obvious that the beds are dipping, use simple terms like "low-dipping" or "high-dipping" to indicate inclination of the unit.</p>
JOINTS AND FAULTS IN UNIT	<p>Intrusives are commonly jointed; often to great depths below the ground. If directions of joints can be measured (or are known), determine averages. Faults are best shown on the factor overlay; joints are usually too numerous to portray graphically except by averages (e.g., Joints in the Granite average N 15° E). Basalts (Extrusives) are commonly jointed, even more so than most Intrusives. Faults in Extrusive rocks are not easily detected on most aerial imagery; where recognized, regardless of the rock type, show them on your overlay.</p>

TABLE 1. CONTINUED

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
SEISMIC ASPECTS OF UNIT	<p>The seismic potential of a map area can only be determined accurately from on-site collected data. Acceptable estimates are possible, however, depending on the amount of broken or dissected terrain underlain by various rock types. In general, igneous rocks transmit seismic energy better than other rock types; where deeply weathered, faulted or densely jointed, seismic properties of rocks are reduced drastically.</p>
WATER POTENTIAL OF UNIT	<p>Intrusive rocks are poor sources of ground water; Extrusive rocks are even worse because of their fine-grained character. The exceptions occur where either rock type is densely jointed. Deep drilling will not improve chances of finding water in such rocks. The best locations of water in the types of rocks are in areas where soils are the deepest and where faults occur. Seismic properties are reduced in saturated granites and basalts.</p>
WEATHERING ASPECTS OF UNIT	<p>Use terms such as deep, shallow to describe the depth of weathering. If the Intrusive rock is coarse-grained, granular soils are commonly produced by weathering, e.g., gravelly sand. Exceptions occur in the tropics where laterites (heavy, thick clays) are formed. Extrusive rocks weather more deeply than Intrusive rocks. Clays are commonly produced in areas underlain by fine-grained Extrusives; locally, however, the soils can be very stoney.</p>
SWELLING DATA FOR UNIT	<p>Intrusive and Extrusive Rocks are not appreciably swellable in laboratory tests. Exceptions are caused by the presence of certain clay minerals, e.g. montmorillinite.</p>
ABRASION DATA FOR UNIT	<p>Coarse-grained rocks commonly have moderate to high abrasion loss in laboratory tests; finer-grained igneous rocks have better (lower) abrasion losses.</p>

TABLE 1. CONTINUED

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
AGGREGATE SUITABILITY OF UNIT	Intrusive rocks, especially when medium- to fine-grained, produce highly suitable aggregate when crushed because of the angular shapes; this is true also of fine-grained Extrusives. Coarser grained granites, used as aggregate, can fail in concrete stress tests.
DRILLING AND BLASTING CHARACTERISTICS OF UNIT	Igneous rocks always require drilling and blasting to excavate except where deeply weathered. If they are deeply weathered they can be ripped to variable depths by heavy equipment. Where the rock is densely jointed, overbreakage at the blast site is common. If layered rock formations (e.g. basalt flows) dips into an excavation, slope failure can occur.
SITE SUITABILITY (FOR STRUCTURES)	Intrusive and Extrusive rocks generally provide an excellent foundation for all structures, including underground complexes. Except where the rock is densely jointed or faulted, ground water is seldom a problem. Stresses at underground openings can be severe enough to cause failures. Depth of weathering over most Igneous rocks is essentially uniform; where uneven, serious differential settling can occur.
GENERAL NOTE	Because relatively little of the terrain over which the Army will operate is underlain by Metamorphic Rocks, this rock group is treated herewith in very general terms. The best term (Rock Type) to employ when an area is underlain entirely or in part by metamorphic rock is, Undifferentiated Metamorphic Rock. Thus a phyllite or a schist would be termed Undifferentiated Metamorphic Rock. If descriptions are unavailable, use Table 1 to complete the Data Table.

TABLE 2. APPROXIMATE CHARACTERISTICS OF SEDIMENTARY ROCKS.

DATA ELEMENT.	IDENTIFICATION CHARACTERISTICS
ROCK CLASSIFICATION	
Sedimentary	
ROCK COMPOSITION	
Limestone	Limestone (for military purposes all carbonate rocks - limestone, dolomite, coquina, etc. - are to be identified as "Limestone.") Use simple modifiers to describe minor constituents, e.g. clayey limestone.
Sandstone	Sandstone (for military purposes all sandstones - sandstone, grits, cemented conglomerates, etc. - are to be identified as "Sandstone.") Use simple modifiers to describe minor constituents, e.g., calcareous sandstone.
Shale	Shale (for military purposes all fine-grained (silt to clay-particle sized) sedimentary rocks - shale, siltstone, mudstone, etc. - are to be identified as "Shale.") If minor constituents are present, describe briefly.
ROCK GRAIN SIZE	Use descriptive terms such as, fine, or medium-grained. Occasionally, a sandstone might be coarse-grained. Where the rock type unit contains cobbles or gravel sufficient to warrant the term, Conglomerate, use it. Variations that might affect engineering properties ought to be mentioned in Data Table 3: "The fine-grained unit is coarse-grained at the base, which might permit ground water to enter the excavation..."
ROCK COLOR	For military purposes use the simplest descriptors. Color is the least important rock type characteristic (for engineering purposes). In general, certain color terms, e.g., "reddish, orange, etc." can suggest the presence of certain rock cementing materials. The analyst might then infer the probability of iron as a cementing agent in the rock.

TABLE 2. CONTINUED

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
ROCK VARIATIONS, INCLUDING DISSECTION CHARACTER	<p>"Variations" means that a rock type underlies an extensive area of the region but locally has significant chemical, physical, or topographic differences. These differences are to be described if the analyst recognizes some relationship to the engineering or structural characteristics of the rock type. Use brief, descriptive terms. Sandstone areas in arid regions can be highly eroded, forming canyons with steep walls; in colder climates the terrain may be more subdued and the valleys more rounded. Shale commonly forms rolling terrain. Limestone areas are often underlain by cavernous zones; sinkholes on the surface are common.</p>
TYPE OF ROCK LAYERING	<p>Use terms such as, thin or thick, to suggest the overall occurrence of the unit. Such terms as <u>crossbedded</u>, for instance, have no military significance.</p>
THICKNESS OF UNIT	<p>Use terms such as thick or thin, but record in meters the known or estimated thickness of either the entire unit (where made up of several beds) or a given unit. For instance, "Sandstone, thin bedded, 10 meters except locally."</p>
STRIKE AND DIP OF UNIT	<p>Use averages where data are known or can be estimated. If precise numbers aren't available, but the geographic orientation is known or is estimable state it, e.g., N 10 E and dips SE at low angles.</p>
JOINTS AND FAULTS IN UNIT	<p>Indicate average strikes and dips for joints. If the dominant joint pattern can be determined, so state. For instance, "The dominant joint trend is N 15° W." Most joints are vertical. Unlike the more common joints, faults should be <u>shown</u> on the factor map. If the fault dips, so indicate the direction of dip and angle (if known).</p>

TABLE 2. CONTINUED

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
SEISMIC ASPECTS OF UNIT	<p>The seismic potential of a region can only be determined accurately from on-site information. Acceptable estimates are possible, however, depending on the rock types present, and the absence or presence of broken or cavernous terrain. Fissured bedrock, regardless of rock type, is seismically poor; carbonate areas underlain by numerous cavities are also seismically poor. The chief factor affecting the seismic characteristics of terrain is soil depth, where soils are thin, seismic potential is seriously reduced. ETL-TR-72-3 is recommended reading for evaluation of terrain influence on sensor emplacement and performance.</p>
WATER POTENTIAL OF UNIT	<p>Highly cemented sandstones are commonly poor aquifers (subsurface sources of ground water) except where deeply weathered or densely jointed. Shales commonly are the poorest bedrock aquifers except where densely jointed or faulted. In general, coarse-grained sandstones, loosely cemented sandstones, or limestone constitute the most favorable sources of ground water.</p>
WEATHERING ASPECTS OF UNIT	<p>Use simple terms such as deep or shallow. Sedimentary rocks vary greatly in their susceptibility to weathering. Sandstone, if cemented with carbonate materials, weathers deeply. Shale, depending on the density of jointing, commonly weathers to great depths. Limestone is highly variable in its susceptibility to weathering; limestone terrain should be considered as cavernous in the absence of accurate data.</p>
SWELLING DATA FOR UNIT	<p>The worst swelling problems can be expected from shale. Sandstones or limestones seldom have serious swelling characteristics except where clay minerals are present in significant amounts.</p>

TABLE 2. CONTINUED.

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
ABRASION DATA FOR UNIT	Sandstones, where cemented with silica, afford the best (lowest) abrasion losses. Limestone abrasion losses can be very high depending on the presence of unsuspected, relatively soft minerals; dolomites and siliceous limestones have the lowest abrasion losses among the carbonate rocks. Shales are without exception high in abrasion loss.
AGGREGATE SUITABILITY OF UNIT	Crushed limestone is generally preferred among the sedimentary rocks; less energy is required for its excavation and it commonly affords desirable angular shapes. Where clay minerals are present (in limestone or sandstone) the suitability for aggregate decreases. Sandstone, especially those cemented by silica, can be a tough and desirable aggregate. Shale commonly produces flat or platy surfaces that reduce its strength in concrete.
DRILLING AND BLASTING CHARACTERISTICS OF UNIT	All sedimentary rocks require drilling and blasting except where deeply weathered. Near the surface shales are usually rippable as are weathered sandstones and limestones (especially if densely jointed and the joints are weathered). Steep slopes in excavations commonly require shoring to prevent failures if the beds dip into the excavation. Overbreakage can be serious in densely jointed sedimentary rocks regardless of the composition.
SITE SUITABILITY FOR STRUCTURES	All sedimentary rocks will bear most loads. The chief problem is drainage of the excavation to prevent slippage or heaving from freezing and thawing. Differential settling is experienced where soils, overlying a foundation, are variable in thickness (a common aspect of sedimentary rocks, especially where different rock types are interbedded and folded). Underground construction sites should be located in thicker rock units that are essentially flat-lying.

TABLE 3. CHARACTERISTICS OF UNCONSOLIDATED DEPOSITS

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
ROCK CLASSIFICATION	
Unconsolidated Deposits	
ROCK COMPOSITION	
Unconsolidated Deposits	All unconsolidated deposits, including those tightly cemented by various materials are grouped as Unconsolidated Deposits. This includes various terrace deposits, alluvium, colluvium boulder beds, etc. Composition to be described by dominant character of the unit such as, "granite boulder", "alluvium, composed of quartz sands with some clay," etc.
ROCK GRAIN SIZE	Use simple terms such as, <u>coarse</u> , <u>medium</u> , or <u>fine</u> , to describe the average size of the ingredients, i.e., sand, boulders, cobbles, gravel - making up the deposit.
ROCK COLOR	Color is important only if it indicates the presence of a binding or cementing material in the unconsolidated deposit. For instance, "Gravel in a red to orange soil" could mean the presence of iron-oxides as a cementing or binding material.
ROCK VARIATIONS, INCLUDING DISSECTION CHARACTER	"Variations" means an unconsolidated deposit varies locally, usually in the topographic expression. For instance, flood plain deposits are mostly level but locally can have deeply cut streambeds. Most unconsolidated deposits are not extensive in area, so the dissection pattern is not too important. However, if the topography will inhibit or reduce cross country movement because of the dissection of unconsolidate deposits, so state.
TYPE OF ROCK LAYERING	Unconsolidated deposits, because they seldom are extensive, are not commonly layered. Alluvium, however, can be described as wedge shaped deposits, evenly-bedded, etc. This factor is not too important for military purposes.

TABLE 3. CONTINUED.

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
THICKNESS OF UNIT	Use simple terms, such as, thick, thin, etc., with actual thickness (average) given for an area. Because this dimension can vary widely indicate the maximum and minimum thickness.
STRIKE AND DIP OF UNIT	This characteristic is not usually described. However, if an unconsolidated deposit is extensive in area and has an appreciable dip, so state. The strike will not be given.
JOINTS AND FAULTS IN UNIT	This characteristic is not important except where the deposits have been strongly cemented or bound by material, such as, iron, silica, or carbonate. Otherwise, joints cannot develop. Faults are not detected unless displacement has occurred. Most faults will be in the bedrock beneath the unconsolidated deposits but can be reflected in the surface material.
SEISMIC ASPECTS OF UNIT	Unconsolidated deposits can have significant seismic properties. The ETL-TR-72-3 is the best source of generalized information for this factor (data element). The presence/absence of a water table is important in seismic energy transmission; a high water table in unconsolidated deposits will ensure better transmission of energy. Structures sited on thick deposits in an earthquake prone area can suffer severe damage; the deposits tend to roll like ocean waves during an earth tremor.
WATER POTENTIAL OF UNIT	Unconsolidated deposits are usually excellent to good sources of ground water. However, these same deposits are commonly used to contain human waste from communities. The porous nature of these deposits ensures good transmission of ground water except where the clay content is high. The difficulty in siting wells in these deposits is that the coarser materials can create problems for drilling tools.

TABLE 3. CONTINUED.

DATA ELEMENT	IDENTIFICATION CHARACTERISTICS
WEATHERING ASPECTS OF UNIT	Unconsolidated deposits seldom experience weathering. However, if a high clay content is suspected in the materials, anticipate lower percolation rates, problems with movement of ground water, settlement under loading, etc.
SWELLING DATA FOR UNIT	For military purposes this data is not required for unconsolidated materials, except for certain clay deposits having excessive swell potential.
ABRASION LOSS FOR UNIT	For military purposes this data is not required for unconsolidated materials.
AGGREGATE SUITABILITY OF UNIT	Unconsolidated deposits are a common source of aggregate materials, especially the sand and gravel deposits. These must be clear of clay fractions, however, and if clay is suspected the analyst should so state. Concrete can fail or have lower strengths from use of rounded gravel common to most deposits; a crushed, angular rock is preferred but unconsolidated deposits are easier to excavate.
DRILLING AND BLASTING CHARACTERISTICS OF UNIT	Unconsolidated deposits seldom require drilling or blasting except where tightly cemented by iron oxides or silica. Usually these deposits are easily rippable or power equipment can be used to remove them. The chief problem is the stability of the excavations; ground water tables near the surface reduce the stability of the slopes.
SITE SUITABILITY (FOR STRUCTURES)	Unconsolidated deposits commonly are adequate for smaller structures; larger structures require pilings to bedrock or to friction limits. Differential settling is common because of the heterogenous nature of these deposits. High water tables are common which reduce the load-bearing capabilities of these deposits. Underground structures are often impossible because of high water tables.

GEOLOGIC MAP ANALYSIS. In this analysis example, the assumption is made that the only source material available is a small-scale geologic map and the report that usually accompanies such maps. Normally, geologic maps will describe the rock types found in an area in such detail, that all of the information required can be obtained from this source.

Step 1. Follow Steps 1 through 6 as presented under Topographic Map Analysis, page 37. Cover the geologic map with the overlay material and locate the area to be analyzed. Place a border around the area covered by the 1:50,000 topographic map.

Step 2. Construct the three Data Tables as described in Appendix A.

Step 3. Carefully read the geologic report that supports the geologic map. Review the geologic map and note the information provided in the legend.

Step 4. Study Tables 1, 2, and 3 and follow Procedure 2, Geologic Map Analysis on page 39 to complete the overlay.

Step 5. When necessary, follow Procedure 3, page 40, to change the scale of the geologic map overlay to that of the topographic map overlay.

Step 6. Clean up overlay and Data Tables. Return all source material to Data Base Files.

AERIAL PHOTOGRAPH ANALYSIS. In this example, the sources of information are limited to aerial photography, which when properly analyzed, provides considerably more geologic information than can be obtained from a standard topographic map. Some of the advantages provided by aerial photography include easier recognition and identification of landforms, recognition of terrain subtleties commonly obscured between contour intervals on a map, and gradations in photographic tone that can indicate changes in rock type.

In general, vertical, aerial photography obtained in adjacent, overlapping strips, with 60 percent end lap between frames permits stereo viewing. Stereo viewing shows the terrain in three dimensions with exaggeration of the vertical dimension. This method of viewing aerial photography enables the analyst not only to view major differences in topography but also to view small changes in slope, gully cross-sections, and the relative relief of different rock units. All of these features can provide indications of surface and subsurface materials.

Interpretation of aerial photography requires an understanding of photographic tones and textures. The grey tones that comprise pan-chromatic aerial photography range from white to black, but are primarily within the grey range. Within an individual photograph, these grey shade variations can indicate such things as differences in grain size in the underlying material and differences in color. For instance, light tones in rocks often indicate coarse grain, and coarse grain often indicates porous materials. Light tone also suggests a less dense rock, because light-colored minerals are usually less dense than dark-colored minerals. Photo tones may also be splotchy or mottled. Mottling sometimes indicates the presence of limestone bedrock on poorly drained soils. Photo texture also provides much information for the identification of rock types. Fine-grain materials produce a fine-photo texture. For instance, land underlain by shale often has a very smooth, even, almost velvety texture. The photographic texture of a cinder cone is also fine; however, it has a rough and blocky surface. Usually, a rough texture indicates bare rock surfaces.

By using Tables 1, 2, and 3 while examining the aerial photography, most Terrain Analysts should have little difficulty completing the Data Tables and the Factor Map Overlay unless the entire area is forested. In heavily forested areas, the texture and tone of the surface materials will be concealed from the analyst. In these instances, the analyst has to rely totally on topographic expression or subtle changes in the slope, in the shape of the hills and valleys, and in the cross-sectional shape of river and stream channels.

Step 1. Using Procedure 4, page 41, construct the aerial photo mosaic of an area that is 5 to 10 percent greater than the area covered by the 1:50,000 topographic map.

Step 2. Construct the Data Tables I, II, and III as specified in Appendix A.

Step 3. Complete Steps 1 through 6, page 37, Topographic Map Analysis.

Step 4. Delineate the major drainage channels on the mosaic with a felt-tipped pen, using the 1:50,000 scale topographic map as a guide.

Step 5. Using stereo viewing conditions, delineate the minor drainage patterns extending the stream channels into the small erosional gullies that can be found in the areas adjacent to the major drainage channels.

Step 6. Step back from the mosaic and view the drainage pattern from some distance. Are there any indications that the surface materials are similar throughout the map sheet?

Step 7. Outline areas of different drainage patterns on an overlay to the mosaic.

Step 8. Study under stereo conditions, the patterns just delineated. Does the relief, the slopes of the hills, the elevation, and the general shape of the hills confirm that the patterns you have delineated on the mosaic are different from each other? If not, redelineate those patterns with similar characteristics.

Step 9. Number each of the patterns beginning in the NW corner, downward in a normal, left-to-right reading manner. Give areas with the same characteristics the same number.

Step 10. Study the cross-sectional profile of the erosional channels of pattern #1 and refer to Procedure 5, Aerial Photography Analysis on page 43. Using the photo keys presented in Procedure 5 identify the rock class/type of this pattern.

Step 11. Continue Step 10 until rock class/type of all of the patterns have been identified.

Step 12. Enter in either Table 1, 2, or 3 by the rock type of each area and complete Data Tables I, II, and III for each pattern or map area. From the photos you can interpret the presence (assuming each is present) of the major rock classes as used in this guide - Igneous, Sedimentary, and Unconsolidated deposits. From Tables 1, 2, and 3 you can tentatively recognize certain outstanding features of each rock type. Next, you will be faced with providing information for the Data Tables. But before this, you must identify the types of rocks in the area from your only source, aerial photos.

Broadly speaking, granites and basalts (Igneous Rocks) will form rough, mountainous or hilly areas that are sparsely populated. The imagery, under stereo viewing, probably shows deep ravines and sharp mountain ridge lines. Drainage (streams) will not be well developed; the streams will be widely spaced over much of the area. These and other tips to interpreting the rock types on aerial photos are found in Procedure 5, page 43, and the references in Appendix C.

Step 13. Complete the labeling of the factor map overlay and the filling in of the required information in Data Tables I, II, and III.

Step 14. Use Procedure 3, page 40, to adjust scale of the photo mosaic overlay to 1:50,000 map scale.

Step 15. Clean up Data Tables and final version of the factor map overlay; redraft if necessary.

Step 16. Return all source material to Data Base Files.

ANALYSIS PROCEDURES

PROCEDURE 1, TOPOGRAPHIC MAP ANALYSIS. Often the only means of obtaining basic geological information is from a topographic map. By carefully inspecting and evaluating the topography, the analysts can deduce useful terrain information. For instance, after studying contours on the map, an analyst probably will detect areas that have different concentrations of contours. By delineating these different densities of contour lines, the analyst is initially defining topographic units that may or may not reflect different rock types. Floodplains, for example, will usually have fewer contour lines, and hills will have more. By outlining these different concentrations of contour lines, the analyst has derived two topographic units. In addition, by identifying a landform, much information about the material composing that landform can be deduced.* For example, floodplains are commonly derived from water-laid deposits called alluvium. By referring to Table 3, page 31, Approximate Characteristics of Unconsolidated Material, the analyst can continue his analysis of this landform and its (probable) compositional makeup. In terrain analysis, it is this next step that is very important. The materials of this hypothetical floodplain most likely were derived from the bedrock in the nearby hills. For instance, if the hills are shale, the analyst can expect the floodplain materials to be very fine-grained, probably clay and silt. In this simple example, the terrain analyst has identified two units, hills and floodplains. He's tentatively guessed that the hills, because of their rounded topography and dense drainage patterns, may be composed of shale. In addition, he has read one or two texts and reports, referenced in the Data Base Files, which indicated that the geographical region of the map sheet is composed of wide spread deposits of sedimentary rocks. In Table 2, Sedimentary Rocks, the analyst will find useful information about shale. This information enables him to input to the Data Tables (See sample Data Tables, Figure 3) as well as delineating the area of shale hills on the factor overlay.

*The landform factor overlay from the Surface Configuration data field can be used for this purpose, if available.

This same approach must be undertaken by the analyst in describing the materials of the floodplains: mapping, describing, and estimating the probable characteristics of Alluvium based on Table 3.

To repeat: Using this example, the analyst has identified two landforms in the area as indicated by topographic contours, hills, and floodplains. He has traced boundaries around these landforms on his base map or on an overlay. He has studied the topographic expression of these landforms and, noting the denseness of the drainage in the hills unit, has tentatively labeled the bedrock as "Shale." Most probably then, the materials of the floodplains adjacent to the hills is comprised of fine-grained matter washed out of the shale hills.

The analyst now refers to Table 2 to obtain additional information on "Shale" (Sedimentary Rock) and on Unconsolidated Deposits. He can begin to fill in the Data Tables. Where he is unable to deduce various structural or engineering characteristics for either shale or unconsolidated deposits, the spaces are left blank.

In the example illustrated in figure 5, the analyst deduced certain information from indications provided by drainage and contour line patterns. Basic to this analysis, however, was the use of Tables 1, 2, and 3, to round out his identification of the rock types in the area.

The steps involved include:

1. Initial penciling in of the most obvious landforms (note recognition of sinkholes).

In general, the homogeneity and density of the drainage patterns and contour lines on a map sheet are indicative of the type of materials that can be found in the region. In other words, if the patterns formed by the drainage channels and the contour lines are constant over the entire map sheet, then the analyst can be reasonably certain that the surface materials are also similar throughout the map sheet.

2. Drainage overlay (do you see any patterns, traces, or relationships, that suggest variations in rock types, geologic structure, and so forth?).

3. Integration of drainage areas or patterns with analyst's landforms. (By reference to Table 2, he has tentatively identified certain rock types.)

4. Careful inspection of topographic expression and reference to Table 2 results in a cleaned-up interpretation of the major rock types (note how the analyst has broken a limestone area into cave and non-cave terrain; the absence of caves and the more rounded topography east of the dashed line suggested shale is present as well as limestone).

5. Refinement of landform and bedrock relationships continues (note how the analyst has redefined an area formerly labeled "Igneous").

6. By putting together landform, drainage, and refined geology overlays, the analyst, using the Tables 1, 2, and 3 as a tool in his interpretation, completes his study by completing the Data Tables with the information he can reasonably deduct from the integrated overlays.

It is impossible with this map-only approach to be more than very approximate in developing the Data Tables. However, military use of geological data may not always warrant the development of more precise information. Rock Composition or type is most important, followed by descriptions of the bedrock (hard, soft, moderately hard) may be all that is required.

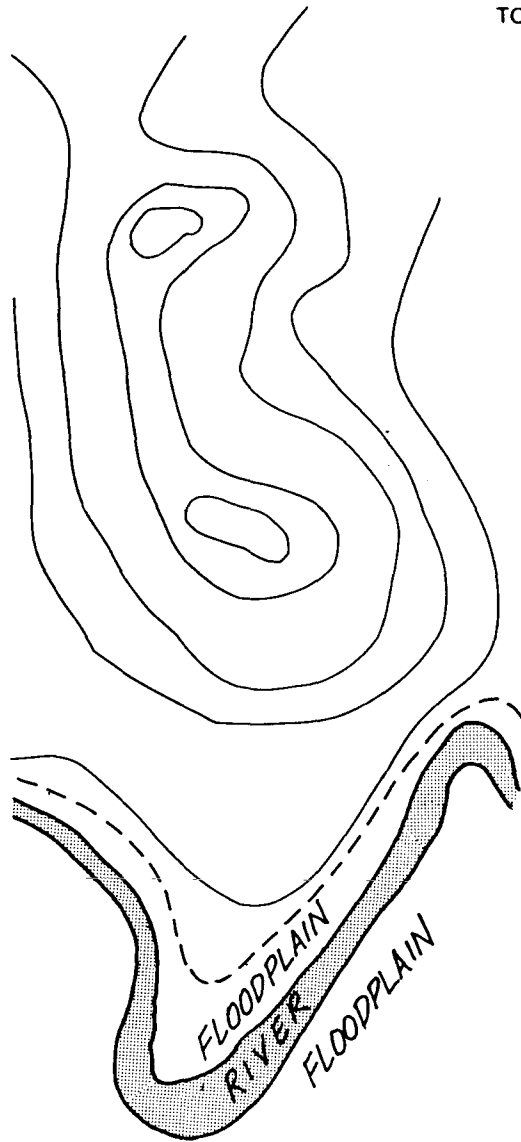
Determining reasonable estimates of many structural and engineering characteristics of the rock types in an area, from topographic maps alone, requires experience. Where experience is limited, the terrain analyst will find Tables 1, 2, and 3 to be of considerable help in organizing and presenting geological data when preparing Factor Overlays. The use of aerial imagery in connection with Tables 1, 2, and 3 will significantly increase the accuracy of interpretation.

Examples P-1 through P-9 illustrate how contour line patterns can often provide the analyst with clues or indications of rock type.

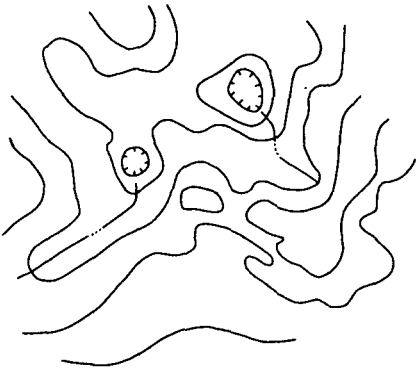
PROCEDURE 2, GEOLOGIC MAP ANALYSIS.

A. Trace the boundaries between rock types as indicated on the geology map on to the overlay material.

B. Study the map legend, and copy all pertinent information in the data tables. The map legend, for example, will often provide depths of the various rock formations and thickness of the beds. The contact line between two different rock types will usually be symbolized to show the strike and dip of the formations.

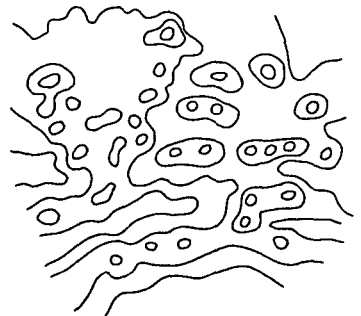


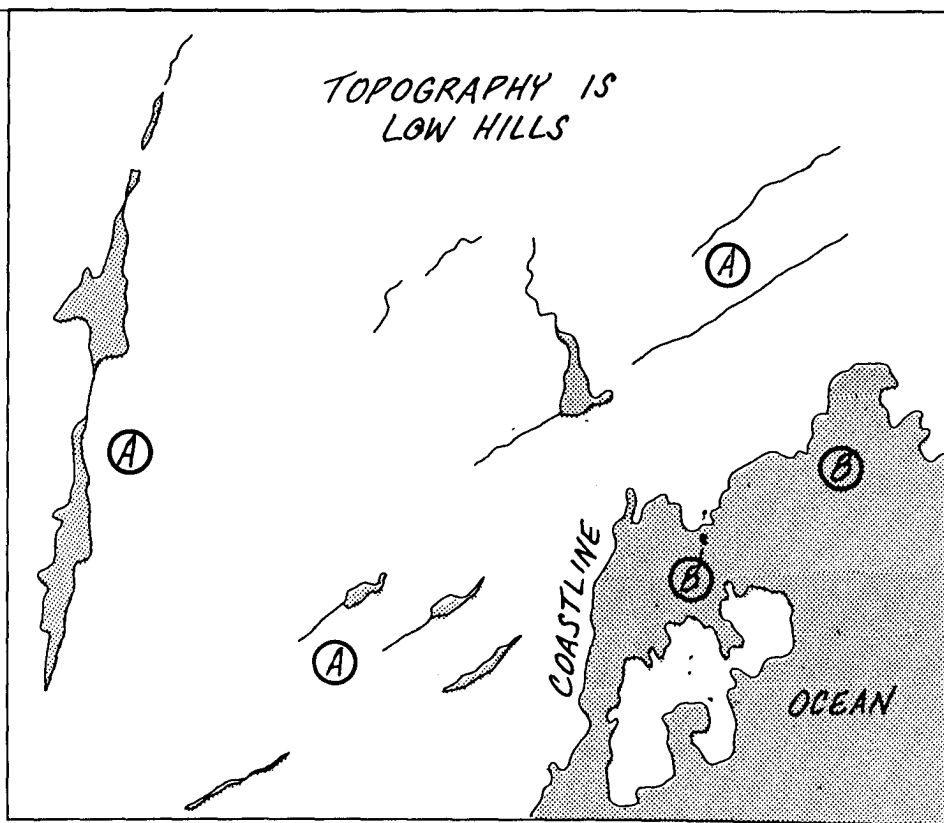
The chief topographic feature is the overall symmetry of the hill, a clear suggestion that the rock formation is flat-lying. The even spacing between contour lines supports this observation. The prominent bend in the river suggests the bedrock is relatively hard. The analyst concludes that flat-lying, thick Sandstone probably underlies the hill. Turning to the ACT he begins to input information about Sandstone to the Geology Data Element Tables.



Example of karst (sinkhole) terrain. The presence of numerous circular depressions (closed contours) in a small area is the key. Very few creeks are common to Limestone terrain because of subsurface drainage.

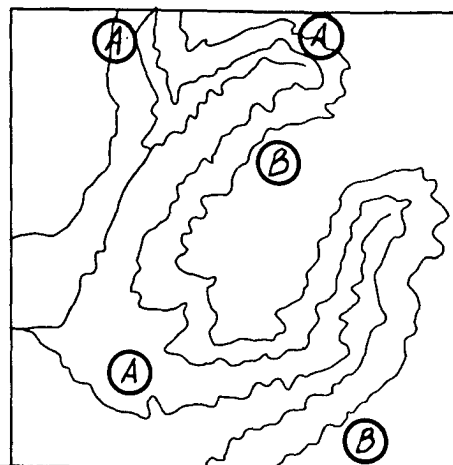
In the tropics, Limestone terrain forms small rock haystacks or pimples. The pattern on maps is "bumpy", caused by numerous rock haystacks.

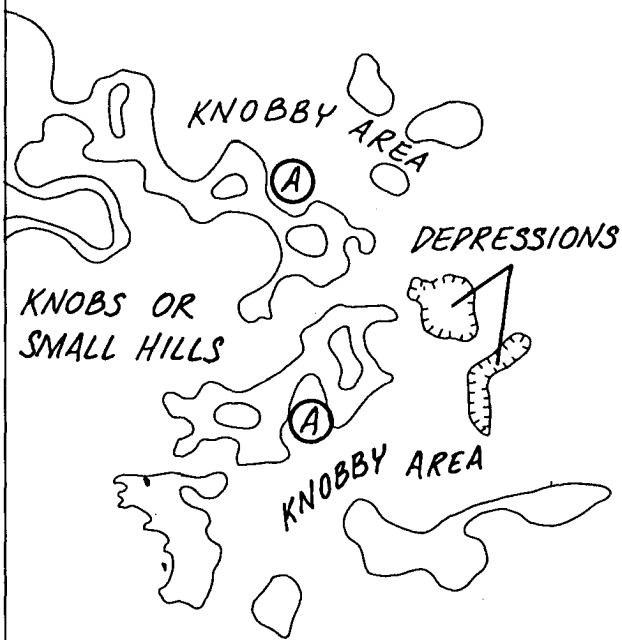




Example of Granite terrain. Note linear features (A) usually occupied by creeks, indicating fractured hard bedrock. Note jagged coastline, especially coastline of island; hard bedrock is indicated (B). Drainage is also poorly developed, a key to Granite. The absence of settlement suggests bedrock is not covered with deep soils, but bare rock and stony soils most probably everywhere. Relief is low, indicating glacial action in the past.

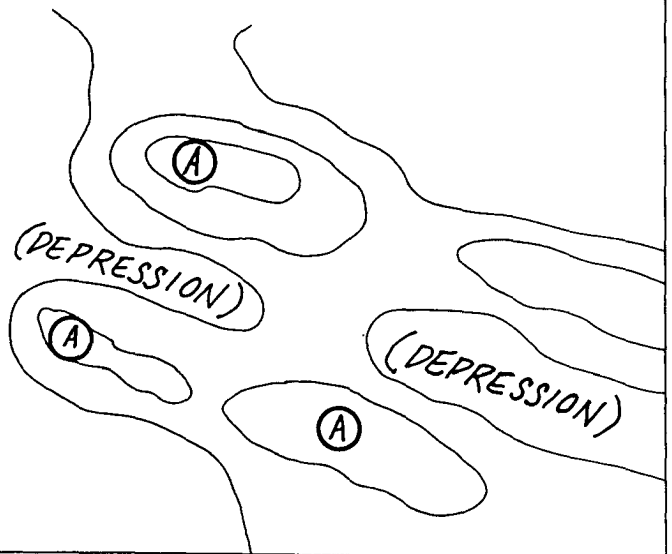
Example of Hard Rock terrain. Analyst has traced drainage divides (A) and noted their angular, jagged trend; only hard bedrock could underlie the mountain. Contour lines (B) also show a jagged trend; hard bedrock (probably Granite) is suspected. The jagged or angular mountain crestline (drainage divide) suggests bedrock is strongly jointed.





