ETL-0329

AIR PHOTO ANALYSIS, PHOTO INTERPRETATION LOGIC, AND FEATURE EXTRACTION

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JUNE 1984

Prepared for
U.S. ARMY CORPS OF ENGINEERS
ENGINEER TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VIRGINIA 22060

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: ETL-0329	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Air Photo Analysis, Photo Interpretation Logic, and Feature Extraction	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): J. N. Rinker and P. A. Corl	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 4A161102B52C and 4A762707A855
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060	12. REPORT DATE: June 1984
	13. NUMBER OF PAGES: 374
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

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

18. SUPPLEMENTARY NOTES

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

Photo Analysis
Photo Interpretation Logic
Feature Extraction
Air Photo Keys
Image Analysis
Remote Sensing
Vegetation Classification
Knowledge Based Systems

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

This is a status report about some of the research efforts within the Center for Remote Sensing (CRS) that are associated with image analysis. Emphasis has been placed on the manual procedure of photo analysis, photo interpretation logic, classification schemes, and knowledge based systems. Information derived from other sources and information presented by contributors are acknowledged in the appropriate sections.

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PREFACE

This study was conducted under DA Projects 4A161102B52C, Task C, Work Unit 0008, "Photo Interpretation Logic," and 4A762707A855, Task C, Work Unit 0034, "Photo Interpretation Logic and Feature Extraction." The study was done under the supervision of Dr. Jack N. Rinker, Team Leader, Center for Remote Sensing, and Dr. Robert D. Leighty, Director, Research Institute.

Special thanks are extended to Ms. Barbara Jayne, Laision Office, for preparing several of the illustrations in Appendixes A and I of this report.

COL Edward K. Wintz, CE, was Commander and Director and Mr. Walter E. Boge was Technical Director of the Engineer Topographic Laboratories during the report preparation.

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INTRODUCTION

The more commonly used image forms are photography, radar, LANDSAT, infrared thermal, and passive microwave. With the exception of LANDSAT, these systems are used in both aircraft and satellites for obtaining general and specific information about the atmosphere, the terrain, and the oceans, as well as for detecting special features and targets. From the standpoint of gathering information about the terrain in terms of identities, composition, and properties, the most frequently used instruments are stereo aerial photography, radar, and LANDSAT. Information can be extracted from these images in three general ways: (1) manual; (2) interactive, which includes using knowledge-based systems and supervised digital classification procedures, such as used with LANDSAT; and (3) automatic, which includes pattern recognition and unsupervised digital classification techniques. Obviously, there can be mixes of these three.

In this report, the term **manual** denotes the minimum of mechanical assistance, i.e. the analysis depends on the images, eyes, mind, hand lens, and pocket stereoscope. The terms **machine** or **machine assisted** will be used to designate those procedures commonly referred to as automatic pattern recognition, digital analysis, and man/computer interactive analysis. The automatic procedures are restricted to a few very obvious types of feature discrimination, and at present, these procedures are of little practical use and are not likely to be significantly improved in the foreseeable future. On the other hand, interactive techniques are constantly being developed and have far less restrictions than do the automatic procedures. Also, interactive techniques based upon digital classification of spectral data will probably improve significantly in the future as satellites with more and narrower spectral band passes are launched.

At present, however, the manual analysis of stereo aerial photography represents the state of the art insofar as obtaining reliable and detailed information about any given region of the earth in terms of its composition, properties, use, and probable response to stress, i.e. items that are of direct and practical use to engineering and military applications. Whatever use of the terrain is envisioned in terms of building on it, tunneling through it, extracting from it, moving over it, or seeking cover and concealment, certain pieces of information are needed before decisions can be made. These pieces can come from several sources, including personal knowledge, field and laboratory work, maps and literature, and remote sensing, especially in the form of stereo aerial photography.

In general, image analysis and interpretation techniques tend to fall into one of two broad overlapping categories, which, at the extremes, can be defined as procedures associated with detecting, targeting, and monitoring on the one hand, and procedures associated with deductive and inductive reasoning on the other. At present, applying machine and machine-assisted procedures tends to be limited to the tasks of detecting and monitoring.

Targeting, detecting, and monitoring techniques require that the feature, whatever it is, have some characteristic that is different from its background and that, hopefully, cannot be confused with any other object in the field of view. These differences can be based on such things as shape, size, arrangement, color, spectral absorption and reflection, temperature, etc. Applications that fall into this category include: (1) detecting discrete objects such as roads, airports, dams, vehicles, specific crops, number of lakes per area, etc.; (2) detecting changes in patterns; (3) detecting and mapping flood boundaries, flood and storm damage, insect damage, diseased crops, alteration zones, and camouflage sites; and (4) estimating values such as crop yield, percent of tree cover, etc. For some of these applications, other remote sensors (radar, thermal, LANDSAT) can be of more use than air photos. As a group, however, it is these applications that have provided the basis for whatever success has been achieved by machine techniques, and of these, those that are based on distinguishing colors and color changes (spectral signatures, multiband, etc.) have had more successes with machine and machine--assisted procedures than have those that rely on identifying shape and arrangement. Because future systems will have more spectral channels and narrower bandpasses, there will be an increase in the ability to discriminate various objects and surfaces. It remains to be determined, however, if there will be a corresponding increase in the ability to identify these various objects and surfaces.

Deductive and inductive reasoning procedures produce information that is broader in scope, and more complex in content, than that derived by using targeting and detecting techniques. These procedures are directed towards gaining as much information and understanding as possible about the area in question, i.e. the nature of the materials in terms of structure, composition, and properties; the characteristics of the vegetation; the climatic factors; and man's activities. This information forms what can be called an environmental data base, which can then be interpreted with respect to such problems as resources inventory (including ground water), regional planning, site selection and evaluation, cross-country movement, and prediction of environmental impact as the result of any given action. This procedure of analysis relies upon the inductive and deductive evaluation of various lines of converging evidence derived from the visual examination of image patterns. Insofar as determining the nature of the terrain in terms of identities, composition, and conditions, the most important pattern elements are those associated with three-dimensional shapes; thus, the mainstay of this type of analysis is stereo aerial photography, and as yet, three-dimensional shapes do not lend themselves to machine evaluation. It is a manual task and the burden of the work falls on the individual. It is a task, however, that might benefit, at least in part, from the use of interactive systems. The benefit in this case would be in using a technique that enables a less skilled and less experienced individual to proceed down paths of reasoning that a skilled and experienced analyst would follow intuitively. Although one might argue that each pattern element, i.e. landform, drainage, soil, tone, etc., can serve as a target and thus lend itself to machine applications, the fact is that most natural pattern elements cannot be held to the rigid and exact descriptions needed in automatic targeting and detecting procedures. The important pattern elements of landform, drainage, and gully cross sections are associated with shape, and these shapes are neither exact nor invariant, but undergo changes as a result of slight variations in composition or in climate. Massive beds of limestone do not have but one shape; neither do beds of sandstone, deposits of basalt, nor patterns of a given drainage type. Although the shapes of massive beds of similar limestone are not identical, neither will they be completely dissimilar, i.e. they will have at least some characteristics in common. It is more a matter of theme and variations. The fact that they are not exact replicas indicates that there are slight differences in composition, conditions, or climate. A skilled and experienced analyst recognizes the similarities and differences and, on the basis of judgment and inference, makes a prediction as to what group of shapes this particular pattern belongs to and what material or conditions it most likely represents.

The photo analysis procedure used by the Center for Remote Sensing (CRS), and on which it concentrates its research, is based on the published and unpublished notes of Robert E. Frost* and other staff members of the School of Civil Engineering of Purdue University during the late 1940's and early 1950's.[1,2] At that time, the procedure was directed towards the photo interpretation of soils and rocks for engineering purposes, and still retains much of that perspective. Over the years CRS and its predecessor organizational units have tested, evaluated, augmented, and modified the procedure by field research and application projects in many areas of the world. The application tasks included engineering and geologic problems ranging from locating engineering materials through site selection for roads, airports, etc., to large Department of Defense (DOD) applications such as the layout of Thule Air Base, Greenland, (done by Robert E. Frost and some of his staff while at Purdue University) or the environmental data base prepared over much of Wisconsin for the Navy Project Sanguine. Included in these

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*Mr. Frost currently works for the U.S. Army Engineer Topographic Laboratories (ETL).

[1]R.E. Frost. 1950. *Evaluation of Soils and Permafrost Conditions in the Territory of Alaska by Means of Aerial Photographs.* Prepared by the Purdue University Engineering Experiment Station for the St. Paul District, Corps of Engineers, Department of the Army.

[2]R.E. Frost, J.G. Johnstone, O.W. Mintzer, M. Parvis, P. Montano, R.D. Miles, and J.R. Shepard. 1953. *A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes.* School of Civil Engineering and Engineering Mechanics, Purdue University, West Lafayette, Indiana.

DOD applications were smaller projects associated with insurgency, tunnels and caves, defoliation, etc. In addition, this photo analysis procedure has formed the basis for a series of intensive short courses that have been presented within the U.S. and Latin America.

This method of photo analysis relies on associating numerous threads of converging evidence and requires an understanding of the origin and relation of landscape features, as well as the relation of these features to their aerial formed images. In practice, the procedure is divided into two phases, the regional analysis and the local analysis.

For the regional analysis, relatively small scale imagery is used, such as LANDSAT or photo index sheets, preferably both. The purpose of the regional analysis is to establish the broad frame of environmental conditions that are contained within, as well as around, the area of interest. In this part of the analysis, general decisions are made as to boundaries separating economic pursuits, vegetation classes, landform units, and soil characteristics.

For the local analysis, effort is focused on the landscape pattern units via larger scale stereo imagery, which provides the detail needed to fill in the regional information and to make decisions as to types and conditions of materials. A number of photo scales are available, e.g. 1:20,000, 1:40,000, 1:60,000, and 1:120,000. In recent years, the tendency has been to take aerial photography at the smaller scales, especially 1:40,000 and 1:60,000. When available, the larger scale of 1:20,000 is usually preferable because it is a very good compromise in terms of the amount of photography needed to cover an area and the size of pattern detail that must be seen. Much of the fine structure such as gully cross section, and subtle changes in gully gradient or concavity of slopes, is not readily seen in the smaller scales, i.e. $< 1:40,000$. In some instances, color photography is also available, either as normal color or false color. Although it is certainly usable, color photography is not needed for a general photo analysis and does not contribute enough additional capability to justify the increased cost. For certain detection tasks, however, such as some vegetation mapping, locating diseased vegetation, or locating wetlands boundaries, it is more useful than panchromatic photography.

Reduced to the simplest of terms, the principles for this procedure, originally stated in Frost,[3] can be expressed as follows:

[3]R.E. Frost, J.G. Johnstone, O.W. Mintzer, M. Parvis, P. Montano, R.D. Miles, and J.R. Shepard. 1953. *A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes.* School of Civil Engineering and Engineering Mechanics, Purdue University, West Lafayette, Indiana.

1. An air photo is a pictorial representation of the various features within the landscape and is composed of pattern elements that serve as indicators of materials, conditions, and events that are related to the physical, biological, cultural, and climatic components of the landscape.

2. Similar materials and conditions in similar environments produce similar patterns, and unlike materials and conditions produce unlike patterns.

3. The type, quantity, and quality of information that can be obtained by photo analysis is proportional to the background, knowledge, skill, and interest of the analyst.

The foundation of this method rests in principle 2, i.e. similar materials and conditions in similar environments produce similar patterns, and unlike materials and conditions produce unlike patterns. There are many patterns to be evaluated and most of them can be evaluated only by stereo viewing. Based upon the statement in principle 2, one can reason that if the patterns are uniform across an image, then the materials and conditions, whatever they might be, will be uniform throughout that area. If any pattern element changes, e.g. gully cross section, gradient, soil tones, hill shape, vegetation texture, etc., then either the materials or the conditions, or both, must have changed. In some cases, specific pattern elements are uniquely related to the identity of a material, or to a given condition. Also, many of the pattern elements must be evaluated in relation to climate and season as these can cause considerable modification.

The analysis of any given pattern involves at least three steps: first, identification; second, description; and third, signification. The last step is the most important and, without doubt, the most difficult, requiring more in terms of knowledge, experience, and judgment than does either of the first two steps.

Identification is the act of recognizing any given pattern and either tracing out its domain or otherwise using it during the analysis. By definition, the pattern must be different beyond that boundary; therefore, there must be a corresponding change in materials or conditions, or both, as that boundary is crossed. Depending on the pattern being considered, the boundary might enscribe a group of items of the same shape, a surface of uniform tone and texture, a drainage net of uniform spacing and arrangement, or some other identifiable property. The boundary denotes the location of a change; it does not necessarily give information about the contents within.

The next step is to describe in detail the characteristics of the subject pattern in terms of size, shape, spacing, arrangement, symmetry, etc. The description is then evaluated in terms of its significance, the last step. Each pattern element signifies, or suggests, something about the nature of the material in terms of its characteristics, its condition, or its probable composition.

Although these points about observation, deduction, identification, and significance seem obvious, if not trivial, they are important. First, they are interwoven to some extent throughout all applications of the photo analysis procedure. Second, an understanding of these issues sheds light on the very real problems associated with applying photo analysis to stated Army needs, evaluating remote sensing techniques against specific tasks, developing classification systems, and determining skill levels required. There are, of course, many patterns yet unknown as well as many patterns that are not understood. There are many different pattern elements within an air photo, and in order to apply the stated principles in an effective manner, one must follow some sort of systematic procedure to ensure that all elements are considered. The scheme that we currently use classifies the pattern elements into the following categories: landform, drainage (plan and elevation), erosion, deposition, vegetation, cultural, photo tones and texture, and special. Each of these factors provides some information as to the nature of the terrain and its materials in terms of their physical properties and probable composition, and it is this sequence of classes that forms the basis for a systematic procedure for the analysis of terrian features by use of air photos. This procedure has a number of practical advantages.

1. **Simplicity.** Although the concept of photo analysis is simple, it does not follow that skill, experience, judgment, and knowledge are not needed to implement it. As is frequently the case, the implementation of a simple procedure requires more skill, capability, and judgment than does the implementation of a complex procedure. Simple procedures rely on the individual to correlate details and render judgment; complex procedures incorporate the details and sequential steps and rely on an individual following them. Simple procedures, however, provide versatility and set the basis for universality, economy, and rapidity.

2. **Universality.** The nature of the various patterns in terms of cause and effect provides a basis for obtaining information about the terrain independent of location or, indeed, without the need of knowing the location represented by the imagery. Although auxiliary information in terms of location, physiographic area, climate, etc., can be useful, and although the location is probably always known, these items are not necessary to the task of obtaining information from the photos.

3. **Economy.** Air photo prints are among the more economical, if not the cheapest, of imagery forms available, and they are readily at hand in the commercial world as well as within the military structure. As a minimum, the needed equipment consists of a large hand lens and a pocket-type folding stereoscope.

4. **Rapidity.** As yet, no other procedure can match the quality and quantity of information that can be derived in a given time frame. An experienced team of four to five individuals can produce an environmental data base of an area some 20 by 40 miles complete with overlays, text, and interpretation with respect to a problem, and do so in 15 to 20 working hours.

Because the pattern sets of landform, drainage (plan and elevation), erosion, deposition, vegetation, cultural, tone and texture, and special are the conveyors of information about the terrain, they are the basic components of this procedure of manual analysis of aerial photography. In the following section, these groups will be discussed in summary form, but with enough information to at least define them and explain why they are important and how they are used. As information and research results accumulate, some of these sections will be expanded into individual reports.

PATTERN ELEMENTS

LANDFORM. This pattern refers to the shape, size, arrangement, and orientation of any given surface feature and its location within, and relation to, the surrounding area. It is the most important of the pattern elements because it is directly related to the nature of the resident material in terms of composition and properties. An understanding of landform development makes it possible to bound areas of similar materials and conditions, determine their physical characteristics, and at times predict their composition and texture. Such events as deposition, sedimentation, and volcanism constantly add new materials to the earth's surface. Other events, such as folding, uplifting, or lowering of the ocean levels constantly elevate these materials above the base level; whereupon other events begin immediately to reduce the mass back to its base level. The force of gravity, coupled to the energy of flowing water or wind, and to the action of freeze and thaw, or of water as a solute, does this by removing bits and pieces and carrying them to the lows. But the bits and pieces are removed in a way unique to the material and action combination. As a result, the landscape shows a variety of shapes and arrangements. Within this variety, however, there are such firm relations between cause and effect that one can frequently glean from the stereo photo patterns of landform some idea of what went on, what is going on, and what is present in terms of general composition and physical properties.

The chemical and physical properties of a substance depend on the identities of the atoms, and collection of atoms, that make up the molecules of the substance. In the case of rocks and their detrital material, these molecules are called minerals. Different minerals have different physical and chemical characteristics with relation to hardness, plasticity, porosity, permeability, solubility, and thermal expansion. As a result, different rocks and soils exposed to the same action, or the same material exposed to different actions, will develop different patterns of shape, tone, and texture. Because the forces that do the shaping vary with climate, the same material can have different landforms in different regions. Limestone, for example, can be a hard, durable, and resistant rock. It is, however, soluble in dilute carbonic acid formed from available water and carbon dioxide from various sources. In a warm region with an abundance of water, limestone can be the easiest to degrade of the resistant materials and, therefore, can be a valley former. In an arid region, without water to act as an agent of dissolution, the limestone can be the hardest and most resistant rock in the area. It can form the highs, such as hills or ridges, or serve as a protective cap over less resistant beds. In either case, other pattern elements are usually present that support the concept for the material being a sedimentary rock, and most probably limestone. Because of these firm relations, shape or landform is considered to be the most important of the pattern elements, and wherever the shape changes in any aspect, there is the basis for a corresponding change in materials or conditions, or both.

In this part of the photo analysis, areas are outlined in which the terrain elements within are uniform in shape, size, spacing, arrangement, and orientation. Wherever any aspect of landform changes, there is a basis for a boundary denoting some change in materials or conditions, or both. The area of study represented by the stereo photography might contain but one shape, a plain for example. Thus, one would expect a uniformity in composition throughout that area, i.e. the surficial soils would be essentially the same all over. On the other hand, the study area might contain three landform units, all hills. Within each bounded area the hills are the same, but each group differs from the others. Thus, the bounded areas also represent three different materials, or material/condition combinations.

Each landform unit must be described in terms of shape, size, spacing, arrangement, symmetry, slope, angularity, etc., and then evaluated with reference to the significance of these observations. Profiles should be drawn across the stereo field of view. As the analysis develops, these can be converted into possible geologic cross sections. The complexities of landform classification found in most texts and articles are beyond the needs of this type of analysis, at least for the present. However complicated, the units can be assigned into one of four general categories: plains, hills and mountains, basins and valleys, and escarpments.