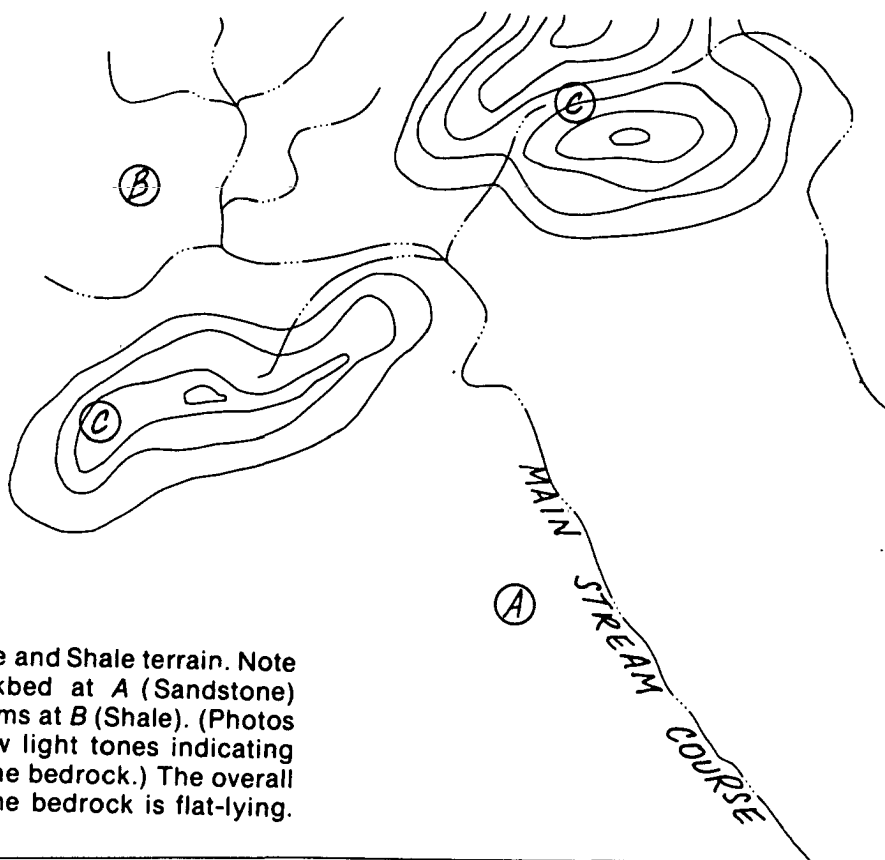
An example of Glacial terrain. Here, the "Fried Eggs" topography (A) is the key. Commonly the knobby areas are underlain by sand and gravel deposits. Finer grained materials (clay, silt) are in the lower depressions.

Example of Glacial terrain. The linear topography indicates the passage of glaciers over bedrock. These *elliptical domes* (A) are commonly 100 feet high and half a mile long; they're called Drumlins. Note the absence of drainage along their sides. The absence of drainage suggests very porous rock, possibly Sandstone or Limestone.

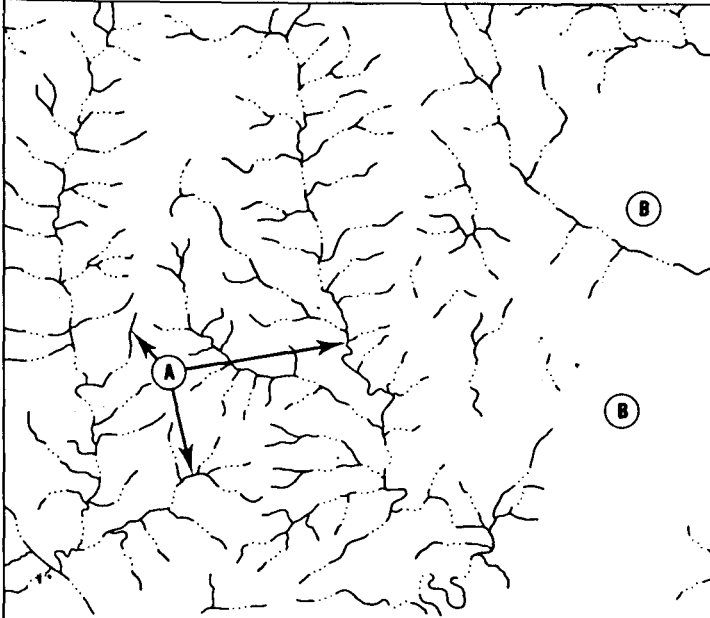


BODY
OF
WATER

Example of windblown sand forming sand dunes. The key is the fish scale topography.

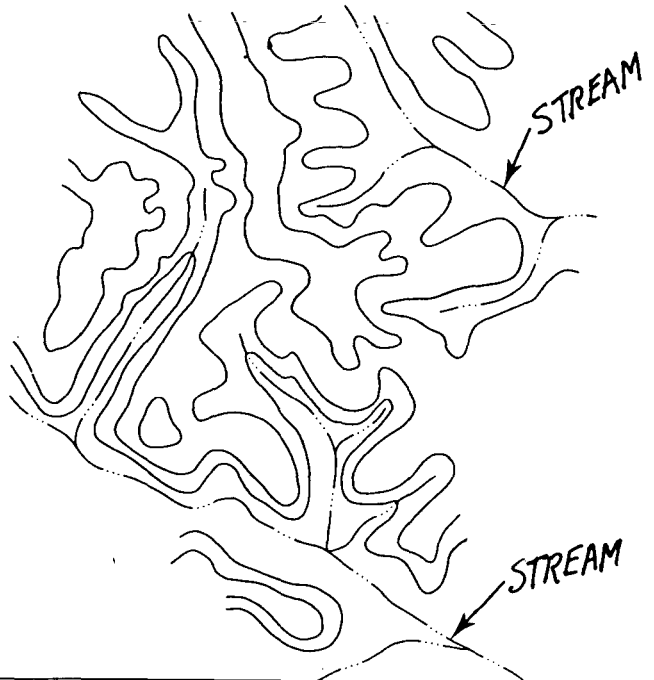


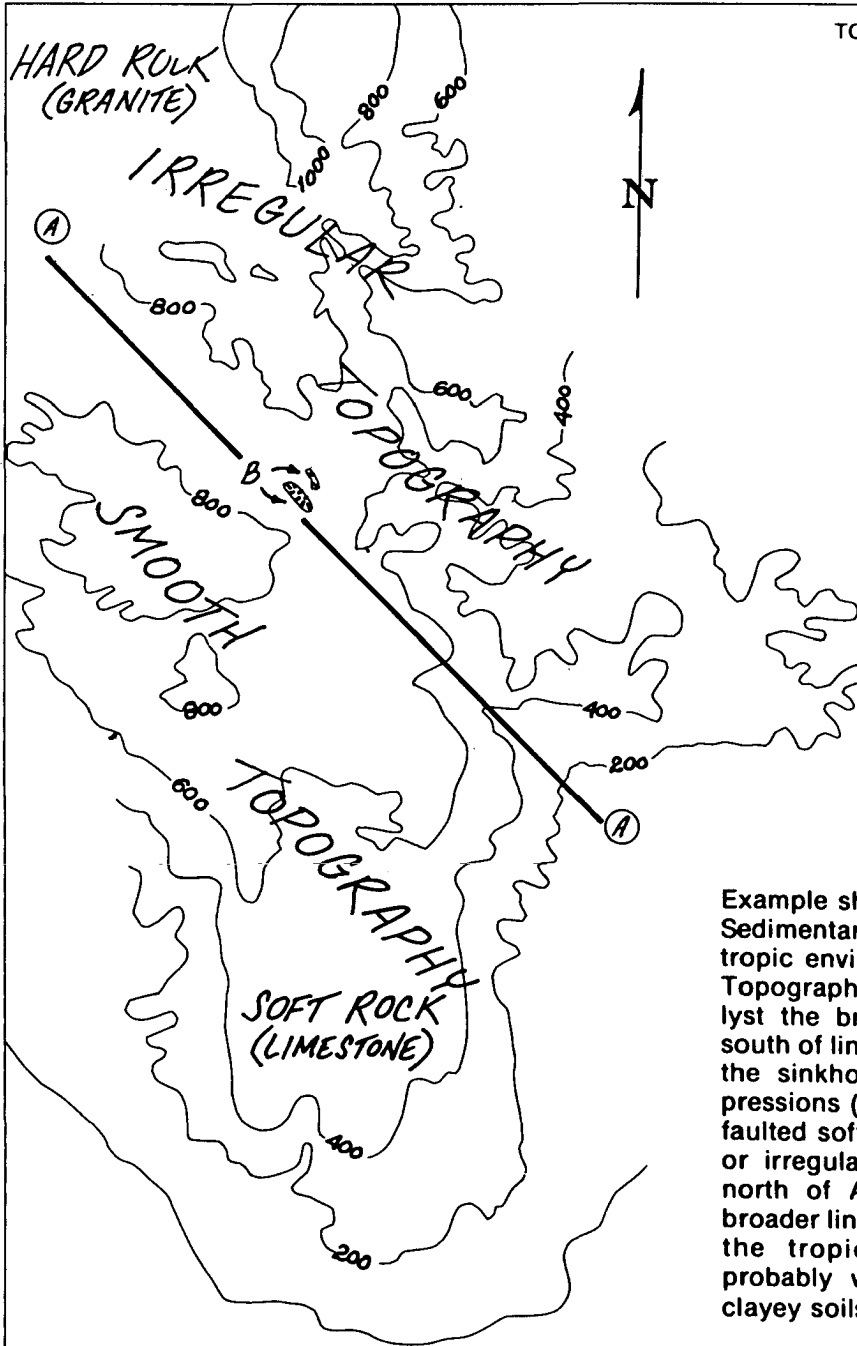
Example of Sandstone and Shale terrain. Note straightness of creekbed at A (Sandstone) versus dendritic streams at B (Shale). (Photos of hills at C will show light tones indicating sand is dominant in the bedrock.) The overall symmetry suggests the bedrock is flat-lying.



An example of dendritic drainage (A); bedrock probably is fine-grained Shale (which explains the many small creeks). Note to the scarce drainage at B, a suggestion of subsurface drainage which commonly means sinkholes in Limestone terrain. The analyst assumes that Limestone underlies the area to the right and Shale to the left. The contact between the two rock types is determined by following prominent topographic trends or differences in landforms (not shown here).

Note the fingers or "glove-like" key common to Limestone terrain. Note smoothness of contour lines. The even spacing between them suggests flat-lying Limestone beds. Drainage is not prominent, another key to the presence of Limestone.

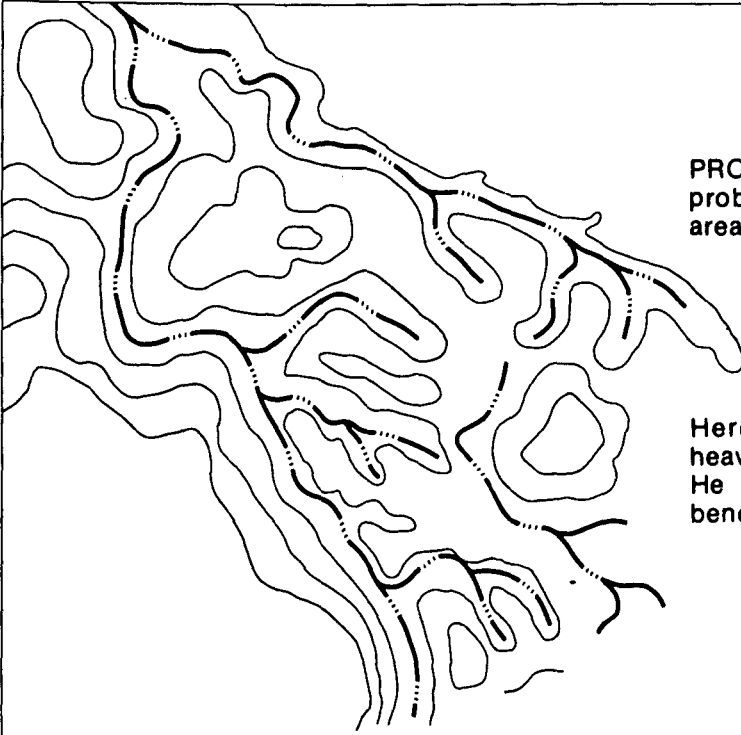




Example showing contact between Sedimentary and Igneous rocks in a tropic environment.

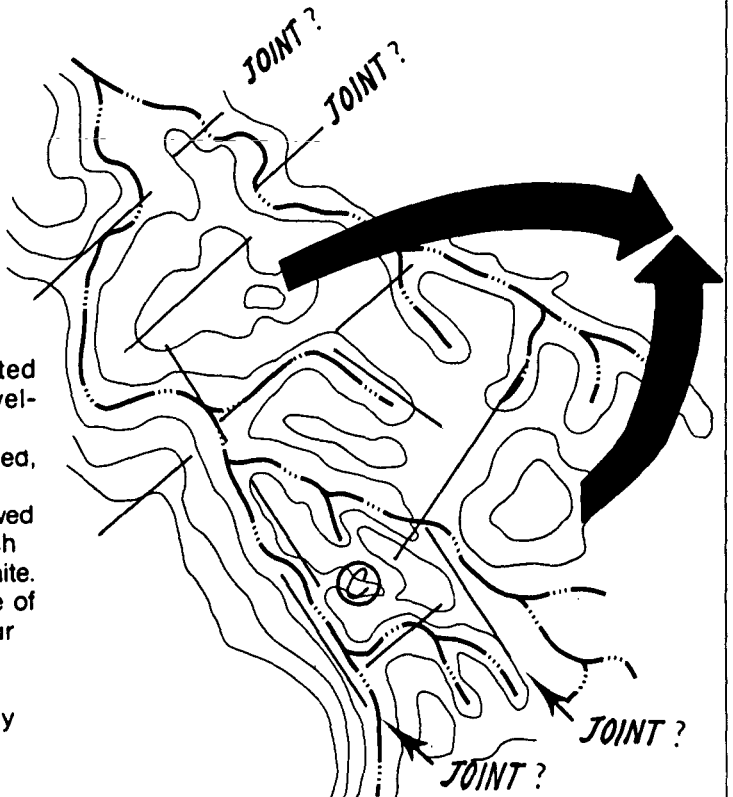
Topographic maps show the analyst the broad division north and south of line A-A. The analyst noted the sinkholes or topographic depressions (B), a key to Limestone or faulted soft rocks. Note the jagged or irregular topographic contours north of A-A; and the smoother, broader lines south of A-A. Being in the tropics, these Limestones, probably were formed very deep clayey soils.

CARIBBEAN SEA



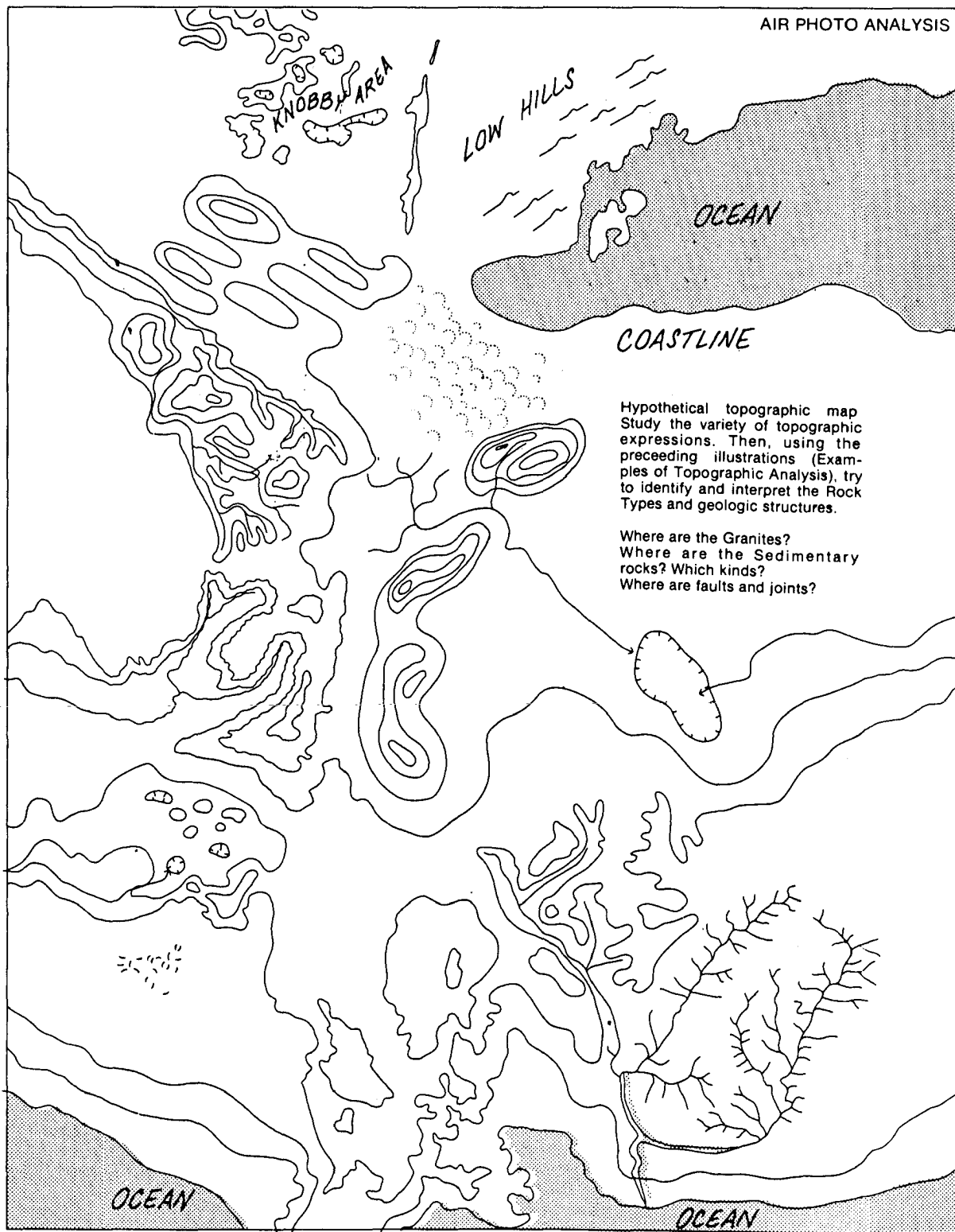
PROBLEM: What type of rock most probably underlies most of this area?

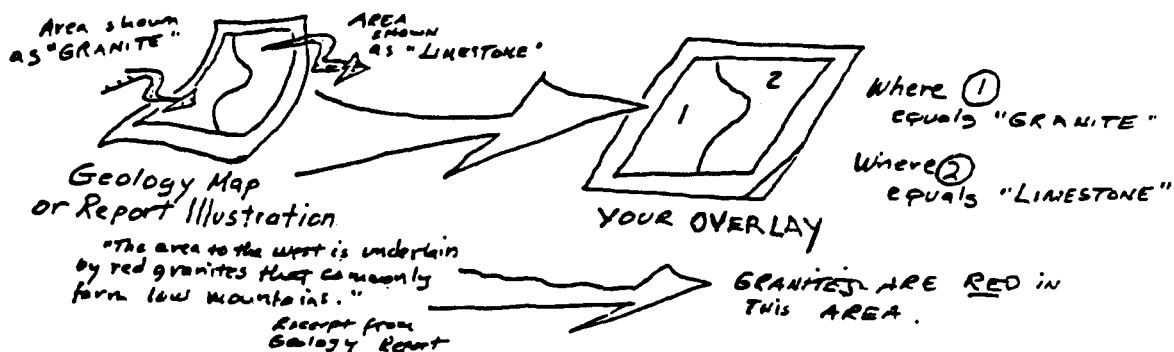
Here, the analyst has already heaved up the drainage lines. He then studies the pattern of bends or kinks in these creeks.



1. Study of the drainage suggested bedrock joints are well developed.
2. Jointed bedrock is widely spaced, forming big blocky areas.
3. Study of the contour lines showed broad, rounded areas for each "block," which suggested Granite. This area is underlain by a type of Granite called porphyry. For our purposes it is Granite.

Area (C) is probably more deeply weathered and jointed.





C. Study the report that may accompany the geology map. Record all pertinent information in the proper Data Table. For instance, if rock color is given, list it under "Rock Color" in the data tables.

D. Properly label all map units on the overlay.

E. Using either Tables 1, 2, or 3, as indicated by the rock type shown on the geologic map, begin to fill in the Structural and Engineering Characteristics portions of the Data Tables; this type of data seldom appears in geologic maps and reports. When these characteristic cannot be obtained from either the geologic map, report, or Tables 1 through 3, leave the columns blank.

PROCEDURE 3, SCALE ADJUSTMENT. When the geologic map or the mosaic overlay are at scales other than 1:50,000, the scales must be adjusted to permit transfer of the data to the factor overlay.

Use one of the following methods:

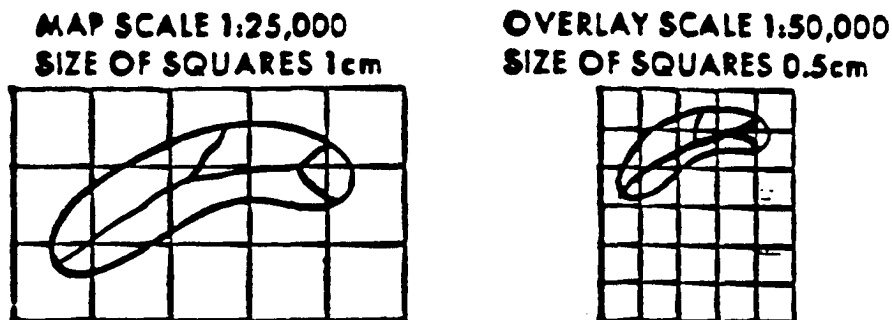
A. Have the mosaic overlay or geologic map photographically enlarged or reduced to the overlay scale, and then trace the boundaries onto the factor overlay. This method requires access to a large copy camera and a photographic laboratory, and may not always be practical.

B. Use a reflecting projector to project the mosaic overlay onto the final overlay at the same scale and then trace the boundaries. This will require that the overlay be folded and worked on in small sections.

C. Use a sketchmaster or zoom transferscope to transfer the boundaries. These instruments can be used only when the scale difference is small and can accommodate only small sections of the overlay.

D. Where available, a pantograph may be used.

E. As a last resort, the boundaries may be transferred by using a system of squares similar to the following example:



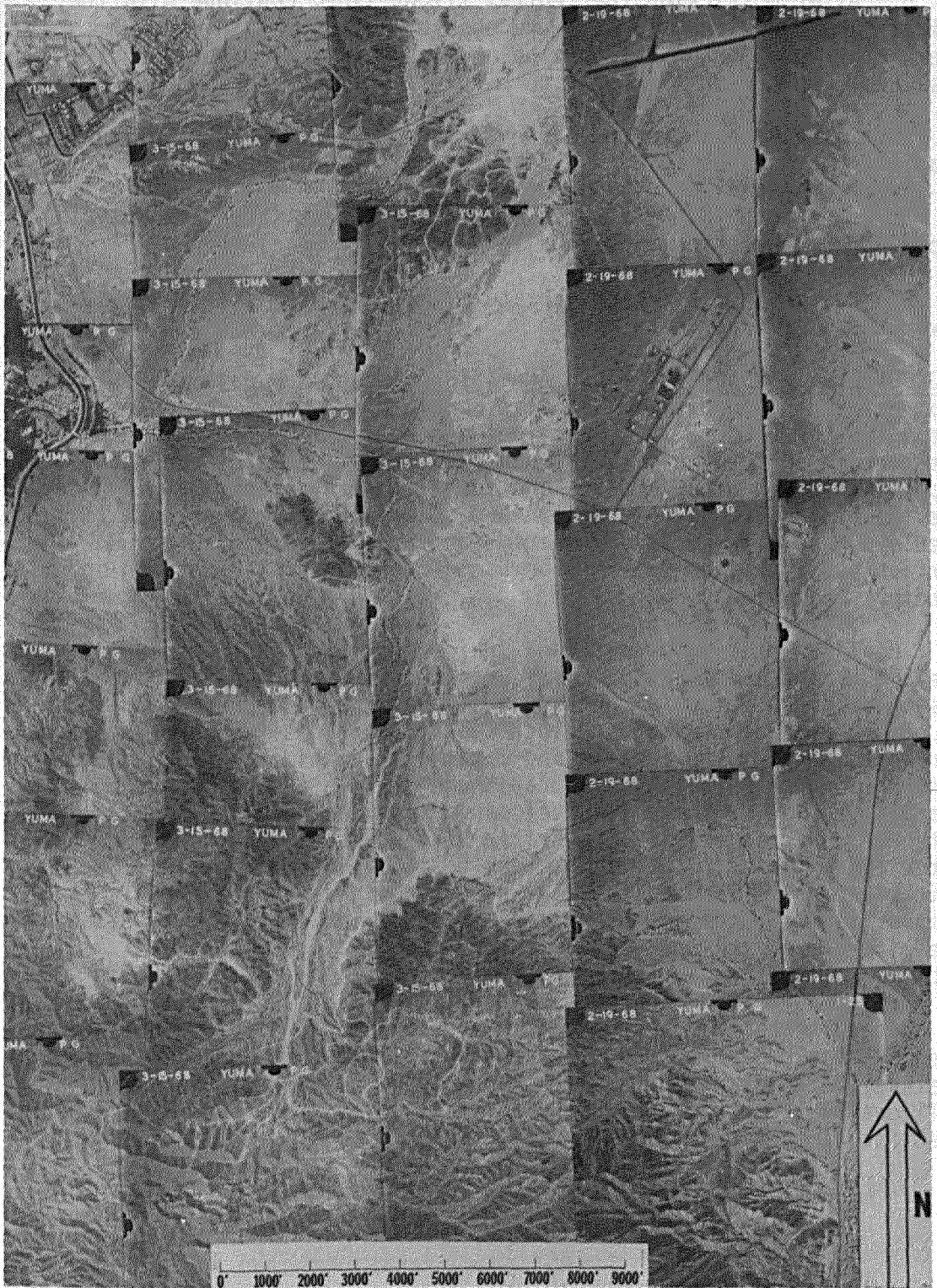
This method of transferring detail is very slow and should be used only when revising or completing small areas on the overlay.

PROCEDURE 4, PREPARATION OF AERIAL PHOTO MOSAIC. All aerial photo mosaics (P4-1) should be constructed on a 4- by 8-foot soft fiber board similar to such commercial products as "Homosote" or "Celotex." These materials will hold staples and can be used again as the areas are changed. During analysis, this board can be placed on a layout table or on a pair of sawhorses supported by a sheet of plywood or planks.

A. Separate the photos of each strip (flight line) into two stacks by pulling out alternate prints. Photos 1, 3, 5, 7, etc. form one group, and photos 2, 4, 6, 8, etc. form the second group. One group of photographs forms the mosaics, and the other group is used later in the analysis when stereo viewing is required.

B. Sequentially lay out and overlay alternate photographs of the flight line that most closely bisects the center of the area of interest (either group of photographs may be used).

C. Mosaic these photographs together, while maintaining as closely as possible the geometric integrity of visible landscape features, i.e. align streams, roads, ridge lines, etc. (do not fasten the photographs with staples at this time).



P4-1. Example of Aerial Photo Mosaic

D. After mosaicking the central flight line, continue with the flight lines on either side of the central one and again lay out every other photograph. It may be necessary to realign previously mosaicked photographs in order to best align linear features.

E. Repeat the above procedure for each flight line. Continually readjust photographs to attain best fit.

F. When each flight line is mosaicked to your satisfaction, staple photograph corners to maintain alignment. See example below.

G. Cut a piece of clear acetate or Mylar of sufficient size to cover the mosaicked photography.

PROCEDURE 5, AERIAL PHOTOGRAPH ANALYSIS. Geological data, derived from aerial photo analysis, is best obtained through a series of steps (P5-1), each of which provides a more complete understanding of the terrain so that the analyst can eventually interpret the rock type in the area of interest. The most important steps in this process are the preparation of a drainage and then a landform overlay. (If overlays have already been prepared for data fields Drainage and Surface Configuration they may be used for the drainage pattern and landform analysis.)

The first step in preparing a drainage overlay is to trace all visible drainageways in the mosaic area with as much detail as possible. Areas of different types of drainage patterns should be bounded. Because drainage reflects both the composition and the structural attitude of the underlying materials, considerable geologic information can be derived from drainage pattern analysis. As an example, radial drainage is developed on conical hills, which are often volcanic in origin. Dendritic drainage develops on homogeneous materials of low dip, and is perhaps best developed in shales. Such criteria provide the analyst with specific clues as to material composition. By continuous reference to the Tables 1, 2, and 3 and the literature, the analyst can then begin filling in the Data Tables.

After the basic drainage patterns have been identified, a landform overlay should be prepared. Information gained through analysis of drainage patterns, slope changes and gulley cross-sectional shapes will enable the broad landform categories to be broken down into more specific categories.

OUTLINE AREAS OF DIFFERING DRAINAGE PATTERNS

STUDY DRAINAGE AND TOPOGRAPHIC EXPRESSION IN DETAIL.

USE LANDFORMS TO REFINE OUTLINED AREAS OF DIFFERING DRAINAGE.

BEGIN FILLING IN DATA ELEMENT TABLES using any specific data from reports or maps. When none exists, analyst must estimate data for tables.

ASSIGN MAP UNIT IDENTIFICATION NUMBER TO EACH OUTLINED AREA. Don't assign letters to the Structural and Engineering Data Elements at this point.

DETERMINE ROCK CLASSIFICATION

From topographic expression if data not available.

DETERMINE ROCK COMPOSITION

From topo expression of outlined areas or from topo maps.

DETERMINE ROCK GRAIN SIZE

From Rock Composition.

DETERMINE ROCK VARIATIONS, INCLUDING DISSECTION CHARACTER

From topo expression of outlined areas or from topo maps.

DETERMINE TYPE OF ROCK LAYERING

From photo measurements or estimate from Rock Composition.

DETERMINE THICKNESS OF UNIT

From estimate based on photo evidence (if seen in outcrop).

DETERMINE STRIKE AND DIP OF UNIT

From photo evidence (if seen in outcrop).

DETERMINE JOINT AND FAULT PATTERNS

From photo evidence.

DETERMINE WATER POTENTIAL OF UNIT

From estimate of Rock Composition.

DETERMINE WEATHERING ASPECTS OF UNIT

From photo evidence (if outcropping) or by Rock Composition.

DETERMINE SWELLING DATA FOR UNIT

From Rock Composition (where clay minerals are suspected).

DETERMINE ABRASION DATA FOR UNIT

From Rock Composition.

DETERMINE AGGREGATE SUITABILITY OF UNIT

From Rock Composition and any quarrying operations in area.

DETERMINE DRILLING AND BLASTING CHARACTERISTICS OF UNIT

From Rock Composition and quarry sites in area.

DETERMINE SEISMIC ASPECTS OF UNIT

From Rock Composition, Structure, Dissection, etc.

DETERMINE SITING (STRUCTURES) SUITABILITY OF UNIT

From Rock Composition, slope study (photos), drainage.

Complete Data
Tables. Where
data not avail-
able, state
"n.a." or
estimate
based on
experience.

EVALUATE DATA ELEMENT TABLES INPUT TO OBTAIN A STRUCTURAL AND ENGINEERING CHARACTERISTICS LETTER. Note: This is subjective and is relative, based on how one outlined area's data elements compare with those of another outlined area's data elements. See Appendix A for additional comments.

ASSIGN LETTER(S) TO OUTLINED AREAS ON YOUR DRAFT MAP OF THE AREA.

P5-1. PHOTO ANALYSIS FLOW CHART.

For instance, large flat areas containing streams should be separated from the surrounding hills. Two or three distinct types of hills may exist within the area of photo coverage. They may be distinguishable by relative elevation differences, differing degrees of dissection by streams, and the amount and type of vegetation cover. Once they have been bounded, they should be defined in terms of mountains, hills, plains, and valleys.

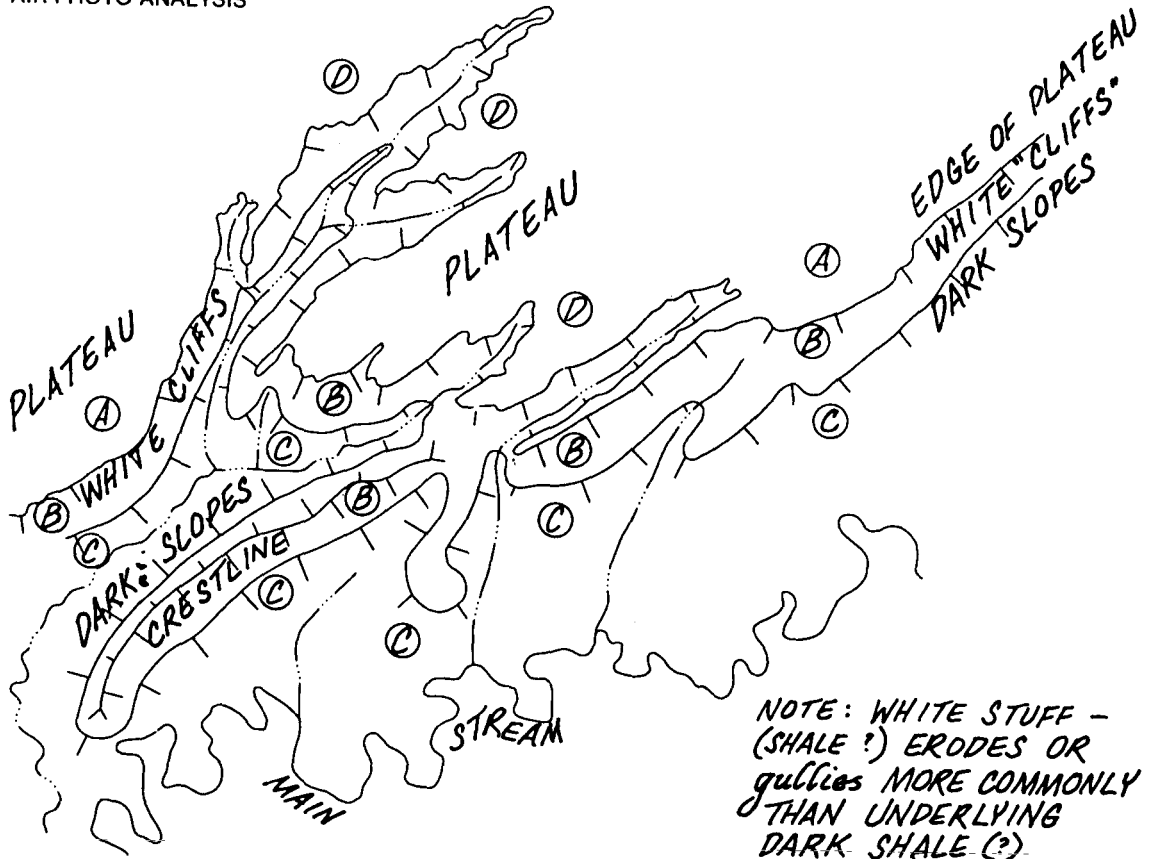
When preparing the above two overlays, the analyst should also have observed such terrain characteristics as the shapes of gully cross-sections and changes in slope. When criteria such as these are defined, they add to the data derived above to make identification of rock type easier. The shapes of gully cross-sections will provide much information on the unconsolidated material overlying bedrock. The V-shaped gulleys with short, steep gradients will be formed in well-drained, granular, noncohesive soils. Broad, U-shaped gulleys with long, shallow gradients will occur in plastic, cohesive poorly-drained soils. These shapes can also provide information as to composition of the underlying bedrock because the unconsolidated material is often locally derived. A U-shaped gully may therefore suggest that nearby bedrock is shale, and when coupled with the identification of a fine, dendritic drainage pattern, further weight is given to this interpretation. Changes in slope usually indicate that two or more rock types occur in that area. In arid climates, for instance, sandstone and limestone will form near-vertical cliffs, where as shale will form gentler, less steep slopes.

The illustrations that follow suggest some of the ways by which you can interpret photos for indicators of the probable rock types (Igneous, Sedimentary, Unconsolidated), structures (faults, joints), or of problems that may affect engineering decisions (high water tables, slope stability).