Plains. This category refers to a flat surface, large or small, but not necessarily level or with any elevation restrictions. Such surfaces can be established by depositing sediments in low areas, by large lava flows, by exposure of flat-lying intrusive masses, and by grinding or eroding an irregular surface into a flatter one. In size such plains range from small stream terraces to large regions, such as the Great Plains of the United States, or extensive areas of the Precambrian Canadian Shield. Identifying a surface as flat depends on one's regional point of view and on the scale of the imagery. Many topographic variations exist that can appear hilly to a person on the ground but which, nevertheless, are properly classified as plains. This has led to descriptors for plains such as rolling, undulating, pitted, dissected, etc. At small scales, such as those associated with LANDSAT (1:250,000 to 1:1,000,000), most of the Canadian Shield would be mapped as a plain. At air photo scales of 1:20,000, much of the shield area would show as rugged terrain, and it would most likely be mapped as containing several landform units, and possibly none of them would be classified as a plain. From the standpoint of this type of photo analysis, the significance of a plain is that it suggests deposition of some sort, for that is the easiest way to establish a plain. This is usually by means of sedimentation, i.e. a settling out of material suspended in a water-filled basin or trough, either marine or fresh. Deposits such as alluvial fans have a hill-like profile across their width and are not usually considered to be plains. On a large fan, the imagery might show only a portion of it, and that portion could be classified as a plain. In any event, the significance is a suggestion of the presence of sedimentary rocks or granular material. Although a lava flow can form a plain, other pattern elements would prevent it from being considered as a sedimentary unit or granular deposit.

Hills and Mountains. This category refers to elevations above the base level of the region in question. The distinction between hill and mountain is a blurred one that is based mostly on local usage, or personal preference. The *Glossary of Geology*[4] gives 300 meters (1000 ft) as the elevation difference between base and summit that divides the two classes, i.e. under 300 m, it is called a hill, and over 300 m, it is called a mountain. Hills can be formed by depositing material on top of the ground; by subsurface material pushing the surface up, or pushing up through the surface; by forcing the surface into a series of ripple-like folds; by faulting; and by cutting into, or eroding into, a previously flat surface. Each of these processes results in patterns that are suggestive of origin, and consequently of materials. A flat-lying area of sediments can be called a plain only so long. There comes a time when the forces of erosion have so extended and deepened the valleys and have removed so much of the original surface that that which is left can only be classified as hills. These hills, however, will still retain clues as to their sedimentary nature. Whatever the source of the hill, or mountain, the characteristics of its shape provide clues as to its origin, which, in turn, serve as indicators of its physical properties, such as hardness, perviousness, cohesiveness, etc. At this point, one can frequently make an inference, based on experience and judgment, as to possible composition.

In general, hills and mountains that are made of hard, durable, igneous and metamorphic rocks have sharp, angular, and irregular outlines in both plan and elevation. They are devoid of symmetry and do not show finger-like extensions or ridges. Granitic rocks can show a softening of the angularity, but it is not a roundedness easily confused with the rounded slopes of soft materials. The surficial characteristics of igneous and metamorphic rocks depend on the molecular groups or minerals involved, the climatic region, and the amount of fracturing. In large masses of granite that are not fractured, or in which the fractures have been sealed by other materials and forces, the whole can have a smooth rounded shape. If the mass is intensively fractured, then the pattern is more jagged and can contain needle-like features. Usually, granite rocks have a lumpy surface

[4]Am. Geol. Inst., 1972. *Glossary of Geology*. Washington, DC.

texture. The pattern of a lumpy surface, or of needle-like spires, is not in itself sufficient to identify the rock type, because similar patterns can be found in other rocks under other conditions. For example, some tropical limestone weathers to present a lumpy surface, and needle-like spires can be found in massive beds of limestone and in columnar basalt.

The sedimentary rocks – sandstone, shale, and limestone – have other shape characteristics. The fact that these rocks are formed by a continuing, or sequential, deposition of suspended matter causes them to have a layered nature. These layers, or beds, can be of one type rock, or they can be different rocks; and the layers can be thin, i.e. measured in millimeters, or they can be thick and measured in tens or hundreds of meters. This originally horizontal, flat-lying, layered structure can be uplifted, tilted, folded, fractured, and weathered in all sorts of complex ways, but not all the basic characteristics associated with a layered system will be destroyed. Flat-lying and nearly flat-lying beds that have been dissected by erosion develop hills with ridges, or finger-like extensions, that have symmetrical profiles across them. If the layers are made of sandstone or limestone and are thick, i.e. measured in tens or hundreds of meters, the hills will be blocky with steep, if not vertical, sides. Clay shale beds do not have this thickness, and even if they were thick, the hills would show a rounded profile because of the cohesive nature of clay. As the beds become thinner, the massive blocky structure is lost and other slope shapes develop. If a more resistant material is interbedded in the sequence, a stair-step pattern becomes evident. With thinner beds, the steps, if present, become imperceptible in conventional stereo aerial photography, with the result that the hills have rather smooth-looking slopes. The shape of the slope can also be a pattern element that is indicative of the nature of the materials. If the rocks are thinly interbedded sandstones and shales, the slopes tend to have a uniform gradient down most of the hillside. If the rocks are thinly interbedded limestones and shales, the slopes tend to become concave and exhibit a noticeable flare in the lower third of the hill. In general, sandstones develop sharper ridge lines and more angular patterns than do limestones. If a sandstone is very soft, or contains a significant amount of calcium carbonate, it begins to resemble the landforms developed in limestones. Clay shales show the ridge-like extensions associated with flat-lying sedimentary rocks, but being made of soft cohesive and plastic material, the profiles and contour lines tend to be very gently rounded.

Sedimentary beds that are tilted retain many of the characteristics mentioned earlier, i.e. blockiness, stair-steps, etc.; but, in addition, they develop other landforms. Sooner or later the edges of tilted beds will become exposed and will weather and erode according to their composition. The resulting landform is a series of parallel V-shaped ridges that form a sawtooth-type profile across them, which can be either symmetrical or asymmetrical. A symmetrical profile suggests that the beds are dipping at 45°. The ridges, which represent the length of the exposed beds, can be very long, i.e. kilometers.

Basins and Valleys. These structures refer to depressions that are sufficiently large to provide a significant separation between the adjacent higher elevations. Basins do not have surface outlets, can vary greatly in size and shape, and are produced by several events, including folding and erosion.Whatever the cause, it is an area in which sediments can accumulate. The characteristics of a basin can provide information as to composition of the parent material and the forces that brought the depression into being. Valleys usually have surface outlets and are usually elongate. Most frequently, they are caused by stream erosion, but are also produced by moving ice, folding, faulting, and solutioning. Solution valleys, such as in limestone areas, can be fairly extensive and complex and yet not exhibit a surface outlet. Although valleys provide passages for the transport of water and materials, they can collect sediments by a variety of processes, e.g. fluvial, glacial fluvial, etc. The shape characteristics of a valley provide information about parent materials and the nature of the processes that created the valley.

Escarpments. Escarpments are usually long, fairly continuous steep slopes or cliff faces that separate some landform units. They also exist, however, as broad, gently sloped bands that most frequently result from faulting and subsequent erosion. Although they are not usually considered as a type of landform, they are included to indicate that, where they do occur, they merit evaluation. They are important pattern elements, and their characteristics can provide information about composition and the nature of the causitive forces.

Refer to appendix G and report ETL–0261[5] for further information about landform patterns for some rock types.

DRAINAGE. This refers to all drainageways, including standing water, as well as channels that water would follow if it fell on the surface. Drainage patterns are next in importance after landform, and they provide information about soil permeability, soil texture, cohesiveness, areal homogeneity, ease of erosion, ground slope, relative depth of soil mantle, presence of and type of rock, and dip of beds. With experience, one can make a judgment from these patterns as to probable general composition. As water flows

[5]Judy Ehlen. 1981. *The Identification of Rock Types in an Arid Region by Air Photo Patterns.* U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, ETL–0261, AD-A109 144.

over a surface, it can scour out ever-deepening and ever-lengthening channels whose shape, intricacies, and arrangement form patterns that are directly related to the materials containing them. These patterns are evaluated in two ways. The first is an analysis, in terms of pattern type and density, of the surficial arrangement of the drainage net as one would see it looking down on it. This is called the Drainage-Plan. The second is an analysis of the cross sectional shapes and gradients of the channels that carry water to the collectors. This is called the Drainage-Elevation.

Plan. Aside from forms of control such as caused by bedding, jointing, and fractures, the drainage pattern and its density are functions of soil permeability, slope, and the climate, especially the amount and distribution of precipitation. Well-defined surface drainage patterns do not develop on pure granular materials, such as sands and gravels, because the water drains downward through the spaces between the granules and downslope until it finds a low, or until it exits from the material. With sufficient water, this mass of material becomes saturated, at which point the water must flow over the surface, and can leave a trace of its passing in the form of an erosional scar, or a series of tone changes. With torrential rains, water can fall on a surface faster than it can drain into the interior, and under such conditions, the water will flow over the surface. Aside from patterns of infiltration basins, drainage patterns do not usually develop on the surfaces of granular deposits. At the edges of a dissected deposit, such as a granular terrace, there will usually be a few gullies, but these will not extend very far into the plain, and they are not branched into ever-smaller tributaries. If the granular material is well graded and contains some small fraction of the fines in its composition, the permeability will be reduced and the gullies will extend farther back.

In materials that are not wholly permeable, such as clays or soils that contain a significant amount of clay and silt, some of the water runs over the surface and scours out a drainage pattern. The less the permeability, the more the surface runoff and the greater will be the erosional scouring and the number of gullies. A relative index of permeability can be obtained for a drainage pattern by expressing the drainage in terms of total length of the combined drainageways in relation to a unit area, e.g. kilometers of drainage per square kilometer of terrain. Lower values of the ratio are associated with the more permeable materials. In making this kind of an evaluation, one should remember that slope differences can cause different drainage densities for materials having the same permeability and also that vegetation can hide drainage channels that would contribute to the overall density, if they could be mapped.

For a soil composed of expansive clay particles and in a dry condition, some initial portion of a rainfall will drain internally through the dessication cracks and voids and not run over the surface. As this water comes in contact with the clay particles, they expand, filling in the cracks and voids, at which point the mass becomes impermeable, and the water must flow over the surface, leaving as a sign of its passage an intensively developed network of drainageways. In general, and for similar slope conditions, the finer the drainage net, i.e. the closer the gullies are spaced, the less the permeability and the finer the texture of the material.

In this part of the stereo photo analysis, all standing water, low spots, and paths that water would follow if it fell on the surface are traced out on the overlay material. It is important to record as much as possible of the fine detail, especially the first-order drainage, i.e. the small unbranched tributaries that terminate at the limits of a watershed. Such detail provides a basis for better identification of drainage basin limits and divides and for developing inferential information as to geological structure and stratigraphy. This overlay can be removed from the photomosaic and placed on a smooth, light-toned background so that the drainage patterns can be examined in isolation. The pattern is evaluated in terms of homogeneity, arrangement, density, and angularity. Wherever any one of these characteristics changes, there is a basis for a boundary that denotes some change in materials or conditions, or both. If, for example, the pattern was uniformly the same throughout the area of study, then one must conclude that surficial materials and conditions, whatever they might be, are also uniform throughout that area. If one can break out three drainage patterns or three variations of a common pattern, then one must assume that the area contains at least three different materials or conditions, or some combination of both. Sometimes it is difficult to locate an exact position for a boundary between two patterns. For example, a drainage pattern might change gradually from one end of the study area to the other, in the sense that at one end the pattern shows fewer contributing gullies to the collectors than at the other end. This could be caused by the fact that the rock, say a sandy, silty shale, contains a gradually lessening amount of sand as one goes across the study area, which would gradually and slightly alter the permeability of the material and the resulting drainage pattern.

Once the boundaries have been established and the various drainage patterns described, the significance of these findings must be determined. There are some relations that apply in general. As stated previously, the denser or more finely divided the drainage net, the more impermeable and fine grained the material. The more angular are the intersections of gullies and channels to their collectors, the harder and more resistant the material. In soft and easily eroded material, such as clay shale, silt deposits, limestone, or soft sandstone, the wanderings and intersections of collectors and gullies are curved and rounded. As the material becomes harder, the intersections become more angular. Sinusoidal roundedness in the drainage plan is indicative of roundedness in the landform profile, and angular paths and intersections are indicative of an angular landform profile.

Several types of drainage patterns, along with the materials and conditions to which they are linked, are listed on the Drainage Factor Pattern Sheet in appendix A. These patterns represent pure, or idealized, forms and although they do occur in the field, they are not found as frequently as are the transitional and combined patterns. The more common patterns of this group are dendritic, parallel, rectangular, trellis, radial, and annular.

The dendritic, or branching tree-like pattern, is probably encountered more frequently than any other. In this pattern there is no indication of control over the direction of flow, other than downhill. The tributaries form acute angles with the main collectors, and the individual streams tend to be curved rather than straight. This pattern develops on materials that have uniform resistance to erosion. As such, it is indicative of homogeneity in composition and structure and is associated with relatively incompetent rock and soil materials. In sedimentary rocks, such a pattern has an added structural connotation in that the units must be horizontal, or nearly so. The significance of this pattern is that it is an indicator of homogeneity in materials and conditions, both areally and vertically, at least to the depth of erosion.

A parallel drainage pattern indicates a single direction of flow. Such patterns are found on soil and rock materials that are uniform in composition and structure and that are on an inclined surface. The tributaries joining the collectors form acute angles that become smaller, or more acute, as the slope increases. Parallel patterns can also be caused by closely spaced parallel fractures in homogeneous rock that is at or near the surface.

A rectangular drainage pattern indicates two directions of flow, or orientation of stream segments, that are about equally developed. Usually the tributaries join their collectors at right angles, and the stream segments tend to be straight rather than curved. This pattern is a result of structural characteristics in the rocks brought about by intersecting sets of fractures or foliations and is indicative of relatively competent material at or near the surface.

A trellis pattern also has a rectangularity established by two directions of stream orientation. In this case, however, the directions are not equally developed, i.e. one direction has more drainage than the other. The tributaries join their collectors at right angles, and stream segments tend to be straight. This pattern develops on structurally altered rocks composed of nonuniform materials at or near the surface. This type of control is most frequently associated with tilted, interbedded, competent and incompetent sedimentary units, and some low grade metamorphic rocks. The longer parallel streams follow the direction of the bedding, i.e. strike, or the principal foliation. In sedimentary sequences, the tributaries on opposite sides of collectors usually show a difference in length, as well as in the patterns of junctures. Tributary junctures that develop on dip slopes tend to be Y-shaped, and those that develop on scarp slopes tend to be T-shaped. Tributaries that are equal in length on both sides of collectors are suggestive of beds dipping about 45°. T-shaped tributaries on both sides of a divide indicate that the bedding, or foliation, is vertical, or nearly so.

A radial drainage pattern arises when the drainage is directed away from, or towards, a central topographic high or low. On a local basis, the drainage channels can be nearly parallel. Drainage that flows from a central high is called centrifugal and is most frequently associated with volcanic cones and plug-like intrusive rocks. Drainage that flows inward towards a central low is called centripetal and is frequently associated with sedimentary basins.

Annular drainage patterns also show symmetry about a central point, either a topographic high or low, but with two components of direction – radial and concentric. The tributaries follow radial courses and intersect at right angles with the collector streams, which are following concentric courses. This pattern is an indicator of structural domes or basins and can be found in areas of sedimentary and low grade metamorphic rocks, as well as in igneous terrain.

Elevation. This pattern refers to the shapes of the gullies in cross section and in gradient. It is an important pattern element because soil textures and soil profile features can be interpreted directly from a detailed study of gully systems and gully characteristics. Bedrock is continuously being broken down by mechanical means into ever smaller pieces, which accumulate in various parts of the landscape as deposits of particles ranging in size from boulders to pieces visible only with a magnifying lens. There are limits, however, to the particle size that can be produced by grinding, and it is about 0.002 to 0.003 mm (2 to 3 micrometers). These smaller particles are called silt. There is another group of particles that result not from grinding, but from weathering (chemical decomposition) and subsequent recrystallization of the soluble products. These are called the clay particles. Although these plate-like particles have a size distribution that overlaps the silt group, the overwhelming majority of them have sizes less than 0.002 mm. The designation of particle sizes associated with gravel, sand, silt, and clay depends on the soil classification system being used. In *The Unified Soil Classification System,*[6] the **approximate** ranges are

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[6]Arthur Casagrande. The Unified Soil Classification System. Corps of Engineers, U.S. Army, Technical Memorandum No. 3–357, Vols. 1 and 3, March 1953. (The Unified Soils Classification System was developed by Dr. Casagrande and was adopted by the U.S. Army Corps of Engineers in 1942 as the Airfield Classification System. Other agencies also used this system and extended its application to all phases of soil work. In 1952 discussions were held between the Corps of Engineers, the Bureau of Reclamation, and Prof. Casagrande. The result was a modification of the Airfield Classification System and a renaming of it as the Unified Soil Classification System. Several references provide details of this system):

Soils Manual for Design of Asphalt Pavement Structures, 2nd Ed., Apr 62. The Asphalt Institute, Manual Series No. 10.

Earth Manual, 1st Ed. revised, 1963. U.S. Dept. of Interior, Bureau of Reclamation. U.S. Government Printing Office.

PCA Soil Primer, 1962. Portland Cement Assoc., Skokie, Illinois, pp. 25.

coarse gravel	—	19 to 75 mm (.75 to 3 inches)
fine gravel	—	4.8 to 19 mm (.19 to .75 inch)
coarse sand	—	2 to 4.8 mm (.08 to .19 inch)
medium sand	—	.4 to 2 mm (.02 to .08 inch)
fine sand	—	.07 to .4 mm (.003 to .02 inch)
fines (silts and clays)	—	less than .07 mm (.003 inch)

Note that in the Unified System size distinction is not made between silts and clays. These are differentiated on the basis of their behavior. Refer to appendix D for further details on particle sizes.

Gravel and sand are the coarse-grained parts of the soil, and the distinction between the two on the basis of size is an arbitrary one, for the engineering properties are similar throughout, varying primarily in degree. As sand becomes finer, it acquires some of the characteristics of silt, especially a decreased permeability, and it can be visually indistinguishable from silt. There are also distinctions based on chemical composition and physical properties that are associated with the various groups of particles. Gravels consist of fragments from igneous, metamorphic, and sedimentary rocks. Consequently, they have a varied chemical, or mineral, composition. It is an infrequent event to find gravel deposited without sand. The two are usually together, either intermixed as in a well-graded deposit, or interleaved as lenses and layers of coarse sandy gravel alternating with coarse sand, etc., and frequently with some amount of precipitated material present. Whatever its composition, a deposit is an indicator of the types of rock available to the stream that formed the deposit, an item of information of little concern to the photo analysis, but which can be of use during a ground reconnaissance.

Sand, on the other hand, is most frequently made of quartz (silicon dioxide), an abundant substance that is hard, resistant, inactive chemically, and durable through long periods of time. There are other kinds of pure sand, such as gypsum and coral, but these represent but a small fraction of the whole. Coarse sand frequently contains other particles, but as the grain size becomes smaller, the quartz fraction becomes larger. Fine sand is usually pure quartz – the sturdy unweatherable residue of the degradation process. Sand grains can be rounded or irregular as a result of how much abrasion they have received. They are neither cohesive nor plastic, and in bulk, their water-holding capacity is very low. Because of the large sizes of the pore spaces, the passage of water can be rapid. Because of the small sizes and the lack of cohesiveness, sand can be carried by the wind.

Silt and clay are the fine-grained components of a soil and are called the nonplastic fines and the plastic fines, respectively. They are important as a group because they significantly alter the engineering characteristics of soil when present in small amounts. If a granular soil contains as little as 10 percent of fines, it can lose much of its permeability and be subject to frost heaving. As a result, soils that contain any significant amount of silt and clay are sources of engineering problems because they can have pronounced changes in physical properties caused by changes in water content or by being disturbed. When in a dry, powdered state, silt and clay are visually indistinguishable. When chewed, silt has a gritty feel, and clay has a creamy feel. In the presence of water, they have very different properties.

Silt particles, the end result of the grinding process, are irregular in shape, are seldom smooth or flat, and are composed mostly of quartz. They could be accurately described as micro-sand particles. Being composed of quartz, both sand and silt are very inactive in a chemical sense. The silts, however, are so small that they have some different physical properties. The pores between the grains are restricted enough to influence the passage of water, and consequently, these soils are not as permeable as sand. By the same token, they have a higher capillary rise and a higher water retention capability. Because silt particles frequently have an adhering film of clay, the smaller ones can show evidence of cohesion, plasticity, and adsorption. Being small and noncohesive, silt can be transported by the wind as well as by water, and it occurs as aeolian and fluvial deposits, both pure and mixed. Silt is unstable when water is present and can turn "quick" when saturated. It is somewhat impervious, it is difficult to compact, and its properties in place are very different from those of the disturbed soil.

Clay particles are small enough so that surface effects override mass effects, and most of the particles are small enough to have colloidal properties. These particles are flat, have about 10,000 times more surface area than an equivalent weight of medium grade sand, and surface forces can be very strong. Consequently, surface phenomena such as cohesion (particles sticking together) and adsorption of water, chemicals, and gasses are very pronounced in the clays. Because the clays are formed by processes of chemical decomposition and recrystallization, they vary greatly in mineral and chemical composition. Clay is highly plastic when moist, and it forms hard cohesive masses when dry. Clay soils are practically impervious, difficult to drain, difficult to compact if wet, and undergo volume changes as a function of water content.

The patterns of drainage-elevation, i.e. gully cross section and gradient, that develop in a soil are determined by the properties of permeability, cohesiveness, plasticity, compressibility, etc., and these are functions of the amounts of clay, silt, sand, and gravel in the soil, the soil profile development, and the climate. In general, there are three basic gully cross section and gradient combinations that correspond to the three textural groups of granular soils (sands and gravels), silty soils, and clayey soils.

In noncohesive granular materials, the gullies are V-shaped in cross section and have short, steep gradients, i.e. the gullies are slightly longer (4 to 6 times) than the width of the gully at the top of the V. With more of the fines present, the gullies become longer. In well-graded deposits that have been dissected, such as river terraces, the exposed walls can be vertical.

In silty soils the gully cross section has a flat bottom and steep-to-vertical sides. The gullies can be relatively long and have a gentle gradient throughout, except where it steepens at the headwall. The manner in which the silt was deposited (aeolian or fluvial) also influences the shape. Flat-bottomed gullies with vertical walls can be formed in any noncohesive deposit as a result of subsurface drainage or ground water sapping. Conditions necessary for this can occur in saturated alluvial deposits as a result of an increase in ground water levels or of excessive rainfall. Vertical walls can also be caused by undercutting, as in a river cutting into a loessal bank, i.e. a bank of wind-deposited silt. In fluvial deposits of silt, the gullies have this boxy shape, which could be the result, in part at least, of subsurface flow undercutting at the base with a subsequent slumping. In aeolian deposits, the gully walls are steep, but not vertical. Based upon our field measurements, the walls are most frequently between 55° and 60°.

Nongranular, cohesive, and plastic soils, i.e. the clays and silty clays, develop a gully with a saucer-shaped cross section and a long gentle gradient. In a relatively pure clay soil, the saucer-shaped cross section is very broad, shallow, and gently rounded.

Additional information about drainage patterns in relation to rock type can be found in appendix G and in ETL Report 0261.[7]

EROSION. Landform, drainage, and erosion are interrelated. Without erosion, drainage patterns and, consequently, landforms could not evolve. There are several forms of erosion, however, and each leaves a pattern that can provide information about the composition of materials, conditions, and climate. The term "erosion" is used here to refer to the overall procedure of breaking down earth surface materials, i.e. soils and rocks, and of moving the pieces from one place to another. In keeping with most usage, weathering as a destructive process is included as a form of erosion even though it does not involve transport of the altered material. Processes that are responsible for loosening, breaking, or dissolving earth surface materials include

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[7] Judy Ehlen. 1981. *The Identification of Rock Types in an Arid Region by Air Photo Patterns.* U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, ETL–0261, AD–A102 893.

Mechanical
- running water
- rainfall
- waves
  - impact
  - compression of air
- moving ice
- corrasion
- expansion in confined spaces
  - freezing of water
  - crystallization

Chemical
- dissolution (limestone, gypsum, etc.)
- weathering

Thermal
- thawing (thermokarst, and the active zone in regions of permafrost)
- temperature changes (differential coefficients of expansion for different crystals)

The forces that are responsible for moving the altered or loosened material are running water (including currents), wind, ice, and gravity. The mechanical destruction of the land, with removal of the pieces by running water, is the most common of the erosive processes, and because of the importance of its patterns, it is discussed and evaluated under the heading of drainage. Each erosional process has associated with it patterns of shape, tone, and texture. Because of these patterns, one can identify the types of erosive mechanisms and, therefore, infer something as to the composition and properties of the material. In this part of the analysis, one looks for indicators of the mechanisms of erosion, describes them, and evaluates their significance. For example, occurrences of blowouts on a surface are suggestive of the presence of a sandy material; the presence of sinkholes, a form of chemical erosion, is indicative of limestone; the presence of depressed center polygons in permafrost regions (freeze-thaw) is indicative of a silt/ice mixture and the possibility of large amounts of subsurface ground ice.

DEPOSITION. Material that is eroded away must be deposited elsewhere, and the resulting patterns are controlled by the nature of the material, conditions, and climate. The regional desposits that form sedimentary rocks are not considered as part of this pattern group. Some depositional formations are large enough to be classified as landform patterns, e.g. large deltas, fans, terraces, dunes, volcanic cones, etc. Even so, their patterns are indicative of composition.

This part of the analysis serves as a checkpoint to review the imagery for indicators of deposition and to evaluate their significance. Some of these patterns are associated with relatively small features, e.g. examining gully mouths to see if fans are present, which, if found, would indicate that there is a source of granular material upstream. Most depositional patterns are caused by mechanisms involving water, wind, ice, gravity, biological material, and man.

The patterns of water-deposited materials that are of interest in this part of the analysis are those forms of depositions brought about by moving water, i.e. rivers and streams, flood (including the sheet variety), currents, and waves. These deposits are mostly materials in the forms of stream terraces, fans, deltas, beaches, beach ridges, bars, eskers, kames, outwash, etc. This deliberately ignores the subaqueous deposits that form in seas, estuaries, lakes, and ponds and which are still submerged. The nature of a deposit in terms of composition is a function of the source of the material and of the speed and depth of the moving water. Consequently, these deposits contain materials that range from silt-sized particles to boulders, show some degree of sorting, and frequently show some degree of stratification. As an example, fans show a lateral sorting, with the coarse fraction at the gully mouth and the finer fraction at the leading edge. The cross section profile of a fan is also related to particle size distribution. The higher the arch of a fan as compared to its width, the coarser is the composition.

Compared to water-associated deposits, wind-deposited material has a more restricted grain size distribution, usually silt and sand-size particles. Most aeolian deposits form features that are large enough to be evaluated as landforms, e.g. dunes, loessal ridges, loessal plains, etc. In general, aeolian deposits show streamlining, smoothly arced edges, interconnected shapes, fluting; and they tend to look "windswept." Shape can provide information about composition. In sand dunes, the shape is related to wind speed and its constancy in direction. Long lineal dunes, i.e. tens of kilometers in length, are shaped by very strong winds with a constancy of direction. Of the dune formations, they are likely to have the most coarse particle-size distribution. Moderate winds are associated with barchane dunes and weak winds with transverse dunes. The latter type usually has a finer soil texture. Irregularly shaped dunes or star-shaped dunes result from changing wind directions.

Deposits associated with ice are complex masses of material that are sometimes difficult to classify because there are many overlapping types, and the precise mode of formation is frequently uncertain. Many of these deposits are poorly sorted and sometimes stratified. Those that are caused by running water (glacial melt) have been mentioned, i.e. eskers, kames, and outwash. Deposits that are formed by action of the ice, in contrast with action of the meltwater, include moraines, drumlins, and till. Moraines can be formed in different ways. A terminal, or end, moraine is formed by the edge of an advancing glacier shoving surface material ahead of it into long, curved, ridge-like features that outline the shape of the advancing sheet of ice. This material is frequently composed of till, but can consist of the resident soil and rocks of a previously unglaciated area. Consequently, this type of moraine can vary greatly in composition, although it is usually unsorted and unstratified. Lateral moraines form at the sides of a glacier as a result of the moving ice plucking and scraping material from the valley walls and distributing it along the edge. Material can also be deposited by melting the ice of a stagnant glacier out from under material suspended in a shear plane or resting on the surface as a perched moraine. Morainal forms are not as well sorted as the water deposited features, and contain more of a nongranular fraction. Drumlins are long, rounded, low-lying hills shaped by the action of the glacier on the till at the ice-ground interface. Ice that melts in cyclic freeze-thaw sequences can also move material, as well as provide some degree of sorting. It is this mechanism that brings large rocks to the surface in a poorly sorted soil, produces frost boils, and contributes to the slow downhill movement of the surficial material in periglacial areas, i.e. solifluction.

Although gravity is the ultimate cause of all deposits, airborne or waterborne, its use here is restricted to those materials that have slid or fallen directly onto their resting places, i.e. water and wind were not involved in the transport. The pattern elements of interest here are associated mostly with talus, avalanches, slides, slumps, etc.

The common biologicial deposits are peat and muck, which are derived from the accumulation of vegetation in low-lying areas such as ponds, bogs, swamps, estuaries, etc. In an aerial photograph, these are seen as dark or black flat surfaces surrounded by higher ground. Although they have a high economic value, they are problem areas for engineering construction.

Man-induced deposits most frequently occur in the forms of tailings piles and ponds associated with mining and ore production, ridge-like mounds and hills from strip mining and quarry operations, and landfill (dredge or hauling).

VEGETATION. As to which photo pattern is next in importance is a moot point. At present we give the edge to vegetation for two reasons. First, vegetation information is important to many different tasks. As an example, the results from an analysis of vegetation patterns can be used to provide information about the vegetation itself in terms of type, spacing, density, canopy closure, stem diameter, vigor, etc.; or to provide information that is directly or indirectly linked to other characteristics such as climate, soil texture, soil or rock type, depth of soil mantle, presence of ground water, potability, etc. Second, and perhaps more important, vegetation patterns have not been exploited to their full potential. Based on the accumulated evidence, one can only conclude that the limit to the indicative uses of vegetation patterns is our lack of knowledge. Consequently, research efforts in this field of study should receive more emphasis. Although much is known, in a general sense, about vegetation and environmental characteristics, very little is known about the details of the intricate network of relations between vegetation type, state and vigor, climate, landform, soil texture, moisture, ground water, chemical composition (of plants and soils), and associated spectral reflectance, fluorescence, and radiometric properties. Once established, these relations might provide usable indicators as to soil composition, soil conditions, mantle depth, water sources, water potability, mineralization, and salinity, let alone provide an improved vegetation mapping capability. As to how much proves to be reliable and useful, only the results from research can tell.

Air photo scales suitable for engineering soils evaluation and environmental data base preparation, i.e. in the 1:20,000 scale range, are too small for use in species identification. Vegetation types or large pure stands can, however, be identified and boundaries established between groups. These boundaries are frequently associated with changes in soil texture, soil moisture, topography, landform, and orientation, and they give supportive information to factor boundaries established in earlier phases of the analysis. Arid regions research done by ETL has established some usable relations between landform, soil texture, and vegetation community.[8] Although these results must be tested in other regions, there is no doubt that knowledge of either landform or soil texture within an area can set the basis for a fairly accurate prediction of the vegetation communities, and vice versa. Also, vegetation patterns can provide information about climate. A closed canopy forest requires over 76 cm (about 30 inches) of rain per year. Some species in certain locations require much more than that. Progressively less rain means progressively less tree cover and more shrubs and grasses. A continuous grass cover requires at least 25 cm (10 inches) of rain per year, with some grasses needing double that amount. When the annual amount of precipitation falls below 25 cm, the grass cover breaks into clumps, specialized species appear, and the vegetation becomes more widely separated.

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[8]Melvin B. Satterwhite and Judy Ehlen. 1980. *Vegetation and Terrain Relationships in South-Central New Mexico and Western Texas.* U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, ETL–0245, AD–A095 159.

The procedure for classifying the vegetation during an image analysis is a function of the nature of the project, and schemes are frequently tailor-made to fit project goals. As will be discussed in the section on data base preparation, the analysis can be simple or complex as a function of the classification scheme used. At present no existing system combines simplicity, photo-based origin, Army needs, and the capability to incorporate other data sources. Such a system is being developed at ETL (refer to appendix E).

CULTURAL. The analysis of cultural patterns can be done for at least three reasons: (1) to derive information about the culture itself, (2) to use the cultural patterns to derive information about other terrain factors, and (3) to use the cultural patterns directly in terms of some military problems. As an example of the first, the economic characteristics of a given society can be deduced by an analysis of the cultural patterns. As an example of the second, a pattern of cultivated fields, such as the alternating tones of fallow farming, can provide clues as to soil texture and the general climate, or the presence of a quarry can support predictions of rock type. As an example of the third, the knowledge of the location of above-ground structures provides information with reference to the military problems of cover and concealment and cross-country mobility. Because cultural information is needed for so many different uses, it has not been possible to provide a single satisfactory classification scheme, let alone a scheme based on the analysis of photo patterns.

From the military point of view, terrain information needs are better expressed as a land cover/land use map, which is a combination of the patterns of culture, vegetation, and surficial geology. Of the classification schemes presently available, none of them adequately meets Army requirements, and none of them is well suited to the use of remote sensing techniques. The classification scheme should be as simple as possible, at least through the first level, and perhaps into the second; and it should provide a basis for incorporating into the higher levels, technical details from the literature or ground surveys. Within ETL, over 20 classification schemes have been evaluated, and one was tested by photo analysis. No one system lent itself readily to the use of remote sensing imagery, and neither did any one system adequately address Army needs. ETL is trying to develop a land cover/land use classification that will meet these goals. A review of this effort is in appendix F.

PHOTO TONES AND TEXTURE. Photo tone and texture are descriptive terms that do not lend themselves to precise definitions. Nevertheless, these patterns can provide information about specific materials or conditions, as well as information to support conclusions developed during the analyses of other factors. When used with respect to black and white photography, photo tones refer to the gray levels in the image. If used with respect to color photography, photo tones refer to the color. When the colors are other than the neutral ones (white, grays, black), they are difficult to describe.

In the case of panchromatic photography, the photo tones represent the brightness of an object as averaged over a very broad spectral bandpass. Evaluating a tone is relative, is frequently done within a frame of photography, and is expressed in such terms as light, dark, lighter than, darker than, redder than, uniform, speckled, etc. Although photo tones can be measured and expressed in terms associated with optical density and Munsell notation, etc., no practical use is gained by such procedures because, for most terrain surfaces, photo tones do not have an absolute relation to anything. Frequently there is some range of tones associated with some range of conditions, but it is not absolute in the sense that if A, then always B, or if the optical density is 0.21, then the surface is granite, or if it has a particular Munsell notation, then it is a wheat field.

The tones in an aerial photograph are the end product of a number of interactive items and events. Included in these are the molecular nature of the surface material; the quality of the light (sunlight, skylight, time of day, season, atmospheric properties); slope and orientation of the surface; angular relations between the surface, the camera, and the sun; off-axis variation in exposure (this can be equivalent to over one-half an f-stop from principal point to edge of format when using a wide angle lens); presence of surficial structure; local meteorological conditions (dry, wet); spectral transmission characteristics of lenses and filters; and characteristics of the emulsion and of the processing method. For high altitude or satellite systems with long focal length lenses or with small scan angles, which are recording at near constant or similar sun times, the variations caused by some of these relations are reduced. For conventional aerial photography, however, the changes can be significant. For example, because of off-axis falloff of exposure, a material can have different gray tones or different colors as a function of whether it is directly beneath the camera or off to one edge of the format. A wide angle lens increases this effect.

The term "wide angle" refers to a lens whose focal length is less than the maximum dimension of the format. A normal lens is one whose focal length is approximately equal to the maximum dimension of the format, and a telephoto is a lens whose focal length exceeds the maximum dimension of the format. As used here, the term "format" refers to the image size recorded by the camera, e.g. 35 mm, 4 by 5 inches, 9 by 9 inches (aerial camera), etc. In the case of the 35 mm camera, the diagonal of the rectangular image formed on the film is about 50 mm, and for that camera, a 50 mm lens is the normal lens. For a 9- by 9-inch aerial camera, the diagonal of the square image recorded on the film is about 12.7 inches, and a 12-inch focal length lens is considered to be normal. A 6-inch focal length lens is frequently used with a 9- by 9-inch aerial camera, and for this camera, that is a wide-angle lens. Consequently, there is considerable falloff of exposure at the edges and corners of the picture.