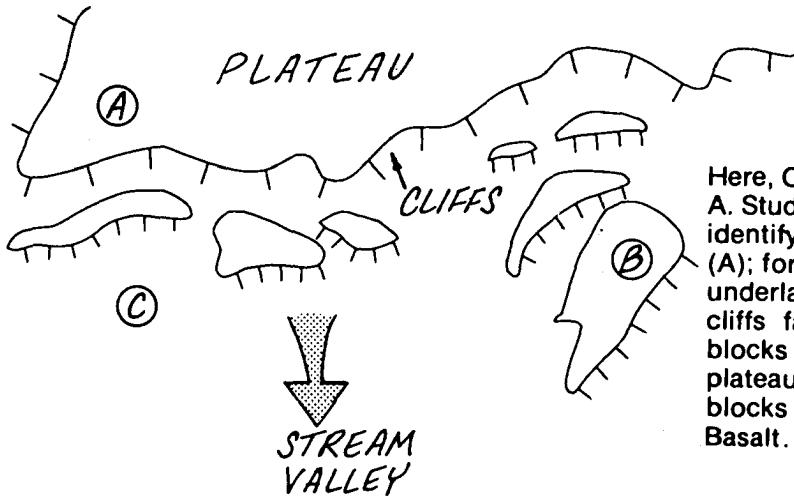
Although this section stresses the use of photos in terrain analysis, it also shows how useful the basic topographic map is for air photo analysis. Obviously, where a change in soil or rock color occurs, maps cannot reflect this, nor can you expect the map to show fallen cliff rocks (indicative of basalt). Nevertheless, the topographic map, used to supplement your analysis of aerial photography, can reveal (or support) terrain subtleties that can be masked by dense cultural patterns, thick woods, or urban sprawl. The point is that in the real world of terrain analysis the analyst uses every means of terrain representation available - map, photo, radar imagery, etc. - to define the physical environment of the area to be mapped.

The main tool you will have to do this work will be black and white aerial photography at scales between 1:20,000 and 1:80,000. Examples P5-2 through P5-10 and the air photo identification keys, P5-11 through P5-40 have been provided to aid in the identification of landform and rock type.

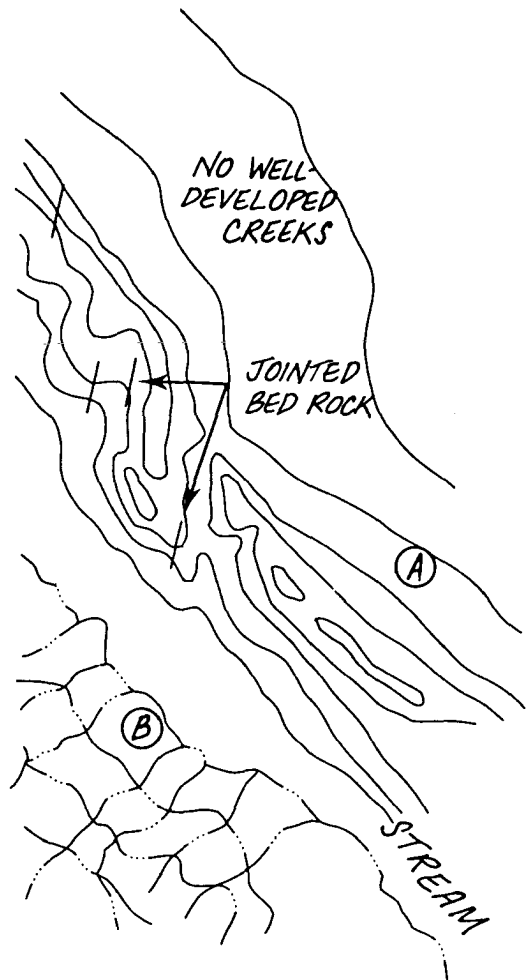
AIR PHOTO ANALYSIS



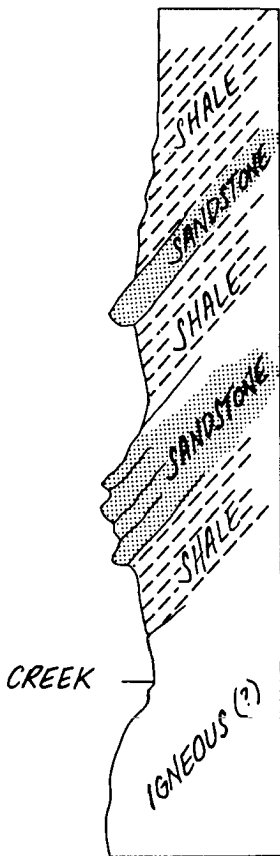
Example of Soft Rocks terrain. The plateau (A) is underlain by a light or white-colored rock that erodes differently from a darker rock below. The analyst, on basis of the difference in erosion patterns and color, identifies (B) and (C). The deep gulleying with scalloped edges along the cliffline (D) suggests soft rocks, probable Shale.



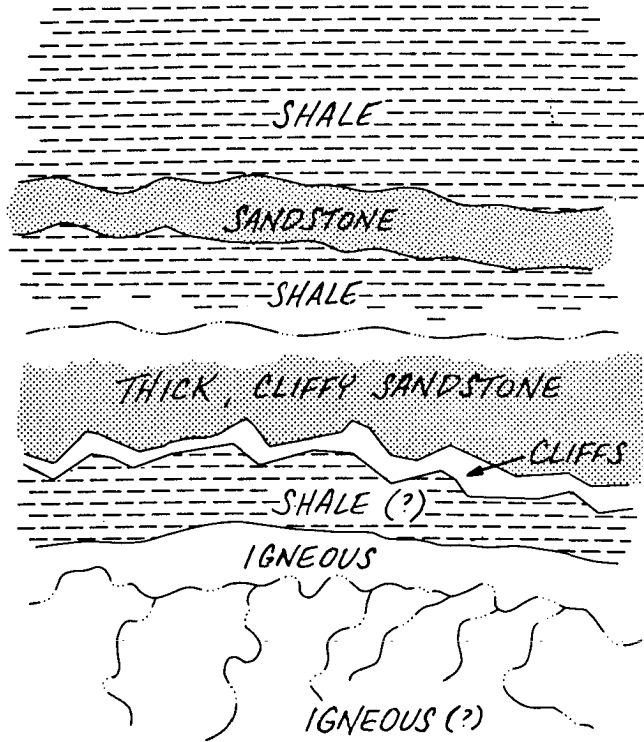
Here, C is a rock type different from A. Study of drainage patterns could identify it. Example of Basalt terrain (A); forms flat surface or plateau. If underlain by softer rocks, Basalt cliffs fail and create giant slump blocks (B). The levelness of the plateau and the presence of slump blocks at foot of cliffs indicate Basalt.



Example of Granite (A) terrain. Maps show smooth topography and photos will show white areas. Bedrock joints usually evident. Sparsely settled area with very poor drainage. Note the dense drainage at B; a different rock type is indicated by this drainage.



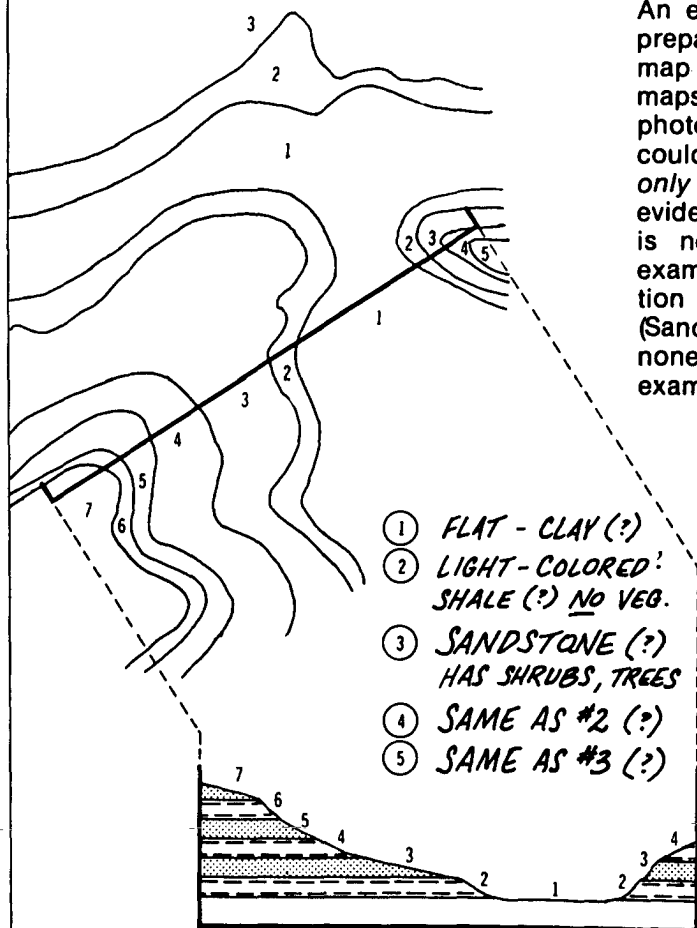
VERY POOR SURFACE DRAINAGE
(WATER STANDS ON SURFACE)



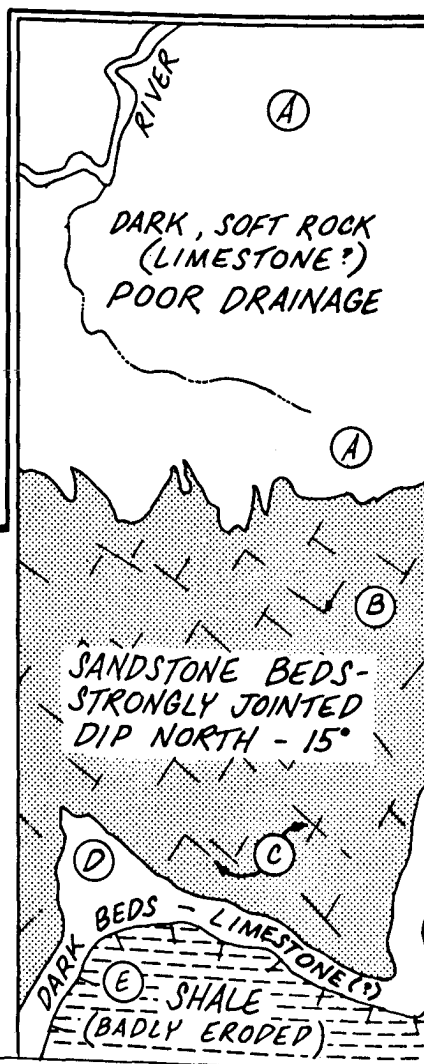
NOTE: SPURS OR CRESTS IN THIS AREA
ARE ROUNDED (SOFT). ROCKS HAVE
FAINT SHEEN IN PHOTOS. (SCHISTS)

Example of area underlain by hard and soft Sedimentary rocks (Sandstone, Shale) and probable igneous rocks. Analyst noted rocks at bottom had rounded slopes and a faint shine or sheen (from shiny rock minerals; probably schists but lumped with igneous rocks). A useful tool is to make a simple not-to-scale geologic cross section sketch to suggest the hard and soft types of rocks in the area.

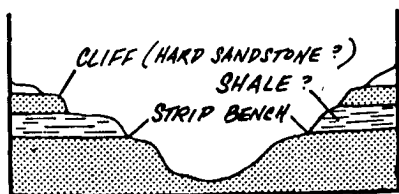
AIR PHOTO ANALYSIS



An example of an analyst's initial preparation of a geological sketch map based either on topographic maps with aerial photos or with photos only. (The topographic map could be used without the photos only if the rock types (beds) are evident from the contour lines; this is not commonly seen). In this example, note the analyst's recognition of vegetation and rock type (Sandstone has shrubs, Shale has none). This is the key for this example.

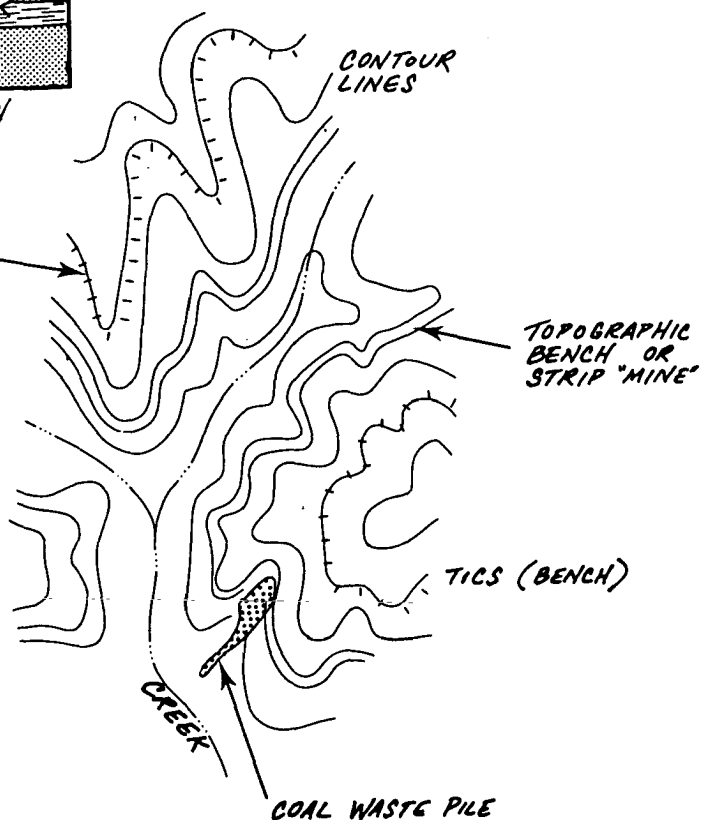


Example to right shows top beds of Limestone (A) overlying a thick Sandstone beds (B). Beneath these lies a probable Limestone (D) and a badly eroded Shale (E). The Sandstone is strongly jointed (C). These beds are estimated to be dipping North at 15°. The analyst, to get the above distinctions between rock types had to use photos. However, a topographic map with contour lines that weren't too widely spaced (vertical relief) might have suggested some of the rock types differences.

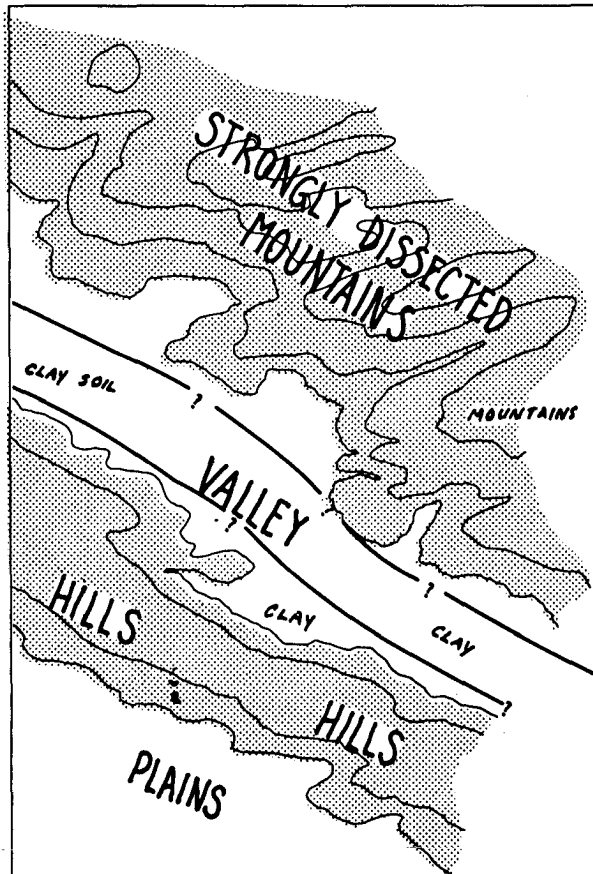


GENERALIZED SECTION

TICS ADDED TO
SKETCH BY ANALYST
TO SHOW
TOPOGRAPHIC BENCH

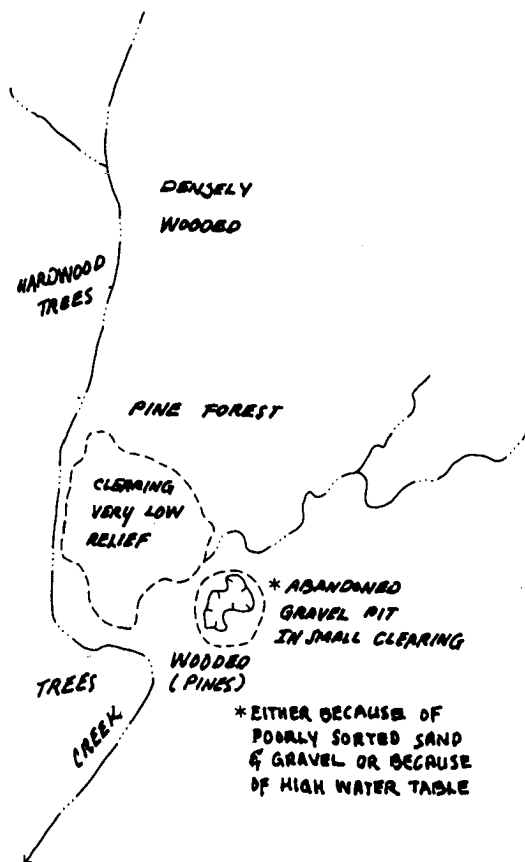


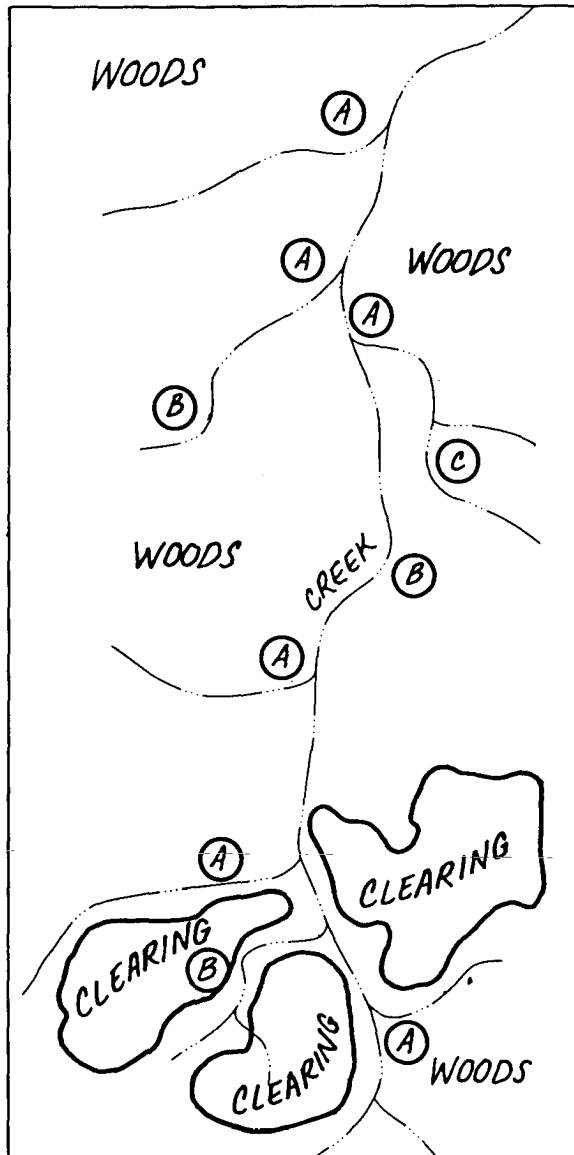
An example of Terrain Analysis in coal-bearing rocks. The levelness of the strip "mine" bench suggests the rocks are flat-lying. The analyst, using aerial photos spotted a higher topographic bench; marked by tics onto base map. This bench probably underlain by hard Sandstone. Between Sandstone beds (which form topo benches) are softer rocks like Shale. Analyst spotted coal waste pile, this suggested an underground coal mine entrance nearby. He concluded the coal bed was both stripped and mined.



Example of faults in valley. The analyst noted the linear trend of the valley; he could trace faint topographic or soil differences that indicated possible surface faults. On the ground these traces can't be easily detected; their linear expression in photos is the key.

Example of Terrain Analysis in heavily wooded area. Linear aspect of main creek suggests good drainage (sand). Small quarry pit suggests sand and gravel bed. Clearing may suggest other sand and gravel beds in the area. The winding nature of smaller creeks suggests clay areas also occur.



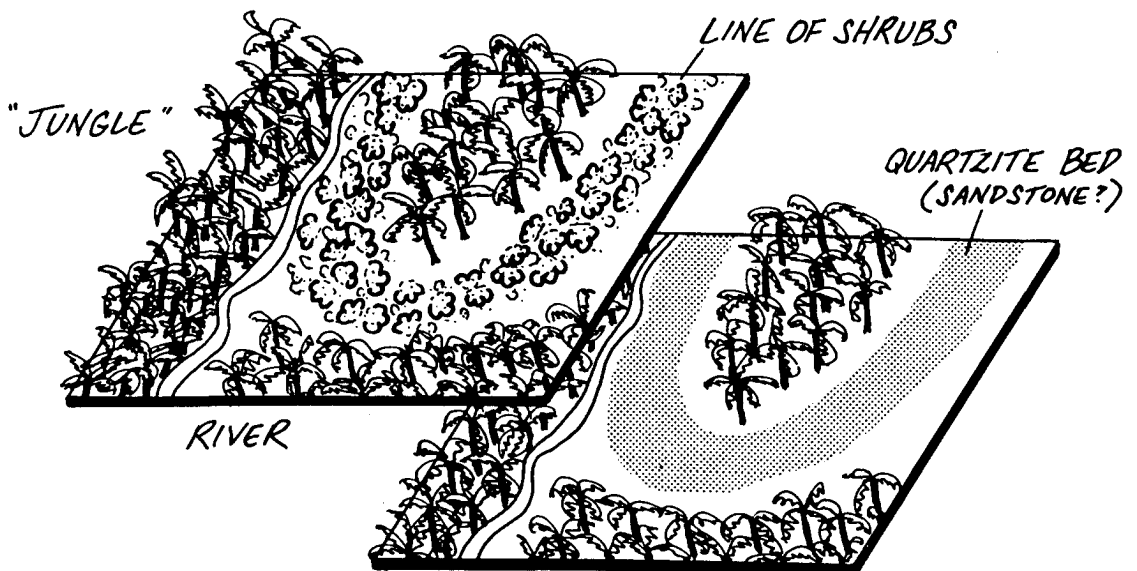


An example of Geology Analysis in heavily wooded terrain where outcrops of bedrock are not evident in photos. The cleared areas have very low relief. The only terrain feature the analyst can use is the drainage. First, there are very few minor tributaries (A) or smaller creeks; this means good drainage in the area (which is a temperate zone), or medium-to coarse-grained soils. These suggest bedrock is Sandstone or Granite. The blocky or angular aspect (B) of the area creeks suggests strong bedrock joints are present; bedrock joints in an area of relatively few creeks suggests Granite. At (C) the analyst notes a common trend for creeks in Granite bedrock, a curved juncture of two creeks. Conclusion: Granite bedrock.

Vegetation & Rocks —

Terrain analysts can often map a particular rock type by recognizing (in photos) a type of tree, shrub, or agricultural/land use pattern that is confined to that rock type.

In the tropic and near tropic zones Quartzite (a very hard Sandstone) beds often are relatively barren areas. Inspection of photos over Quartzite areas can reveal the presence of a shrub that grows on Quartzite soils and rocks.



Another Example of Vegetation & Rocks —
Cedar trees commonly grow well in soil derived from Limestone rocks.



CONTOUR

LINE OR BELT OF CEDAR TREES

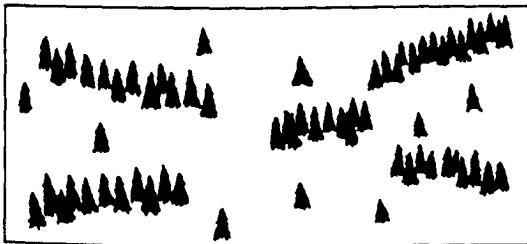
CONTOUR

ANALYST CONCLUDES THE SOILS ARE
PROBABLY FROM UNDERLYING BEDS.
HE/SHE MAPS THE LINE OR BELT AS
"PROBABLE LIMESTONE".

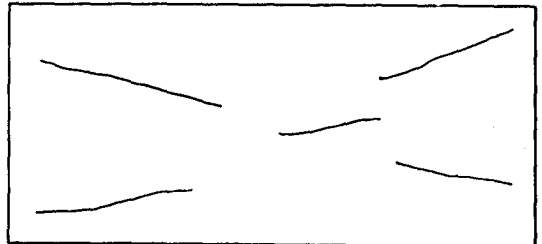
The point? Look for vegetation that follows a pattern or that suggests a pattern which may be an indicator of a specific soil or rock.

Vegetation can also indicate rock structure. Fissured rock usually holds more moisture. Tree or shrub roots seek that water. Thus, vegetation can follow the bedrock joints, faults or contacts between different rocks.

GRANITE



PROBABLE BEDROCK JOINTS



AERIAL PHOTO KEY P5-11

INDICATOR: Mountain, volcano, broad rounded

INDICATES: Shield volcano

1. EXAMPLE LOCATION: Newberry Crater, Deschutes Co., Oregon
2. EXAMPLE CLIMATE (Trewartha, 1957): Undifferentiated highlands (H)
3. COMMENTS: This very low, rounded profile, a., is characteristic of a shield volcano. A shield volcano is formed of multiple flows of fluid basaltic lavas. The diameter is measured in tens of kilometers. The lumps on the profile are remnants of parasitic cinder cones, and indicate this is an old shield volcano. Convex slopes are typical.
4. VERIFICATION: Personal communication, Howell Williams, Professor Emeritus, University of California at Berkeley; and Judy Ehlen at this location.

5. <u>PATTERN IDENTIFIABLE BY:</u>	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	?	?
d. IR Thermal		X
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	?	?

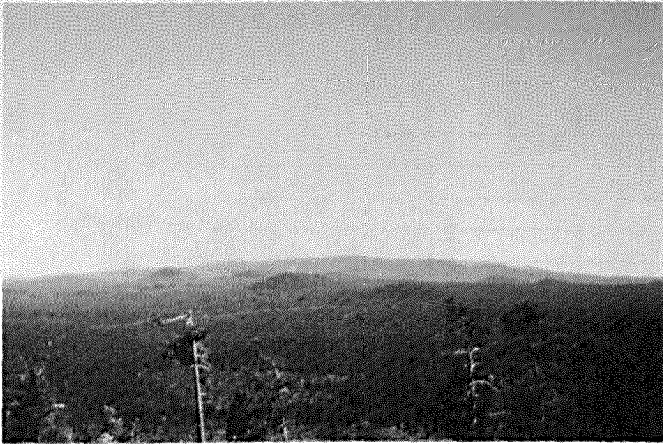
6. PHOTO CREDITS:
 - a. Judy Ehlen, USAETL
 - b. Judy Ehlen, USAETL
7. COMPILER: Judy Ehlen, USAETL
8. DATE: 23 March 1978

ENGINEERING CHARACTERISTICS AND PROBLEMS:

1. Excavation is difficult due to rock hardness.
2. Source of engineering materials.
3. Vertical variation in material type must be taken into consideration.
4. Surface roughness may hinder mobility.



- a. The profile of a strato volcano: the diameter is much greater than than the apparent height.



- b. Most of Newberry Volcano forms the horizon. The cinder cones in the foreground occur along a large rift or vent, through which more recent volcanic material has been extruded.

AERIAL PHOTO KEY P5-12

INDICATOR: Hill, truncated cone

INDICATES: Cinder cone (effusive volcanism)

1. EXAMPLE LOCATION: Twentynine Palms Military Reservation,
San Bernadino Co., California

2. EXAMPLE CLIMATE (Trewartha, 1957): Tropical and subtropical
desert (BWh)

3. COMMENTS: The shape of a cinder cone is that of a truncated cone. The truncation is caused by the crater at the top. Cinder cones are formed of cinders, ash, and other ejecta which have erupted from the crater. Because they are formed of fine, particulate material, the photo texture is usually fine. Flow material extrudes only from the lower sides and base. When heavily vegetated, many cinder cone characteristics cannot be seen; the distinctive conical shape, however, remains as a key to identification.

4. VERIFICATION: Judy Ehlen at this location, Lava Butte, Jordan Craters, and Wizard Island in Crater Lake, Oregon.

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	L	
d. IR Thermal		X
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	X	

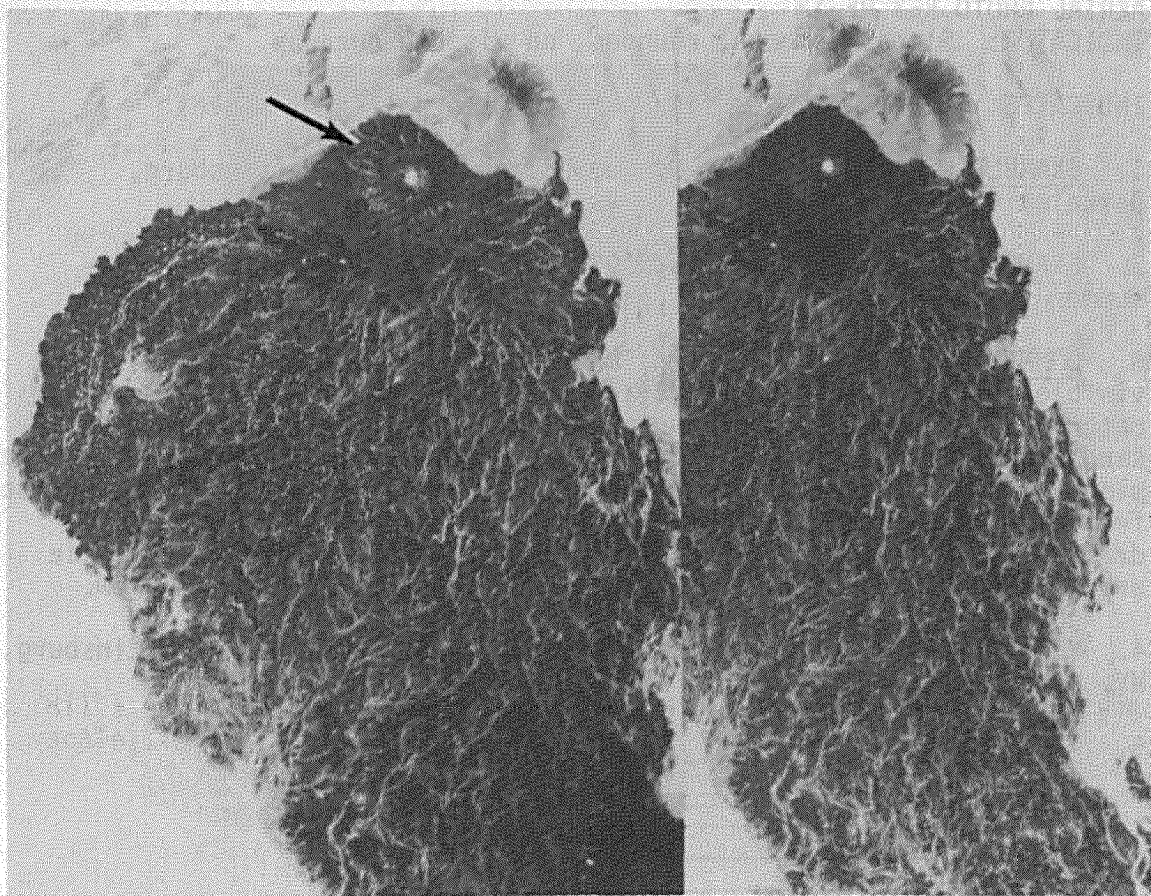
6. PHOTO CREDITS: Oregon National Guard, 1977

7. COMPILER: Judy Ehlen, USAETL

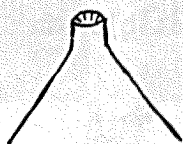
8. DATE: 27 March 1978

ENGINEERING CHARACTERISTICS AND PROBLEMS:

1. Cinder cones make a good source of engineering materials, including aggregates.
2. Slopes are unstable--unloading at the toe causes instability.
3. Steep slopes hinder mobility.



Profile showing
composite slope.



This cinder cone (arrow) has a somewhat unusual profile (see below) which suggests it is actually two cinder cones, a younger one built directly above an older one. This in turn indicates two phases of volcanism. The well-developed drainage on the cinder cone and lava flow area indicate this is a fairly old complex.

AERIAL PHOTO KEY P5-13

INDICATOR: Slopes, smooth, rounded, no visible outcrop

INDICATES: Easily-eroded, fine-grained material (e.g. shale)

1. EXAMPLE LOCATION: Along Opequon Creek, east of Martinsburg, Berkeley Co., West Virginia

2. EXAMPLE CLIMATE (Trewartha, 1957): Humid subtropical, warm summer (Caf)

3. COMMENTS: In a temperate climate, smooth, rounded slopes with no visible outcrop are characteristic of easily eroded, fine-grained material. This pattern occurs on unconsolidated material, including sand dunes, and on various rock types. Characteristics such as drainage, slope, and hill shape, allow different material types to be distinguished from each other. In areas underlain by shale, such as this example, drainage is dendritic and of medium to high density. Slopes in shale are gentle and the hills are rounded both in profile and plan view.

4. VERIFICATION: Personal observation by CRS staff in the Martinsburg, WV, area.

5. <u>PATTERN IDENTIFIABLE BY:</u>	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	L	
d. IR Thermal	?	
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing		X

6. LIMITATIONS:

a. Emulsion/Filter: None

b. Scale: Should be compatible with element size.

c. Season: None

d. Other: None

7. PHOTO CREDITS:

a. USAETL, Mbg 1-4, 1-5, June 1976

b. Alan E. Krusinger, USAETL

8. COMPILER: Judy Ehlen, USAETL

9. DATE: 21 April 1978



a. Hills underlain by shale. Note the smooth, rounded contours. Original scale 1:5,000.



b. Ground stereopair of shale slopes slightly west of a. above.

AERIAL PHOTO KEY P5-14

INDICATOR: Solution cavities
Collapse features

INDICATES: Limestone, massive beds, subsurface solutioning, humid climate (at least during formation).

1. EXAMPLE LOCATION: Puerto Rico, 17.5 km (11 miles) SW of Arecibo on the Río Camuy. 18°21'00" N and 66°49'06" W

2. EXAMPLE CLIMATE (Trewartha, 1957): Tropical Rainforest (Am)

3. COMMENTS: (Universal Indicator) The sink marked Tres Pueblos, the worm-like valley to the right of it, the sink marked Empalme, and the deep sink above that, were subsurface solution cavities that enlarged to such an extent that the resulting roofs could no longer support themselves. Limestone is mostly calcium carbonate (CaCO_3), a material that is somewhat soluble in slightly acid water. These are caused by the gradual dissolution of limestone by the acidic ground water trickling through the various fractures within the rock. The more humid the climate the more rapid the dissolution of the limestone. The abruptness of the edges, the steep sides, the exposure of fracture or joint faces, the intersection of lineations or fractures, the presence of the rubble at the bottom, are all associated with collapse features. In the stereo of Tres Pueblos at least two wall sections seem to be exposed faces of fracture planes (b). In the oblique photo of Empalme sink, the hole is a relatively small collapse section of the roof (c). The sink becomes much wider beneath the hole. Tres Pueblos is about 600 feet (180m) in diameter, and about 500 feet (150m) in depth. Such large collapse, or solution, features require very thick beds of limestone that have been exposed to chemical weathering in a hot, humid climate for thousands of years.

4. VERIFICATION:

a. Literature: Exists as common knowledge in geology and related fields; e.g. Lobeck (1939), Rinker (1974), and Monroe (1976).

(1) Lobeck, A. K., Geomorphology. McGraw-Hill Book Co., 1939.

(2) Rinker, J. N., An Application of Air Photo Analysis to a Cave Location Study, Proceedings of American Society of Photogrammetry, March 1974.

(3) Monroe, W., The Karst Landforms of Puerto Rico, Geological Survey Professional Paper 899. Superintendent of Documents, U.S. Government Printing Office, Washington, D. C. 20402, 1976.

b. Other: Field checked by J. N. Rinker, USAETL, and Watson Monore, USGS.