Tone variations can also occur as a result of changes in the angle between the sun, the features on the ground, and the camera. For example, considering only sunlight and neglecting skylight, an area on the ground that is towards the sun from the camera station can add a specularly reflected component of sunlight and show as a light tone in the positive image. When this same area is away from the sun, with reference to the camera station, then its image cannot receive a specular contribution and is formed only from backscattered sunlight, which results in a darker tone in the positive image. Surface roughness also influences the directional scattering of incoming light. Frequently occurring surficial variations in relief that are equal to, or greater than, the wavelength of the incoming radiation will cause the light to be scattered in different directions. The light that is of concern to photography has wavelengths that are less than 1 micrometer. Consequently, most surfaces are rough and scatter light in all directions, sometimes more in one direction than another. As a result of these effects, two materials can have a high contrast at the trailing edge of the format, with A being dark gray and B being light gray, and they can show a reversal of this contrast when the same materials occur near the leading edge of the format. The boundary of a tone pattern can also have a shape that can be frequently related to other events and conditions.

Texture refers to the visual impression of surface structure, and in some instances it is difficult to describe texture separate from tone. Descriptive terms include smooth, coarse, silky, mottled, speckled, banded, etc. For example, an area containing a dense stand of pine trees will have a different texture than a mixed hardwood stand, and a plantation of pine trees with its 2-dimensional arrangement of rows has a very different texture than a natural pine forest. Large areas of sedimentary rocks exposed across the beds can present a striated appearance, and when closely spaced these striations can give a grain-like appearance to the terrain similar to wood grain. Some examples and further discussion of tone and texture patterns as used in the context here can be found in other publications.[9,10]

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[9] R.E. Frost. 1950. *Evaluation of Soils and Permafrost Conditions in the Territory of Alaska by Means of Aerial Photographs.* Prepared by the Purdue University Engineering Experiment Station for the St. Paul District, Corps of Engineers, Department of the Army.

[10] J.N. Rinker. 1975. Some technical aspects of film emulsions in relation to the analysis and interpretation of aerial photographs. *Aerial Reconnaissance for Archaeology.* Ed. D.R. Wilson. The Council for British Archaeology, 7 Marylebone Road, London NW1 5HA. CBA Research Report No. 12. Derry and Sons, Ltd., Nottingham, England.

In most cases, these patterns are associated with areas of relatively bare or exposed soil and rock or with an area of uniform vegetation cover. Although photo tones and texture are important sources of information, care must be taken in evaluating them, especially those of soils because climate and season greatly influence the development and the detectivity of these patterns. With respect to soils, tones and textural patterns can provide information about identity, origin, uniformity, horizon development, moisture relations, etc. As an example, in panchromatic photography, silt has a bright uniform photo tone and a silky texture. Soils of the Wisconsin glacial till show an intricate mottling of light and dark gray tones that are related to soil texture and moisture conditions, and soils of the Illinoian glacial till develop white fringes around gullies, which are indicative of a profile development, i.e. a gradual alteration of the soil into layers of different composition. Curvilinear tone streaks on low flat areas are suggestive of fluvial deposition. A rectangular light-toned network in flat farmland is indicative of the presence of drainage tiles, which in turn suggests a high water table and waterlogged soils. With respect to exposed rocks, tone and texture can provide supportive information as to type. For example, in igneous rocks, the mafic group, which includes basalt and gabbro, has dark photo tones; and silicic rocks, such as granite, tend to have lighter tones. For further information on tone and texture characteristics of some rock types, refer to appendix G. With respect to vegetation, tone and texture can provide information about composition or vegetation type.

SPECIAL. This category includes items that do not easily fit under other factor headings, or items that although discussed under other factors, are sufficiently direct indicators of identities and conditions that they warrant additional evaluation. This part of the analysis serves as one more checkpoint to examine the imagery for clues to support previous findings or to suggest new relations or identities. These patterns frequently depend on some inherent quality of the material or on some inherent nature of an action. Typical patterns include joints, faults, soil slumps, mudflows, tears, and some patterns of drainage, erosion, and tones. As an example, windblown silt deposits have an internal vertical structure that accounts for several patterns that serve as direct indicators of the presence of such a material. These include the pinnate drainage pattern, flat-bottomed steep-sided gullies, terracettes and pinnacles on gully walls, and vertical-faced road cuts. The pinnate, gully cross section, and road-cut patterns would be evaluated under their respective sections, i.e. drainage and cultural. The terracettes and pinnacles, too small to be considered as landforms, would probably be discussed under this section. Another example, slumps and tears in an otherwise smooth valley wall would be indicative of instability and potential engineering problems.

Within this category, an important member is that collection of pattern elements called lineations, including curvilinears. They are called lineations because they are seen in the imagery as lines of various lengths and distinctness crossing the landscape. One group of lineations is associated with fractures in the rocks, i.e. joints and faults. The term "fault" indicates a perceptible displacement between the sides of a fracture along the fracture plane. In length, these features range from small cracks barely discernible with a handlens to transcontinental lineations. These fractures are a record of the rock's response to stress applied through a variety of forces, such as tension, compression, torsion, thrust, shearing, mass expansion, mass shrinkage, etc. The causative agents include movement of molten rock that can result in a surface upwelling, i.e. a dome; the folding, twisting, bending, and stretching of rock as a result of plate movements; the expansion of a previously compressed mass; or the volume changes as a result of cooling from a liquid phase to a solid phase. Another form of lineations can be seen in the exposed beds of tilted sedimentary rocks. In these instances, the lines mark the contact between beds of different composition. Lineations are usually visible in the imagery as a series of alined discontinuous tone changes, such as light streaks in the soil caused by better drainage over a fracture, dark streaks where water has been blocked and the soil is moist, lines of taller vegetation due to more available moisture, segments of drainage channels, escarpments, etc.

The patterns of lineations are important for several reasons. In an evaluation of an area from an engineering or construction standpoint, a rock that has a pattern of closely spaced intersecting fractures would certainly be suspect as a zone of weakness and potential instability. In limestones, the fracture pattern, in conjunction with the drainage and overall structure, can be indicative of possible subsurface voids. Fractures also serve as conduits to recharge the ground water table. The path to the water table can be short and direct or a very long, slowly descending lateral one. Consequently, the fracture pattern, in conjunction with geological structure and soil and rock composition, is important to the task of searching an area for a possible source of water.Being conduits, the fractures can convey unwanted material into a water table. Thus, they must be evaluated when searching for a site for waste disposal, either surface or deep-seated.

This summarizes the important characteristics of the factor patterns associated with this manual procedure of photo analysis. As results from in-house research and the scientific literature accumulate, some of these sections will be rewritten and illustrated. Without doubt, new pattern relations will emerge, and equally without doubt, some of our current concepts will need modification. In some of the factor groups a classification of the pattern elements would be of use, and in some instances such an effort has been started. In other instances, there is a hodgepodge of information to be sorted, evaluated, and tested before a semblance of a classification scheme can emerge or a decision made to abandon the effort. This is particularly true for the photo tone and texture group of patterns. In any event, these are the patterns that carry information about the terrain and on which an analysis is based. The following section discusses some of the problems associated with getting the information from the photos, classifying it, and converting it into some form of data base.

FEATURE EXTRACTION AND DATA BASE PREPARATION

J. N. Rinker and P. A. Corl

The manual procedure of image analysis, particularly of stereo aerial photography, provides a versatile and rapid means for obtaining reliable information about the terrain in terms of its origin, composition, properties, climate, and probable response to stress. The results of a photo analysis can be expressed as an environmental data base, i.e. a collection of photomosaics and factor overlays, which, in turn, can be interpreted with respect to a specific problem. Consequently, this procedure has direct application to many general problems, as well as to specific tasks. Examples of these include

1. General worldwide problems associated with
   a. Identifying and mapping geological structure, rocks, soils, vegetation, or land cover/land use
   b. Engineering site selection and evaluation
   c. Location of engineering materials
   d. Land use planning
   e. Probable location of minerals
   f. Probable location of ground water
   g. Waste disposal
   h. Environmental data base preparation
   i. Environmental impact prediction

2. Specific military problems such as
   a. Cross-country movement
   b. Cover and concealment
   c. Analysis of an area of operations
   d. Data base development for MGI, DLMS, TTPDB, etc.

The first step in obtaining information for a data base by image analysis is to extract information from the imagery. A general understanding of how this is done provides insight into both manual and machine procedures, as well as into the nature and level of competence required in a manual analysis and in data base preparation.

Regardless of the pattern elements involved, or the goal of an analysis, there are but three ways of obtaining information from imagery. They are direct observation (d), measurement (m), and inference (i). Direct observation denotes the act of seeing or detecting a feature or pattern element directly in the image. Examples include detecting, marking, tracing, or bounding roads, structures, airports, bridges, rivers, ponds, wooded areas, hills, drainage nets, landform units, etc. In general, it is easier, in the sense of requiring less skill, to detect cultural objects than natural features. There are exceptions to this, of course, because some cultural features, such as isolated towers, can be difficult to find, and some natural features, such as rivers, ponds, isolated volcanic cones, etc., are readily detected by direct observation. Natural features such as landform, drainage net, and gully cross section require more skill and experience in order to observe their shapes accurately. Some of the direct observation tasks can be done by machine or can be greatly assisted by machine procedures, particularly for features with well-defined shapes and sharp boundaries or with well-defined spectral characteristics.

Measurement refers to the use of devices to determine distance, length, width, height, slope, area, volume, tree density, direction, etc. There are also measurements such as optical density and the handling of density changes by fourier transforms. These, however, are not considered in this discussion. Again, different levels of skill and training are required for different types of measurements. For example, measuring height and slope is more difficult than measuring width and length.

Inference refers to inductive and deductive reasoning and judgment to derive or predict information not directly apparent in the image. Examples of the type of information produced by this procedure include predicting physical properties and conditions, probable composition and classification (rocks, soils, vegetation, etc.), and response to stress, etc. This procedure requires higher levels of skill, experience, and knowledge than the others. Although obviously based on direct observation and supplemented at times by measurements, the inferential procedure contains the added task of determining the significance of that which is seen. It is the assembled statements of significance that guide the reasoning towards an understanding of and conclusions about the landscape in terms of its properties, conditions, probable composition, and response to stress. Shape, arrangement, tone, and texture can be seen directly, significance cannot. It must be deduced. Consequently, inferential procedures require levels of knowledge, experience, and skill beyond those needed for direct observation and measurement. Fortunately, inferential procedures are not required for many data base information needs. Table 1 lists some of the associations that exist between the basic methods of extracting information and the types of information.

There is an added complication in evaluating skills and associated tasks because direct observation and inference can overlap when one considers the relations between detection, identification, and classification. At times, these three steps are combined into one operation using a single skill level and a single extraction method. At other times, these tasks are distinctly separated with each based on a different method of extracting information and a different level of skill. In general, as an object or a pattern becomes either less distinct or more complex, the steps of detection, identification, and classification become more separated and require more skill and experience. For example, on large-scale stereo aerial photography, an analyst could detect, by direct observation, an isolated object, identify it as a tree, and classify it as a pine tree, all in one glance. When working with complex patterns, less distinct imagery, smaller scale imagery, or cluttered background patterns, these steps become separated. To continue with the tree as an example, the analyst would first detect an object. Because of its general shape, height, and location, it is identified as a tree. A further evaluation of shape, tree shadow, and tone in relation to that of other trees might lead the analyst to the inference that it is a conifer, possibly a pine tree. A definite separation of steps has occurred.

Cultural patterns also suffer these complications. If a bridge is off center in the format so that there is some obliquity in the stereo view and if the scale is suitable, the analyst could detect, identify, and classify the bridge in one glance. If that same structure, however, is alined along the flight line and the road and bridge surface have the same brightness, then it is possible that the bridge will not show in the image, that is, it cannot be detected by direct observation. Therefore, its presence is inferred simply because the road crosses a water body. In this instance, the classification cannot be done from the photos.

The goal of the classification also influences the relations between detection, identification, and classification. A simple land cover/land use classification can be done by lower skilled analysts using mostly direct obervations, some measurements, and little if any inferential information. In this case, the steps of detection, identification, and classification will be near simultaneous for most units. If the requirements call for a detailed classification of some aspect of the terrain, then the analysis becomes complicated, requires higher levels of knowledge and experience, and is based mostly on inferences drawn from an evaluation of all the pattern elements, as well as a consideration of the climatic regime in which they occur. For these applications, the steps of detection, identification, and classification will be widely separated in both complexity and time requirements.

In some instances, the classification step will be difficult, in others it cannot be completed, and in others the steps of detection and identification might not exist. For example, assume that an analyst has detected a pattern and identified it as a group of buildings among other buildings. The structures are directly noted and duly marked. The next level of classification could be in terms of building type, building height, building use, or building composition. Which of these is chosen depends on the purpose of the analysis. An economic data base would have the classification in terms of use. A military data base might require all four. Building type can be obtained from the photos by direct observation and by using photo keys. Building height can be estimated or measured. In most cases, building use must be determined inferentially or from other information. With few exceptions, information about building composition must come from other sources. In this example, assume that the analyst wants to identify the building in terms of its use. This identification rests on an evaluation of the relations of the specific structure or group of structures to the surrounding patterns. These include location of the site in relation to the terrain and to other buildings and their types, as well as the absence or presence of transportation, parking, loading docks, etc. From these considerations, the analyst might decide that the buildings are used for commercial/retail operations. Detection and identification took place with ease and near simultaneity; whereas, classification was complicated and time consuming. There are instances, of course, that although the buildings have been detected and identified, the use cannot be determined. For instance, a group of two-story row houses built as single family residences could now contain small retail operations, government offices, and a religious group, without a consequent change in photo pattern.

An example that has the steps of detection and identification missing can be found in the task of trying to get soils information in an area that has a dense, continuous cover of vegetation. Because of the vegetation cover, the soil and rock surfaces cannot be seen. Consequently, the determination of soil properties, i.e. its classification, is the only step involved, and it will be a complex one relying on inferences derived from an evaluation of other pattern elements. In any event, whether dealing with natural features or cultural features, the road from detection, through identification, to classification can be short, long and tortuous, or dead ended.

The human factors of interest and enthusiasm have such a strong bearing on the quality and quantity of work produced by an individual that it is difficult to state absolute training and educational requirements or to assign absolute levels of skill to any given task. Nevertheless, some general statements can be made as to the types of expertise associated with different analysis efforts. For simplicity, three levels of training and experience are presented, essentially the extremes and a midpoint (table 2). A number of typical analysis tasks are listed in table 3. For each task, the associated methods of extracting the information and the level of skill needed to do it are indicated. Note that the task of classification is listed three times and that each entry requires a different level of competency. This supports the earlier statements indicating that classifying pattern elements is a troublesome issue, simple in concept, but not necessarily simple in practice. Nevertheless, it is an issue that is always present because basic to the development of any data base is the fact that some sort of classification scheme is needed in order to express the information. Each pattern element, or group of pattern elements, must be assigned a name or symbol that is indicative of the characteristics of that pattern element and its relation to other members within its group. These classifications can be based on different principles and can be expressed in different terminology. In a very real sense, it is the classification requirements that determine both the complexity of the analysis and the level of skill needed to do it. For example, one could classify the land cover of an area on the basis of very broad categories, such as vegetation cover, no vegetation cover, water bodies, structures, roads, and railroads. Although simple, the classification does provide information and requires only a minimum of skill. A more informative classification would be vegetation (forest, brush, grassland, mixed), cultural (structures, roads, railroads, bridges, cultivated land), and barren (rock, soil, water). Obviously, this would be a more complete analysis and would require higher levels of skill and experience. Classification can also be based on specific type, use of the land, properties of its components, or origin to name a few alternatives. For example, a soil map could show a first level of classification based on origin because that information is an early step in the logic of predicting soil composition and texture. In table 4 some examples of classification schemes are listed, the types of analysis tasks needed to do them (direct, measurement, inference), and the associated levels of skill required.

The information presented in tables 1 through 4 is of an obvious general nature and, as such, is suggestive rather than absolute. Even so, the tables do show that much practical information that is of direct use to both Army and civilian needs can be obtained by the lower level of the skill groups. Table 5 lists categories that such a group should be able to map, trace, or otherwise identify on stereo aerial photography in the scale range of 1:20,000 to 1:100,000. Although these categories form a relatively simple land cover/land use data base, they provide information directly linked to perhaps half or more of stated specific needs, as well as to general problems such as cross-country movement, evaluation of areas of operation, a first cut at cover and concealment, etc. With a slightly increased skill level, and photo pattern sheets, additional classifications could be made as to canopy closure, road type, general structure type, etc. If classification requirements go much beyond this, then more than a slight increase in skill is needed. Classifying the patterns on the basis of soil composition, surficial geology, or vegetation composition, etc., requires a greater outlay in time, effort, and knowledge. If this increased level of information is worth the extra expense is a moot point. In some cases yes, but in the majority of cases, the answer might well be no. There is a universal and continual need for reliable general information. There is not an equivalent need for specific information. However important that need is when it does exist, it is neither universal in time nor location. A reliable general information data base can usually be augmented as need arises. The routine requirement for levels of, or types of, information above that needed and using a poorly designed classification system can result in getting little, if any, information and in creating a situation that seems hopelessly complex.

During an analysis, a variety of photo-derived information is produced in the form of overlays, sketches, and notes. Some of this information can be portrayed on overlay material in place on the photomosaic by tracing out the factor in question, e.g. the drainage net or the road net. These overlays are referred to as direct factor overlays, and some of them can be prepared by the lower skill level groups. Other elements of information cannot be drawn in place on the overlay and exist as separate sketches and notes. These elements include terrain profiles, gully cross section and gradient, and some measurements. By evaluating the direct factor overlays, sketches, notes, and measurements, other types of information are deduced that can also be expressed on a map-like overlay keyed to the photomosaic. These overlays are referred to as derived factor overlays. For the most part, these involve some form of classification, and consequently, their preparation requires using individuals from the higher skill levels. Table 6 lists the various information groups and data base elements that are routinely obtained from an air photo analysis. Furthermore, these elements and information groups are representative of many of the MGI needs of the Army. At present, machine and machine-assisted techniques seem to be of little consequence in generating any of the material that goes into the overlay, either direct or derived. Even so, they are of consequence in storing, filing, and presenting such information. Attempts to apply machine techniques to data production are being made in several places. Exactly where and how they will be used and the levels of efficiency, practicality, and reliability they can achieve remain to be learned.

TABLE 1. Basic methods for extracting information from imagery by manual procedures

METHOD	SYMBOL	PROCEDURE	COMMENTS
Direct	d	Direct observation or detection of objects, shapes, patterns, arrangement, tone and texture, etc. Identification of simple pattern elements.	In general these methods require less training, experience, and judgment. Of direct help here are photo keys, Air Photo Indicator Sheets, Feature Identification Sheets, and machine assisted techniques of analysis and measurement.
Measurement	m	Determination of dimensions (width, length, height), volume, area, slope, tree density, direction, etc.	
Inferential	i	Inductive and deductive reasoning from associated clues and convergent lines of evidence to derive information not directly apparent in the imagery.	This method requires more ability, training, experience, and knowledge. Of assistance here are P.I. Logic Sheets, Air Photo Pattern Summaries, Air Photo Indicator Sheets. Logic software plus an example data base in an interactive system could also be of assistance.

For each factor, information element, or classification unit, some or all of the following characteristics are wanted.

DETECTION (d)	
IDENTIFICATION/CLASSIFICATION (d, m, i) Type, species, road/bridge class, etc.	SIGNIFICANCE (i) Suggests materials, composition, bearing load, etc.
DESCRIPTION (d, m, i) Shape (plan and elevation), arrangement, orientation, extent, depth, dimensions, slope, gradient, structure, areal and vertical homogeneity, boundary specification, color, tone, texture, etc.	SIGNIFICANCE (i) Suggests materials, conditions, nature of the climate, classification, use, etc.
CONDITIONS (d, i) Status, wet-dry, frozen, unfrozen, seasonality, growth stage, active, abandoned, under construction	SIGNIFICANCE (i) Suggests materials, climate, development, classification, presence of instability, limits of use, potential for change, etc.
PROPERTIES (i, m) Hardness, porosity, permeability, erodibility, density, spacing, etc.	SIGNIFICANCE (i) Suggests materials, conditions, limits of use, classification, potential for change, etc.
SUPPLEMENTAL FEATURES (d, m, i)* Bedding, joint/fractures, faults, strike, dip, slips, sinks, voids, bars, cones, polygons, burns, actual use, etc.	SIGNIFICANCE (i) Suggests properties, conditions, materials, development, subsurface characteristics, instability, limits of use, etc.
DYNAMICS (i) Historical development, environmental interaction, mechanisms of change, effect of weather, etc.	SIGNIFICANCE (i) Suggests development, climate, limits of use, potential for change, response to stress (natural and cultural), etc.

*Denotes that the d and m procedures require a higher level of skill than normal.

TABLE 2. General Training and Experience Associated with Three Levels of Skill that Represent the Extremes and the Midpoint [1]

1	Minimum level of training – High school diploma, 4 weeks of specialized training, plus 4 weeks of on-the-job training for each specialty, and 12 weeks experience.
2	In addition to the above, this level requires 1 or 2 years of experience and considerable knowledge (college level) about at least one specialty, such as soils, geology, vegetation, landform, drainage, land cover classification, some land use classification, bridges and road classifications, etc.
3	This level requires an unusual depth of knowledge (graduate level) about a specialty as well as a working knowledge of several disciplines, plus considerable working experience.

[1] Based on material in:
J.N. Rinker, J. Ehlen, A.E. Krusinger, T.R. Currin, A.O. Poulin, P.B. Mc Cracken. 1976. *Capabilities of Remote Sensors to Determine Environmental Information for Combat.* U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, ETL–0081, AD–A035 139.

TABLE 3. **A list of common photo analysis tasks and associated methods of information extraction and skill levels. The methods for extracting information are defined in table 1. Skill levels are described in table 3. Note that the first five tasks contain a large amount of the basic information needs and that they can be done by the lowest skill level group.**

	Task to be Done	Methods for Extracting Information	Skill Level
1.	Detection/Identification – Simple. Mark, bound, and trace simple objects and pattern elements, e.g. roads, railroads, water bodies, structures, towns, airports, forest, cropland, barren, some landforms, some drainage patterns (subhumid and arid regions), etc.	d	1
2.	Classification of some elements such as roads, bridges, etc., and simple land cover/land use.	d, m	1
3.	Measurement – Plan. Dimensions, direction, orientation, etc.	d, m	1
4.	Description – Simple. Layout, arrangement, orientation, and shape.	d, m	1
5.	Measurement – Elevation. Heights, slopes, and measure or estimate areas and volumes.	d, m	1–2
6.	Detection/Identification – Complex. Mark, bound, and trace complex objects and pattern elements, e.g. landform, drainage, profiles, cultural, vegetation.	d, m, i	2
7.	Classification of land cover/land use patterns, vegetation patterns, cultural patterns, surficial materials.	d, m, i	2
8.	Description – Complex. Shape, slope, structure, symmetry, areal and vertical homogeneity, etc.	d, m	2
9.	Interpretation of data as applied to specific problems and prediction of simple forms of environmental impact.	d, m, i	2
10.	Detection/Identification – Supplemental Features. Mark, trace, or indicate supplemental features such as bedding, joints/fractures, strike and dip, slips, tears, flows, etc.	d, m, i	2–3
11.	Prediction of properties and conditions. Examples include resistance to erosion, hardness, stem spacing, stem diameter, presence of subsurface voids, and unstable materials and conditions.	d, m, i	2–3

TABLE 3. (Continued)

	Task to be Done	Methods for Extracting Information	Skill Level
12.	Significance of information elements, singly and collectively.	i	2–3
13.	Classification of rocks, soils, and complex versions of landform, vegetation, land cover/land use, etc.	d, m, i	2–3
14.	Preparation of environmental data base.	d, m, i	3
15.	Interpretation of an environmental data base for construction site selection and evaluation, environmental impact, and prediction of responses to stress.	i	3

TABLE 4. Classification plans, methods of information extraction, and needed skill levels. None of the categories in any of the columns can be rigorously separated from the others. There is a transition. In general, however, the classification schemes that are needed for the preparation of any given data base determine the complexity of the photo analysis and the levels of skill and experience needed to complete the task.

Types of Identification and Classification	Example	Methods for Extracting Information	Skill Level
Generic	forest, tree, shrub, grassland, cultivated land, road, bridge, hill, bare soil, etc.	d	1
Specific	rain forest, oak tree, closed evergreen, broadleaf shrubland, cereal grain crop, interstate, truss bridge, barchane hill, windblown silt	d, m, i	2
Composition	mixed hardwood forest, cement concrete road, wooden bridge, sand hill	i	2
Use	Recreational forest, rangeland, cropland, railroad bridge, quarry, etc.	d, i	1–2
Property	closed canopy forest, thorny shrubland, impermeable soil, 30% slope, average stem spacing, etc.	d, m, i	2–3
Conditions	Gypsy moth infested forest, diseased crops, saturated soil, unstable slopes, potable water, etc.	d, i	2–3
Origin	residual soils, transported soils (aeolian, glacial, fluvial, etc.)	i	2–3

TABLE 5. Land cover and land use categories that should be identifiable by skill level 1 individuals, i.e. the lower of the three skill levels. This is based on using stereo aerial photography within the 1:20,000 to 1:100,000 scale range. Although these items form a simple land cover/land use data base, such information is directly applicable to many stated needs. If supplied with suitable Air Photo Indicator Sheets, this same group should be able to classify within some of these categories, e.g. amount of canopy closure, road type, bridge type, crop type, dam type or purpose, structure type and probable use, landform type, etc.

- Trees
- Brush
- Grassland
- Mixed
- Cropland
- Barren
- Water bodies
- Drainage-plan
- Roads
- Railroads
- Airports
- Bridges
- Dams
- Rights of way
    - Power lines
    - Pipelines
- Fence lines, hedgerows
- Structures
- Collections of structures (strip, town, etc.)
- Mixes of trees and structures
- Some landform and slope classes

TABLE 6. Data base information obtainable from air photos. Some of the direct observation type of information abstracted from the photos can be portrayed in the form of tracing, or other notation, directly on transparent material covering the photos. These are Direct Factor Overlays. Other types of information, i.e. observations and measurements, are recorded as notes and sketches. Information that is derived by inference and judgment can also be presented on overlays keyed to the air photos. These are Derived Factor Overlays, and usually consist of classification terms assigned to bounded areas and special identifications. These overlays, notes, and sketches form an environmental data base that can be evaluated with respect to a given problem or task.

AIR PHOTO PATTERN ELEMENTS

Landform
Drainage-Plan
Drainage-Elevation
Indicators of erosion
Indicators of deposition
Vegetation
Cultural
Tone and texture
Special

OBSERVATIONS, SKETCHES, AND NOTES

Information obtained by direct ob-observation but which cannot be mapped or traced in place on the photos

1. Landform: profiles, shape characteristics, cross sections
2. Drainage-Elevation: gully cross section and gradient
3. Indicators of erosion
4. Indicators of deposition
5. Tone and texture

EXAMPLES OF INFORMATION THAT CAN BE MEASURED, OR APPROXIMATED

1. Dimensions of objects
2. Radius of curvature
3. Areas and volumes
4. Tree height and density
5. Canopy closure
6. Stream width
7. Slope
8. Spacing and orientation

DIRECT FACTOR OVERLAYS

Patterns and features traced or marked in place by direct observation

1. Drainage-Plan
2. Ridgelines
3. Lineations
4. Dip and strike
5. Pattern boundaries
   landform
   drainage
   vegetation units
   vegetation damage
   land cover
   land use
   flood damage
   structures
   tone and texture
6. Cultural objects: roads, railroads, trails, canals, airports, pipelines, power lines, towers, buildings, bridges, some property boundaries
7. Special features: locations of slumps, tears, gradient changes, cross section changes

DERIVED FACTOR OVERLAYS

Examples of classifications and predictions based on inference and evaluation of the stereo photos, Direct Factor Overlays, sketches, and descriptive material

1. Geology: rock type, distribution, structure, properties, cross sections
2. Soils: type, distribution, depth, properties, conditions
3. Vegetation: type, distribution, properties (closure, spacing, diameter, vigor)
4. Slope classes
5. Land cover/land use identities
6. Critical areas: sites of potentially unstable soils, rocks, slopes, etc.
7. Probable locations of subsurface voids, ground water, minerals, contamination points, etc.
8. Change (needs sequential imagery): land use, population, economics, landform, etc.

PRODUCTS AND IMAGE ANALYSIS DOCUMENTATION

J. N. Rinker and P.A. Corl

If this manual procedure of analysis is to be improved, be more routinely applied, be involved in technology transfer, or be a guide to help develop computer-assisted techniques, it is a prerequisite that its logic and information elements be tested, certified, and documented in a readily usable and reliable manner.

There are but two sources of information for such documentation. One is the review, evaluation, and acceptance or rejection of existing information, including our own reservoir of knowledge, experience, field data, and imagery. The other is the discovery, testing, and establishing of new information. At ETL, the Center for Remote Sensing (CRS) is actively working on both aspects, i.e. the evaluation and refinement of existing knowledge, and the search for and development of new knowledge. Aside from the technical papers in the open literature, much of the CRS documentation is being put into formats designed to present and relate small single elements of information. In the case of manual image analysis (photo, radar, LANDSAT), the information unit is a pattern element that has proven to be an indicator of some aspect of the terrain. In the case of LANDSAT digital analysis, our information elements to date are spectral reflectance measurements and band intensity measurements associated with certain materials and conditions, or combinations of materials. The spectral reflectance measurements include information about pure materials, i.e. a material uniformly filling a field of view, as well as combined responses, such as varying ratios of vegetation and soils within a field of view. In the case of infrared thermal radiation, the information units contain specifications of time, bandpass, and meteorological conditions associated with feature/background contrast ratios. At present, the air photo pattern elements are receiving more attention than are the others. Each element, regardless of source, must be tested. Is it false, or is it true? If true, is it always true, or true only under certain conditions, and if so, what are the conditions? In order to answer these questions, it is necessary to consider ground observations, and measurements, as well as the pattern elements in the aerial photography or other imagery. Only by such a procedure of image analysis, field checking, arguing, and technical critique can one separate opinion from fact, establish validity, and set the basis for subsequently putting the material into a printed form.

Of the elements from the literature that have gone through the test and critique cycle, many have fallen by the wayside because they were proven to be either inaccurate or of too limited an application. Many others, including our own, have needed extensive modification. Very few have made it through to the final product without alteration. Of necessity, a large amount of printed material has been, and is being, collected and reviewed. This includes Army manuals, the open literature, internal reports, data bases, classification schemes, etc. Many of these items had what proved to be a surficial plausibility that read well, but which fell apart upon testing and critical review. Additional complications included inconsistencies within the internal logic, contradictions within and between documents, and a noticeable lack of clarity. As a final test, one must be able to sit down with the images and the associated document, do what is said, see what is claimed can be seen, deduce what is claimed to be possible, and then go to the field and find that the results are correct. If this cannot be done, then that element or procedure must either be modified to make it true, or discarded. Before progress can be made in all of the ramifications associated with the applications of air photo and image analysis and their potential transition into a machine-assisted procedure, the bits and pieces, and the logic that binds them together, must be documented, and it is equally important that the documentation be correct.

In addition to conventional research reports, the information about patterns, materials, conditions, procedures, and radiometric characteristics is being expressed in a series of related documents that can be expanded or otherwise modified in the future. As field work, laboratory work, and literature review progress, deletions, alterations, and additions will be made. At present the proposed series consists of

- Summary Sheets
  - Factor
  - Materials
  - Air Photo Patterns
- Air Photo Indicator Sheets
- Photo Interpretation Logic Sheets
- Spectrophotometric Data Sheets
- Radiance Data Sheets

- Classification Schemes
  - Soils
  - Vegetation
  - Land Cover/Land Use

- Application Summaries
  - Ground Water
  - Minerals
  - Soils Mapping

In general, the items in the top group are in formats that, in addition to other uses, can provide a means for selecting and transferring information into programs associated with machine-assisted or interactive procedures, such as a knowledge-based expert system, or into programs associated with digital feature extraction. Items in the middle group are associated with data base preparation. Items in the lower group are meant to outline sequences of pattern elements associated with a given task. Those products in the upper group entitled "Materials, Air Photo Patterns, Air Photo Indicator Sheets, and Photo Interpretation Logic Sheets" are part of the documentation for the manual procedure of air photo analysis. In addition, they serve to evaluate the applicability of machine processes and to supply information in a form that can be incorporated into knowledge-based expert systems.

These documents supplement each other and, as a set, are designed to portray and illustrate the reasoning processes that an expert in air photo analysis would follow in making decisions and predictions about the nature of the terrain in terms of its identities, composition, conditions, practical utilization, and response to stress or cultural impact. This information can then be codified into rules and some form of logic network based on sequential questions and answers. With the rules and the yes/no answers, the nonexpert can be led through the reasoning steps by a sequence of "If yes, then . . ." type of statement that leads to some conclusion. At any point, the user should be able to query the system as to the why of the statement.

It was mentioned earlier that the state of the art for obtaining detailed terrain information was the manual procedure of air photo analysis. This will continue to be true, even if one assumes the existance of a perfectly designed interactive system. In order to make use of the stored rules so that predictions can be made, a series of direct questions must be answered, and the answers to these questions come from the photos. For such questions as "Is the gully bottom flat?" (yes or no), "Is the gully gradient uniform?" (yes or no), "Do the walls of the gully have uniform slopes?" (yes or no), etc., the answers can come only from an analysis of the stereo photo, and this is a manual procedure, except for those features that can be identified by automatic machine recognition techniques. Nevertheless, an interactive system can direct the analyst to consider pattern elements that might have been overlooked and into paths of reasoning that were missed and, of more importance, to enable the nonexpert to produce results similar to those of an expert analyst. There is, however, this basic division of labor: the analysis of the photos is manual, and the interpretation of these results is by the computer. An example of a question and answer sequence of a type associated with knowledge-based systems is in appendix I.

SUMMARY SHEETS

Factor Summary Sheets. These are single sheet descriptions of each of the pattern element groups of landform, drainage-plan, drainage-elevation, erosion, deposition, vegetation, cultural, photo tones and texture, and special. Where appropriate, a first-order classification is, or will be, included. These represent a first draft, and changes will be made as work and discussion continue. Insofar as earth surface materials are concerned, the more important members of this group are landform, drainage (plan and elevation), erosion, deposition, and tone and texture. These groups are easier to organize and illustrate than are the other pattern elements. In any event, it may turn out that this sort of information is better presented in text form rather than as a series of summary statements. If so, these sheets will be dropped. The Factor Summary Sheets completed to date are in appendix A.

Materials Summary Sheets. These are single sheet descriptions of general characteristics and properties of earth materials. Because the physical and chemical properties of any material set the bases for the kinds of patterns that erosion and weathering can develop in that material, an understanding of these properties is of help in making judgments about patterns, pattern variations, and significance. The list of materials that will be treated in this section includes members of the igneous, metamorphic, and sedimentary rocks, and some soils. Examples of sheets completed to date are in appendix A.

Air Photo Patterns Summary Sheets. These single sheet summaries serve as reference guides to the photo pattern elements associated with a given material, in a given condition, and in a given climate. Each sheet is for a specific material and climate relation. As an example, one sheet is entitled "limestone, flat-lying, humid and subhumid areas." Each summary describes the characteristic landforms one can expect to find, the patterns associated with drainage (plan and elevation), the indicators of erosion that one should look for, depositional patterns that can form, vegetation associated with the material, typical cultural patterns that can occur, the nature of the tones and textural patterns, and special pattern elements that are uniquely related to the subject. These sheets provide basic relations that can be codified into rules for an interactive system. The materials to be described in this manner include members of the igneous and metamorphic rocks; the sedimentary rocks in the forms of massive pure beds, thin beds, and interbedded units; and some soils and surficial deposits. Air Photo Indicator Sheets will be used to illustrate the pattern elements that are discussed. Examples of these sheets are in appendix A.