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	L	
d. IR Thermal		X
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	L	

6. LIMITATIONS:

- a. Emulsion/Filter: None
- b. Scale: Scale must be compatible with size of feature. Sinks the size of Tres Pueblos can be identified at 1:50,000.
- c. Season: None
- d. Other: None

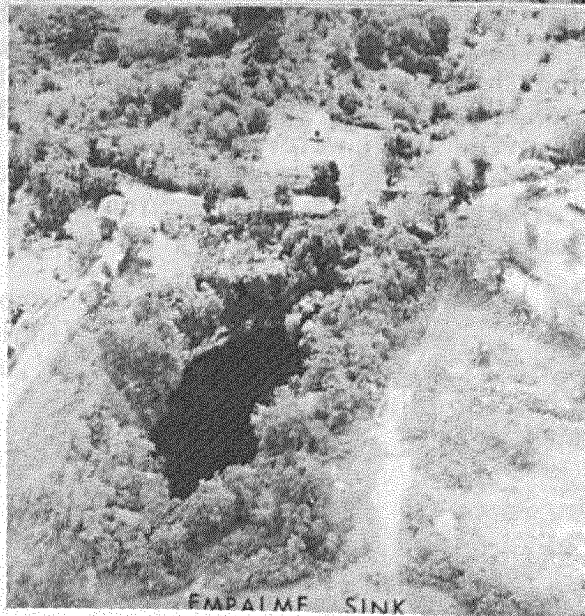
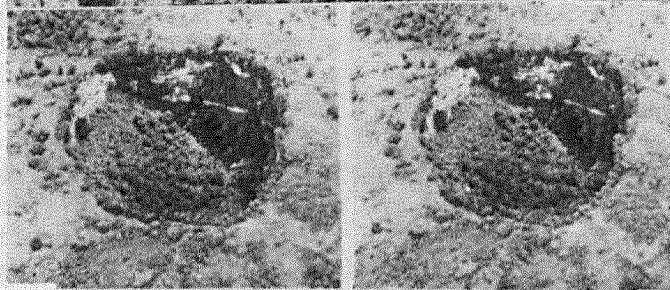
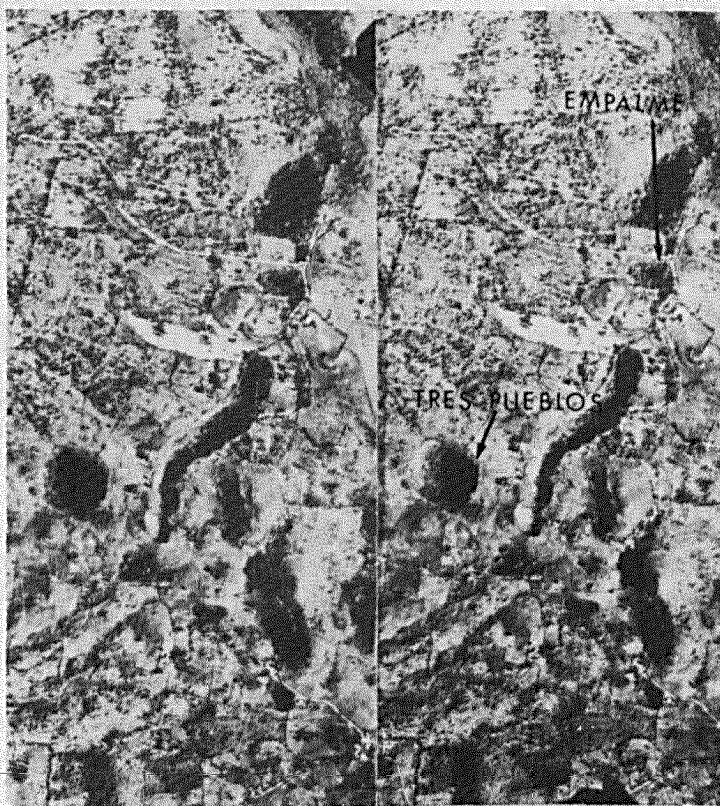
7. PHOTO CREDITS:

- a. Vertical stereo: USGS, 1951, 1:15,000
- b. Oblique stereo: Dave Atwood, USACRREL, Hanover, NH
- c. Oblique: Dave Atwood, USACRREL, Hanover, NH

8. COMPILER: Jack N. Rinker, USAETL

9. DATE: 21 April 1978

ENGINEERING CHARACTERISTICS AND PROBLEMS: In this type of region, where erosion is severe, cross-country movement can be difficult on foot, and impossible by vehicle. With reference to construction the problems are associated with (1) extensive rock cuts, (2) variable subgrade conditions, (3) the presence of unknown subsurface voids, and (4) the presence of fractures, or joints. Depending on the outcome of field evaluation the limestone itself can be a potential source of aggregate, and of raw material for the making of cement. Wells are frequently drilled to provide local water needs, and with such an unknown and interconnected subsurface plumbing system of caves and tunnels it is quite possible to contaminate a source by an action that, on the surface at least, seems far removed.



AERIAL PHOTO KEY P5-15

INDICATOR: Hill, truncated cone

INDICATES: Cinder cone (effusive volcanism)

1. EXAMPLE LOCATION: Cerro Negro, Nicaragua

2. EXAMPLE CLIMATE (Trewartha, 1957): Undifferentiated highlands (H)

3. COMMENTS: The shape of a cinder cone is that of a truncated cone. The truncation is caused by the crater at the top. Cinder cones are formed of cinders, ash, and other ejecta which have erupted from the crater. Because they are formed of fine, particulate material, the photo texture is usually fine. Photo tone is uniform. Flow material extrudes only from the lower sides and base. When heavily vegetated, many cinder cone characteristics cannot be seen; the distinctive conical shape, however, remains as a key to identification.

4. VERIFICATION: Personal observation at Lava Butte, Jordan Craters, and Wizard Island In Crater Lake, Oregon

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	L	
d. IR Thermal		L
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	X	

6. LIMITATIONS: Radar can have difficulty in near field.

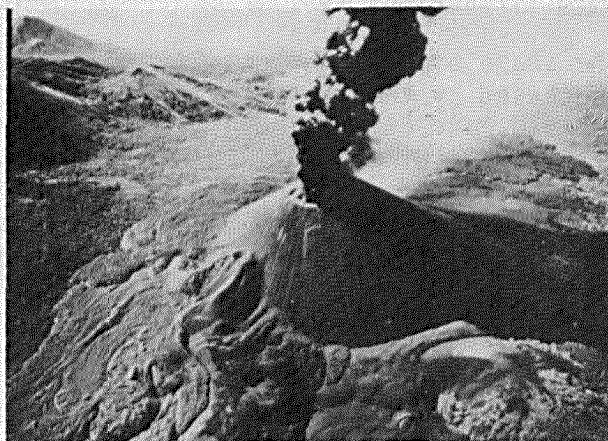
7. PHOTO CREDITS: American Geological Institute

8. COMPILER: Judy Ehlen, USAETL

9. DATE: 8 June 1978

ENGINEERING CHARACTERISTICS AND PROBLEMS:

1. Cinder cones are a good source of engineering materials, including aggregate.
2. Slopes are unstable; unloading at the toe causes instability.
3. Steep slopes hinder mobility.



Note the fine texture and the shape of the cone and that flow material extrudes only from the lower slopes on the left.

AERIAL PHOTO KEY P5-16

INDICATOR: Plain, pockmarked
Plain, sinkhole studded

INDICATES: Limestone (youthful stage)

1. EXAMPLE LOCATION: Lawrence Co., Indiana

2. EXAMPLE CLIMATE (Trewartha, 1957): Humid subtropical, warm summer (Caf)

3. COMMENTS: (Universal Indicator) This dimpled, or pockmarked plain, is characteristic of the type and extent of early, or youthful, land-form development that occurs in thick beds of limestone in a relatively humid region. The limestone, being slightly soluble in acidic ground water, is slowly dissolved away along the more important water channels, which are the various fractures, or joints, within the bedrock. These depressions, or sinkholes, begin to develop along fractures, and more especially at fracture intersections, for these locations are the most subject to solutioning and weathering. Surface water flows into the sinks and drains away internally through a myriad of interconnected subsurface channels of various size. When a channel, or the bottom of a sinkhole becomes clogged with sediment, that depression can become a pond. Thus, at any given time some of the sinks can be dry while others can have varying amounts of water in them. Most of the sinkholes in this illustration are circular, which suggests that the limestone beds do not dip strongly in any given direction. As the tilt of the bed increases, the sinkholes tend to become elongate.

The original photography was taken with a six inch lens, which causes a vertical exaggeration of about 2.5 times. In the stereo image, the terrain appears to be something over twice as rugged as it actually is.

4. VERIFICATION:

a. Literature:

(1) Lobeck, A. K., Geomorphology, McGraw-Hill, 1939.

(2) Thornbury, W. D., Principles of Geomorphology, 2nd Edition. John Wiley and Sons, Inc., 1969.

b. Other: Field verification by J. N. Rinker, USAETL, and R. E. Frost, USAETL

5. <u>PATTERN IDENTIFIABLE BY:</u>	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	L	
d. IR Thermal	L	
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	X	

6. LIMITATIONS: Similar terrain has been identified at scales as small as 1:100,000

7. PHOTO CREDITS: U.S. Dept. of Agriculture, ASCS, QY-2HH-91, 92, 93, 21 Oct 1967, original scale 1:20,000. Scale of this reduction is about 1:57,400.

8. COMPILER: J. N. Rinker, USAETL

9. DATE: 8 June 1978

ENGINEERING CHARACTERISTICS AND PROBLEMS: The engineering problems are associated with rock cuts and fills, changing subgrade conditions, and the presence of unknown subsurface voids that could collapse. This latter problem is more important in maturer terrains. For a large structure, or roadway, it may not be possible to avoid all of the sinkholes, and hence the need for cuts, extensive filling or even capping of the sinks. A drilling program may be needed to evaluate subsurface conditions, e.g. extent of voids, in critical areas. The soil mantle is formed by the accumulation of material left behind as the limestone is dissolved away. Thus, subgrade conditions can vary from that of bedrock to a deep residual soil; commonly some arrangement of silt and clay. These soils are usually well drained internally until their structure is destroyed by compaction, at which time they become poorly drained. Pumping can be severe. Depending on the outcome of field evaluation, the limestone can be a source of dimension stone, aggregate, or raw material for the making of cement. The intricate subsurface interconnection of the sinkholes also provides a means for the inadvertent contamination of water points.

AERIAL PHOTO KEY P5-17

INDICATOR: Plain, deeply pitted Karst topography

INDICATES: Limestone, massive beds (mature stage)

1. EXAMPLE LOCATION: Arecibo River, south of Arecibo, Puerto Rico

2. EXAMPLE CLIMATE (Trewartha, 1957): Humid subtropical, warm summer (Caf)

3. COMMENTS: This deeply eroded plain is characteristic of the type of mature landform that develops in thick beds of limestone in a relatively humid region. Because other materials can develop deep erosional scours, one must consider the pattern elements associated with drainage and erosion before forming a conclusion. In this example, the presence of sinkholes and solution valleys and the shapes of the hills and ridges are more suggestive of limestone than of any other material. The limestone, which is slightly soluble in acidic water, has been dissolved away along fractures in the rock. Because fracture intersections are more subject to solutioning and weathering, sinkholes tend to develop there and form most of the drains down which water flows into the subsurface network of channels. In this area, the relief between the tops of the hills and the bottoms of the sinkholes is something over 400 feet (122m). In places sinkholes have coalesced to form solution valleys. In this instance, the limestone hills and ridges are aligned in such a way that the overall pattern resembles a series of large ripple marks, or dunes.

Traces of some of the fractures responsible for setting the erosional pattern are visible throughout the image. One that stands out is along the east wall of the Arecibo River valley in the left-hand stereopair (north is at the top of the illustration). It trends NNW and, in places, forms vertical portions of the valley wall. Other fractures trend near perpendicular to this example, crossing the river valley and heading ENE. A trace of one of this set extends WSW and ENE from the dam/land juncture in the NW corner of the reservoir. Others of this set account for the ENE trending sections of the river channel.

4. VERIFICATION:

a. Literature: Exists as common knowledge in geology and related fields; e.g. Lobeck (1939), Thornbury (1969), and Monroe (1976).

(1) Lobeck, A. K., Geomorphology, McGraw-Hill Book Co., 1939.

(2) Thornbury, W. D., Principles of Geomorphology, 2nd edition, John Wiley and Sons, Inc., 1969.

(3) Monroe, W., The Karst Landforms of Puerto Rico, U.S. Geological Survey Professional Paper 899, 1976.

b. Other: Field verification by J. N. Rinker, USAETL

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	X	
d. IR Thermal	L	
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	L	

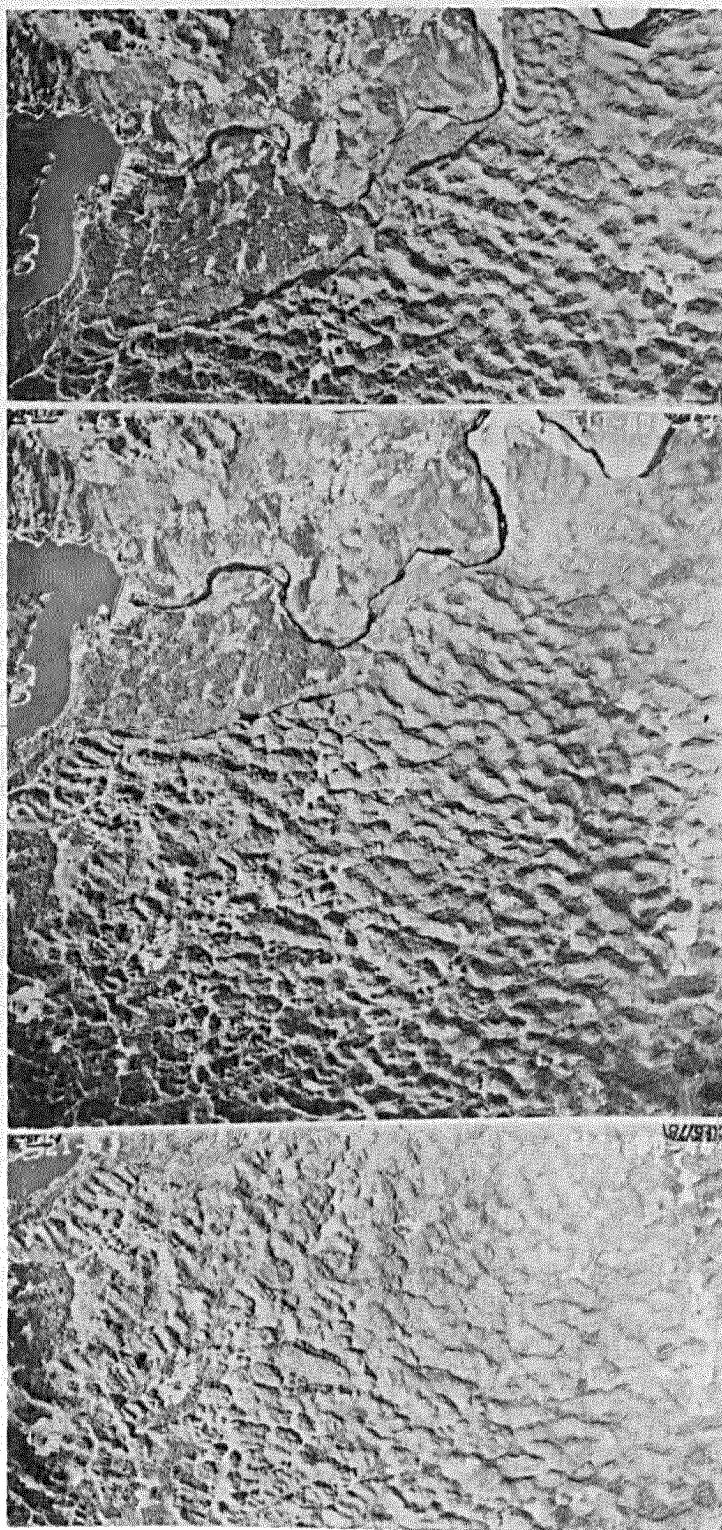
6. LIMITATIONS: Should be compatible with size of sinks. This landform type readily identifiable at 1:100,000. The ripple like pattern in Puerto Rico has been noted in Landsat imagery (scale 1:500,000).

7. PHOTO CREDITS: U.S. Geological Survey, ELT-8DD-44, 45, and 46, 21 March 1963. Original scale 1:20,000. Scale of this reduction is about 1:57,400.

8. COMPILER: Jack N. Rinker, USAETL

9. DATE: 30 June 1978

ENGINEERING CHARACTERISTICS AND PROBLEMS: Cross-country mobility in this type of karst region is impossible by vehicle, and difficult by foot. For construction activities, such as roads, the engineering problems are associated with large rock cuts and fills. Chances of encountering large unknown subsurface solution cavities are not as great as in a less mature stage, because most of them will have collapsed by this stage of limestone development. Fractures, sinkhole alignments, and probable avenues of subsurface drainage should be evaluated prior to empoundment of water by dam construction. Depending on the outcome of final evaluation, the limestone can be a source of aggregate or raw materials for the making of cement.



AERIAL PHOTO KEY P5-18

INDICATOR: Discontinuous drainage pattern

INDICATES: Limestone

1. EXAMPLE LOCATION: Lawrence Co., Indiana

2. EXAMPLE CLIMATE (Trewartha, 1957): Humid subtropical, warm summer (Caf)

3. COMMENTS: This highly segmented and interrupted drainage pattern is typical of that which develops in thick beds of limestone in the youthful stage of the erosion cycle. Because limestone is an impervious material, water flows over the surface and enters the interior of it through fractures. Bowl-shaped depressions, or sinkholes, tend to form by solution along fractures and at fracture intersections, and once developed, become the route through which water enters the interior. Some of the sinkholes can become clogged so that they drain slowly or not at all. Thus, at any given instant, some sinks can be dry while others can contain water. In the drainage fact that most of the sinks in this example are approximately circular suggests that the limestone bed is nearly level. A discontinuous drainage pattern can develop in other materials, e.g. in dolomite or in permafrost, but is most commonly developed in limestone terrain. Discontinuous drainage in limestone is often called swallow-hole or sinkhole drainage.

4. VERIFICATION:

a. Literature: Exists as common knowledge in geology and related fields.

b. Other: Field verification by J. N. Rinker, USAETL, and R. E. Frost, USAETL.

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	L	
d. IR Thermal	L	
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	L	

6. LIMITATIONS: Although such patterns have been mapped at scales as small as 1:100,000, it is difficult to map the fine detail on scales as small as 1:30,000.

7. PHOTO CREDITS:

a. U.S. Dept. of Agriculture, ASCS, QY-2HH-92, 21 Oct 1967. Original scale 1:20,000. Scale of this reduction is about 1:38,000.

b. Drainage map by Judy Ehlen, USAETL.

8. COMPILER: Jack N. Rinker and Judy Ehlen, USAETL

9. DATE: 30 June 1978



a. Aerial photo showing youthful limestone terrain.



- b. Drainage map of above aerial photo showing discontinuous drainage pattern.

AERIAL PHOTO KEY P5-19

INDICATOR: Contour banding (natural)

INDICATES: Flat-lying sedimentary rocks

1. EXAMPLE LOCATION: Hays Co., Texas

2. EXAMPLE CLIMATE (Trewartha, 1957): Middle latitude steppe (BSk)

3. COMMENTS: The bedding or layers of flat-lying or nearly flat-lying sedimentary rocks can produce obvious banding or contouring on hillsides. In aerial photo, the pattern resembles contour lines on a topographic map, with each band circling the hill at a constant elevation. The natural banding pattern can be emphasized by: different types of vegetation, different amounts of vegetation, differences in slope caused by differential erosion, or differences in tone and color caused by differences in material type. The bedding of flat-lying sedimentary rocks is more obvious in arid or semiarid climates. If the strata are uniformly thin, the hill slopes tend to appear smooth and uniform. If the sequence is thickly bedded, a stair-step pattern can be seen. Natural banding also occurs in basaltic areas. However, this can be distinguished from that in sedimentary rocks by flow marks and sharp, jagged cliffs associated with basaltic terrain.

4. VERIFICATION:

a. Literature: Ta Liang, R. B. Costello, G. J. Fallon, R. J. Hodge, H. C. Ladenheim, D. R. Lueder, and J. D. Mollar. A Photo-Analysis Key for the Determination of Ground Conditions, Landform Reports, Vol. II, Sedimentary Rocks, U.S. Naval Photographic Interpretation Center, Technical Report 3, 1951.

b. Other: Field observation by CRS staff members at Ft. Bliss, Texas, and in Hays and Blanco Cos., Texas.

5. PATTERN IDENTIFIABLE BY: YES NO

- | | | |
|--------------------------|---|--|
| a. Ground Recon. | X | |
| b. Low Alt. Recon. | X | |
| c. Radar | X | |
| d. IR Thermal | L | |
| e. Vert. Aerial Photog. | X | |
| (1) Stereoscopic Viewing | X | |
| (2) Monoscopic Viewing | X | |

6. PHOTO CREDITS:

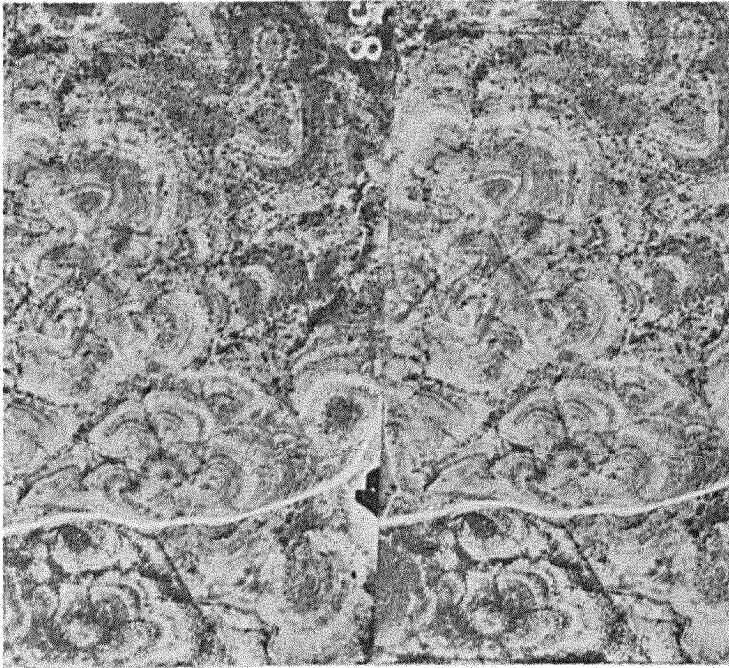
a. U.S. Dept. of Agriculture, ASCS, 1958, DMG-3V-235, 236, and 237

b. Melvin B. Satterwhite, USAETL, 1976

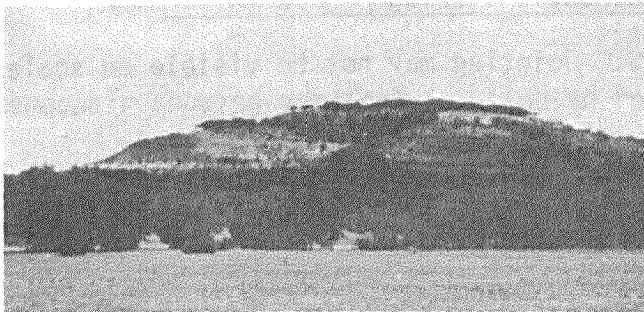
7. COMPILER: J. Ponder Henley, USAETL

8. DATE: 30 June 1978

ENGINEERING CHARACTERISTICS AND PROBLEMS: These soils will generally be shallow with rock fragments. Because of the rugged topography, road or airfield construction will involve a great detail of rock excavation. Limestone and sandstone can provide possible sources of aggregate and gravel and borrow material will be scarce. Leakage can occur through sandstone or through fractures in thick beds of limestone. Very little leakage will occur through shales.



a. Scale 1:20,000.



AERIAL PHOTO KEY P5-20

INDICATOR: Hill, lumpy surface, visibly jointed

INDICATES: Granitic rock

1. EXAMPLE LOCATION: Hueco Tanks, El Paso Co., Texas

2. EXAMPLE CLIMATE (Trewartha, 1957): Tropical and subtropical desert (BWh)

3. COMMENTS: Granitic rocks are characteristically rounded in any climatic region, but rounding is particularly prominent in arid climates, where mechanical weathering predominates. The rounded shape of the outcrop in profile is due to weathering along curvilinear sheeting joints. The smaller scale roundness, or lumpiness, on the surface of the outcrop is due to weathering along closely spaced vertical joints that break the outcrop into a series of blocks. If the vertical joints are widely spaced, a large, smooth dome will result (see Indicators 0027 and 0028). The closer the vertical joints are to each other, and the greater their number, the more blocky the surface of the outcrop will be (see Indicator 0025). These blocks weather to give a lumpy appearing surface. Because the spacing of the vertical joints is only moderately close, the weathered shape of each block or lump is smooth, rounded, and even. A later result of weathering on this type of granite outcrop will be an in-place pile of boulders.

4. VERIFICATION:

a. Literature: Twidale, C. R., Structural Landforms, landforms associated with granitic rocks, faults and folded strata. Cambridge: The MIT Press, 1971, pp. 59-71.

b. Other: Personal observation by Judy Ehlen in the Ft. Bliss, Texas, area and at Yuma Proving Ground, Arizona

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar		X
d. IR Thermal		X
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	X	

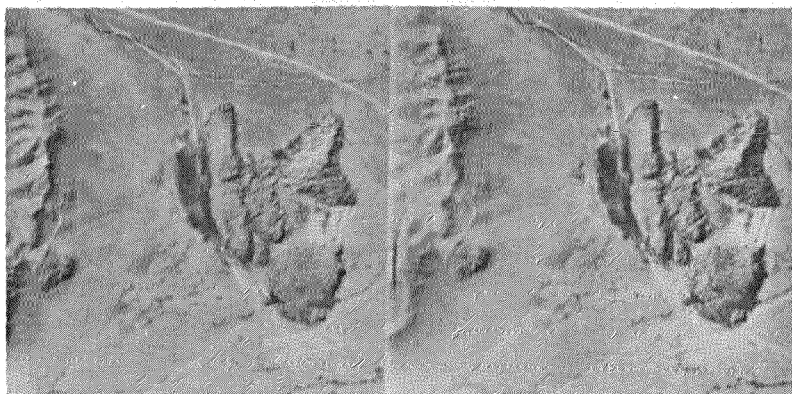
6. LIMITATIONS: Jointing may not be visible on scales smaller than 1:20,000.

7. PHOTO CREDITS:

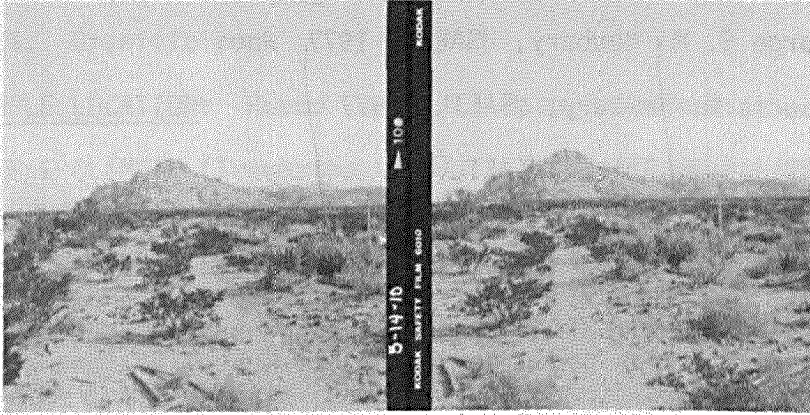
- a. U.S. Air Force, 69-35, frames 130 and 131, 1969-1971
- b. George E. M. Newbury, USAETL, 1977
- c. Claudia M. Newbury, USAETL, 1977

8. COMPILER: Judy Ehlen, USAETL

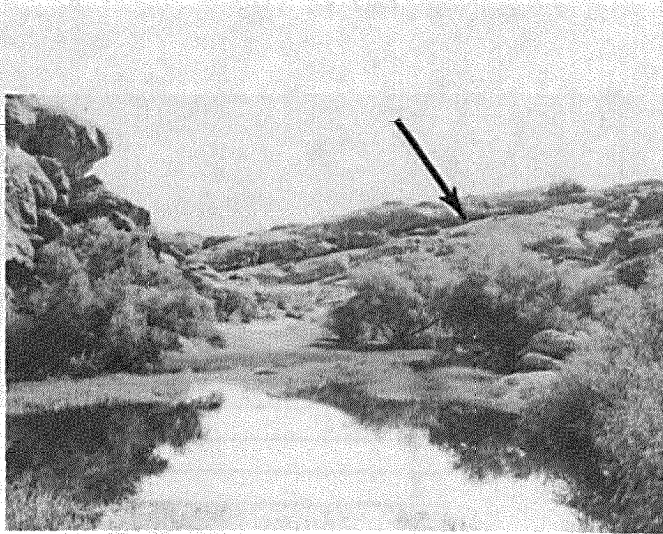
9. DATE: 4 August 1978



- a. Vertical stereopair showing vertical jointing in rounded granitic outcrops.



b. Ground stereo view showing the rounded shape of the outcrop in profile.



c. Ground view showing granite outcrops. Each block or lump is bounded by sheeting joints (arrow) at top and bottom and vertical joints on the sides.

AERIAL PHOTO KEY P5-21

INDICATOR: Hill, lumpy surface, visibly jointed

INDICATES: Granitic rock

1. EXAMPLE LOCATION: Laguna Mountains, Yuma Proving Ground, Yuma Co., Arizona

2. EXAMPLE CLIMATE (Trewartha, 1957): Tropical and subtropical desert (BWh)

3. COMMENTS: Granitic rocks are characteristically rounded in any climatic region, but rounding is particularly prominent in arid climates, where mechanical weathering predominates. The rounded shape of the outcrop in profile is due to weathering along curvilinear sheeting joints. The smaller scale roundness, or lumpiness, on the surface of the outcrop is due to weathering along closely spaced vertical joints that break the outcrop into a series of blocks. If the vertical joints are very widely spaced, a large, smooth dome will result (see Indicators 0027 and 0028). The closer the vertical joints are to each other, and the greater their number, the more blocky the surface of the outcrop will be. These blocks weather to give a lumpy-appearing surface. The size of the weathering product is probably due to a combination of joint spacing and grain size: the closer the joints, and the coarser the grain size as in this example, the more broken up will be the surface of the outcrop. Less coarse-grained granites tend to form rounded boulders (see Indicator 0024).

4. VERIFICATION:

a. Literature: Twidale, C. R., Structural Landforms, landforms associated with granitic rocks, faults and folded strata. Cambridge: The MIT Press, 1971, pp. 59-71.

b. Other: Personal observation by Judy Ehlen in the Ft. Bliss, Texas, area and at Yuma Proving Ground, Arizona

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar		X
d. IR Thermal		X
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	X	

6. LIMITATIONS: Jointing may not be visible on scales smaller than 1:20,000.

7. PHOTO CREDITS:

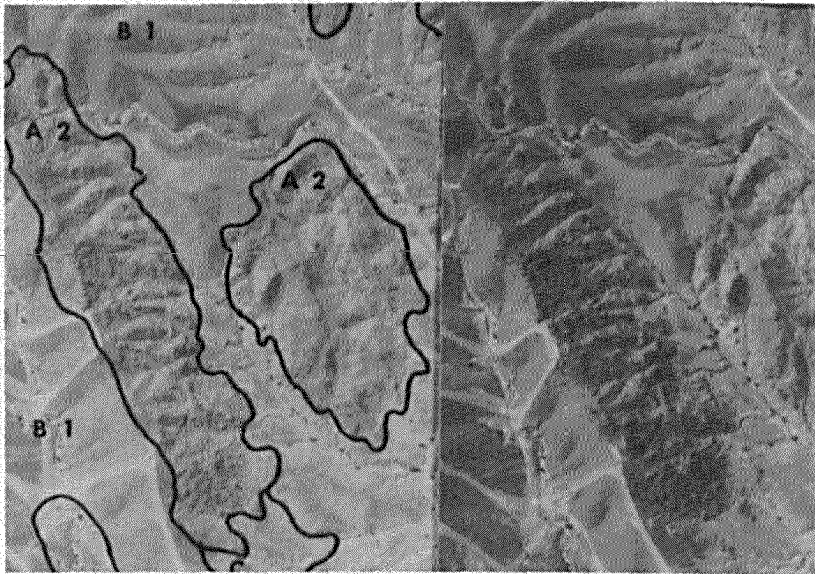
a. Source unknown, but available from Frank Barnett, USAETL

b. Judy Ehlen, USAETL, 1973

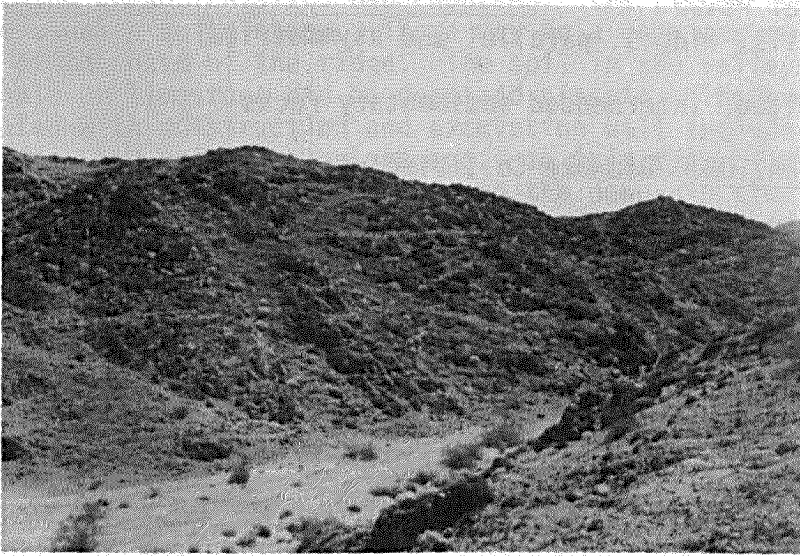
c. Same as (a) above

8. COMPILER: Judy Ehlen, USAETL

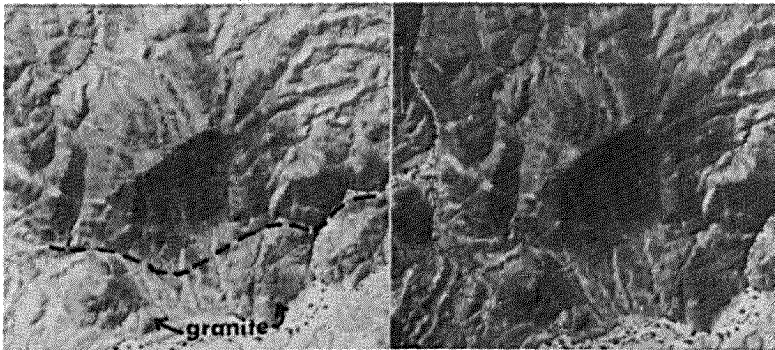
9. DATE: 4 August 1978



a. Vertical aerial stereopair at a scale of 1:10,000. The granite is labeled A-2. B-1 is gravel.



- b. Ground shot of granite outcrop typical of the Yuma area. Located at arrow in stereopair.



- c. Stereopair showing differences between lumpy granite and a metamorphic rock.