AIR PHOTO INDICATOR SHEETS

These single sheet guides illustrate and describe specific pattern elements that are related to or indicative of a given material or condition. The pattern elements to be presented are those within the factors of landform, drainage (plan and elevation), erosion, deposition, vegetation, cultural, tones and texture, and special. Each sheet contains an air photo example, stereo if needed, plus ground photography when available. Along with each indicator are given the condition or the material that it indicates, the geographic location, the climatic zone (based on Trewartha, 1957), comments about the pattern, how the relation was verified, sensors that can detect the pattern, limitations in terms of film/filters, season, etc., and the engineering significance where appropriate. The pattern elements listed in the Air Photo Patterns Summary Sheets as well as the dominant and supportive indicators in the Photo Interpretation Logic Sheets will be illustrated with this form of indicator. Because these sheets illustrate the basis for making a judgment, or a decision about a pattern element and its relations to terrain components, they form a portion of the knowledge-base part of an interactive system. Specifically, they are meant to illustrate questions in the analytical sequence (refer to appendix I). These sheets can also serve as general reference material, as image keys, and as training aids. Indicator Sheets completed to date are in appendix B. Whether or not a similar approach will be taken with other forms of imagery remains to be determined.

PHOTO INTERPRETATION LOGIC SHEETS

The original purpose of these sheets was to provide a means for evaluating the manual procedure of photo analysis and determine what steps, if any, lent themselves to machine procedures, interactive systems, etc. Although the sheets do serve this purpose, they have been arranged to meet other goals as well. They provide a sequential listing of the pattern elements used in photo analysis. Next to each element are listed the dominant and supportive pattern indicators that the "expert" uses to identify or gain information about the specific element. Each of these pattern indicators is judged in terms of stereoscopic aerial photography, monoscopic aerial photography, automatic pattern recognition, and interactive systems. Adjacent to these evaluation columns is a column for comments. As many as possible of the dominant and supportive pattern indicators will be cross referenced to appropriate Air Photo Indicator Sheets. The pattern elements listed are from the factor groups of landform, drainage (plan and elevation), erosion, etc. At present, work will be restricted to landform and drainage (plan and elevation). When these are completed to some acceptable level and if it is still the intent to continue, then attention will be turned to erosion, deposition, and tone and texture. At this point, the evaluation columns for manual and machine procedures will be eliminated to provide space for additional comments and for cross-referencing the pattern indicators into appropriate data bases, e.g. MGI, Digital Land Mass System (DLMS), Tactical Terrain Products Data Base (TTPDB), etc. These sheets, along with the Air

Photo Indicator Sheets, provide the data units and basic elements of logic for incorporation into an interactive system. Specifically, they are the source of the questions that guide the analysis (refer to appendix I). Examples of the Photo Interpretation Logic Sheets are in appendix C.

SPECTROPHOTOMETRIC DATA SHEETS

Although there are several uses for these sheets, including camouflage and signature studies, they are oriented towards feature extraction based on supervised digital classification of LANDSAT scenes. An absolute spectral reflectance curve also enables one to estimate emissivities and thereby predict spectral emittance. Many materials have reflectance curves that are identical over some portion of the electromagnetic spectrum, but which differ in other parts. In this instance, one sensor would depict them as the same and another sensor would note a difference. The use of various film/filter combinations and multiband sensors to separate different materials is based on these relations.

The LANDSAT Multispectral Scanner (MSS) is perhaps the best known and most frequently used of the multiband techniques. It collects reflected sunlight from each instantaneous field of view (IFOV), which is about 70 by 70 m, and records the intensities in each of four spectral bands. The bands, which for LANDSAT 1 through 3 are numbered 4, 5, 6, and 7, have the respective wavelength passes of 0.5–0.6 μm (green), 0.6–0.7 μm (red), 0.7–0.8 μm (infrared), and 0.8–1.1 μm (infrared). On LANDSAT D, the new Thematic Mapper on board provides six more bandpasses. The approximate wavelength ranges are 0.45–0.52 μm, 0.52–0.60 μm, 0.63–0.69 μm, 1.55–1.75 μm, 2.08–2.35 μm, and 10.4–12.5 μm. The latter bandpass is commonly used in infrared thermal techniques. If one considers satellite systems other than LANDSAT,[11] then a variety of reflectance and emittance data are becoming available throughout the visible, photo infrared, thermal infrared, and microwave regions of the spectrum. Aside from conventional manual analysis of the imagery, such data can be manipulated by digital techniques, and a variety of programs have been developed for this purpose, most notably for the LANDSAT MSS.

Successes in digital classification, or at least in digital discrimination, are most frequently associated with features that have strong and unique spectral differences from their surroundings. Such features include damaged vegetation, vegetation units, exposed zones of alteration in soils and rocks, lakes, sediment loads, snowfields, etc. Discrimination and identification are, of course, two different things and the latter is the more difficult task. Even for discrimination, however, a program developed for one scene will not necessarily work on another scene of the same area or for the same type of terrain

[11]NOSS National Oceanic Satellite Systems, 23 March 1979. A joint effort by National Aeronautics and Space Administration, Department of Commerce (National Oceanic and Atmospheric Administration), and Department of Defense (Navy, Air Force, and Army).

components in a different area. Nevertheless, a supervised classification, i.e. a classification procedure wherein the analyst is directly involved and can correct or eliminate obvious misclassifications and otherwise modify selection rules, is increasingly being used. Although a nonsupervised, or automatic, classification might work for a few features, such is not yet applicable for deriving general terrain information. There are several problems associated with classifying digital spectral information, including (1) variations in the quality and quantity of incoming sunlight as a result of atmospheric changes and seasonal changes, (2) variations in surface orientation, (3) lack of baseline spectral reflectance measurements, and (4) the IFOV being frequently composed of different surfaces.

Because of the obvious importance of spectral relations to many scientific needs, as well as the continual improvement of airborne and satellite systems to record spectral intensities in narrower and more numerous bandpasses, the abilities to discriminate and, in some cases, to identify, will be improved. Consequently, there will be an increasing use of digital analysis and digital classification techniques. Because in such procedures detection and identification are based on differences in spectral characteristics, it is important to establish the relations between cause and effect, determine the variances within scenes, and gain an understanding of the practical limits of reliability. Towards these ends, we are collecting from soils and plants a variety of laboratory and field spectral measurements (reflectance, fluorescence, absorptance) as functions of age, moisture, salinity, mineral content, stress, illumination characteristics, season, and percent cover in an IFOV. With reference to reflectance studies, the experiments include spectral, diffuse, and total hemispheric measurements, with the latter being done by means of integrating spheres. In some cases, the vegetation and soil samples are chemically analyzed to find out if there are any relations between the spectral reflectance, vegetation composition, and soil composition. Results of this research have been presented in the open literature, as well as via internal reports.[12,13,14,15] A single sheet format is being developed at ETL to display this type of information on a feature-by-feature basis. In addition to the spectral data, regression equations will be included where appropriate. Such a data sheet might help in making decisions about LANDSAT band choice and band ratioing for digital classification, as well as provide information for photographic detection. A sample sheet is in appendix H.

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[12]M.B. Satterwhite. "Changes in Soil Spectral Reflectance by Vegetative Cover." *Proceedings, Am. Soc. of Photogrammetry.* 1981 Annual Meeting, Washington, DC, February 1981.

[13]M.B. Satterwhite, J.P. Henley, and M. Treiber. 1982. *Vegetation Cover Effects on Soil Spectral Reflectance.* U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, 1982, ETL–0284, AD–A123 817.

[14]M.B. Satterwhite. 1982. *Vegetation and Terrain Effects on Digital Classification of LANDSAT Imagery.* U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, ETL–0292, AD–A124 236.

[15]M.B. Satterwhite and J.W. Eastes. 1981. *Spectral Reflectance of Plant Indicators of Saline and Nonsaline Soils.* ILIR No. 1191D010091 Final Report, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia,

RADIANCE DATA SHEETS

Infrared Thermal. Research at the CRS-instrumented test site at ETL has generated a large amount of data associated with infrared thermal techniques, and some of these results have been released in the form of scientific reports.[16,17,18,19] Single sheet summaries can be prepared that show radiation characteristics of various features/ background combinations. Such sheets could include radiation variances as a function of time, meteorological conditions, physical conditions (material type, temperature, moisture, etc.), time of maximum contrast between feature and background, etc.

Microwave (Active and Passive). Cooperative research efforts with the Naval Research Laboratory (NRL), U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), and National Aeronautics and Space Administration (NASA) include evaluating passive microwave radiometers, a microwave imager, and radar with reference to vegetation type, canopy closure, soil, canopy contribution, canopy masking of ground radiation, and canopy obscuration of the terrain to radar. As these flights are infrequent, the data accumulate slowly. Variations in the recordings from the passive systems have shown some correlation with vegetation patterns, but whether these are due to differences in vegetation radiation properties, changes in soil type, or soil moisture is not yet known. Chemical analysis of the vegetation, especially for metallic elements, will be done to find out if there are any relations between such data and microwave emittance and reflectance. The research into the spectrophotometric, radiometric, and chemical characteristics of vegetation, soils, and rocks helps to develop knowledge applicable to specific feature extraction and to data base preparation in general. Figure 1 shows the ways in which this type of research supports the overall problem of data base generation and feature extraction. At present, we do not know if the results of these studies will lend themselves to summary sheet presentation.

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[16]A.O. Poulin and A.E. Krusinger. 1980. "Instrumented Test Site for Infrared Backgrounds." *Presented at Meeting of the IRIS Specialty Group on Targets, Backgrounds and Discrimination.* 26, 27 August 1980.

[17]A.O. Poulin, A.E. Krusinger, M.B. Satterwhite, and L.K. Balick. "Observations of the Nocturnal Thermal Characteristics of an Isolated Conifer." ILIR No. 1091D010085 Report, October 1980, unpublished.

[18]A.O. Poulin and A.E. Krusinger. "Thermal Structure of Point-Source Vegetation Targets." ILIR No. 1191D010090 Final Report, 1 October 1981, unpublished.

[19]A.O. Poulin and A.E. Krusinger. *The Nocturnal Relationship of Isolated Tree and Air Temperature.* U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. Report in progress.

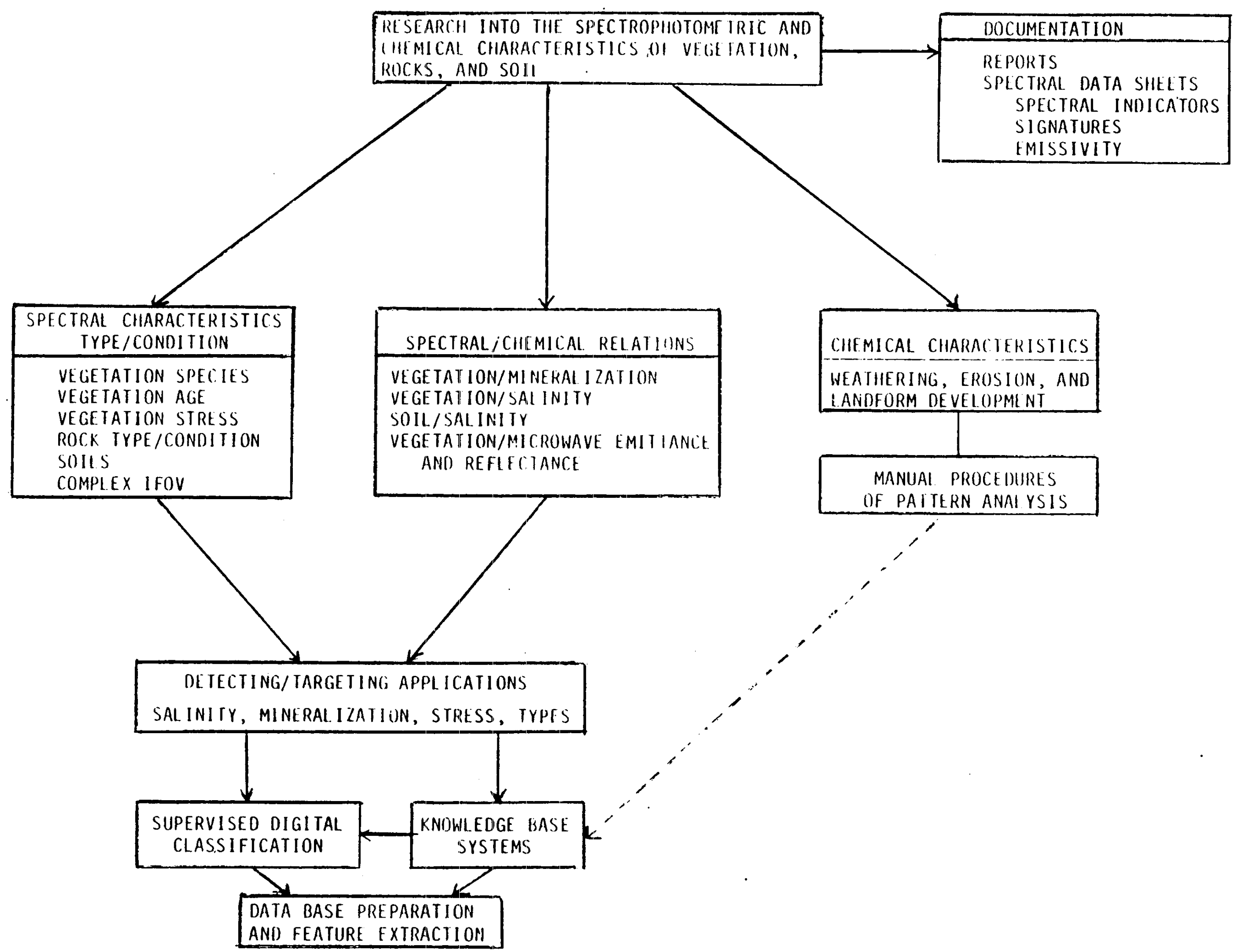


FIGURE 1. Diagram showing the ways in which research into the spectrophotometric, radiometric, and chemical characteristics of vegetation, soils, and rocks interact to develop knowledge applicable to specific feature extraction, or to data base preparation in general.

CLASSIFICATION SCHEMES

Whenever a large assortment of information elements is to be presented in a data base, some sort of classification system is needed to relate the pieces to each other and to establish a hierarchy. By and large, classification systems that are usable with photo analysis and that are directed towards, or at least include, information elements related to Army needs are not readily available. Consequently, effort has gone into developing classification systems for soils mapping, land cover/land use, and vegetation.

With reference to soils mapping, existing classification systems are based on laboratory or field measurements, not on photo patterns. Within ETL, a scheme has been developed that is based on the manual procedure of photo analysis and that has been critiqued but not tested. With reference to land cover/land use, 20 classification systems were evaluated, one of which was tested by photo analysis. None of the systems were satisfactory, either in being usable with imagery or in supplying sufficient amounts of terrain information needed by the Army. In view of the fact that the systems were designed around economic considerations, the latter finding is not surprising. Within ETL, work is continuing on developing a system that meets three goals: first, it must be applicable to manual techniques of image analysis, at least at the first level; second, it must be able to assimilate other sources of information at higher levels of classification without the need of altering the basic structure; and, third, it must include Army information needs. A similar situation exists with reference to the vegetation classification and a scheme has been developed that is based, in part, on work in ETL Report 0058, "Study of Classification and Nomenclature of Vegetation." This scheme has been critiqued, partially tested, and is being modified.

There are some characteristics that all classification schemes should share. A report by Liu lists qualifications that a soil classification system should have.[20] Because these comments apply equally to other subjects, they are paraphrased below.

1. Use of distinct attributes, but as few as possible, as the basis for forming groups.

2. Develop a logical, simple, and concise scheme that is easily remembered.

[20] T.K. Liu. 1970. "A Review of Engineering Soil Classification Systems." In: *Special Procedures for Testing Soil and Rock for Engineering Purposes.* ASTM Special Technical Publication 479. Am. Soc. for Testing and Materials, 1916 Race St., Philadelphia, Pennsylvania 19103.

3. Groups should have meaning, i.e. the grouping of the elements should provide an indication of the general broad properties or behavior of the members.

4. Terminology should consist of descriptive, easily understood, and commonly used terms.

5. Symbols cannot properly substitute for descriptive names, but when they must be used they should have specific meaning and be easily associated with the element in question, i.e. avoid codes that have meaning only to a specialist or that require constant reference to tables for translation.

6. Flexibility. The scheme should be capable of adsorbing additions, deletions, or the creation of subdivisions without affecting the basic structure.

7. At least in the early levels of classification, the system should be capable of being used by relatively unskilled personnel.

To these qualifications we have added the following:

1. The scheme must lend itself to photo analysis techniques.

2. It must be able to absorb information from other sources.

3. It must include information elements required by the Army.

Summaries of the work on classification systems for soils, vegetation, and land cover/land use are in appendixes D, E, and F.

APPLICATION SUMMARIES

These are to be basic outlines that show the sequence of steps and the important pattern elements associated with an image analysis directed towards a specific task, such as finding the most probable areas for locating minerals, ground water, or subsurface voids, etc. Accompanied by indicator sheets, they could be of use with an interactive system. There are interactive programs that are analogous in concept, ranging from early ones in chemistry and diagnostic medicine up to more recent ones in exploration geology. This is a low priority item, and furthermore work cannot start on it until more of the photo analysis documentation is done.

In figures 2 and 3, the relations among the topics that have been discussed are summarized. Figure 2 shows the general relations between the research work and the forms of documentation with respect to an analytical procedure, i.e. based on inductive and deductive reasoning. Figure 3 shows the relations of the various types of documentation and their intended uses with respect to manual analysis, supervised digital classification, and knowledge-based systems for interactive procedures of analysis.

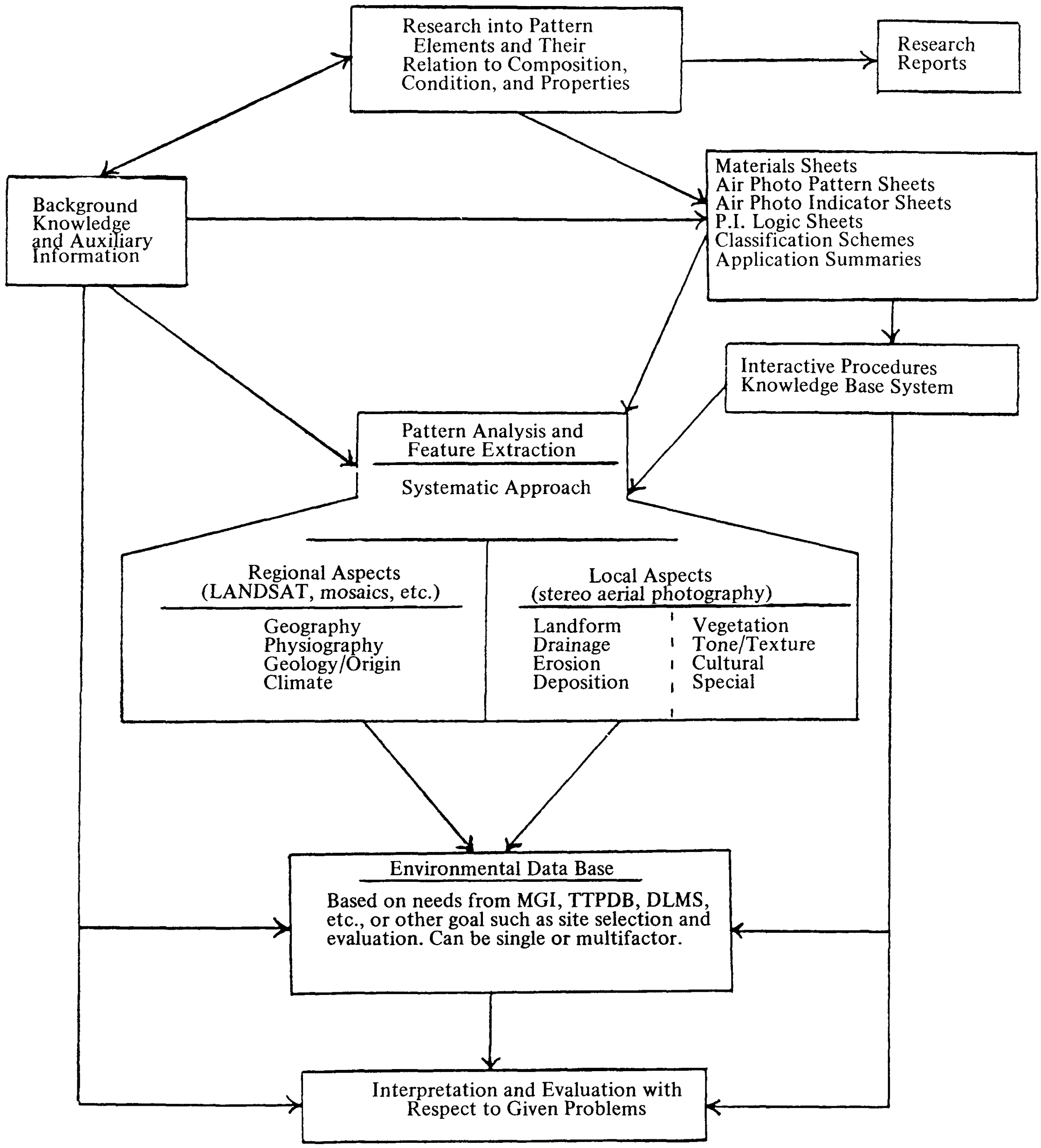


FIGURE 2. Relations between background knowledge, research, and documentation in the development of analytical procedures based on deductive and inductive reasoning.

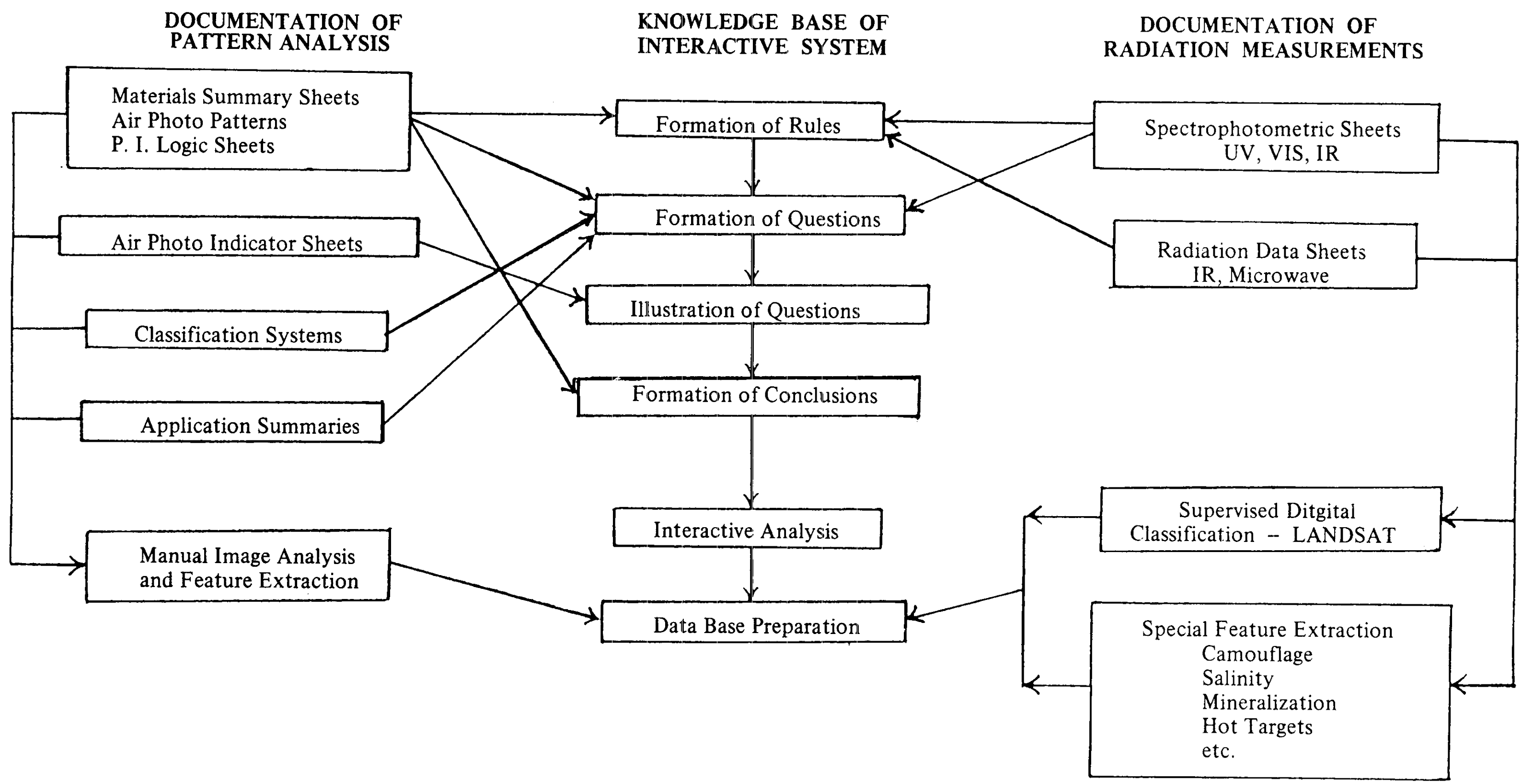


FIGURE 3. **Documentation Uses. Documentation forms associated with pattern analysis are listed at the upper left and those associated with spectroradiometric measurements and radiation characteristics (infrared and micrcwave) are listed at the upper right. Both types of documentation can be used to support specific projects, as shown in the lower part of the figure, or contribute a knowledge-based system that can be used for interactive analysis and subsequent data base preparation.**

APPENDIX A.
FACTOR PATTERNS, MATERIALS,
AND
AIR PHOTO PATTERNS SUMMARY SHEETS

CRS Staff and R.E. Frost

LANDFORM

Landform refers to the shape, size, and orientation of any given surface feature and its location within and its relation to the surrounding area. It is the most important pattern element because it is so closely associated with the origin of the material and the subsequent erosional history. An understanding of landforms and their origin makes it possible to bound areas of similar materials and predict their composition, textures, and physical characteristics. In this part of the photo analysis, areas are outlined in which the terrain elements within are uniform in shape, size, spacing, arrangement, and orientation. An area might contain but one item or one shape, for example a plain, or it might contain a collection of shapes, such as a group of similar hills. Each bounded area must be described in terms of shape, size, spacing, arrangement (vertical and horizontal), symmetry and asymmetry, dip, slope, angularity, roundedness, and ratio of top area to basal area (for hills). These pattern element items are indicative of materials and conditions, and they must be evaluated in terms of significance. For example, sharp angularity in the hills, or mountains, is descriptive of the shape. The significance of this pattern is that it suggests the presence of a hard resistant material. Conversely, where hills have soft, gently rounded shapes, it is indicative of a soft material. Climate modifies these aspects and must be taken into consideration. A clay shale can have gently rounded slopes in a moist temperate region, and rugged precipitous slopes in an arid region subjected to seasonal rains and flash flooding. Profiles should be drawn along several transects through the stereo field of view. Upon completion of the analysis the profiles can be converted into predicted cross sections. Classification decisions frequently depend on the purpose of the analysis, scale of the photography, and a definition of the minimum area to be mapped. The complexities of landform classification found in most texts are beyond the needs of air photo analysis; however complicated the shape, it can be assigned into one of four general categories.

Plains. Any relatively flat surface of sufficient extent to be a mappable unit at the scale of imagery used. This includes surfaces that are flat over large regions, such as the Great Plains; surfaces of valley floors, old lake bottoms, terraces, benches, large fans, etc.; and perched flat surfaces such as mesas or buttes. The significance of this shape is that it suggests sedimentation or deposition. Usually, this is indicative of clays, silts, sands, and gravels, either in the form of sedimentary rocks or as soils. Lava flows can form layered sequences, the surfaces of which are flat over extensive areas. These would be mapped as plains. Other pattern elements, however, would direct the chain of reasoning away from considering the material to be sedimentary. The surface of a plain can have variations in relief that lead to such descriptions as: a gently rolling plain, a pitted plain, a dissected plain, etc.

Hills and Mountains. Shapes that have significant positive relief within the area of study, i.e. variations beyond the range of the adjectives used to describe modifications of a plain. Such topography can result from dissection of a plain, doming, or local uplift caused by the intrusion of igneous material, volcanic activity, aeolian deposits, or uplift and folding of the crust. The patterns of hill shape, in plan and elevation, are indicative of the nature of the materials in terms of igneous, metamorphic, and sedimentary rocks and in terms of structure such as dipping, flat-lying, etc.

Basins. Shapes that have significant negative relief and size within the study area, i.e. a depression of some sort. These include old marine and lake beds, large river valleys, solution valleys and depressions, subsidence depressions, etc.

Escarpment. A significant and obvious boundary that separates landform units. When present it is most often as a steep and abrupt change in relief that is continuous over some distance.

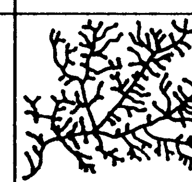
SUMMARY SHEET **FACTOR PATTERNS**

DRAINAGE - PLAN

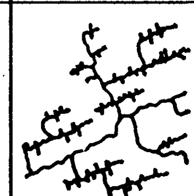
Drainage refers to the paths that water follows as it flows over a surface. It is next in importance after landform and provides information about general soil permeability, ground slope, relative depth of the soil mantle, presence of and type of rock, and dip of beds. Aside from forms of control such as caused by bedding, jointing, and fractures, drainage is a function of soil permeability and slope. Surface drainage patterns do not develop on highly permeable materials such as sand. In materials that are not permeable, such as plastic clays and silty clays, the water runs over the surface and develops an erosional scour or drainage pattern. In general, the finer or denser the drainage net the less the permeability and the finer the material. Parvis (1947) identified six basic patterns, dendritic, trellis, annular, parallel, radial, and rectangular. In addition, there are a few patterns that are uniquely related to a given material or to a given set of conditions. These are anastomotic (Zernitz, 1932), pinnate, discontinuous, and braided. There are many variations of the six basic types and it is seldom that one finds the ideal situation where a pure type forms the pattern.

NONE: The absence of a drainage pattern, or erosional scour, indicates that the material is permeable. Water falling on the surface drains down into the interior, rather than flowing over the surface. Such permeability is characteristic of granular materials.

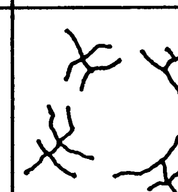
DENDRITIC: This tree-like pattern indicates homogeneity in composition and conditions and is frequently found on soils of very low permeability, large intrusive igneous masses, and flat-lying sedimentary rocks (sandstone, shales). A drainage pattern can be dendritic on a regional basis and exhibit other patterns at specific sites.



TRELLIS: This pattern indicates bedrock control of drainage and is characteristic of strongly folded or dipping sedimentary rocks where the edges of the beds have been exposed at the surface, as the leaves of a book. The longer channels result from the erosion of weaker beds along the contact with a more resistant bed. Such channels follow the strike of the beds. The short channels are caused by erosion down the exposed surfaces of the beds.

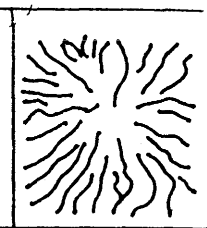


ANNULAR: This is a variation of the trellis pattern and is associated with maturely dissected domes. The arcuate paths result from erosion of a weak bed along the contact with a more resistant one.

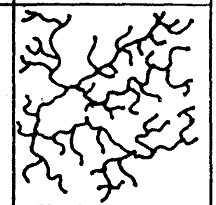


PARALLEL: This pattern indicates that the surface, though relatively flat, has a gentle but uniform slope in a given direction. This pattern can occur on the side slopes of valleys and alluvial fans, as well as on extensive areas of a plain underlain by slightly dipping sedimentary rocks.

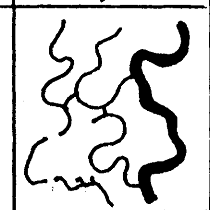
RADIAL: This pattern is associated with a central high (hill, dome, volcano), or a central low or basin. In the case of a central high, the water flows from the center outward and is called centrifugal drainage. In the case of a low, the water flows inward toward a central area and is call centripetal drainage. Depending on the size of the dome or basin and the photo scale or area covered, a segment of the radial pattern could be classified as parallel.



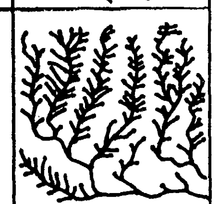
RECTANGULAR: The angularity of this pattern is caused by joints and fractures within the rock or by changes in materials for flat-lying rocks.



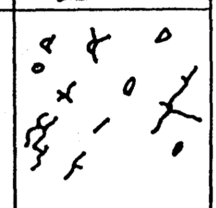
ANASTOMOTIC: This pattern of tortuous windings, interlocking channels, and ox bow lakes is characteristic of flood plains and deltas. It is indicative of a soil of smaller particle sizes than those associated with braided drainage.



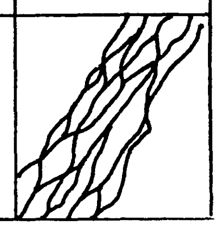
PINNATE: This feather-like pattern, with the relatively close spaced, uniform short gullies feeding into the tributaries is indicative of loessal material, that is, windblown silt. The regional pattern of the tributaries can be dendritic, parallel (as in this illustration), or even show evidence of bedrock control.



DISCONTINUOUS: This pattern of isolated channel segments and small depressions is usually associated with limestone beds. Discontinuous or interrupted drainage can occur also in thermokarst areas and in permafrost areas.



BRAIDED: This pattern results from the deposition of coarse-grained material (mostly sand and gravel) in the channels of a heavily loaded stream where stream speed suddenly decreases. As any one channel is filled, new channels develop. Such patterns occur on alluvial fans, desert washes, deltas, and outwash plains of receding glaciers.



The dendritic, parallel, rectangular, trellis, annular, and radial patterns are from Parvis, M., 1948, *Regional Drainage Patterns in Indiana,* reprint No. 35, Engineering Experiment Station, Purdue University, Lafayette, Indiana. They can also be found in Frost, R.E., 1950, *Evaluation of Soil and Permafrost Conditions,* Vol. I, p.46c, Engineering Experiment Station, Purdue University, West Lafayette, Indiana. These, plus the pinnate pattern, are based on a thesis by Merle Parvis entitled *Regional Drainage Patterns,* 1947, School of Civil Engineering, Purdue University, West Lafayette, Indiana. The anastomotic pattern is based on Zernitz, E.R., 1932, *Drainage Patterns and Their Significance.* Jr. Geology 40(6):498–521.

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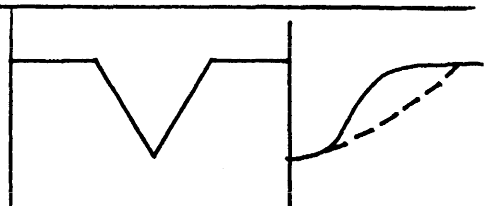
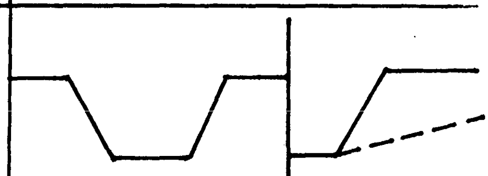
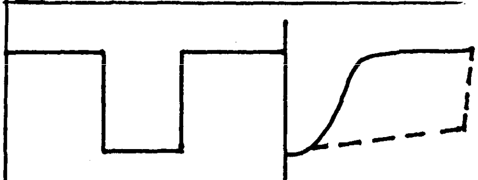
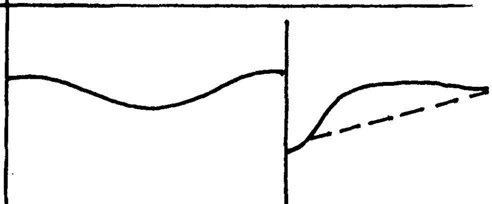
DRAINAGE–ELEVATION

This pattern refers to the shapes of the gullies in cross section and in gradient. It is an important pattern element because soil textures and profile features can be interpreted directly from a detailed study of gully systems and gully characteristics. These features are closely associated with specific soil types and are not duplicated in unlike soils. For example, gullies with a nonuniform cross section and an interrupted gradient are indicative of changes in materials, e.g. stratified soil conditions, or a soil having a developed profile consisting of contrasting horizons. In general there are three basic gully cross section shapes that correspond to the three major textural groups of granular soils, silty soils, and clayey soils. In granular soils, erosion will develop gullies with a sharp V-shaped cross section and with a short, steep gradient. In silts, the gully cross sections tend to be V-shaped with flat bottoms or box-shaped with flat bottoms. Loessal materials, i.e. the windblown silts, develop very steep gully walls, but they are not usually vertical unless undercut by running water or cut in place during road construction. These soils are removed by headward erosion through flat-bottomed gullies of low gradient. Water-deposited silts tend to develop vertical box-shaped gullies. Although marine sand-clays of the eastern U.S. coastal plain also develop a box-like gully, other pattern elements can be used to separate and identify these materials. Nongranular, cohesive, and plastic soils, i.e. the clays, develop a gully whose cross section has a broad, softly rounded saucer shape and whose gradient is gentle and extends well back into the upland.