AERIAL PHOTO KEY P5-22

INDICATOR: Hills, ridges, parallel and asymmetrical

INDICATES: Tilted, interbedded sedimentary rocks

1. EXAMPLE LOCATION: Roanoke Co., Virginia

2. EXAMPLE CLIMATE (Trewartha, 1957): Humid subtropical, warm summer (Caf)

3. COMMENTS: Tilted, interbedded sedimentary rocks form nearly parallel ridges and valleys. The ridges are formed of the more resistant rocks for the climatic area in which they occur. In this example, the ridge-forming material is sandstone. The valleys between the ridges are formed of more easily eroded material, such as shale or limestone.

The tilting of these beds from their original flat-lying position was caused by folding or faulting. The ridges are formed by differential weathering of the exposed beds. In this example, each ridge has an asymmetrical profile in cross section (see below). In general, the amount of asymmetry is a function of the amount of tilt. Although asymmetrical profiles can occur in other materials, e.g. sand dunes, these can be identified by other pattern elements.

4. VERIFICATION: Ta Liang, R. B. Costello, G. J. Fallon, R. J. Hodge, H. C. Ladenheim, D. R. Leuder, and J. D. Mollard. A Photo-Analysis Key for the Determination of Ground Conditions, Landform Reports, Vol. II, Sedimentary Rocks. U.S. Naval Photographic Interpretation Center, Technical Report 3, 1951.

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar	X	
d. IR Thermal		X
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	X	

6. PHOTO CREDITS: U.S. Dept. of Agriculture, ASCS, DTS-8L-18 and 19, 1953.

7. COMPILER: J. Ponder Henley, USAETL

8. DATE: 9 August 1978

ENGINEERING CHARACTERISTICS AND PROBLEMS: The ridges have thin soil and are usually quite stony. There may be a deep accumulation of rock debris at the base of the ridge. The soil in the valleys if formed from shale or limestone can be deep and plastic. The problems associated with construction and excavation will include rock and landslides, and ground water seepage. In this type of climate, problems with stability are greater on the down-dip side. The limestone and sandstone members can be used as source of aggregate. Cross-country movement in such an area as this has a number of difficulties. Movement is controlled by the orientation of the ridges and the location of gaps in the ridges. Gaps are militarily significant. Valley soils can become soft and slippery when wet, impairing the trafficability.



Scale: 1:20,000

AERIAL PHOTO KEY P5-23

INDICATOR: Hill, dome, exfoliating

INDICATES: Granitic rock

1. EXAMPLE LOCATION: Stone Mountain, Dekalb Co., Georgia

2. EXAMPLE CLIMATE (Trewartha, 1957): Humid, Subtropical, warm summer (Caf)

3. COMMENTS: Landform shape in granitic rocks is controlled by two types of joints, curvilinear sheeting joints and vertical joints, both of which occur in all outcrops. Where vertical joints are numerous and closely spaced, they will control surface expressions on the outcrop, so that it will be somewhat broken up, and will appear to be formed of pebbles, cobbles or boulders, depending on joint spacing. When vertical joints are either few in number or very widely spaced, curvilinear sheeting joints will control outcrop shape, which will be smooth, even, and broadly rounded as in this example. When the sheeting joints are closely spaced and closed, exfoliation, the splitting away of layers along these sheeting joints, can occur. Whereas the dome shape appears to be characteristic of granite, exfoliation occurs in other rock types, such as sandstone, but on a much smaller scale. Other criteria important to formation of domes are relative grain size and homogeneity. Domes appear to form only in granites of relatively moderate grain size that are homogeneous in composition.

4. VERIFICATION:

a. Literature:

(1) Gilluly, James, Aaron C. Waters, and A. O. Woodford. Principles of Geology, 3rd edition. San Francisco: W. H. Freeman and Co., 1968, pp. 48-49.

(2) Twidale, C. R., Structural Landforms, landforms associated with granitic rocks, faults, and folded strata. Cambridge: The MIT Press, 1971, pp. 59- 71.

b. Other: Personal observation by Judy Ehlen, USAETL, at this location and at Yosemite National Park, California

5. PATTERN IDENTIFIABLE BY:	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar		X
d. IR Thermal		X
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	L	

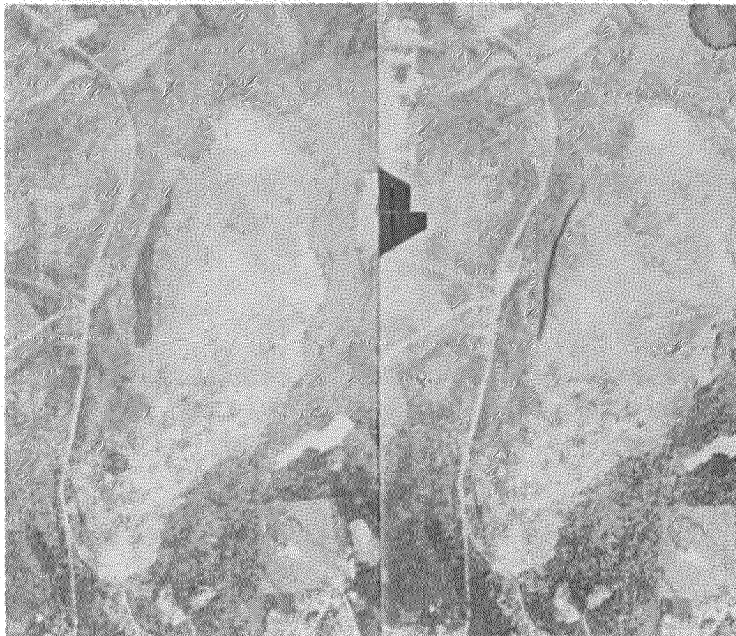
6. PHOTO CREDITS:

a. U.S. Geological Survey, GS VIP-1, 112, and 113, 1955, original scale 1:20,000

b. Judy Ehlen, USAETL

7. COMPILER: Judy Ehlen, USAETL

8. DATE: 3 August 1978



a. Stereopair showing Stone Mountain.



- b. Ground view of Stone Mountain. The light-toned area is a carving commemorating the Civil War. The vertical striae are surficial stains.

AERIAL PHOTO KEY P5-24

INDICATOR: Hill, dome, exfoliating

INDICATES: Granitic Rock

1. EXAMPLE LOCATION: Half Dome, Yosemite National Park, Mariposa Co., California

2. EXAMPLE CLIMATE (Trewartha, 1957): Undifferentiated highlands (H)

3. COMMENTS: Landform shape in granitic rocks is controlled by two types of joints, curvilinear sheeting joints and vertical joints, both of which occur in all outcrops. Where vertical joints are numerous and closely spaced they will control surface expression on the outcrop, so that it will be somewhat broken up, and will appear to be formed of pebbles, cobbles, or boulders, depending on joint spacing. When vertical joints are either few in number or very widely spaced, curvilinear sheeting joints will control outcrop shape, which will be smooth, even, and broadly rounded, as in this example. When the sheeting joints are closely spaced and closed, exfoliation, the splitting away of layers along these joints, can occur. Whereas the dome shape appears to be characteristic to granite, exfoliation occurs in other rock types, such as sandstone, but on a much smaller scale. Other criteria important to formation of domes are relative grain size and homogeneity. Domes appear to form only in granites of relatively moderate grain size that are homogeneous in composition.

4. LITERATURE:

a. Literature:

(1) Gilluly, James, Aaron C. Waters, and A. O. Woodford.

Principles of Geology, 3rd edition. San Francisco: W. H. Freeman and Co., 1968, pp. 48-49.

(2) Twidale, C. R., Structural Landforms, landforms associated with granitic rocks, faults, and folded strata. Cambridge: The MIT Press, 1971, pp. 59-71.

b. Other: Personal observation by Judy Ehlen at this location and at Stone Mountain, Georgia

5. <u>PATTERN IDENTIFIABLE BY:</u>	YES	NO
a. Ground Recon.	X	
b. Low Alt. Recon.	X	
c. Radar		X
d. IR Thermal		X
e. Vert. Aerial Photog.	X	
(1) Stereoscopic Viewing	X	
(2) Monoscopic Viewing	L	

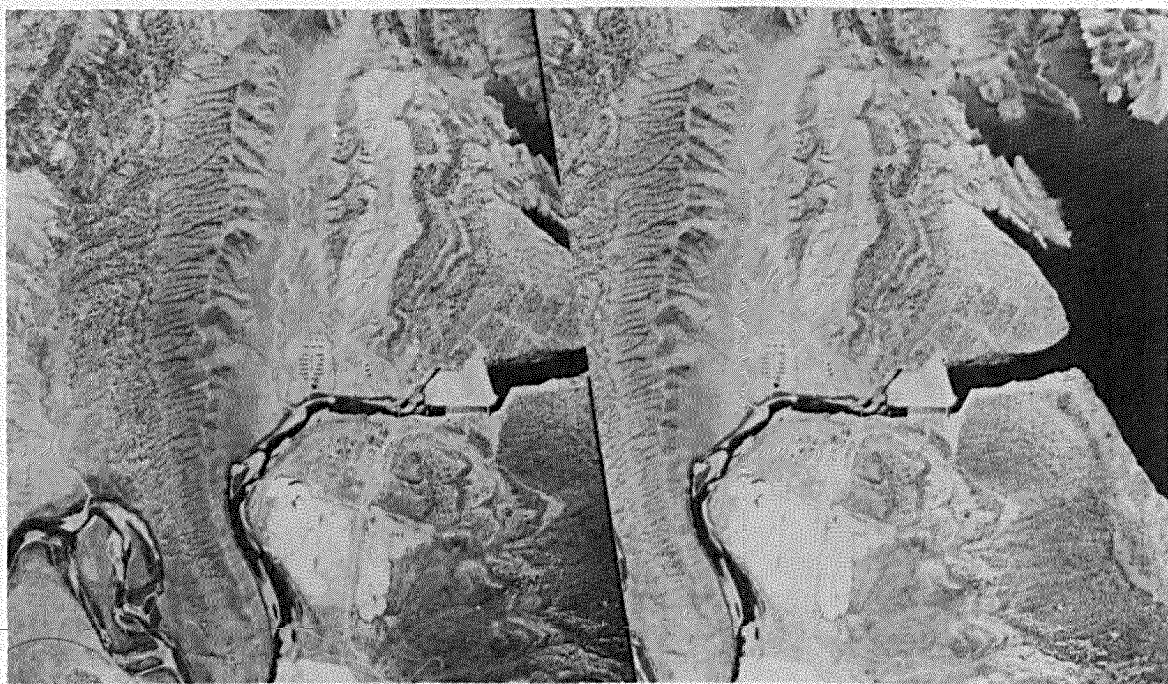
6. PHOTO CREDITS:
a. & b. Judy Ehlen, USAETL
7. COMPILER: Judy Ehlen, USAETL
8. DATE: 4 August 1978



- a. Half Dome in Yosemite National Park. The front of the dome has been removed by glaciation.



- b. Cross-sectional view of an exfoliating surface. Joint spacing ranges from inches to feet: spacing here is about 4 to 10 inches.

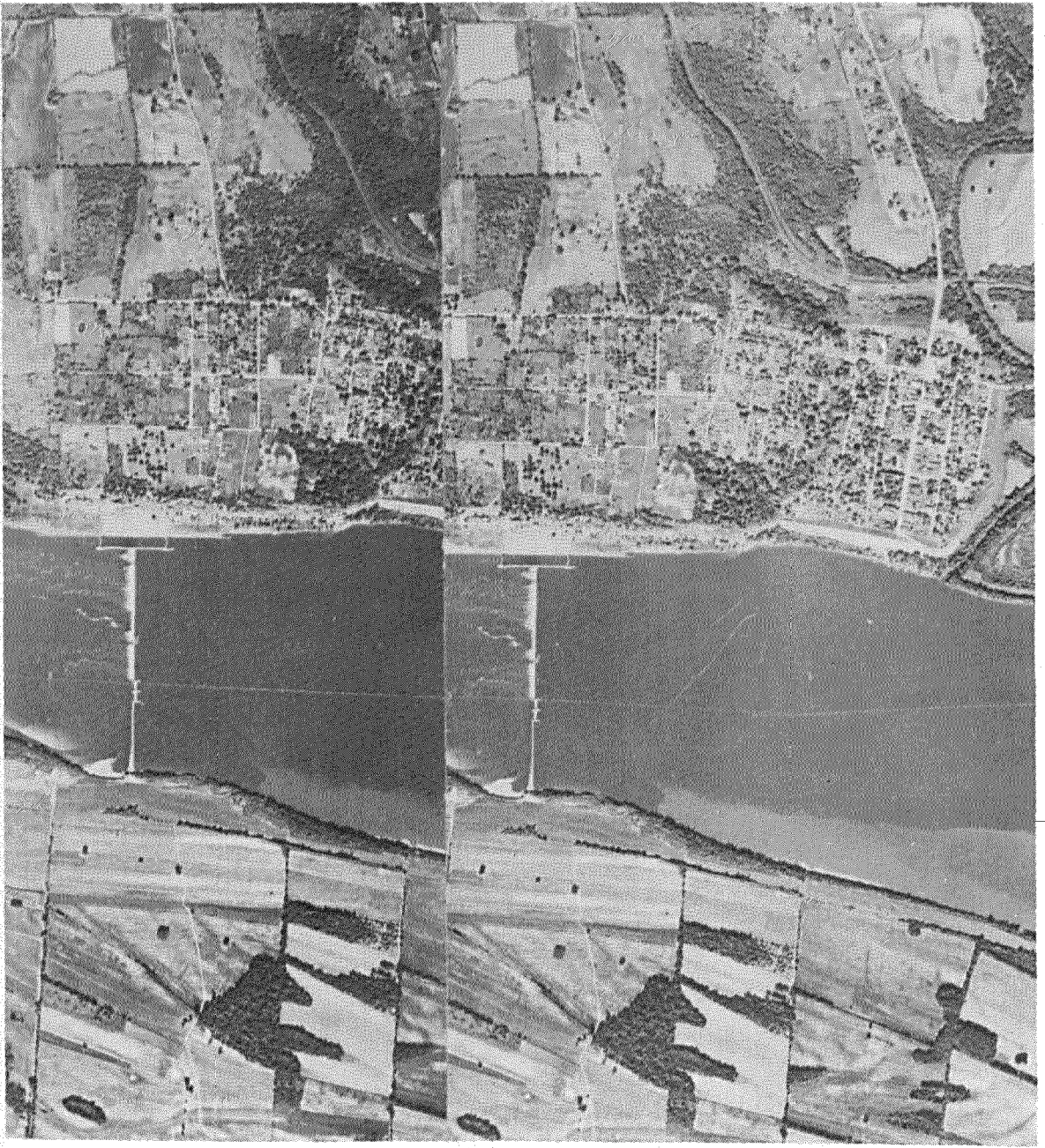


AERIAL PHOTO KEY P5-25

ALCOVA DAM
Natrona County, Wyoming, USA
April 22, 1939
RF = 1:36,000 H = 13,700 Feet

Prepared from USDA-FS
photography by the
University of Illinois
Committee on Aerial Photography.

The dam is built close to the axis of an anticline that exposes thick-bedded sandstone. Note the cliffy nature of the sandstone; because of the siliceous cementing materials these sandstone beds are equal to quartzites in hardness. Note the differences in drainage expression on the sandstone slopes and on the softer shale formations of the prominent ridge downstream of the damsite.



AERIAL PHOTO KEY P5-26

OHIO RIVER LOCK AND DAM NO. 51
Livingston County, Ken. &
Pope County, Illinois
August 1, 1952
RF = 1:21,000 H = 14,425

Prepared from USDA-CSS photography
by the University of Illinois
Committee on Aerial Photography

The bluff on the west side of the river (top of photo) is part of a gently dipping sandstone that overlies a shale formation. Sandstone is indicated by the relative absence of drainage; porous material would cause a rapid loss of surface water. Sandy, accretionary deposits occur on the opposite shore.



AERIAL PHOTO KEY P5-27

COVE MOUNTAIN

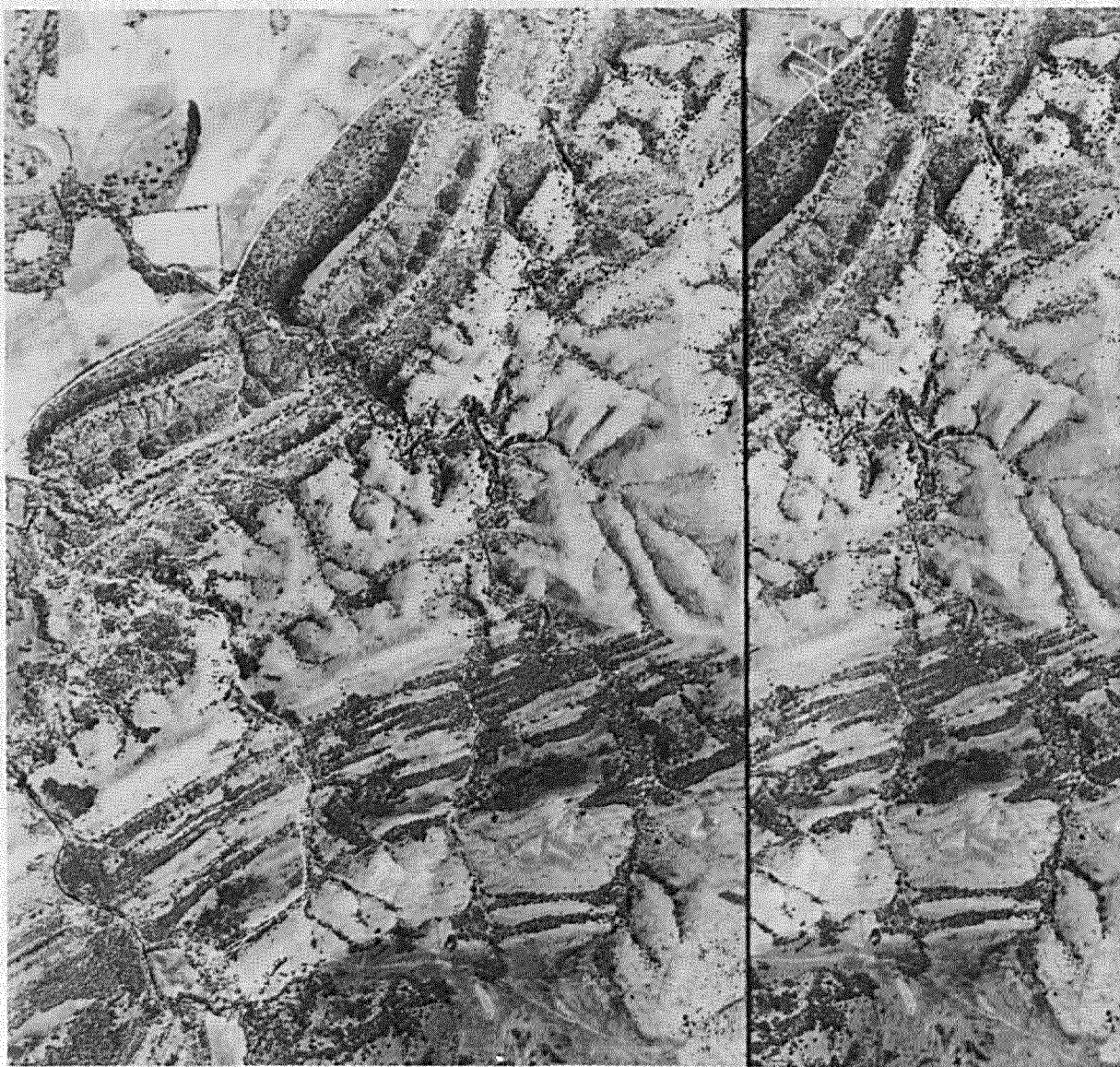
Dauphin & Perry Counties,
Pennsylvania

August 21, 1938

RF = 1:21,500 H = 14,800 feet

Prepared from USDA-AAA photography
by the University of Illinois
Committee on Aerial Photography

A water gap in nearly vertical thick sandstone beds. Note the continuation of the sandstone ledges in the heavily wooded areas. Riverbed rapids are expressions of the hard sandstone ledges; their trend (strike) agrees with the exposed sandstone beds. This suggests that faulting is not present in the riverbed.



AERIAL PHOTO KEY P5-28

HONEY CREEK

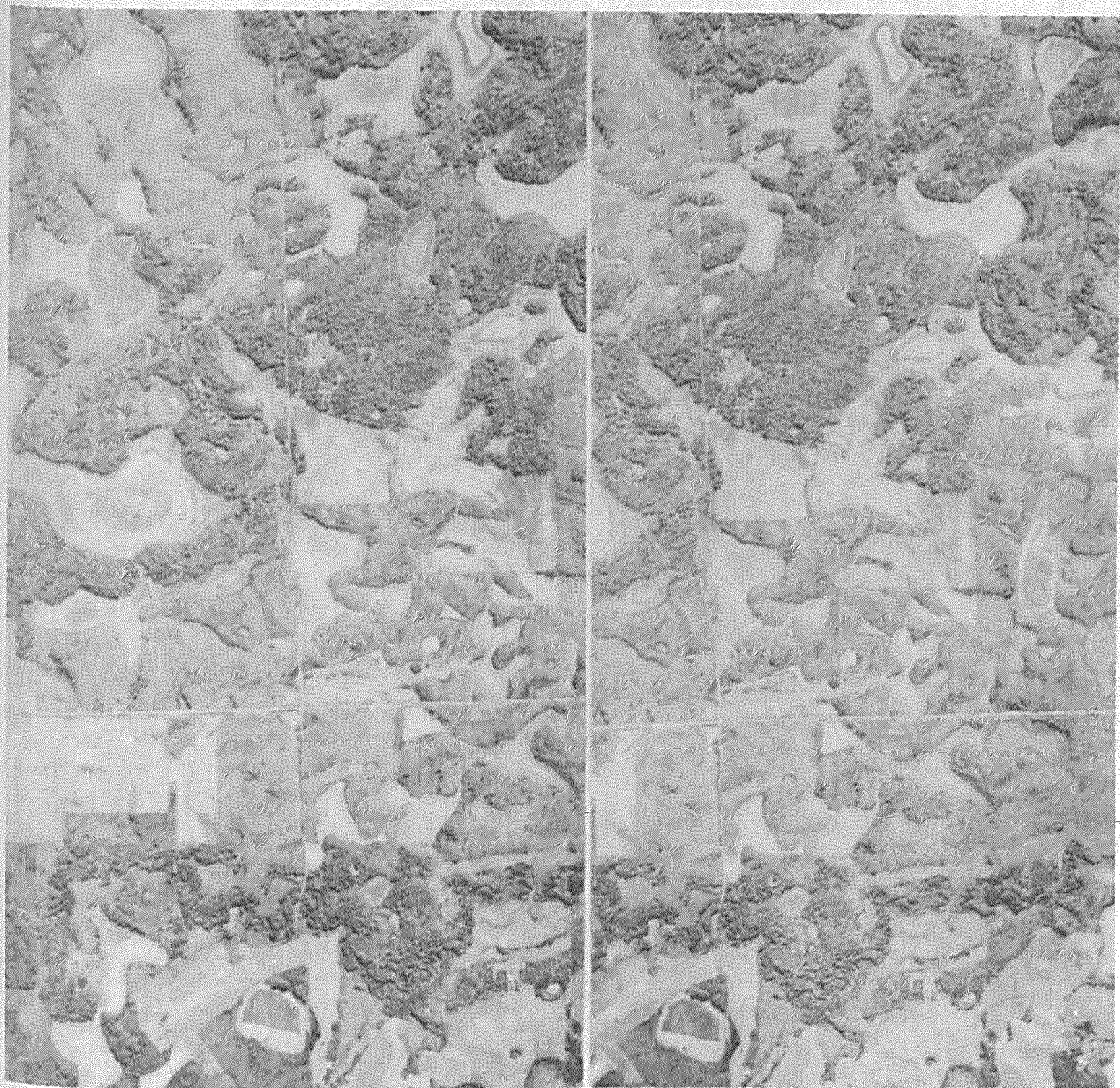
Carter County, Oklahoma, USA

March 20, 1937

RF = 1:22,300 H = 15,300 ft

Prepared from USDA-SCS photography
by the University of Illinois
Committee on Aerial Photography.

An area underlain by strongly deformed limestone and shale units. The presence of another rock type (in this case, a conglomerate) is suggested by the prominent dendritic drainage in the uppermost formation. Analysis will suggest that the uppermost unit (conglomerate), because of its flat-lying character, must be a unit deposited much later than the deformed limestone and shale beds.



AERIAL PHOTO KEY P5-30

INKSPOT

Rolette County, North Dakota

August 11, 1938

RF = 1:20,800 H = 14,300 feet

Prepared from USDA-AAA photography
by the University of Illinois
Committee on Aerial Photography

An uneven and poorly drained surface, typical of glaciated terrain. When the overlying ice sheet melted, unconsolidated detritus carried within the glacier was deposited over the bedrock surface; these unconsolidated deposits, locally removed by erosion, form the knob and kettle topography shown.



AERIAL PHOTO KEY P5-31

ZION CANYON

Kane and Washington Counties,
Utah July 18, 1939
RF = 1:45,000 H = 15,000 ft.

Prepared from USGS photography
by the University of Illinois
Committee on Aerial Photography

A canyon, 2500 feet deep, cut into flat-lying sandstone. The lower canyon walls are underlain by thick shale and minor sandstone beds. A series of joints have been weathered deeply to form tight side canyons.



AERIAL PHOTO KEY P5-32

HAYSTACK

Puerto Rico

Date: 1941

RF = 1:25,300 H = 10,900 feet

Prepared from Puerto Rican photography
by the University of Illinois
Committee on Aerial Photography

Limestone terrain in warm moist climate. This form of karst topography is a pattern of deep sinkholes and adjacent sharp, haystack-like peaks. Landuse is minimal and access is exceedingly difficult. Locally, linear trends are seen which suggest possible bedrock joints. A prominent curvilinear trend (lower right) is unexplained; it may reflect former stream channeling over a now-eroded surface, or the presence of a deeply buried igneous mass.



AERIAL PHOTO KEY P5-34

CEDAR CITY

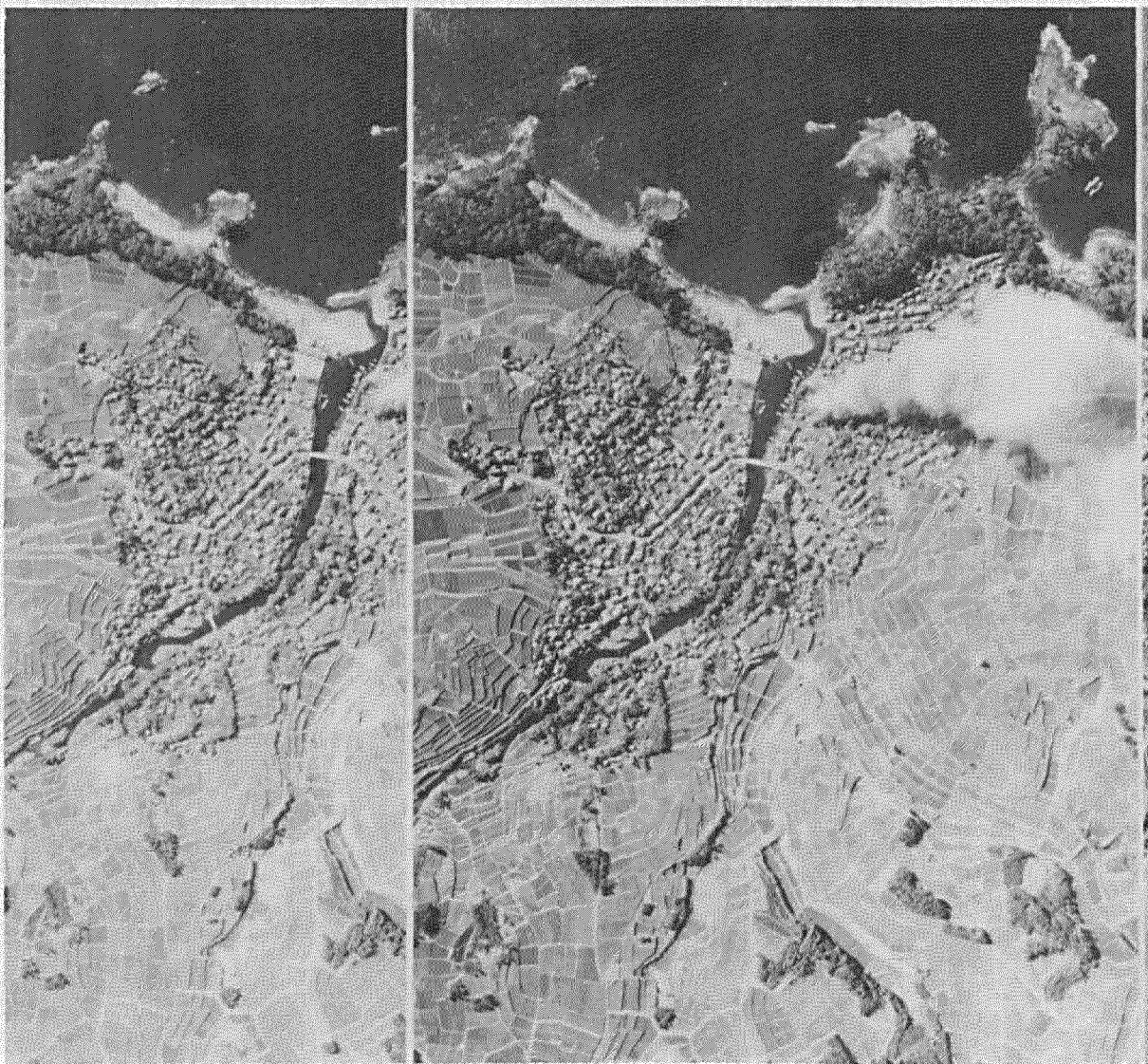
Leelanau County, Michigan

May 11, 1953

RF = 1:91,000 H = 30,300 feet

Prepared from USGS photography
by the University of Illinois
Committee on Aerial Photography

Drainage patterns in deep sandy till areas. Variations in the forest cover may reflect changes in the clay/stone components of the unconsolidated deposits.



AERIAL PHOTO KEY P5-35

ISHIGAKI

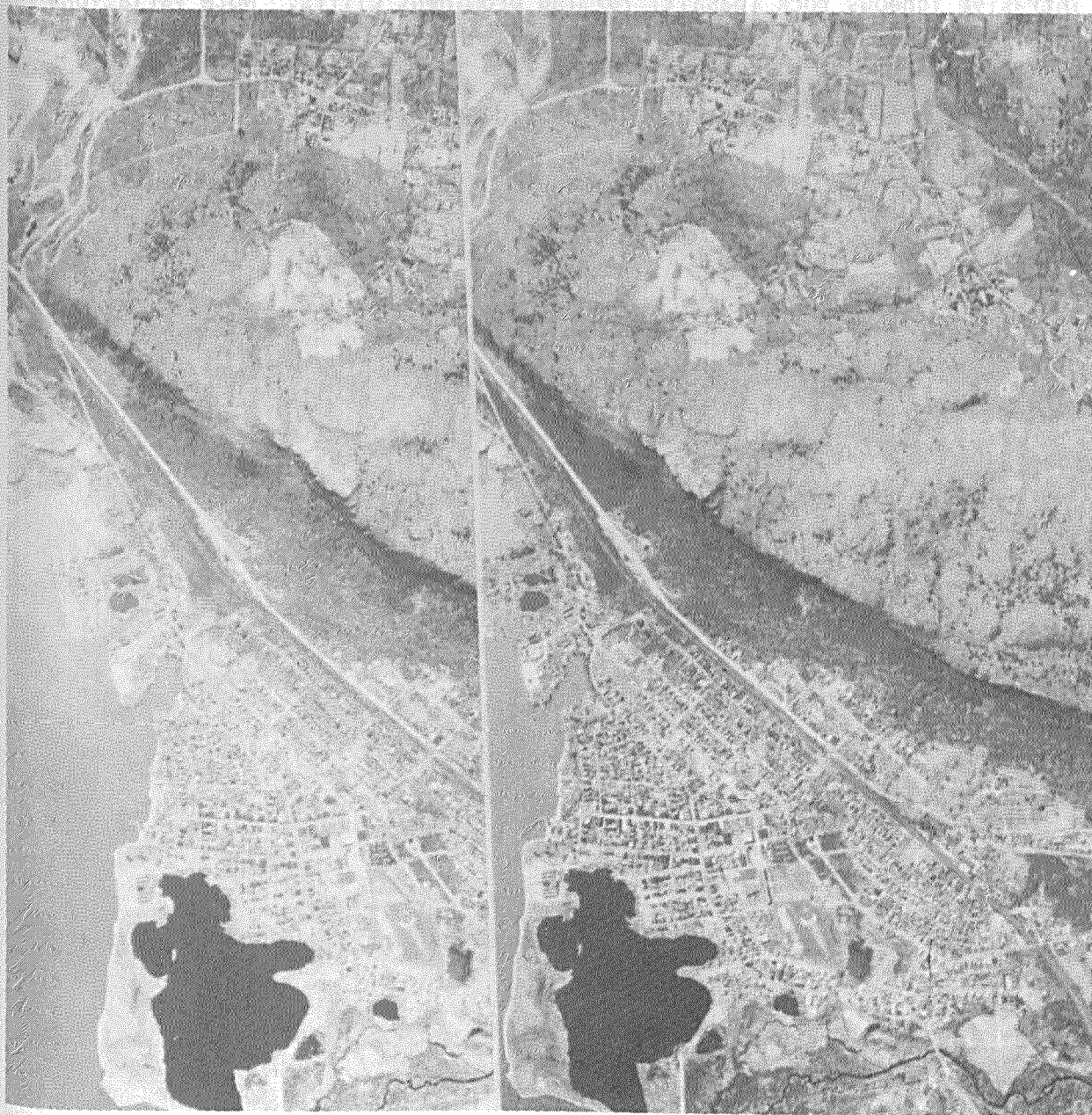
Southwestern Kyushu, Japan

March 29, 1945

RF = 1:9,950 H = 4,975 ft

Prepared from USAF photography
by the University of Illinois
Committee on Aerial Photography

The evidence of joints in the bedrock along the shore indicates that a relatively hard rock (probably basalt) is present. The success of the intricate terracing effort indicates that stone in abundance is available. The most likely source would be deeply weathered (jointed) bedrock, capable of being broken by hammers and not quarried.



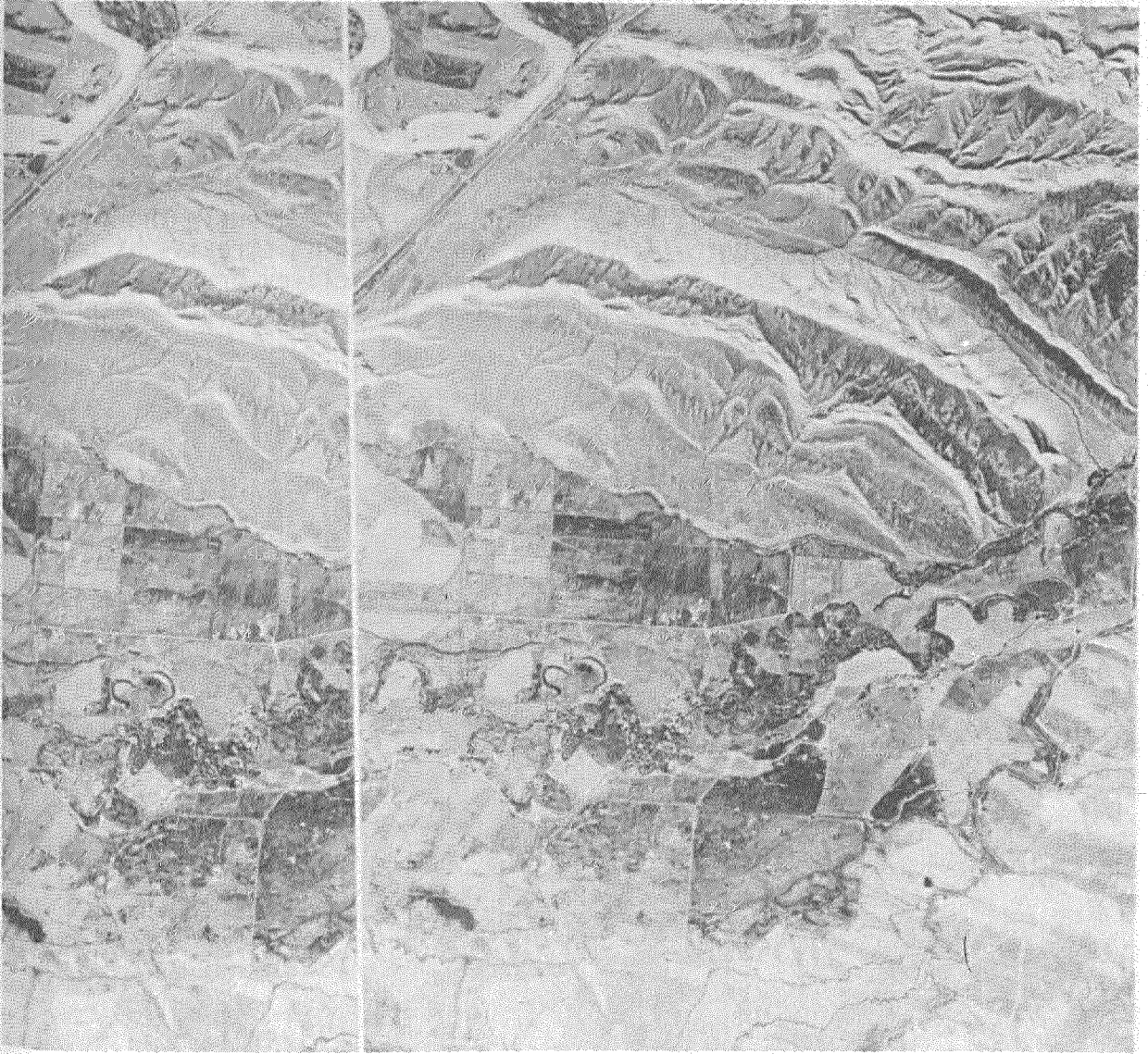
AERIAL PHOTO KEY P5-36

PALISADES OF THE HUDSON
Rockland County, New York
April 15, 1953

RF = 1:20,300 H = 10,200 feet

Prepared from USGS photography by
the University of Illinois
Committee on Aerial Photography

Intrusive igneous rock (basalt) forming prominent cliffs. Note variations in the vegetal cover that might assist in mapping the rock types present. Beds above the intrusive are softer sedimentary materials (shale, sandstone). Water wells sited in the overlying sediments ought to be prolific sources of ground water because of the tighter nature of the underlying igneous rock.



AERIAL PHOTO KEY P5-37

OWL CREEK

Hot Springs County, Wyoming
October 25, 1941

RF = 1:48,500 H = 25,500 ft

Prepared from USDA-AAA photography
by the University of Illinois
Committee on Aerial Photography

By carefully tracing the contact between gross features (e.g., cliffs versus valleys, trees versus grass cover, light-reflecting slopes versus darker toned slopes, etc.), military terrain analysis can provide initial definition of rock characteristics in any area. Here, erosion patterns suggest variations exist in the rocks that form the ridges: gullies and rounded lower slopes indicate shale; sharp crest lines and differences in vegetal cover suggest relatively harder lithologies (probably sandstone) lie adjacent to the shale beds. Some sense of the relative abundance of shale-derived or sandstone-derived (or limestone, if present) materials washed out of the mountains and ridges ought to be considered in the analysis. In the plain shown, hydrological considerations (sluggish streams, ox bows, meanders, drainage patterns) indicate a dominance of clayey or silty materials, probably shale or a widespread veneer of unconsolidated materials is present.



AERIAL PHOTO KEY P5-38

UNDERGROUND DRAINAGE

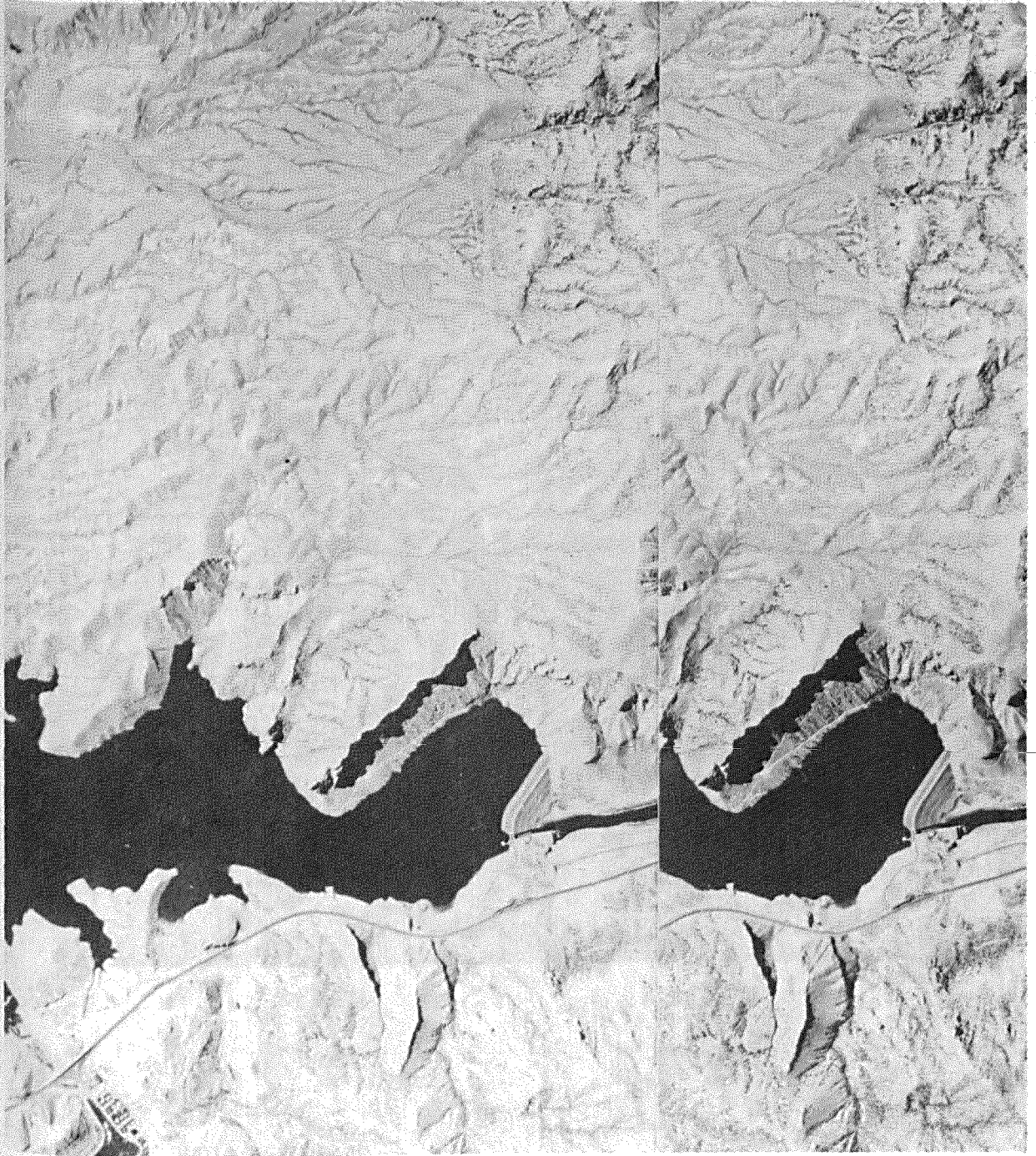
Municipalities of Camuy, Hatillo
& Lares, Puerto Rico

Date: unknown

RF = 1:26,000 H = 10,900 ft

Prepared from Puerto Rican Photography
by the University of Illinois
Committee on Aerial Photography

An area in the tropics almost entirely underlain by limestone beds. Careful analysis will reveal three variations of topographic expression despite the homogeneity of the bedrock (limestone). These variations ought to be mapped because they might reveal important subtleties of bedrock weathering, variations in rock composition locally, and structural anomalies. Here, note the sudden disappearance of streams indicating a subsurface (buried) channel condition. Variations in soil patterns, tree or grass cover, topographic expressions or certain statistical observations (e.g., concentrated areas of sinkholes) can lead to valuable insight for terrain analysis.



AERIAL PHOTO KEY P5-39

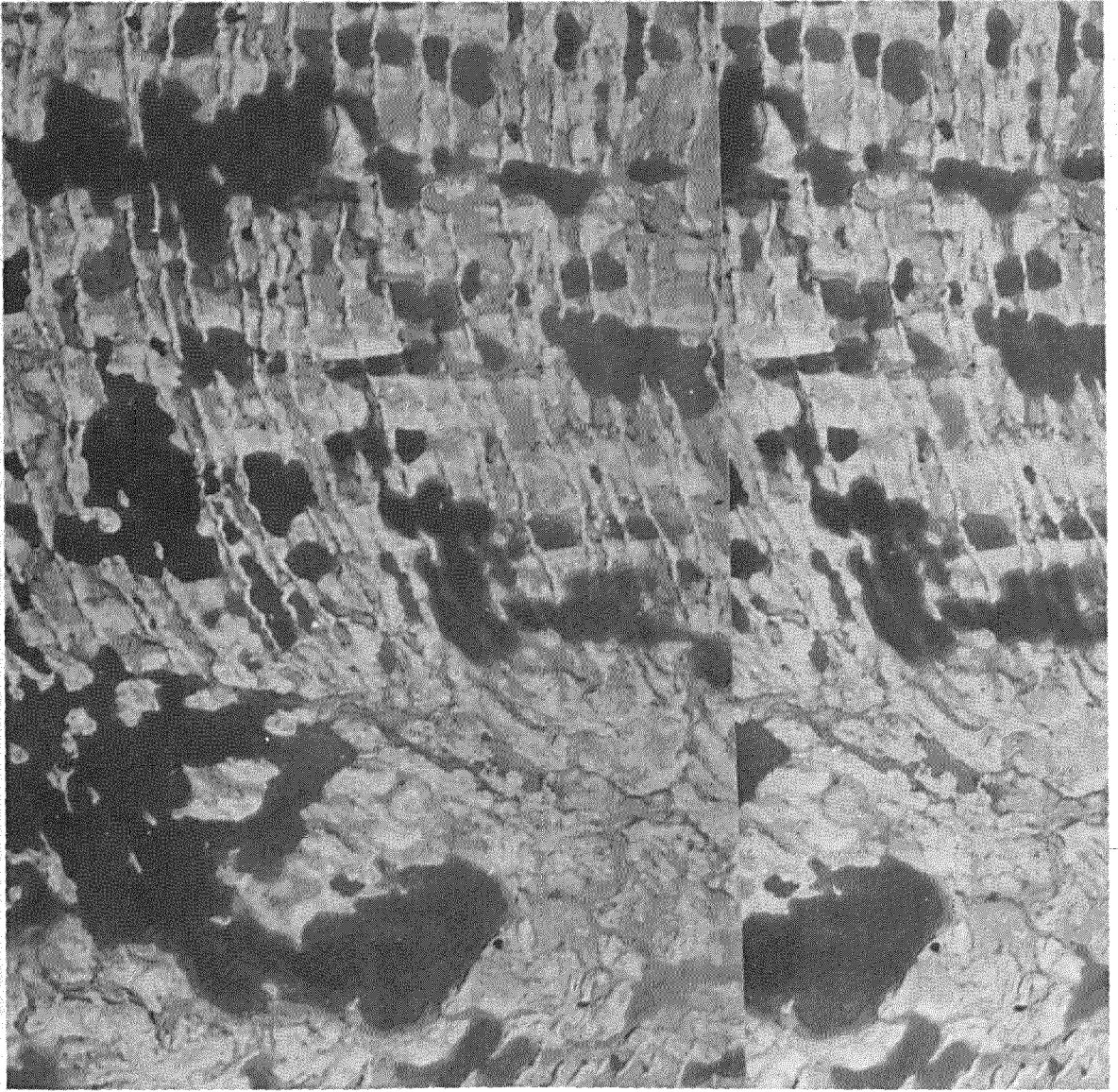
BOYSEN DAM

Fremont County, Wyoming
September 8, 1954

RF = 1:22,400 H = 13,750 feet

Prepared from USDA-AS & CS photography
by the University of Illinois
Committee on Aerial Photography

Note the rugged character of the terrain to the right and north of the damsite in contrast to that to the left. The rugosity, relief, and paucity of surface drainage indicates a vastly differing lithology to that lying west of the damsite. Study will suggest an igneous rock (granite) in fault contact with softer sedimentary rocks; can you locate the fault trace? Note the differing expressions of surface drainage over the area underlain by the sedimentary rocks; careful mapping may suggest the presence of a local sandstone unit as well as the predominant shale beds.



AERIAL PHOTO KEY P5-40

WASHBOARD MORaine

Quebec, Canada

August 28, 1955

RF = unknown H = 20,000 ft.

Prepared from Royal Canadian Air
Force Photography by the University
of Illinois Committee on Aerial
Photography

A glaciated till plain consisting of narrow ridges, equally spaced, elevated about 20 feet above the surrounding surface. The ridges consist of unconsolidated deposits of debris that accumulated near the front of the glacier. The area is characterised by many small lakes (indicating poorly integrated surface drainage), scoured out bedrock depressions and difficulty of movement by foot or vehicle.

APPENDIX A. SPECIFICATIONS FOR THE PREPARATION OF FACTOR OVERLAYS

I. Objectives and Design Elements Common to All Factor Overlays

A. Objectives

The objectives of this section are to establish the operational concepts for the production of factor overlays and to prescribe the design and formats for those elements and components common to all factor overlays.

B. Operational Concepts

1. Factor overlays are intended primarily for use within the mapping and intelligence community, and in addition as quick reaction terrain products for distribution to the user.

2. Factor overlays provide formatted geographic data that can be readily retrieved and used in various combinations for terrain analysis and for production of special terrain products.

3. Factor overlays will be prepared in the form of stable base overlays that will accept photographic reduction to 70 by 105 mm and retain their legibility when enlarged back.

4. Normally each data field will require several factor overlays for each area. Data elements to be portrayed on each factor overlay, the symbology to be employed, and unique formats are specified separately for each data field.

5. These specifications do not treat methods of collecting or reducing data. Their purpose is to specify the manner of graphically recording collected and reduced data.

C. Format

1. General format specifications are indicated in Figures A1 and A2.

2. No single factor overlay will exceed 660 by 860 mm (26 by 34 inches), including titles, legends, and other marginal data. Where use of a base map exceeding these dimensions is desired, the base will be subdivided and separate factor overlays prepared for each part. When an oversized base is subdivided, each subdivision will be assigned an identification and an index of parts prepared as per Figures A1 and A2.

3. Whenever possible, factor overlays will be registered to a standard scale U.S. military map. Base maps other than U.S. military maps will be clearly identified in the upper right corner of the factor overlay.

4. Each factor overlay will be punch registered to the base map at the four corners of the neat line.

5. A neat line 0.5 mm wide will be placed on each factor overlay. This neat line will normally coincide with the neat line of the base map.

6. Legend information will be placed on the areas identified as A, B, C, and D on Figures A1 and A2 in that sequence. Area A will be used first, B second, etc. Where the legend is too large to be accommodated in the areas provided, it will be placed on a second piece of overlay material. This legend overlay will be prepared in the same format as the factor overlay and will bear the same identification data.

D. Symbolization

Symbols are specified separately for each data field. However, the following general guidelines will be followed:

1. All lines will be at least 0.09 mm (0.004") wide with a minimum spacing of 0.18 (0.008") between lines. When adjacent linear features would overlap if symbolized in their true position, the least significant feature will be displaced to provide the 0.18 mm clearance.


2. All letters will be at least 3.2 mm (0.125") high (Elite typewriter type).

3. All letters, numbers, and symbols will be positioned so as to be readable from the bottom or right side of the sheet.

4. All symbols, letters, and numbers will be drawn in black (plastic for Mylar sheets) ink or black "Prisma" pencil.

5. Areas with a greatest dimension less than 2 mm will not be delineated. Areas with a greatest dimension less than 8 mm (.32") will be identified by lead lines.

6. Tick marks will be placed on the four outermost grid intersections so as to form a rectangle. Each leg of the tick marks will extend 3 mm from the intersection. These ticks are required to permit addition of the grid during the reproduction process.



3

7

**BELVOIR
GEOLOGY**

9

8

5561 IV	5561 I	5561 IV
5561 III		5561 III
5560 IV	5560 I	5560 IV

5561 II

V734

JULY 72

11

12

13

15

14

16

1. Factor maps will be drawn on stable base translucent film base (.004" to .007" thick) not exceeding 660 x 860cm (26 x 34 inches).
2. Only black ink will be used. All lines must be at least .09mm (.004") wide. No character will be less than 2mm high.
3. A clear area at least 2cm wide will be allowed on all edges. No lines, letters, symbols, or other data will be placed in these clear areas.
4. The scale of the factor map will be placed in the upper left corner adjacent to the clear area. Letters will be 4mm high.
5. The data file identification code will be placed 2mm below the scale; letters will be 4mm high. The data field subtitle (if appropriate) will be placed in parenthesis to the right of the I. D. code.
6. The identification of the organization preparing the overlay will be placed 2mm below the data file code.
7. Title of the base map to which the factor overlay is registered will be centered at the top of the sheet. Letters will be 6mm high with the top of the letters at least 16mm above the neckline.
8. The data field name will be centered 2mm below the sheet name. Letters will be 6mm high.
9. An index to adjoining sheets will be placed in the upper right corner. Letters will be 3mm high separated by a 3mm vertical distance.
10. A true north arrow 16mm long will be placed just to the right of the index to adjoining sheets.
11. The sheet number of the base map will be placed in the upper right corner to the right of the north arrow and in line with the scale (4). Letters will be 4mm high. The words "sheet number" will be omitted. If the base map is oversized and has been subdivided the identification of the part will be placed in parenthesis to the right of the sheet number.
12. The series number of the base map will be placed 2mm beneath the sheet number in letters 4mm high. The words "series number" will be omitted.
13. The month and year of the preparation or revision of the factor map will be placed 2mm beneath the series number in letters 4mm high.
14. The top neckline of the map will be positioned approximately 20mm beneath the top clear area. Sheets with the longest dimension north-south will be centered. Sheets with the longest dimension east-west will be positioned so the left neckline falls 1cm inside the clear area.
15. Tick marks will be placed on the four outermost grid intersections so as to form a rectangle. Each leg of the tick mark will be 6mm long.
16. A metric bar scale will be centered beneath the bottom neckline. Numbers will be 2mm high.
17. An index of the parts of the subdivided sheet will be placed in the lower right corner of each part. To avoid encroaching on space required for legends and other explanatory data this index will be kept small.
18. A coverage or reliability diagram will be placed to the left of the index whenever a variety of sources are used or the quality of the data varies.
19. All overlays will be punch registered to the base map and to each other. Sheets with the long axis north-south will be registered in left clear area. Sheets with the long axis east-west will be registered in the top clear area.
20. Areas with a greatest dimension less than 2mm at the scale of the map will not be delineated. Areas with a greatest dimension less than 8mm will be identified by lead lines.
21. Marginal areas are identified as either A, B, C, or D. When preparing legends area A will be completely used before recording data in B, area B before C, and area C before D.

15

16

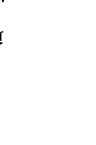
21

A

21

B

18



17

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OF PARTS**

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4	3

FIGURE A-1 Format for Factor Maps with Long Axis N-S

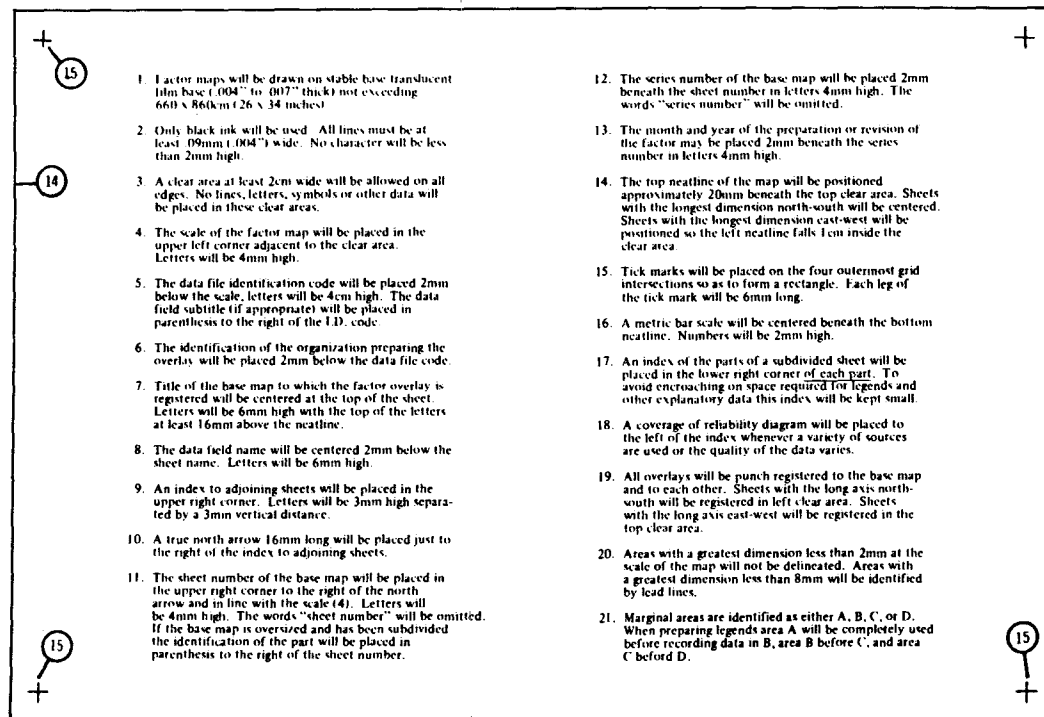
1:25,000
V.G.
USAE TL



7-BELVOIR
GEOLOGY

5561 IV	5561 I	5561 IV
5561 III		5561 III
5560 IV	5560 I	5560 IV

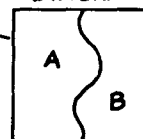
10 5561 II 11
V734 12
JULY 72 13
N



105.

COVERAGE
DIAGRAM

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OF PARTS



1	2
4	3

FIGURE A- 2 Format for Factor Maps with Long Axis E-W.

II. Specifications for the Preparation of Factor Overlays for Geology

A. Introduction

1. This section of the appendix prescribes the format and symbols to be used in preparing factor overlays for the data field "Geology" (figures A1, A2, and A3).

2. It is anticipated that not all data required by these specifications will be available during the initial preparation of a factor map. Lack of complete data, however, should not preclude preparation of a factor map. The factor map concept envisions the systematic recording of data as it is acquired, periodic revision of the maps, and the accumulation of data over a period of time.

B. General Description. The geologic factor overlays will consist of two parts as follows:

1. An overlay registered to a 1:50,000 scale map with areas consisting of essentially uniform rock type conditions outlined and identified (Figure A3). The principle basis for definition of these similar geological conditions will be the type of rock underlying such areas.

2. A series of accompanying Data Tables describing the geological conditions within each area (Figure A4).

C. Data Elements. The following data elements will be presented by the factor map and accompanying Data Tables I, II, and III:

1. Map unit identification.
2. Rock classification.
3. Rock composition.
4. Rock grain size.
5. Rock color.
6. Rock type variations, including dissection character.
7. Type of rock layering.
8. Thickness of unit.
9. Strike and dip of unit.

ROCK TYPES

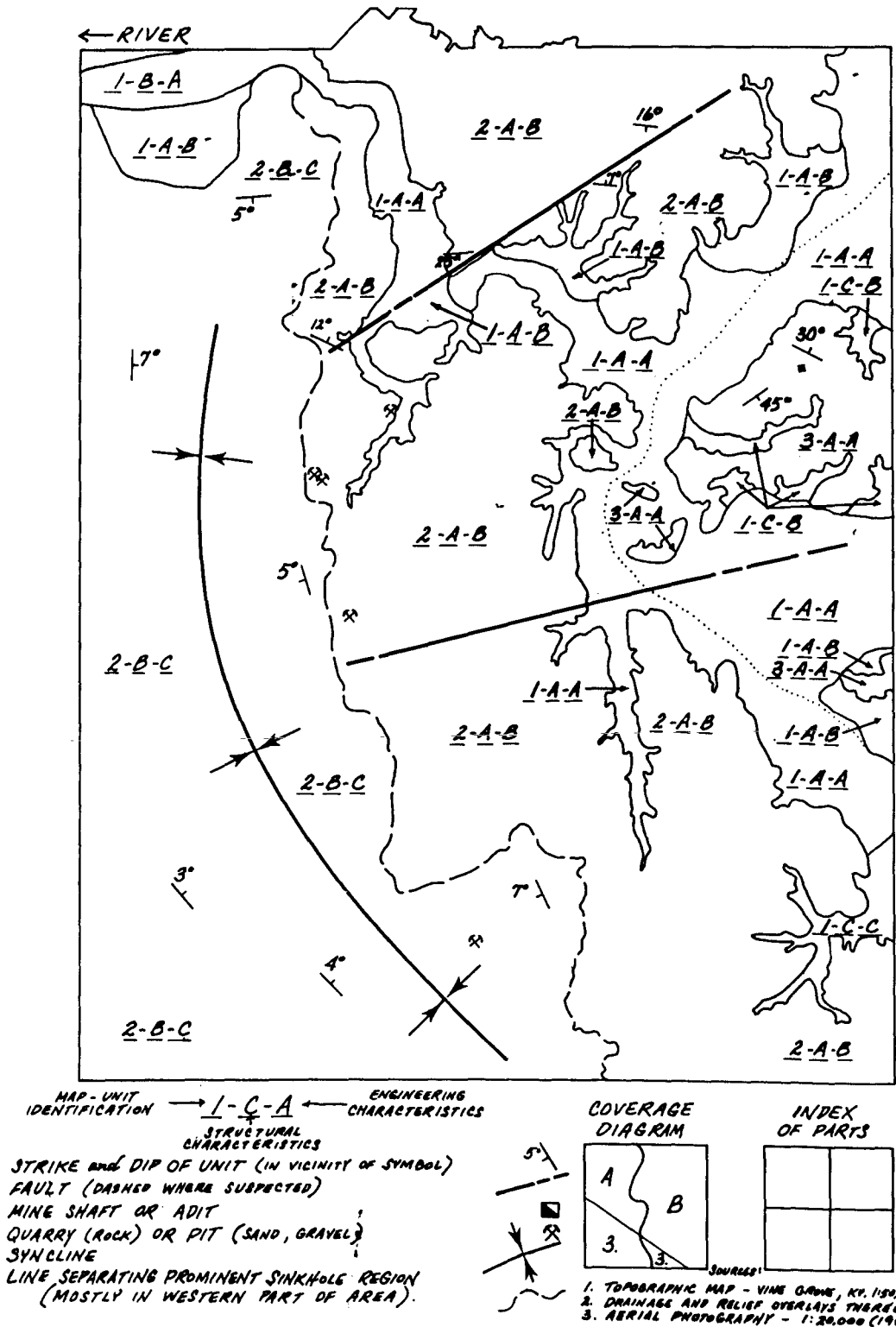


FIGURE A3. Sample Factor Overlay.

DATA TABLE I

MAP UNIT	ROCK		TYPE		
	Classification	Composition	Grain Size	Color	Variations, including dissection, in area

DATA TABLE II

STRUCTURAL			CHARACTERISTICS		
Types of Layering	Thickness	Strike/Dip	Joints/Faults	Seismic Aspect	Water Potential

DATA TABLE III

ENGINEERING			CHARACTERISTICS		
Weathering Aspects	Swelling Data	Abrasion Data	Aggregate Suitability	Drill/Blast Aspects	Siting Suitability

Figure A-4. Format for Data Tables

DATA TABLE I

Map Unit	R O C K				T Y P E
	Classification	Composition	Grain Size	Color	Variations, including dissection, in area
2	Sedimentary formation (locally, quarry operations shut down because of serious cavern development)	Limestone; some shale, very little sandstone. Usually limestone is dense, hard and a good cliff maker.	Fine.	Gray to gray blue; shale us. red or brown. Sandstone seldom seen.	Bedrock (mostly limestone) us. outcrops in large sinkhole region west of the broken line symbol. East of this line outcrops seldom seen as bedrock has more shale and sandstone. Soils thin-to absent. Very hilly, knobby terrain. Sinkholes very common over this plateau area. Caverns common over entire area.

DATA TABLE II

B	S T R U C T U R A L C H A R A C T E R I S T I C S					
	Type of Layering	Thickness	Strike/Dip	Joints/Faults	Seismic Aspects	Water Potential
	Bedded	Thin to thick (maximum ? 35') Total thickness of Ft. Knox limestone 500'.	As shown on map. Generally rocks are less than 10° but locally dip more.	Dominant joints trend N16° E. Deeply weathered causing sinkhole development. Faults suspected but sinkholes hide clear evidence.	Poor: thin soils and common cavities preclude transmission of seismic waves.	Good to excellent (yields of 300 gpm reported in deep wells) Sinkholes suggest widespread farm/industry contamination. Eastern areas probably yield less, require deeper wells due to higher shale (clay) content.

DATA TABLE III

C	E N G I N E E R I N G C H A R A C T E R I S T I C S					
	Weathering Aspects	Swelling Data	Abrasion Data	Aggregate Suitability	Drill/Blast Aspects	Siting Suitability
	Deeply weathered. Locally, to 200'. Outcrops are misleading as cavities may be just below surface. Clay fillings common along joint surfaces.	NA	No active quarries in limestone; hardness of cliff edges suggests sound, tough limestone, however.	Probably adequate, esp. where fresh. Near eastern edge, clay content may reduce aggregate potential.	Requires: drill/blasting except where limestone is deeply weathered; there, rippable.	Good for most structures. Larger structures require deep core holes. Cavities are very common but without surface evidence. Uneven subsidence likely where foundations rest on mixed shale/limestone, esp. eastern areas of unit. Ground water table not a problem. Heavy rains disappear quickly in limestone terrain.

Example of Data Table

Figure A-5. Example of Data Table for One Map Unit

10. Joints and faults in unit.
11. Seismic aspects of unit.
12. Water potential of unit.
13. Weathering aspects of unit.
14. Swelling data for unit.
15. Abrasion data for unit.
16. Aggregate suitability of unit.
17. Drilling and blasting characteristics of unit.
18. Siting Suitability (for structures).

D. Format

1. Factor Overlay (Figure A1).

a. The general format for the factor overlay will be as prescribed in Figures A1, A2, and A3 of these specifications.

b. Source(s) used in preparing the factor overlay and tables will be entered at Location B (Figures A1 and A2) to the left of the coverage diagram, where they are not adequately described in the coverage diagram. Where a single source is used or all sources apply to the entire sheet, the coverage diagram may be replaced by the source listing.

c. A legend describing each outlined area will be placed at location A of the margin (Figures A1 and A2). As an example 1-C-A would define the following:

1 = Map Unit Identification

C = Structural Characteristics

A = Engineering Characteristics

NOTE: The letters and numeral are shown as an example only.

2. Data Tables

a. The general format of the data tables will be as prescribed in Figures A4, A5, and A6. Note that there are three data tables (Figure A5) and entries are made in all three tables for each map unit.

b. All three tables will normally be placed on a single sheet (Figure A4). Where a high number of map units produces an excessive number of data tables entries that crowd the sheet, additional sheets may be used. Figure A6 shows sample data tables with three map unit areas described.

c. The index to adjoining sheets, coverage diagram, and source listings will be omitted from the data table overlays.

III. Symbolization

A. Factor Overlay (Figure A3)

1. Each area of uniform rock, will be assigned an identification number and will be outlined by a solid line, 0.2 mm wide, except where the rock type is overlain by unconsolidated materials and is therefore buried. Map unit areas with the same rock classification will be assigned the same identification number, except where in the analyst's judgement subdivision of the same rock classification is warranted because of radically different structural characteristics or of radically different engineering characteristics.

2. The map unit identification number, the structural characteristics, and the engineering characteristics will be entered in each map unit area in black letters at least 3.2 millimeters high.

B. Data Tables

1. Geology Data Table I (Figure A6)

a. The purpose of this table is to provide those data that describe the type of rock formation within the boundaries of the map unit.

b. Map Unit Identification: Identification numbers will be listed in numerical sequence in the first column of the table.

c. Rock Classification: Igneous or metamorphic (hard rock), Sedimentary (soft rock), or Unconsolidated (loose deposits) will be recorded in Column 2.

DATA TABLE I					
Map Unit	R O C K	T Y P E			
	Classification	Composition	Grain Size	Color	Variations, including dissection, in area
1	Alluvial deposits	Mostly sand; fine gravel locally. Flatter areas may have more clay than sand.	Sand: mostly SM with minor ML and CL. Flatter areas probably more SC/CL than SM. * Unified soil classification	NA	Sand, some gravel (in lenses or layers) in stream terraces and floodplains. Dissection seldom significant except in upper reaches of most stream valleys. Usually flat to rolling terrain over the entire area. Broad flat areas, especially in the east, may have more clay content; dissection could be significant to GCM.
DATA TABLE II					
S T R U C T U R A L			C H A R A C T E R I S T I C S		
Type of Layering	Thickness	Strike/Dip	Joints/Faults	Seismic Aspects	Water Potential
A	Blanket; some wedge-like deposits. Blanket.	0 - 60' (est)	NA	NA	Excellent
B		0 - 100' (est) (avg. 40')	NA	NA	Good; locally excellent.
C	Usually wedge-like deposits	0 - 30' but in discontinuous deposits	NA	NA	Poor: too much "noise" to interdict seismic waves.
					100 gpm common; locally more. Water tables high; us. within 15' of ground surface.
					100gpm and more commonly reported. Water table depths not known; prob. within 20' of surfaces.
					High water tables. Yields not known (less than 100gpm probable)
DATA TABLE III					
E N G I N E E R I N G			C H A R A C T E R I S T I C S		
Weathering Aspects	Swelling Data	Abrasion Data	Aggregate Suitability	Drill/Blast Aspects	Siting Suitability
A	NA	Broad, flatter areas may have swelling clay	NA	Good but washing is necessary. Clay areas not suitable. Not suitable.	Easily excavated with power equipment
B	NA	Possibly serious.	NA	"	"
C	NA	Unacceptable ?	NA	Not suitable	"
					Excellent most places; low areas adjacent to creeks may overflow. Clayey areas retain surface water for weeks in wet season.

DATA TABLE I					
Map Unit	R O C K	T Y P E			
	Classification	Composition	Grain Size	Color	Variations, including dissection, in area
2	Sedimentary formation (locally, quarry operations shut down because of serious cavern development)	Limestone; some shale, very little sandstone. Usually limestone is dense, hard and a good cliff maker.	Fine.	Gray to gray blue; shale us. red or brown. Sandstone seldom seen.	Bedrock (mostly limestone) us. outcrops in large sinkhole region west of the broken line symbol. East of this line outcrops seldom seen as bedrock has more shale and sandstone. Soils thin to absent. Very hilly, knobby terrain. Sinkholes very common over this plateau area. Caverns common over entire area.
DATA TABLE II					
S T R U C T U R A L			C H A R A C T E R I S T I C S		
Type of Layering	Thickness	Strike/Dip	Joints/Faults	Seismic Aspects	Water Potential
B	Bedded	Thin to thick (maximum ? 35') Total thickness of Fr. Knox limestone 500'	As shown on map. Generally rocks are less than 10 but locally dip more.	Dominant joints trend N16°E. Deeply weathered causing sinkhole development. Faults suspected but sinkholes hide clear evidence.	Poor: thin soils and common cavities preclude transmission of seismic waves.
					Good to excellent (yields of 300 gpm reported in deep wells). Sinkholes suggest widespread farm/industry contamination. Eastern areas probably yield less, require deeper wells due to higher shale (clay) content.
DATA TABLE III					
E N G I N E E R I N G			C H A R A C T E R I S T I C S		
Weathering Aspects	Swelling Data	Abrasion Data	Aggregate Suitability	Drill/Blast Aspects	Siting Suitability
C	Deeply weathered. Locally, to 200'. Outcrops are misleading as cavities may be just below surface. Clay fillings common along joint surfaces.	NA	No active quarries in limestone; hardness of cliff edges suggests sound, tough limestone, however.	Probably adequate, esp. where fresh. Near eastern edge, clay content may reduce aggregate potential.	Requires drill, blasting except where limestone is deeply weathered; there, rippable.
					Good for most structures. Larger structures require deep core holes. Cavities are very common but without surface evidence. Uneven subsidence likely where foundations rest on mixed shale/limestone, esp. eastern areas of unit. Ground water table not a problem. Heavy rains disappear quickly in limestone terrain.

DATA TABLE I					
Map Unit	R O C K	T Y P E			
	Classification	Composition	Grain Size	Color	Variations, including dissection, in area
3	Igneous	Granite	Medium to coarse Veins of quartz common near mine shaft.	Gray, to pink and black	Densely dissected. Forms hilly slopes with narrow steep ravines; bouldery streambeds. Contact with adjacent rock units is buried beneath alluvium (see map).
DATA TABLE II					
S T R U C T U R A L			C H A R A C T E R I S T I C S		
Type of Layering	Thickness	Strike/Dip	Joints/Faults	Seismic Aspects	Water Potential
A	Crudely layered, especially on smaller knobs south and west of main area	NA	As shown on map. Most evident near mine/fault contact.	Granite appears strongly jointed. Joints trend N10°-15° East.	Excellent except in area near fault. Penetration devices will fail to penetrate water. Shallow wells more productive than deeper wells.
					Poor except along fault. However, if areas of densely jointed granite can be found, yields may exceed 100gpm. Mine (abandoned) could provide large sources of mineralized ?
DATA TABLE III					
E N G I N E E R I N G			C H A R A C T E R I S T I C S		
Weathering Aspects	Swelling Data	Abrasion Data	Aggregate Suitability	Drill/Blast Aspects	Siting Suitability
A	Sporadic and very irregular in depth. South slopes most deeply weathered. Fault probably deeply weathered.	NA	Finer grained zones should produce low abrasion losses.	Finer grained granite zones provide excellent aggregates	Requires drilling/blasting. Near fault excessive overbreak is likely. Where layered, granite will not provide difficulty.
					Underground openings ought to open only on North slopes (less weathered). Lack of adequate ? topographic relief (maximum 600') and narrowness of divides may preclude use for major underground sites. Load-bearing capability usually excellent for all structures.

Figure A-6. Example of Data Table with three Map Units. Note upper left hand corner; three separate Map Units (1, 2, 3) are indicated. The letters (A, B, C) are Ratings. Note that each Map Unit has three Geology Data Tables: Rock Type, Structural Characteristics, Engineering Characteristics.

d. Rock Composition: The more common field terms will be used in column three. These terms include granite, limestone, sandstone, gravel, etc.

e. Rock Grain Size: Only the most common field terms are to be used and shown in column four. Such terms as fine-, medium-, or coarse-grained will be used.

f. Rock Color: There is no need for precise soil chart color description. Recommend use of simplest terms only, such as white, gray, red, brown, etc.

g. Rock Variations, including dissection variations in region: In column six of Data Table I, describe the briefest terms variations of Rock composition that, because of the small area involved, do not warrant listing under another map unit identification number. For instance, a limestone unit underlying a large area may have portions that are distinctly different in stream dissection patterns; their small size do not warrant breaking out into another map unit. Hence, the entire map unit is limestone and under the column headed, Rock Variations, the differences will be described.

2. Geology Data Table II (Figure A6)

a. The purpose of this table is to provide data that describe the structural characteristics of the map unit. Note that a subjective evaluation of the structural characteristics of the map unit is given in the map unit identification column. The basis for this evaluation is as follows:

RATING

BASIS FOR RATING

A, B,
or C

Consideration of all listed structural data. (The analyst's overall experience is paramount in this evaluation.) If the data for a given map unit indicates a superior unit (less structural defects) than for another map unit, the unit is rated above that unit. Thus, the rating A, B, or C is subjective based on a map unit's position to other map units with regard to the dominance of structural characteristics in another map unit. Note that a map unit having more structural defects than another can, however, have a different engineering classification.

b. Type of Layering: In column two show the bedding, layering, or physical nature of the map unit with respect to its top and bottom. Use the most common field terms, e.g. bedded, dikes, massive, etc.

c. Thickness of Unit: In column three show the thickness (in meters) of the map unit, when it can be determined. If thickness cannot be determined, e.g. a granite map unit, place a question mark (?) to indicate unknown.

d. Strike and Dip of Unit: In column four show average strike and dip readings for the map units where applicable. If significant variations occur in a given map unit, describe briefly these variations, e.g. "N 10° E (avg.) except N 35° E (avg.) in southwest."

e. Joints and Faults in Unit: Describe in column five those faults or fractures that warrant description. However, only major (regional) faults should be referenced. Joint sets in bedrock (more than one prevailing direction of joints) should be listed also. Deterioration or weathering of the faults or joints should be described below (see Weathering). Use averages for directional data of joints.

f. Seismic Aspects of Unit: In column six briefly describe known or inferred seismicity potential of the area underlain by the map unit. For instance, if the terrain (map unit) is underlain by cavernous rock, this rock type would inhibit transmission of seismic energy. Hard or igneous rock types, unless badly faulted, ought to have sound or good energy transmissibility.

g. Water Potential: Where data for depths to the water table, quality of the surface or ground waters, or quantities expected are known, show these in column seven. Where not known, estimate and list in column seven.

3. Geology Data Table III (Figure A6)

a. The purpose of this table is to provide data that describe the engineering characteristics of the map unit. Note that a subjective evaluation of the engineering characteristics of the map unit is given in the map unit identification column. The basis for this evaluation is discussed above (see Geology Data Table II).

b. Weathering Aspects: In column two, briefly describe in general terms, e.g. deep, poor, muddy, soft, etc., the character of the rock deterioration. If weathering is confined to joints or to faults, it should be so stated. However, weathering usually applies to the entire map unit. Hence, describe depths, products that result (stony soils locally), or significant soils that have resulted.

c. Swelling Data: This engineering data usually cannot be estimated. Unless engineering reports are available that give laboratory data, complete column three with a question mark. Sometimes, map units consisting of thick clays or certain shales will swell when excavated; if suspected, so indicate. If the data is given in numerical form, use it with a descriptor, e.g. "Poor."

d. Abrasion Loss: Where loss data is known (from an engineering report), list it in column four. Estimates of probable losses are possible for many rock types. Grain size is a useful indicator: the coarser the grain size, the more likely is the rock type to have a higher abrasion loss when crushed. Use only the most general terms unless precise data is available. Where data are not available, use a question mark (?).

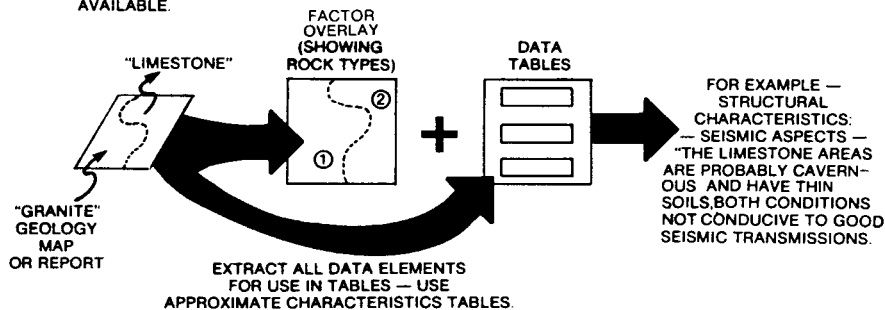
e. Aggregate Suitability: In column five, use only the most common terms, e.g. good, poor, excellent, to describe the known or estimated suitability of the map unit Rock composition for aggregate purposes. The chief criteria is, are there any known or suspected conditions (minerals, weak cementing materials) that would cause the rock, when crushed, to create concrete deterioration? This column data also includes estimates of the map unit rock type's crushing characteristic. If the rock is otherwise sound for aggregate use but tends to become rounded during transportation to the cement/concrete plant, this reduces its acceptability.

f. Drill/Blast Aspects: In column six briefly describe known or suspected drilling and blasting characteristics of the map unit rock type. Consider depth to hard or sound bedrock, overblasting aspects, expectancy of soft or broken rock at depth, need to drill and blast (unit may be excavable by power equipment), etc.

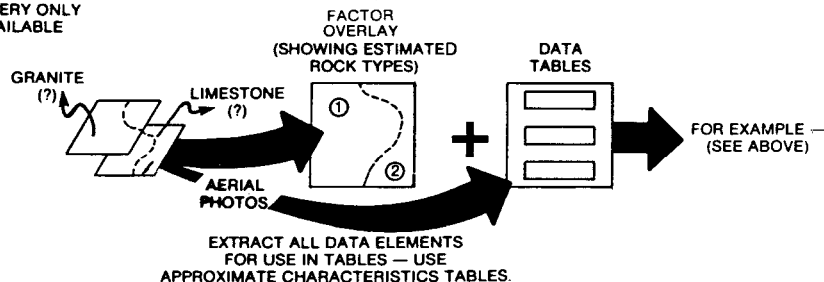
g. Siting Suitability: In column seven consider problems of foundations for various surface (buildings) and subsurface (ammo igloos, guerilla hideouts, storage depots) structures. Consider importance of the water table, stability of open excavations, differential settling, cavernous conditions, etc. Use brief descriptions.

For a graphic portrayal of the flow involved in Factor Map Preparation (Geology), including use of overlays and Data Tables, see Figure A-7.

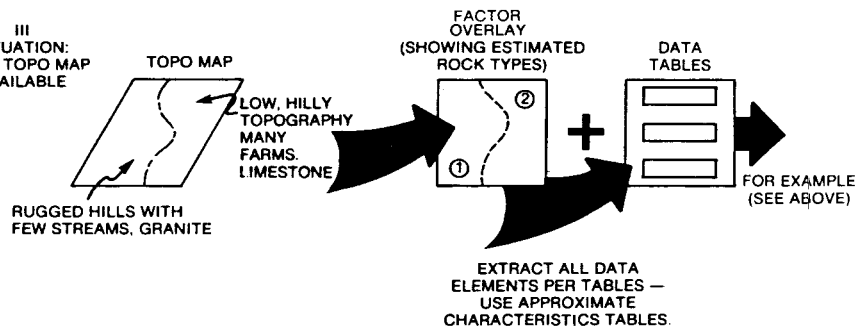
I
SITUATION:
GEOLOGY MAP OR REPORT
AVAILABLE.



II
SITUATION:
IMAGERY ONLY
AVAILABLE



III
SITUATION:
ONLY TOPO MAP
AVAILABLE



AFTER AN ENTRY IS MADE FOR AS MANY DATA ELEMENTS AS CAN BE DETERMINED, THE ANALYST COMPLETES THE MISSING DATA ELEMENTS IN THE THREE DATA ELEMENT TABLES BY INTERPRETATION OF THE RECORDED DATA USING THE APPROXIMATE CHARACTERISTICS TABLES. FOR INSTANCE, IF BASALT BEDS OCCUR IN THE AREA, "DRILLING AND BLASTING WILL BE NECESSARY," ETC. AS SUGGESTED BY THE APPROXIMATE CHARACTERISTICS TABLES. THEN, A SUBJECTIVE EVALUATION (DISCUSSED LATER) MUST BE MADE TO ASSIGN A LEGEND FOR THE FINAL MAP UNITS USED ON THE FACTOR COMPLEX MAP.

(*SEE APPENDIX A)

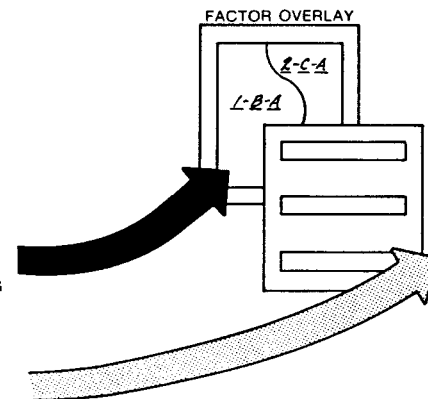


FIGURE A-7. Sketch Showing Three Situations

APPENDIX B1

FEDERAL MAP AND DOCUMENT SOURCES

United States Geological Survey
Library
Newton Square East
Reston, VA 22090

Defense Intelligence Agency
ATTN: DS4A
Arlington Hall Station
Washington, D. C. 20301

Defense Mapping Agency
ATTN: ESSG
6500 Brooks Lane
Washington, D. C. 20315

Library of Congress
Geography and Map Division
Washington, D. C. 20540

National Geographic Society
17th and M Streets, NW
Washington, D. C.

Soil Conservation Service, USDA
Cartographic Division, Federal Building
Hyattsville, MD 20783

National Archives and Records Service
Cartographic Archives Division
General Services Administration
Washington, D. C. 20408

Tennessee Valley Authority
Map Information and Records Unit
Maps and Surveys Branch
101 Haney Building
Chattanooga, TN 37401

APPENDIX B2

SOURCES OF AERIAL IMAGERY

U.S. Government Agencies

Aerial Photography Field Office

Agricultural Stabilization and Conservation Service
Department of Agriculture
Western Laboratory
2505 Parleys Way
Salt Lake City, Utah 84109 (Source for all states)

Defense Intelligence Agency
ATTN: DIAAP-10
Washington, D. C. 20315

Worldwide survey photography held by DMATC
6500 Brooks Lane
Washington, D. C. 20335

Bureau of Land Management
Department of Interior
Washington, D. C. 20240

Cartographic Archives Division
National Archives (GSA)
Washington, D. C. 20408

EROS Data Center
U.S. Geological Survey
Sioux Falls, South Dakota 57198

National Cartographic Information Center (Headquarters)
Geological Survey
Department of Interior
Reston, VA 22090

NCIC-Mid-Continent
USGS, 1400 Independence Road
Rolla, Missouri 65401

NCIC-Rocky Mountain
USGS, Topographic Division
Stop 510, Box 25046
Denver Federal Center
Denver, Colorado 80225

NCIC-Western
USGS, 345 Middlefield Road
Menlo Park, California 94025

National Ocean Survey
Department of Commerce
Washington Science Center
Rockville, Maryland 20852

Soil Conservation Service
Department of Agriculture
Federal Center Building
East-West Highway and Belcrest Rd.
Hyattsville, Maryland 20781

Tennessee Valley Authority
Maps and Surveys Branch
210 Haney Building
Chattanooga, Tennessee 37401

EASTERN U.S. FOREST SERVICE PHOTOGRAPHY

Chief Forest Service
U.S. Department of Agriculture
Washington, D. C. 20250

WESTERN U.S. FOREST SERVICE PHOTOGRAPHY

Region

- 1 Federal Building, Missoula, MT 59801
- 2 Federal Center, Building 85, Denver, CO 80025
- 3 Federal Building, 517 Gold Ave. SW, Albuquerque, NM 87101
- 4 Forest Service Building, Ogden, UT 84403
- 5 630 Sansome St., San Francisco, CA 94111
- 6 P.O. Box 8623, Portland, OR 97208
- 10 Regional Forester, U.S. Forest Service, P.O. Box 1628, Juneau, AK 99801

Technology Application Center
The University of New Mexico, Code 11
Albuquerque, New Mexico 87131

State Agencies

Arizona Highway Department
Administrative Services Division
206 South 17th Avenue
Phoenix, Arizona 85007

State of Arkansas Highway Department
Surveys, 9500 New Denton Highway
P.O. Box 2261, Little Rock, Arkansas

State of Nebraska
Department of Roads
14th & Burnham Streets
Lincoln, Nebraska 68502

State of Ohio
Department of Highways
Columbus, Ohio 43216

Oregon State Highway Division
Salem, Oregon 97310

Virginia Department of Highways
Location and Design Engineer
1401 East Broad Street
Richmond, Virginia 23219

State of Washington
Department of Natural Resources
600 North Capitol Way
Olympia, Washington 98501

Southeast Michigan
Council of Governments
1249 Washington Boulevard
Detroit, Michigan 48226

Illinois Department of Transportation
2300 South - 31st Street
Springfield, Illinois 62734

Southeastern Wisconsin Regional Planning Commission
916 North East Avenue
Waukesha, Wisconsin 53186

Wisconsin Department of Transportation
Engineering Services
4802 Sheboygan Avenue
Madison, Wisconsin 53702

Indiana Highway Department
608 State Office Building
Indianapolis, Indiana 46204

Commercial Firms

Aerial Data Service
10338 East 21st Street
Tulsa, Oklahoma 74129

Aero Service Corporation
4219 Van Kirk Street
Philadelphia, Pennsylvania 19135

Air Photographics Inc.
P.O. Box 786
Purcellville, Virginia 23132

Alster and Associates, Inc.
6135 Kansas Avenue, NE
Washington, D. C. 20011

Ammann International Base Map & Air Photo Library
223 Tenth Street
San Antonio, Texas 78215

Burlington Northern Inc.
650 Central Building
Seattle, Washington 98104

Cartwright Aerial Surveys Inc.
Executive Airport
6151 Freeport Boulevard
Sacramento, California 95822

H. G. Chickering, Jr.
Consulting Photogrammetrist, Inc.
P.O. Box 2767
1190 West 7th Avenue
Eugene, Oregon 97402

Fairchild Aeromaps Inc.
14437 North 73rd Street
Scottsdale, Arizona 85254

Grumman Ecosystems Corp.
Bethpage, New York 11714

Henderson Aerial Surveys Inc.
5125 West Broad Street
Columbus, Ohio 43228

L. Robert Kimball
615 West Highland Avenue
Ebensburg, Pennsylvania 15931

Lockwood, Kessler & Barlett, Inc.
One Aerial Way
Syosset, New York 11791

Mark Hurd Aerial Surveys, Inc.
345 Pennsylvania Avenue South
Minneapolis, Minnesota 55426

Merrick and Company
Consulting Engineers
2700 West Evans
Denver, Colorado 80219

Murry - McCormick
Aerial Surveys Inc.
6220 24th Street
Sacramento, California 95822

Photographic Interpretation Corporation
Box 868, Hanover, New Hampshire 03755

Quinn and Associates
460 Caredean Drive
Horsham, Pennsylvania 13044

Sanborn Map Company, Inc.
P.O. Box 61
629 Fifth Avenue
Pelham, New York 10803

The Sidwell Company
Sidwell Park
28W240 North Avenue
West Chicago, Illinois 60185

Surdex Corporation
25 Mercury Boulevard
Chesterfield, Missouri 63017

Teledyne Geotronics
725 East Third Street
Long Beach, California 90812

United Aerial Mapping
5411 Jackwood Drive
San Antonio, Texas 78238

Walker and Associates Inc.
310 Prefontaine Building
Seattle, Washington 98104

Western Aerial Contractors, Inc.
Mahlon Sweet Airport - Route 1, Box 740
Eugene, Oregon 97401

APPENDIX B3
SOURCES OF GROUND IMAGERY

U.S. Army Imagery Interpretation Group
Bldg. 213, Washington Navy Yard
Washington, D. C.

Defense Intelligence Agency
ATTN: RPP-3
Washington, D. C. 20301

U.S. Army DARCOM Service Support Activity
Audio-Visual Presentations Division
Room 1C13, Pentagon
Washington, D. C.

Canada

National Air Photo Library
Surveys and Mapping Building
615 Booth St.
Ottawa, Canada K1A 0E 9

APPENDIX C

SUPPLEMENTARY REFERENCES

Remote Sensing

Manual of Remote Sensing, 2 Volumes, 1975; American Society of Photogrammetry, 105 N. Virginia Ave., Falls Church, Virginia 22046.

-The definitive single source reference on all aspects of remote sensing.

The Surveillant Science - Remote Sensing of the Environment; Robert K. Holz, editor; 1973, Houghton Mifflin Co., Boston, Mass.

- The collection of selected articles by various authors related to remote sensing technology.

Remote Sensing - A Better View; Robert D. Rudd; 1974, Duxbury Press, a division of Wadsworth Publishing Company, Inc., Belmont, California.

- An excellent basic text on the purposes and methods of remote sensing.

Remote Sensing of Earth Resources - 1972; Committee on Science and Astronautics, U.S. House of Representatives; U.S. Government Printing Office, Washington, D. C. 20402 (\$1.25)

- A compilation of Papers prepared for the 13th meeting of the Panel on Science and Technology.

Remote Sensing with Special Reference to Agriculture and Forestry; 1970; Committee on Remote Sensing for Agricultural Purposes, Agricultural Board, National Research Council; National Academy of Sciences, Washington, D. C. 20418

Remote Sensing: Techniques for Environmental Analysis; John E. Estes and Leslie W. Senger, Editors; 1974; Hamilton Publishing Company, Santa Barbara, California.

- A good collection of selected papers on the principles and applications of remote sensing technology.

Photointerpretation

Manual of Remote Sensing, 2 Volumes; 1975; American Society of Photogrammetry, 105 North Virginia Ave., Falls Church, Virginia 22046.

Aerial Discovery Manual; Carl H. Strandberg; 1967; John Wiley & Sons, Inc., New York, NY.

Interpretation of Aerial Photographs (2nd Edition); T. Eugene Avery; 1968; Burgess Publishing Company, 426 South Sixth Street, Minneapolis, Minn. 55415.

Aerial Photographic Interpretation; Donald R. Lueder; 1959; McGraw-Hill Book Co., Inc., New York, NY.

Aerial Photo Interpretation; G. B. Sully; 1970; Bellhaven House Ltd., Scarborough, Ontario, Canada.

APPENDIX D

GLOSSARY OF GEOLOGICAL TERMS

Only the most common geological terms are listed. Many of the terms are not used in this report.

Abrasion hardness - measured generally as the portion by weight of material worn away - principally by the Dorry (U. S. Department of Agriculture, 1916) test for whole rock, but also by the Taber, Deere and Miller, A.S.T.M. C 418, and other methods; principally by the Los Angeles test machine but also by the Deval, Burbank, and other methods for aggregate (Deere and Miller, 1966).

Absorption - a measure of the maximum amount of water that a material will absorb into its pores when submerged.

Accessory minerals - minor minerals more or less common overall as rock constituents but not critical to the rocks in which they occur.

Accretions - concentration of minerals in rocks chiefly by external growth into modules, crystal clusters, and similar forms as a result of precipitation from percolating solutions.

Acidic rocks - igneous rock high in silica and containing considerable feldspar and appreciable amounts of free silica (quartz); generally light colored and low in density.

Active zone - the zone situated above permafrost characterized by alternating freeze and thaw; generally the most important zone for engineering operations at ground level, such as road building, foundations, and quarrying.

Aggregate - crushed rock or soil used in a mix with cement or asphalt to form asphalt-macadam or concrete. May be fine, as sand, or coarse, as gravel.

Alkali flat - same as a Playa, a dry lake. These ancient silt and clay beds can be used as emergency airfields if the surface bearing strengths are adequate.

Alluvial fan - A fan-shaped deposit, commonly developed at the mouth of a canyon, ravine, or gorge. Commonly characterized by coarse materials, principally gravel.

- Alluvium - A general term for materials deposited by running water. Gravel, silt, clay, either sorted or mixed. Usually unconsolidated. Where consolidated, can be tough enough to require blasting. Common source of ground water.
- Alteration - in its broad sense, any change in a rock after it is deposited or emplaced, but usually excluding diagenetic (formative) changes in pre-consolidation stages, such as compaction and cementation.
- Angular - Useful term for rock materials having a sharp breaking surface.
- Artesian water - When ground water encountered in a drilled well rises above the surface of the ground or the top of a drilled well, it is under pressure and is termed Artesian.
- Asphalt film stripping - a measure of the degree of failure of bituminous binder to adhere to the surface of particles of a particular rock used as aggregate, owing to surface moisture, polish, and other causes.
- Attitude - the inclination of a line or planar surface such as a fold axis or bedding plane, in relation to a horizontal datum, and its compass bearing; measured by dip and strike, or plunge and bearing.
- Authorized rock list - see separate attachment.
- Axial plane - a plane containing the axis of a fold and bisecting the fold longitudinally as symmetrically as possible.
- Axis - a line representing the crest of a fold at a constant stratigraphic level. The attitude is measured by plunge and bearing.
- Badlands - Excessively eroded terrain, usually underlain by poorly consolidated materials. Cross country movement is extremely difficult, even on foot. Coarse materials seldom occur; mostly finer-grained silt, clay, shale. Usually in arid regions.
- Ballast - crushed rock or gravel laid down to solidify a natural surface and aid in grading, especially on a railroad bed to keep the ties in place.
- Banding - subparallel layers of different textures, colors, or minerals; often applied to igneous and metamorphic zonation by crystal settling, plastic flowage, and injection as well as from bedding carryovers.
- Basalt - Useful general term for fine-grained, dark igneous rocks. Commonly jointed. Usually difficult to drill and shoot.

Base course - crushed rock or gravel generally laid on a scrapped natural surface to distribute the load and provide drainage below the surface course.

Basic rocks - igneous rocks low in silica and containing no free silica but appreciable amounts of feldspathoid, feldspar, and ferromagnesian minerals; generally dark-colored and high in density.

Bearing strength - the resistance of a rock or soil in its natural occurrence to deformation and ultimately rupture by a load placed on it, as of a building, bridge pier, dam, or other structure. The "usable" bearing strength is measured as the load (pressure) at which deformation is only a few percent (<5).

Bed - A general term for a rock unit differing from the rock unit above or below. Signifies layering, usually in sedimentary rocks.

Bedding - the layers in which a sediment or rock of sedimentary or volcanic origin was deposited, commonly reflecting differences in grain-size, mineral composition, or grading.

Bedrock - common, but useful, field term for hard rock in place. When a drill or a piling "takes up," it usually means bedrock is encountered. Can be viewed as the top of relatively hard, unweathered rock below the zone of weathering overlying materials, or where significant changes in physical properties of the materials occurs. Drill holes may show, however, the "bedrock" is merely a hard bed or zone beneath which occurs softer materials.

Binder - fine material, such as silt or clay, added to coarser material, such as sand or gravel, to enhance the overall cohesiveness of the mass.

Break planes - any planes of weakness along which a rock tends to or is relatively easy to separate. In quarrying, the rift is the direction of greatest ease, the grain is intermediate, and the hard way is the direction (or directions) of most difficult separation, generally structureless.

Building stone - a general term for stone quarried and dressed for use as masonry blocks (dimension stone), for roofing, or for facing and ornamentation.

Cavern - openings in rocks, usually of large size, often below ground and caused by ground water solution of limestone rock. If a cave falls in, the opening at the surface is termed a Sinkhole.

- Cement - material precipitated from solution or suspension into the pores or interstices of a rock, generally a sedimentary rock.
- Cemented - when a medium- a coarse-grained (sandstone, is the best example) has been hardened so that it breaks with difficulty, it is termed, cemented. However, even a soft rock can be cemented if the principal components are held together by another material.
- Characterization - convenient and recognized though often ill-defined or imprecise geological terms with which rock assemblages may be labeled, such as "basement complex," "crystalline basement," "crystalline complex," "flysch," "molasse," and "cyclothem."
- Clastic - applies to sedimentary rocks such as sandstone and shale consisting of fragmental material derived from pre-existing rocks, generally transported mechanically (as by streams) to the site where deposited.
- Color - representable quantitatively by letter and number for hue (color proper), lightness (degree of gray), and saturation (depth of color) as outlined by the Rock Color Chart Committee established by various geological organization (Goddard, 1948).
- Conglomerate - coarse to extremely coarse gravel, boulders, cobbles. Can be a cemented formation (conglomeratic sandstone). The word connotes size and usually degree of rounding of constituents. Can be a source of ground water because of porous character.
- Consolidation (revised) - the complex of processes, from diagenesis through hydrothermal alteration to metamorphism, by which a newly deposite sediment is converted to rock or a soft rock is hardened; generally begins with compaction by weight of overlying rocks and cementation by precipitates from solutions.
- Contact metamorphism - localized metamorphism of rocks at and near the contacts of igneous rocks, brought about largely by heat and thermal fluids.
- Coquina - Commonly thought of as "soft limestone," this collection of broken shells, and other calcareous matter, can be extremely tough. Some islands underlain by coquina have to be drilled and blasted to excavate this "soft" rock. When pulverized, coquina makes suitable aggregate materials, unless tests show it to be too soft.
- Damping - the quality of reducing vibrations in a medium and thereby absorbing rather than transmitting shock energy.

Dendritic drainage - the tree-like skeletal pattern of regional drainage.

Density - ratio of the weight of a body to its volume; if pore spaces are unoccupied, it is the dry unit weight and if filled with water, the saturated unit weight. Normally bulk density, unless void space is specifically compensated for to define grain density.

Dielectric - relating to the degree of electron, ionic, or molecular polarization induced by an electric current. Reflects the mineral content and water-bearing characteristics of a rock.

Dikes/veins - roughly tabular bodies of igneous rock that cut across bedding or other layering in rocks; when formed from late or telemagmatic fluids, termed a "vein," and where parallel to such structure, a "sill."

Dip - term indicating the angle from the horizontal that a rock surface is inclined. If a bed "dips" this means it is inclined from the horizontal so many degrees (usually stated by a symbol on a geological map).

Displacement - the extent of separation and direction of relative movement of two formerly continuous rock or soil masses along a fault.

Drillability - the ease with which a rock can be drilled. Involves resistance to indentation, abrasion, crushing, and shear stress, etc. Only in part an index of hardness; in rotary drilling, chiefly compressive and shear forces are operative, and only secondarily abrasive forces.

Effusive - designating an igneous rock that solidified at the surface after eruption from a volcanic opening (lava).

Elastic strength - a measure of the resistance to change in size or shape upon application of static forces short of permanent deformation at the elastic limit.

Electrical resistivity - a measure of the resistance to transmission of an electric current. Often a diagnostic index of water-bearing characteristics of a rock.

Essential mineral - a rock-forming mineral, one whose presence is more or less implied by the basic rock name: chiefly quartz, feldspar, pyroxene, amphibole, mica, salt (halite), gypsum, anhydrite, serpentine, chlorite, olivine, feldspathoid, calcite, dolomite, chalcedony (chert, jasper) glass, kaolin (and other clays), carbon, and bitumen. Locally other minerals may assume major rock-forming proportions (e.g., soda niter, barite, bauxite, phosphorite, iron oxides, sulfur) but are not normally regarded as essential minerals.

Extrusive - a large series of igneous rocks that are extruded or forced into overlying formations such as to reach the surface. Their rapid ejection results in formation of fine to very fine grained textures.

Fabric - the spatial orientation of the grains, crystals, and fragments of which a rock is composed; c.f. foliation, lineation.

Facies - a lateral variation of a stratigraphic unit.

Fault - any fissure or fracture in rock (or indurated soils) along which some movement has occurred. If the rocks undergo grinding during this movement, they are termed, Breccia (Italian for Broken). Faults create problems for engineers: heavy buildings can settle unequally over a fault; broken rock, requiring extensive cement (termed, Grout) treatment, in foundations; loss of water in reservoirs, etc., not to mention the possibility of movement during an earthquake.

Fault plane - the contact between two rock masses along which movement has taken place. The movement may be reflected by grooves and ridges (mullion), striations and steps (slickensides), a crushed and polished zone (mylonite), clay (gouge), and other features.

Fill - large or small rock fragments or soil usable to build up depressions, roadbeds, embankments, stream dikes, and the like.

Filler - material used to build up the "body" of an aggregate but not essential thereto; generally should fall within the silt size range.

Fissure - in contrast to fractures, connotes isolated and/or irregular and generally extensive cracks in rock.

Floodplain - a strip of relatively smooth land bordering a stream, usually built up of sediment deposited by the stream during flood stages. Man commonly builds structures on floodplains that are subject to flash floods, settlement, variations in soils in foundations and severe earthquake damage. The materials are generally soils, although locally stony deposits are dominant.

Fold - a structural deformation of rock layers ranging from a broad flexure to a tight pleat in which the layers may be drastically reoriented and even, in extreme cases, overturned in one or both limbs.

Fold belt - a generally extensive and elongate area in which the geologic formations have been deformed into a group of folds with common characteristics and trends, usually of common origin.

Foliation - parallel arrangement of flat or tabular minerals forming planes of weakness along which rocks tend to separate into slabs or laminae. A fabric with major influence on the overall structure of a rock, ranging in metamorphics from coarse (gneissose) to fine (slaty) in character. Primary if of igneous or sedimentary origin, secondary if of metamorphic origin.

Fossil - any evidence of a previously living organism preserved in rock, sediment, or other material; may be preserved intact or as an imprint, cast, mold, track, trace, or fragment. Generally significant for engineering purposes only if three-dimensional, especially in major assemblages.

Fracture - any crack in a rock, but generally connotes parallel groupings, as of faults and joints forming sets and systems; fracture cleavage is extremely closely spaced and restricted to hard beds caught up in folding.

Fracture permeability - the capacity for transmitting a fluid through fractures. Thus, a nonporous rock such as granite may be nevertheless highly permeable.

Frost heave - disruption of a rock or soil by forces exerted in the alternate freeze and thaw of water in pores and fractures.

Geologic age - time of formation of a rock in relation to a distinctive chronology of geologic history based on dating by fossils. Successively shorter divisions and subdivisions are eons, eras, periods (rock systems), epochs (rock series), and ages (rock stages). A convenient method of representing age by a series of integers is outlined by the American Association of Petroleum Geologists (Cohee, 1967).

Geomorphic - relating to the characteristic topographic forms assumed by rocks by virtue of hardness, bedding, folding, faulting, and other properties as affected by weathering and erosion.

Geotectonic - structure of rock masses on a broad scale (see tectonic).

Glaciation - alteration of a landscape by passage of ice; involves sculpturing as well as debris-laying activity.

Graben/horst - a fault-formed and fault-bounded sunken/uplifted rock mass.

Grading - relates to the degree of variation in grain size, generally of a sediment or sedimentary rock. Poorly graded types have relatively little grain-size variation, and well graded types have relatively uniform distribution of grain sizes from coarse to fine. Not to be confused with scraping and other earth or rock moving construction activities, commonly also called grading.

Grain - a useful term to describe the individual particles (whether crystals or fragments) seen in a rock specimen.

Granite - a field term for igneous rocks, usually coarse-grained and light colored. Connotes hard, sound crystalline rock unless known to be badly broken, deeply weathered, or fractured.

Gravel - loose or unconsolidated granular material, larger than sand grains. If a deposit is mostly gravel, it can contain considerable water unless it has been cemented by impervious material. Commonly found in stream beds, terraces, and floodplains.

Ground water - water that is beneath the ground level. The Ground Water Table is the upper zone of saturation beneath the ground surface. Sometimes an impervious layer can trap water and cause a false Ground Water Table to occur beneath the surface; this is termed, a Perched G.W.T.

Hardness - in engineering, the degree of resistance to abrasion, indentation, and impact. Loosely, the degree of consolidation but also compressive, tensile, shear and elastic strength, or the like.

Hardpan - hardened soil layer, commonly found in arid regions, although many temperate regions have hardpan zones. Some zones are so hard a pick cannot penetrate them. Often these zones begin just beneath the ground surface.

Hydrothermal alteration - formation of new minerals, structures, and textures by the action of infusing hot solutions and fluids or molecular diffusion, generally of magmatic origin. If intensive, may be regarded as a partial or incipient metamorphism in which the original character of the rock is still evident. In extreme cases, passes into a low grade of metamorphism. The most common types of hydrothermal alternation, in some cases involving a whole host of secondary minerals, are as follows: argillization, albitization, carbonatization, epidotization, chloritization, garnetization, griesenization, uralitization, alunitization, propylitization, sericitization, serpentinitization, saussuritization, zeolitization, luxullianitization, axinitization, scapolitization, silicification, and tourmalinization.

Hypabyssal - designating an igneous rock, commonly fine- to medium-grained and inextensive, that solidified at relatively shallow depths below ground, often in a tabular (sills, dikes) or columnar (plugs) form.

Igneous - a class of rock solidified from a molten or semi-molten state. In some instance, may have formed by nonmolten processes, such as molecular diffusion and intimate solutional infusion.

Igneous rock - hot mobile rock material formed many kilometers beneath the earth's surface. These mobilized materials are entirely crystalline.

Indentation hardness - measured as the depth/area/diameter of indentation upon impact (short of failure by rupture), as by the Knoop, Ludwick, Brinell, Vickers, Rockwell (A.S.T.M. E 18), and Durometer (A.S.T.M. D 1706) tests (Deere and Miller, 1966).

Instrumentation - the extent to which mensural devices and apparatus, ranging from simple surveyor instruments such as compasses and alidades to sophisticated sensors and lab equipment such as radiometers and strength-testing machinery, are employed in obtaining quantitative geologic and engineering geologic data.

Intermediate rocks - igneous rocks moderately high in silica but containing little or no free silica, and little or no feldspathoid but considerable feldspar and ferromagnesian minerals.

Intermittent stream - a stream or creek that flows only part of the time.

Intrusive - designating an igneous rock that solidified below the surface after penetrating other rocks, as along fissures, bedding planes, etc. May have invaded and assimilated a vast volume of rock to form batholiths, stocks, and bosses.

Intrusive rock - a series of igneous rock that has been forced into surrounding rocks.

Joint - very common partings, usually vertical, in most rocks. Represent various stresses that the rocks have experienced. Joints are a serious engineering matter: ground water can percolate freely along joints; soils can develop deeply along joints; densely jointed bedrock produces overbreakage when blasted, etc.

Karst - term for landforms developed in limestone terrain where many depressions are formed, or irregular outcrops of ribbed limestone ledges occur, or other rough surface features are found because streams are almost nonexistent.

Landslide - perceptible downward and outward movement of earth or rock materials. Can be ancient and stable deposits without present day movement. Large blocks of bedrock can be triggered into movement when excavations remove the toes of certain mountainous areas.

Layer - a general term for the visible top and bottom of any rock unit.

Limb - the curved flank of a fold. A rough measure of steepness of that flank by dip can be made at the inflection level, where the direction of curvature reverses.

Limestone - a bedded sedimentary deposit consisting chiefly of calcium carbonate. Caves commonly formed in limestone terrain. Makes suitable aggregate unless tests show a peculiar tendency to recrystallize (causing road surfaces to become very slippery).

Lineation - the parallel arrangement of crystals and fragments in a rock; a fabric that may result in a tendency to separate into irregular elongated, fluted, or riffled pieces. Primary if of igneous or sedimentary origin, secondary if of metamorphic origin.

Magnetic susceptibility - a measure of the intensity of magnetization induced by a magnetic field. Can serve as an index of rock texture, orientation, and magnetite content.

Matrix - normally the bulk materials of a rock, in which large crystals or fragments may be embedded; var., groundmass.

Mechanical analysis - determination of the percentage by weight of each particle-size range of a sediment or friable sedimentary rock. The particle-size ranges vary according to the classification system used. The degree of grading or size variability is readily derivable from the analysis as a sorting index, of which the most common is that of Trask. The standard size-range terms for sedimentary rocks are clay: fine, medium, coarse; silt: fine, medium, coarse; sand: fine, medium, coarse; gravel: pebbles, cobbles, boulders (see Mechanical Analysis in Surface Materials glossary).

Metamorphic - igneous or sedimentary rock altered by heat, pressure, and solutions to a form, often foliated, in which the original characteristics are largely or totally destroyed; c.f. alteration.

Metamorphic rocks - rocks that have been altered or changed by pressure, time, overburden, or earth heat. Depending on the original materials, the rocks have a variety of types (Phyllite, schist, gneiss, etc.). Most outstanding aspect is a platyness or tendency to break along lines of weakness.

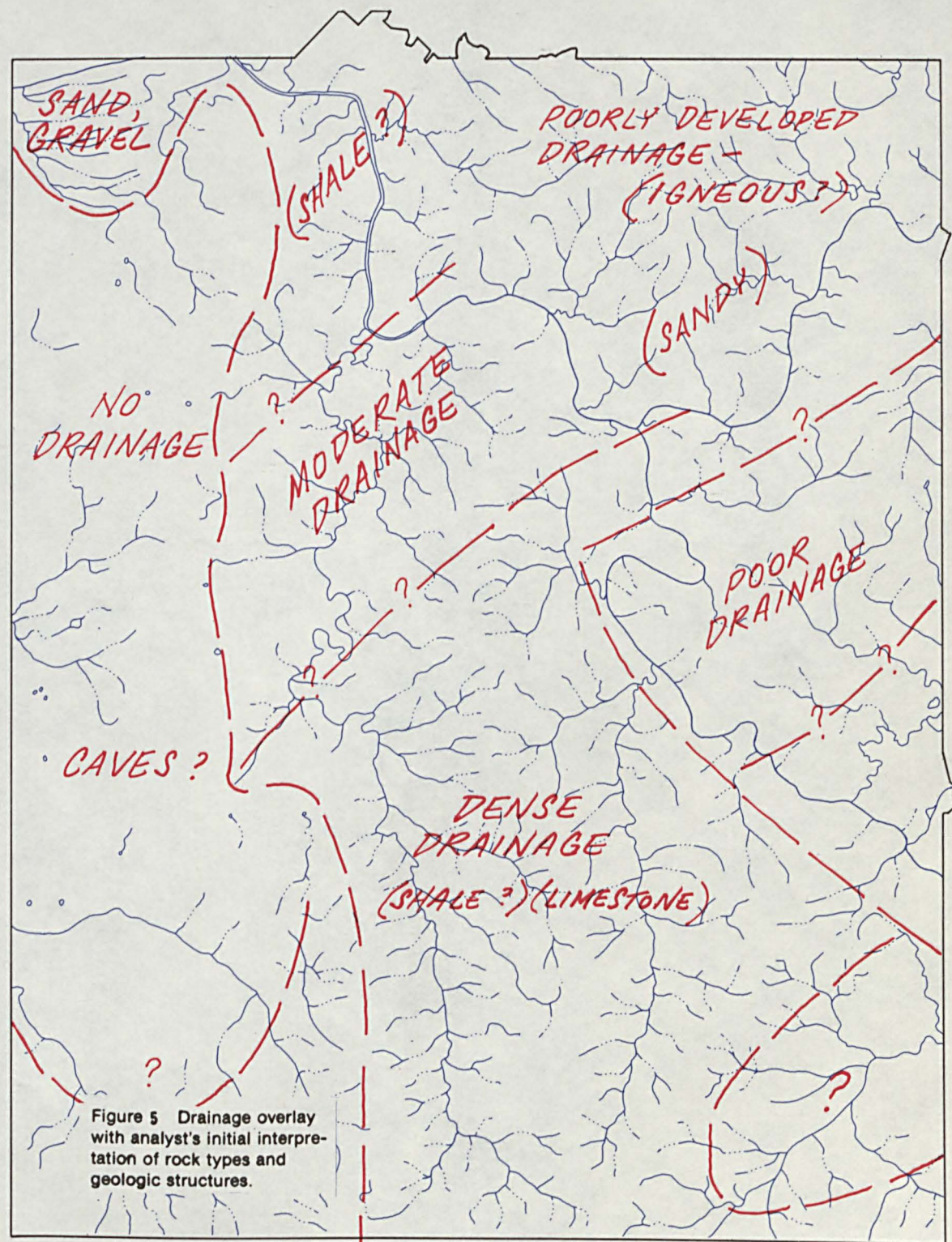
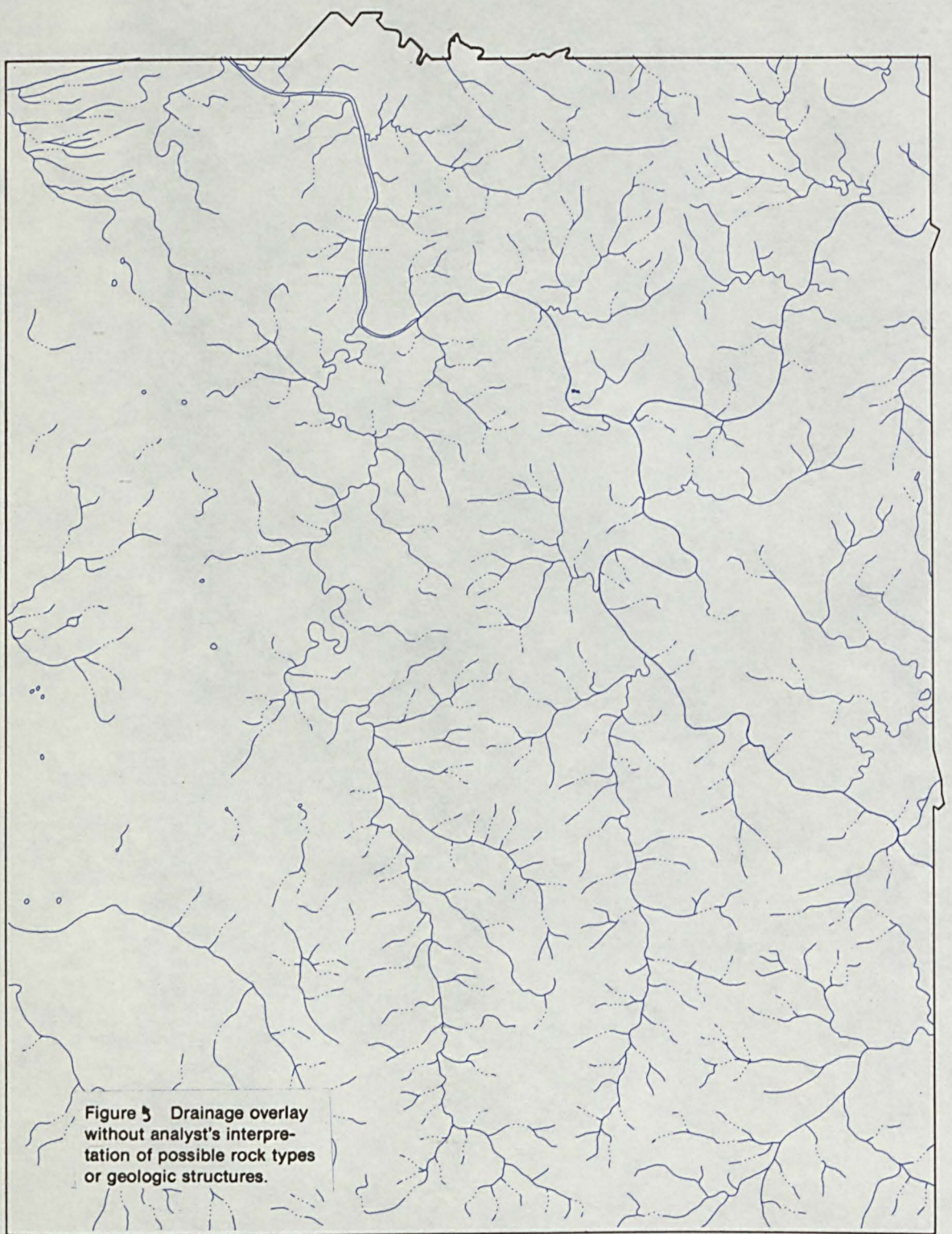
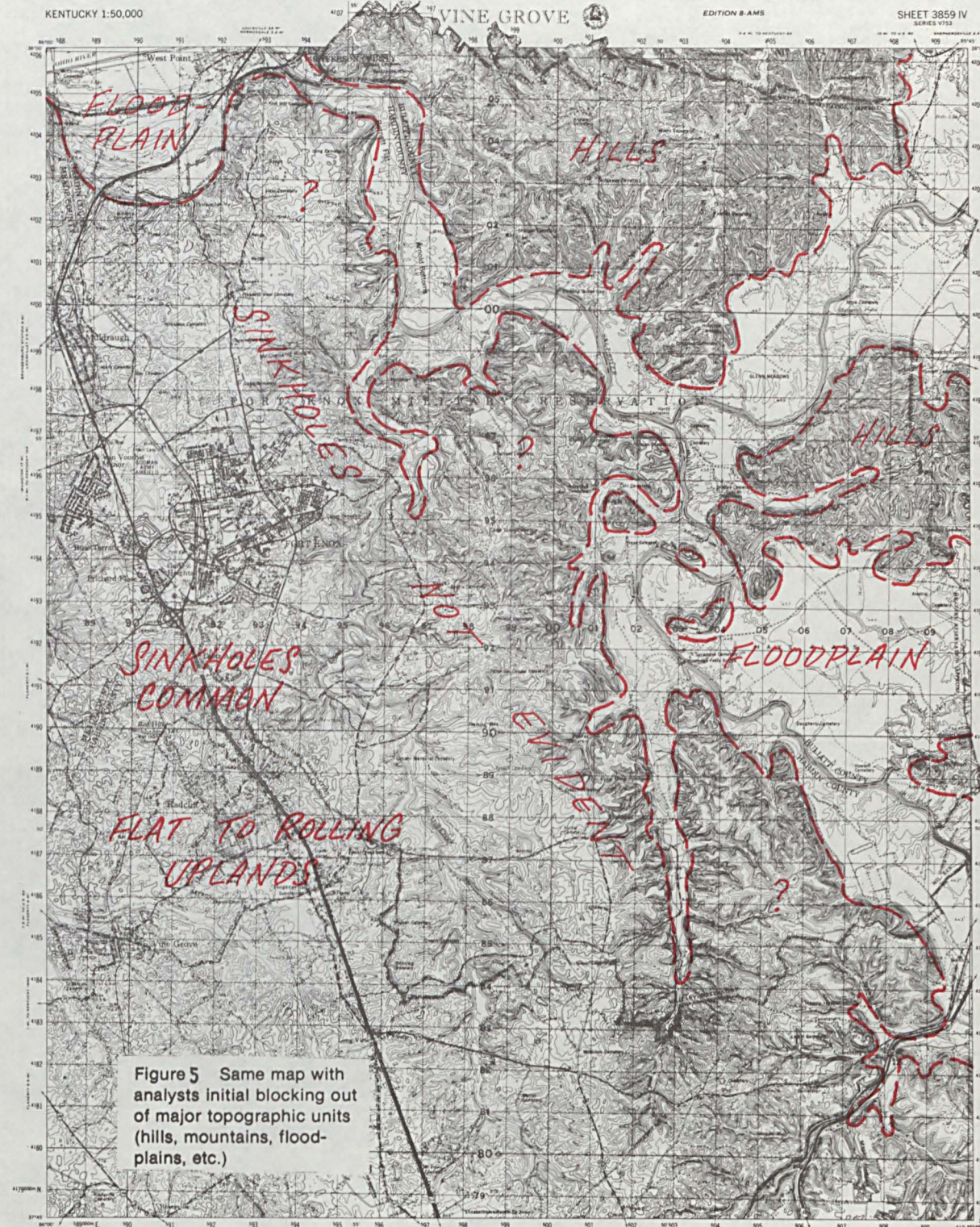
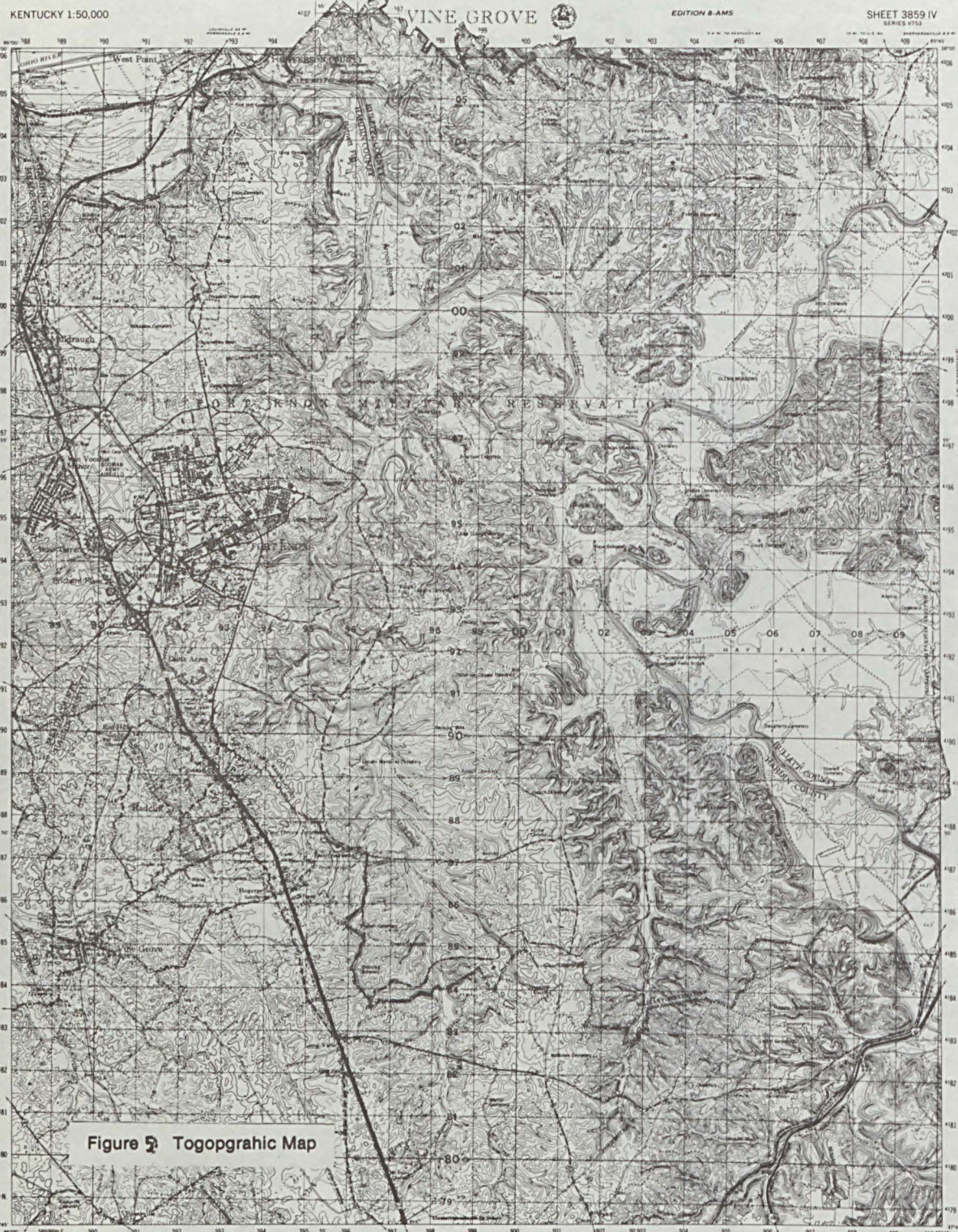
Nappe - either an extensive flap of an overturned and recumbent fold or an extensive slice of fault-overthrust rock lying on formerly adjoining rocks. Often both overfolding and overthrusting are involved.

Natural moisture content - a measure of the amount of water contained in a rock or sediment in its natural state.

Natural foundations - the naturally occurring rocks or soil surface on or in which structures are emplaced or materials such as surface or base courses are laid, often after grading operations.

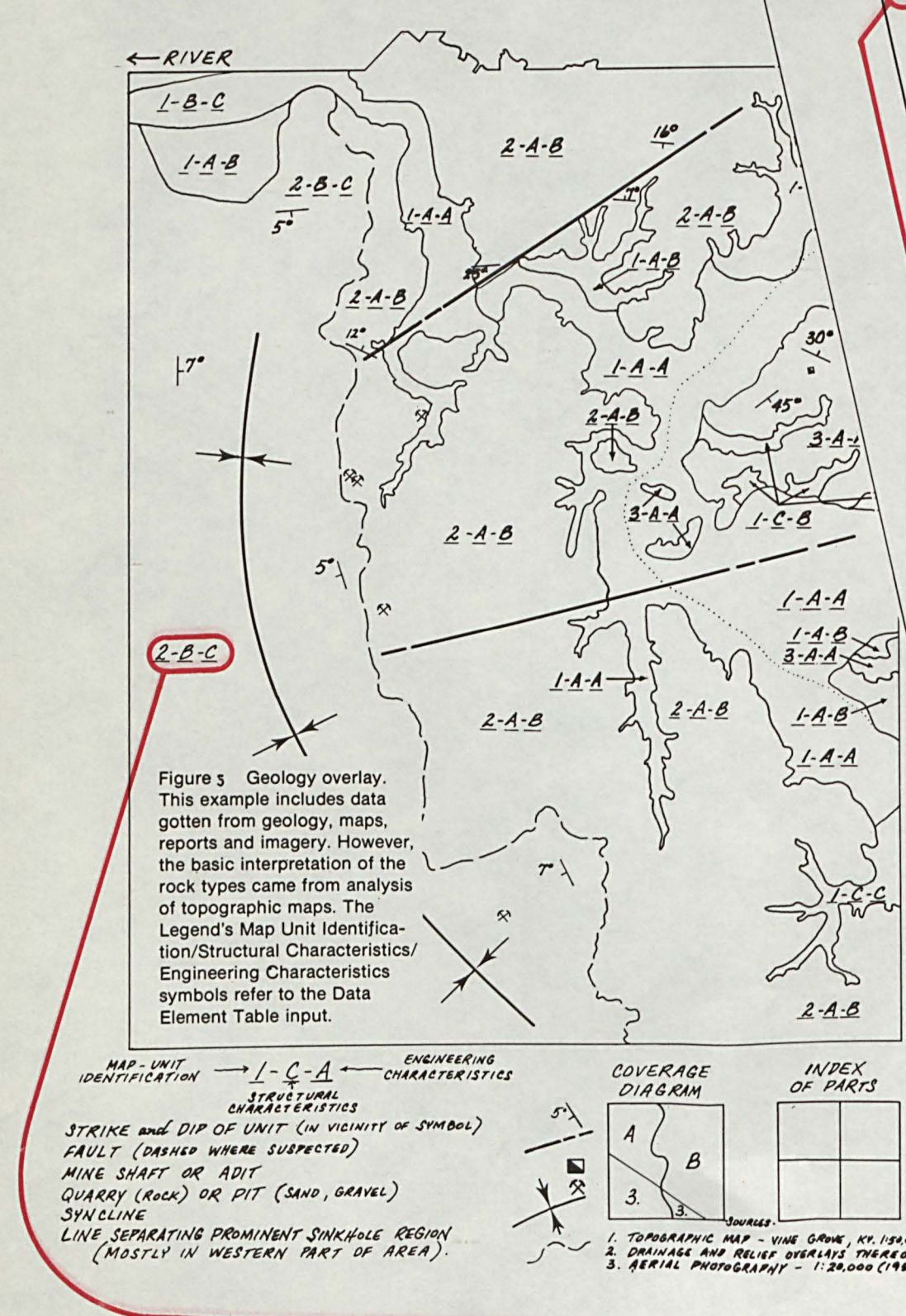
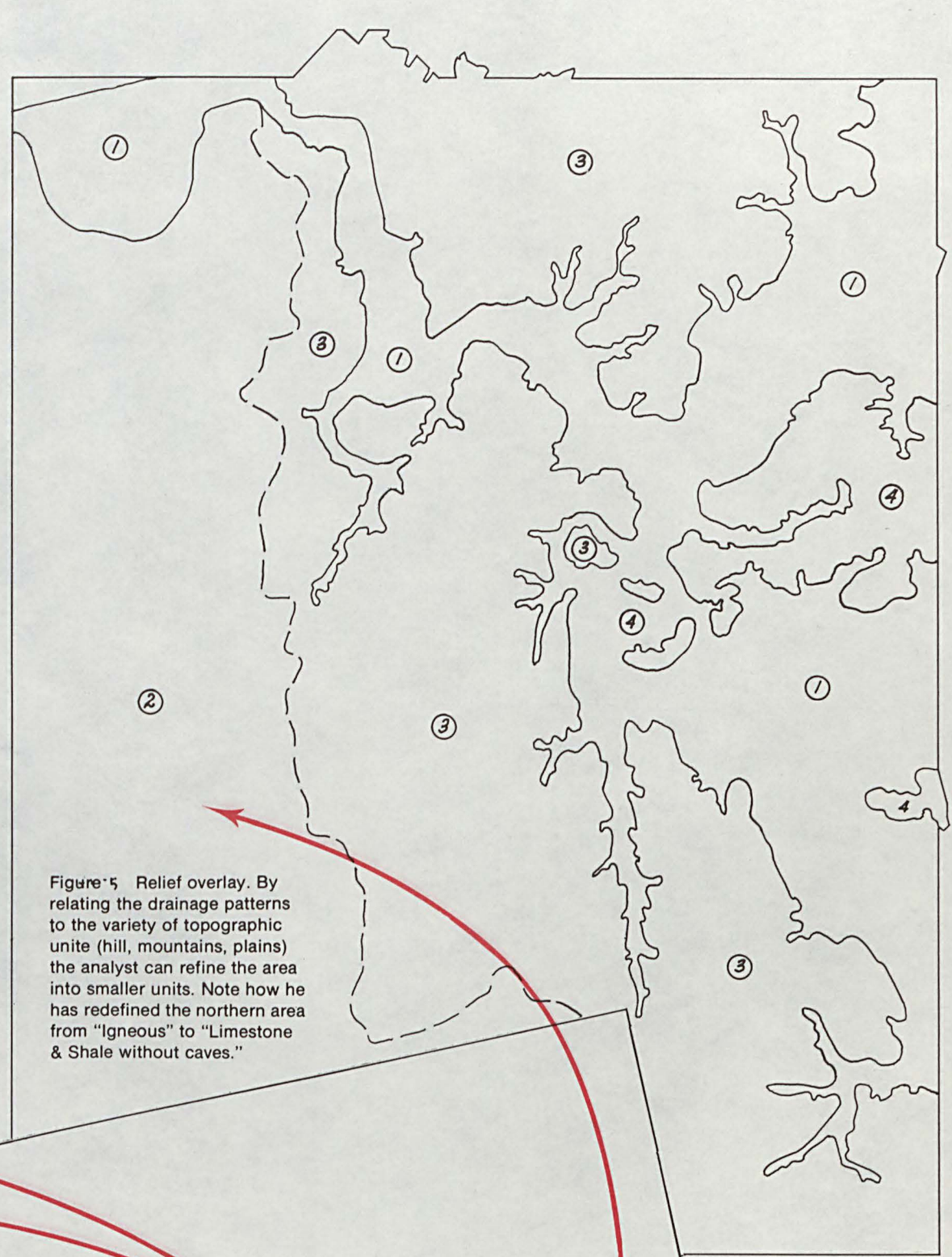
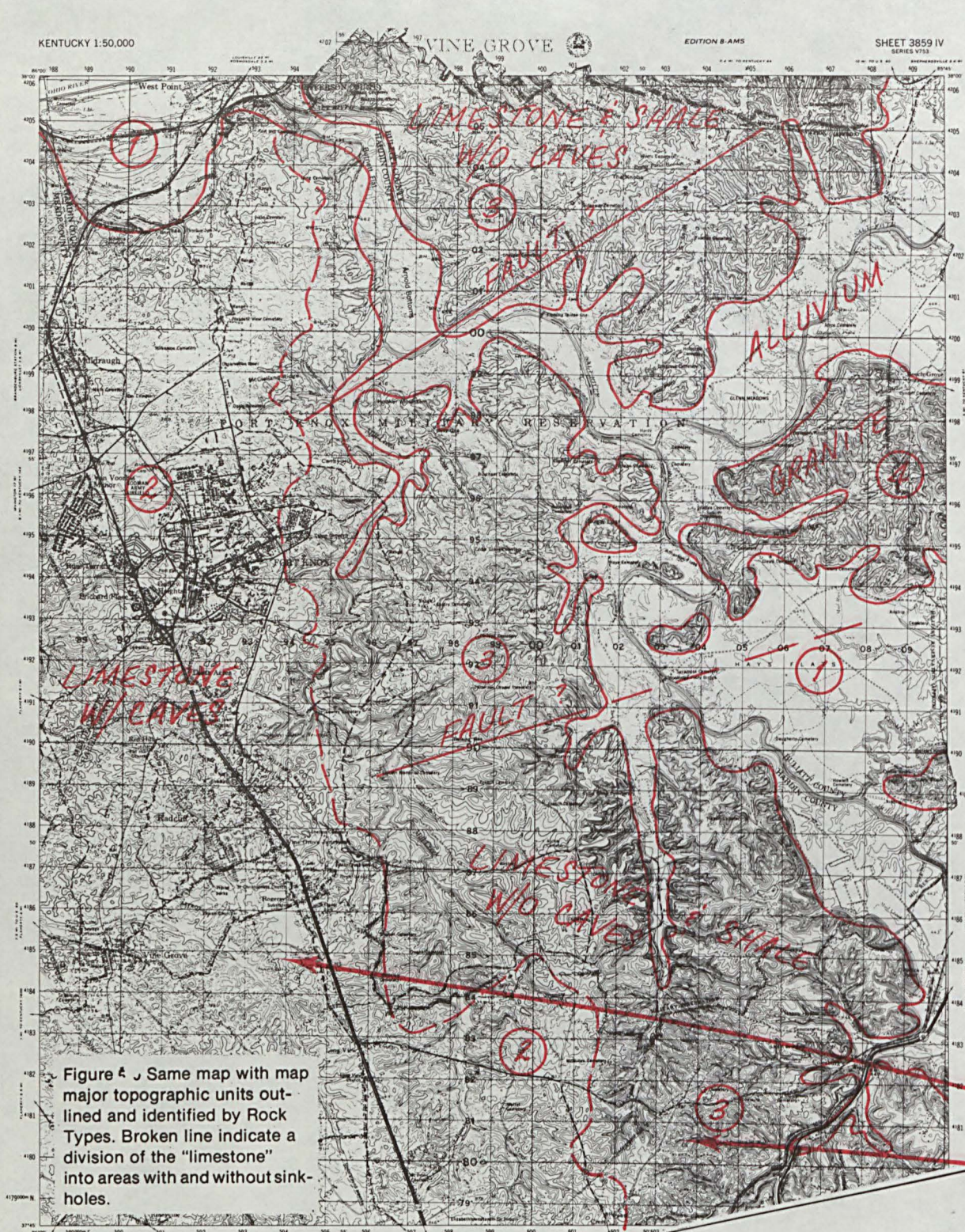
- Net slip - the total displacement along a fault, measured along a line. The horizontal component of that line in the fault plane (parallel to the strike) is the strike slip and the component along the dip is the dip slip. Plunge angles and bearing are measured as well as the distance moved.
- Outcrop - rock that stands above the soil and is in place. The outcrop then is a surface expression of a much larger mass beneath the surface.
- Plateau - a tableland or relatively level area of considerable extent elevated above the surrounding area. Locally, erosion can cut deep canyons in the surface of plateaus.
- Rip rap - common term for stone placed by man to protect a surface from rising waters, heavy windstorms, etc. Either handplaced or dumped. Upstream reservoir (dam) surfaces commonly are rip-rapped to reduce wave action.
- Sandstone - a consolidated rock composed of sand grains cemented together sufficient to form a cohesive mass. If the rock is really indurated (hardened) it often is referred to as Quartzite.
- Sedimentary - any rock or series of rocks in which bedding is developed and which has resulted from formation by water transport of mud, sand, clay, stones, etc. These Sediments become layered in time and and indurated, forming deposits of Sandstone, Limestone, Chalk, Coquina, etc.
- Shale - a general term for indurated muds, clays, or silts that are capable of being fissile (i.e., breaking along certain planes when struck). The chief feature is the fineness of grain common to most shales.
- Talus - common expression for areas, usually along steep slopes, having boulder deposits. These talus deposits can severely slow cross country movement if of significant size.
- Terrace - a Berm or naturally developed level in a valley or near a stream, usually elevated above the present terrain. Commonly underlain by water deposited sediments.
- Terrain analysis - the process of interpreting a geographical area to determine the effect of the natural and man-made features on military operations.

Unconsolidated deposits - rocks or beds of sand, gravel, or clay that have not undergone cementation or hardening from pressure. Soil is an example of an unconsolidated deposit if it has been transported from its place of origin. Usually lenticular in occurrence but can be tabular.



SURFACE DRAINAGE OVERLAY FOR USE IN GEOLOGY FACTOR MAP ANALYSIS

SURFACE DRAINAGE OVERLAY FOR USE IN GEOLOGY FACTOR MAP ANALYSIS



VINE GROVE, KY
GEOLOGY DATA TABLES

DATA TABLE I

Map Unit	ROCK		Grain Size	Color	TYPE
	Classification	Composition			Variations, including dissection, in area
2	Sedimentary formation (locally, quarry operations shut down because of serious cavern development)	Limestone, some shale, very little sandstone. Usually limestone is dense, hard and a good cliff maker.	Fine.	Gray to gray blue; shale us. red or brown. Sandstone seldom seen.	Bedrock (mostly limestone) us. outcrops in large sinkhole region west of the broken line symbol. East of this line outcrops seldom seen as bedrock has more shale and sandstone. Soils thin to absent. Very hilly, knobby terrain. Sinkholes very common over this plateau area. Caverns common over entire area.

DATA TABLE II

STRUCTURAL			CHARACTERISTICS		Water Potential
Type of Layering	Thickness	Strike/Dip	Seismic Aspects	Water Potential	
Bedded	Thin to thick (maximum 35') Total thickness of Knox limestone 500'.	As shown on map. Generally rocks are less than 10° but locally dip more.	Dominant joints trend N16° E. Deeply weathered causing sinkhole development. Faults suspected but sinkholes hide clear evidence.	Poor: thin soils and common cavities preclude transmission of seismic waves.	Good to excellent (yields of 300 gpm reported in deep wells) Sinkholes suggest widespread farm/industry contamination. Eastern areas probably yield less, require deeper wells due to higher shale (clay) content.

DATA TABLE III

ENGINEERING			CHARACTERISTICS	
Weathering Aspects	Swelling Data	Abrasion Data	Aggregate Suitability	Siting Suitability
Deeply weathered. Locally, to 200'. Outcrops are misleading as cavities may be just below surface. Clay fillings common along joint surfaces.	NA	No active quarries in limestone; hardness of cliff edges suggests sound, tough limestone, however.	Probably adequate, esp. where fresh. Near eastern edge, clay content may reduce aggregate potential.	Good for most structures. Larger structures require deep core holes. Cavities are very common but without surface evidence. Uneven subsidence likely where foundations rest on mixed shale/limestone, esp. eastern areas of unit. Ground water table not a problem. Heavy rains disappear quickly in limestone terrain.

Example of Data Table

Figure 6 This sequence of steps (left to right) illustrates how to use topographic maps and overlays to obtain basic rock type data. As the rock type boundaries are refined, the analyst (using the Approximate Characteristics Tables) can begin filling in the Data Element Tables (lower right). The example in heavy lines is for the limestone west of the broken line on the maps.