V-shaped gullies. These gullies are usually short and stubby with a short, steep gradient. In general, the coarser the material, the shorter and steeper the gully. Alluvial fans are frequently found at gully mouths. Granular and semigranular, nonplastic, noncohesive soils, i.e. sands, gravels, and combinations.	
Flat-bottomed V-shaped gullies with a long gentle gradient ending in a steep face. Alluvial fans are not formed at the gully mouths. These are indicators of loessal material (i.e. very fine sand and silt).	
Box-shaped gullies with vertical sides, flat bottoms, and long gentle gradients. These are indicators of water-deposited silts and sand/clay mixtures of the coastal plains, as well as indicators of subsurface drainage or ground water sapping.	
Saucer-shaped gullies with gentle side slopes and broad cross sections. The gully gradient is gentle, and gullies extend for great distances, gradually feathering out to become indistinguishable. Nongranular, cohesive, and plastic soils, e.g. clay, silty clay.	

EROSION

The patterns of erosion provide information about the nature of the material, conditions, and climate. Each mechanism of erosion leaves a telltale pattern of shape or tone. In this part of the analysis one looks for indicators of the mechanism of erosion, describes them, and assesses their significance. For example, the occurrence of blowouts on a surface is suggestive of the presence of a granular or sandy material; the presence of sinkholes, a form of chemical erosion, is suggestive of limestone; the intensity of water erosional patterns suggests something about the nature of the resistance of the material to erosion. In general, these patterns are related to

Water
Wind
Gravity
Ice
Chemical
Thermal
Man-Induced

DEPOSITION

Material that is eroded away must be deposited elsewhere, and the resulting patterns are controlled by the nature of the material, conditions, and climate. Some depositional formations are so large that they can be classified as landform patterns, e.g. large deltas, fans, terraces, dunes, etc. Even so, their patterns are indicative of composition.

This part of the analysis serves as a checkpoint to review the imagery for indicators of deposition and assess their significance, e.g. examining gully mouths to see if fans are present, which, if found, would indicate that there must be a source of granular material someplace. In general, depositional patterns are caused by the following mechanisms:

Water (terraces, fans, braided channels, deltas, tone streaks, etc.)
Wind (dunes, sheet cover)
Gravity (talus)
Ice (glacial till, eskers, moraines, drumlins)
Man-induced (tailing piles, dredging piles)

VEGETATION

The results derived from an analysis of vegetation patterns can be used to provide information about the vegetation itself in terms of type, density, vigor, stem diameter, etc., or to provide information about other terrain characteristics and climate. Air photo scales suitable for engineering soils evaluation and environmental data base preparation, i.e. in the 1:20,000 scale range, are too small for use in species identification. This task usually requires scales of 1:5,000 and larger. On the smaller scales, however, vegetation types or large pure stands can be identified and boundaries established between groups. These boundaries are frequently associated with changes in soil texture, soil moisture, topography, and orientation and give supportive information to factor boundaries established in earlier phases of the analysis. Knowledge of landform and soil within an area can frequently set the basis for a fairly accurate prediction of vegetation types. The vegetation patterns can also provide some information about climate. A mixed hardwood forest with a closed canopy and in a temperate region requires some 40–45 inches of rain per year. Progressively less rain means progressively less tree cover and an increase in other vegetation types. These relations are not exact but they can provide qualitative information about the area in question. Under certain conditions, usually in subhumid and arid regions, a vegetation type or species can be a unique indicator to such things as the soil mantle depth or soil type. Although there are several ways of classifying vegetation, some of them task oriented, a first-order breakdown based soley on photo patterns usually includes the following:

Forest	Closed Canopy	
	Open Canopy	Sufficiently open to expose ground surface and subarboreal layers to observation (50–75% trees).
Shrubs	Closed Canopy	
	Open Canopy	With or without scattered trees, and sufficiently open to expose ground layer to observation.
Mixed trees and grassland		About 50% of each.
Grasslands		
Agricultural	Plantations	
	Cropland	
Wetlands		
Barren		

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CULTURAL

As in the case of vegetation the analysis of cultural patterns can be done for two purposes: to derive information about the culture itself and to use the cultural patterns to derive information about other factors. As an example of the first purpose, the economic characteristics of a given society can be deduced through an analysis of the cultural patterns. As an example of the second, a pattern of cultivated fields, such as the alternating tones of fallow farming on a flat surface, can provide clues as to soil texture and general climate. Cultural information is needed for many different purposes, e.g. economic evaluation, planning, military operations, etc. As a result, no single classification system satisfies all users. Classification systems are usually tailored to the problem at hand. Complicating the issue is the fact that most classification systems are some combination of land cover and land use categories. Land cover can be determined by image analysis. Identifying the land use, however, frequently rests on ground determination. Based solely on photo patterns, i.e. without auxiliary information, one can bound and trace the following first-level categories. Some second-level categories can also be obtained directly from imagery.

Structures. This includes patterns for all types of buildings, ranging from multibuilding farmsteads to metropolitan development.

Transportation and Communication. This includes highways, railroads, airports, canals, pipelines, transmitter towers, power lines, etc.

Agricultural and Livestock. This category includes cultivated fields, orchards, plantations, pasture, feed lots, etc.

Recreation. This includes those areas that have little or no structural development, but do show patterns that link them to some activity such as golf, skiing, camping, etc.

Special. This category is for cultural features that do not readily fit into other classifications, such as quarries (including gravel pits), cemeteries, transition zones, etc.

Natural. This classification is for those areas that do not show cultural patterns and which cannot therefore be assigned into any cultural category. Many of these areas will be identified on the factor patterns of drainage, vegetation, and surficial geology.

PHOTO TONES AND TEXTURE

Photo tones and textural patterns can provide information about specific materials or conditions, as well as provide information to support conclusions developed during the analysis of other factors. In most cases these patterns are associated with areas of relatively bare or exposed soil and rock, or with an area of uniform vegetation cover. Although photo tones and texture are important sources of information, care must be taken in evaluating them, especially those of soils, because climate and season greatly influence the development and detectability of these patterns. For instance, it is generally true that well-drained soils record as light tones or colors in a photograph and poorly drained, fine-textured soils tend to record as dark tones and colors. Under some conditions, however, these general statements are not true. A dry mound of sand on a sand plain in a humid region can show as a light tone against a darker background although the materials are the same for both the plain and the mound. The tone will be different due to the influence of topographic position of the mound on its drainage characteristics. The mound would probably show as a lighter tone than its background. In an arid region a sand dune on a sand plain will probably have tones very similar to those of the plain. Soil tone patterns can also alter their contrast, and even disappear, as a function of season or local weather conditions. With respect to soils, tones and textural patterns can provide information about identity, origin, uniformity, horizon development, moisture relations, etc. For instance, on panchromatic photography silt has a bright, uniform photo tone and a silky texture. Soils derived in glacial till generally show intricate patterns that are related to the complex character of the mantle. As examples, soils of the Wisconsin glacial till show an intricate mottling of light and dark gray tones that are related to different soil texture and moisture conditions; Illinoian till is characterized by a light fringing around the gullies, which is indicative of a soil profile development. Other tone patterns are associated with marks left as a result of wind action, or flowing water, which, in themselves are indicative of the nature of the surficial materials. With respect to rocks, tone and texture can provide supportive information as to type. In igneous rocks, for example, the mafic classes such as basalt and gabbro have dark photo tones. The silicic rocks such as granite tend to have lighter tones. In many subhumid and arid regions, however, the rock surfaces can be covered with another material such as lichens, desert varnish, or alterations produced by weathering which can darken or lighten the surfaces of the rock. The tones that are recorded by the sensor represent some unknown mixture of bare rocks, weathered surfaces, varnish surfaces, and lichen-covered surfaces. In some instances this cover can be as much as 80%, thereby causing a light colored granitic rock to have a very dark, almost black, photo tone. With respect to vegetation, tone and texture can provide information about composition or vegetation type.

SPECIAL

This pattern category includes items that do not easily fit under other factor headings or items that, though discussed elsewhere, are in themselves sufficiently direct indicators of identities and conditions that they warrant additional evaluation. Furthermore, this part of the analysis serves as one more checkpoint to examine the imagery for clues to support previous findings or suggest new relations or identities. Frequently these patterns depend on some inherent quality of the material or on some inherent nature of an action or force. When this is so, they can be important to such matters as evaluating construction sites, assessing potential instability, locating ground water, etc. For example, wind-blown silt deposits have an internal vertical structure that accounts for some patterns that serve as direct indicators of the presence of such material. These include the pinnate drainage pattern, flat-bottomed steep-sided gullies, terracettes and pinnacles on gully walls, and vertical road cuts. The pinnate drainage pattern, gully cross section, and road cuts would be evaluated under their respective sections. Terracettes and pinnacles, too small to be considered as landforms, would probably be evaluated within this category. As another example, slumps and tears in an otherwise smooth valley wall are indicative of instability and potential engineering problems. Patterns that merit special attention include joints, fractures, and faults; soil slumps, landslides, mudflows, and tears; certain landforms that are direct indicators of materials or conditions (barchan dunes, drumlins, colluvial slopes, etc.); and some patterns of drainage, erosion, and tones.

SEDIMENTARY ROCKS

Sedimentary rocks are formed by the compaction and cementation of particulates, or grains, that have settled out of a transporting medium of water, wind, or ice. The grains that form these rocks are produced by the weathering and disintegration of preexisting rocks or by chemical precipitation and are deposited as horizontal layers or beds, with the oldest deposit on the bottom and the most recent at the top. This bedding is characteristic of sedimentary rocks. There are two main types based on origin: clastic and chemical.

Clastic rocks. Clastic rocks are those formed by the weathered products of preexisting rocks and are made up of particles ranging in size from boulders to clay. The common names given to these rocks are descriptive of the particle size, i.e. conglomerate (boulder to sand-sized particles), sandstone (sand-sized), silt stone (silt-sized), and shale (fine silt to clay-sized). The physical characteristics of these rocks, such as color and hardness, are determined by the mineralogy of the grains and the type and degree of cementation binding the grains together. Conglomerate and sandstone, for example, are usually composed of strongly cemented, resistant minerals such as quartz and are resistant to weathering, whereas shale is very weakly cemented and is softer.

Chemically deposited rocks. These rocks are formed by minerals precipitated from solution, secreted by organisms, or left as a residue from evaporation. They are more susceptible to chemical weathering and dissolution than the clastic rocks. The most common of the chemical sediments is limestone, which is composed of calcium carbonate in the form of calcite. Most limestones are of marine origin and were originally deposited as a limey mud on the ocean floor. Some limestones could be called clastic as they are composed of fragments of shells or coral cemented together. Dolomite is similar to limestone in appearance, but is somewhat more resistant to chemical weathering. Limestone and dolomite have the widest distribution of this group of rocks. Evaporites are formed by the evaporation of mineral bearing waters, usually in an arid environment. They are not as widely distributed or as abundant as limestone and dolomite, but are important from an economic standpoint. The evaporites are usually softer than other sedimentary rocks and are highly susceptible to chemical weathering. Gypsum and rock salt are the most common of the evaporites. As with most natural phenomena, sedimentary rocks do not always fall into clear-cut classes. It is possible, therefore, to have clastic sediments and chemical sediments being deposited at the same place and at the same time, giving rise to combinations such as sandy limestone, silty sandstone, gypsiferous sandstone, and so on for as many combinations as there are sizes and chemical classes.

COMPILER: J. Ponder Henley, USAETL.

SEDIMENTARY ROCKS
SOLUBLE ROCKS

Rocks formed from chemical sediments (precipitates or evaporites) are susceptible, in varying degrees, to dissolution. The rate of chemical weathering is dependent on the solubility of the rock, the presence of a solvent, and adequate drainage to remove the dissolved products. Limestones are the most widely distributed and recognized of the chemical sediments, and their spectacular cave systems with solutional and depositional features are well known. Most limestone is of marine origin, the calcium carbonate being deposited directly by chemical precipitation from sea water or deposited by organisms. Coral, bryozoans, and some algae have calcareous skeletons which form reefs, the voids of which can be filled with detritus or precipitated calcium carbonate to form a solid rock mass. All the shells of marine animals, such as gastropods, pelecypods, and brachiopods, contain calcium carbonate, and they can be cemented together into a limey matrix to form another type of limestone. In calm water very fine-grained limey mud can accumulate, forming a smooth compact limestone. In its purest form, limestone is composed of the mineral calcite (calcium carbonate). Many formations, however, contain varying amounts of impurities such as chert, sand, or clay minerals which can affect the weathering characteristics. The solvent available for the dissolution of limestone is water from atmospheric precipitation. Limestone is only slightly soluble in pure water. Rain and glacial melt water contain varying amounts of carbon dioxide, which produces a weak carbonic acid solution. This carbonic acid reacts with the calcium carbonate to produce calcium bicarbonate, which is soluble in water and is carried away. The chemical reactions and the changes in equilibrium are complex. Factors that influence the rate of dissolution include the presence of organic by-products and calcium dioxide in the soil, temperature of the solution, the amount of rainfall, and purity of the limestone. As impurities increase, especially the more granular types (sand and silt), weathering becomes a combination of mechanical and chemical.

Dolomite, a calcium magnesium carbonate rock, is similar to limestone in formation and appearance. Although it is generally considered to be less soluble than limestone, solution features are common in dolomite.

Evaporites. Gypsum (calcium sulfate) is the most abundant of the evaporite rocks at the surface, and is much more soluble than limestone or dolomite, especially in higher temperatures. Gypsum is usually more evident in arid areas, preserved because of the lack of rainfall.

The chloride rocks, the best known being halite (sodium chloride, or rock salt), are even more soluble and rarely persist as landforms.

COMPILER: J. Ponder Henley, USAETL.

SEDIMENTARY ROCKS
SHALE

Shale is a fine-grained clastic sedimentary rock and is the most common and widely distributed member of this group. It is formed by the compaction and induration of mud or silt and clay particles. Although shale contains silt, and at times larger particles, it always has an appreciable amount of the clay minerals. A fine silt represents the lower limit of particle sizes that can come from a grinding process, a size that is from about 0.002 mm to perhaps 0.005 mm (2–5 μm). Clay particles are the result of chemical reactions (alteration, decomposition, recrystallization) and have sizes less than 0.004 mm or 0.005 mm, depending on the classification used. Many of the particles are less than 0.002 mm. Being this small, the effects of surface charge are very large, and the particles cling together, a property called cohesiveness. Being a sedimentary rock, the structure of shale is a layered one, with the layers being finely stratified and having thicknesses that are but fractions of a millimeter. It has a fissility that is parallel to the bedding plane, i.e. it readily splits into thin sheets parallel to the bedding plane. If the rock is more massive and not fissile, it is a mudstone, siltstone, or a clay stone, depending on the grain size distribution. There are several classifications for shale, usually based on the relative percentages of clay, silt, and other material contained in them, but no one scheme is used universally. For example, there are argillaceous (clay) shales, arenaceous (sandy or siliceous) shales, calcareous (limey) shales, ferruginous (iron rich) shales, and carbonaceous (organic) shales. Clay shales are a valuable economic resource, and for commercial purposes are usually classified as kaolin, ball clay, fire clay, bentonite, fullers earth, and miscellaneous clay.

Because of the very small particle sizes and the resultant small pore size, shales are essentially impermeable, and intergranular cementation does not occur. Consequently, shales have little resistance to erosion and they are easily affected by mechanical weathering. Although shale can be indurated enough so that it does not fall apart when wet, it is usually relatively soft and easily broken. A shale can take on one of several different colors; for example, red, yellow, brown, blue/green, gray, black, and in some instances a very light gray. In general, shale is less durable than sandstone and limestone. Some clay shales and the residual soil covering them can absorb water and show a tendency to expand or shrink if they become wet or dry.

Engineering Characteristics and Problems. The residual soil mantle over a clay shale is plastic, cohesive, and has little or no dry strength. In general, the problems associated with clay shales are poor subgrade support, pumping, and poor natural drainage. Subgrade support and compaction of shale for fill present problems because of the expansive nature of clay shales when wet. Because of the poor natural drainage and the fissile nature, shales can also become a problem in stability. For example, ground water can collect on a shale's impervious surface, especially if located below an aquifer, and if this bed is dipping, this lubricated surface can cause sliding and slumping of the material above it.

COMPILER: J.N. Rinker, USAETL.

IGNEOUS ROCKS

Igneous rocks, formed from the cooling of molten material (magma), are divided into two groups: plutonic (intrusive), rocks that solidify deep within the earth's crust, and volcanic (extrusive), rocks that solidify on or near the surface of the earth. Chemical composition in both types of igneous rocks ranges from silicic to mafic, i.e. from rocks composed of light-colored minerals containing large amounts of silica to those composed of dark-colored minerals containing less silica and enriched in iron, magnesium, and calcium.

Plutonic Rocks. Plutonic rocks are formed from molten material that cools slowly deep within the earth's crust and are, therefore, coarse grained. Granitic magmas, for example, may be emplaced as deep as 20 kilometers below the surface; other magmas are emplaced at greater depths. Plutonic rocks appear on the surface of the earth only as the result of uplift and/or erosion. The most common forms of plutonic rocks are batholiths, dikes, and sills. Batholiths are very large bodies, usually formed of granitic rock, that are more than 100 sq. km. (40 sq. mi.) in diameter; dikes are narrow, relatively small linear bodies that cut across adjacent layers; and sills, similar to dikes in size and shape, parallel adjacent layers.

Common plutonic rocks are granite, diorite, monzonite, and gabbro. Granites, the most common, are composed of highly silicic, light-colored minerals, primarily quartz, light-colored plagioclase feldspars, potassium feldspars, and mica. In addition to forming from molten materials, granite can form as a result of metamorphic processes. Diorite and monzonite are medium grained and intermediate in color and composition, containing intermediate composition plagioclase, biotite, hornblende, and/or pyroxene and quartz. Diorite is intermediate in grain size, but usually is treated as a "granitic" rock. Monzonite can be coarse grained. Gabbro is dark in color, mafic in composition, and relatively rare; it consists primarily of dark-colored plagioclase, pyroxene, hornblende, and olivine. Pegmatites, very coarse grained rocks of granitic composition (crystals are often measured in meters), are also relatively rare. They usually occur as veins and form during the last stages of development of, and in association with, granitic batholiths.

Volcanic Rocks. Volcanic rocks are fine grained because they are formed from molten material that cools rapidly on or near the surface of the earth. Some volcanic material, such as obsidian (the most common volcanic glass), cools so rapidly that it is grainless. Volcanic rocks, forming as deep as several hundred meters below the surface of the earth, are divided into two groups: flow materials that result from quiet, nonexplosive eruptions from volcanos and fissures; and pyroclastics that form from molten material explosively erupted into the air.

Flow Materials. Common flow materials are basalt, andesite, and rhyolite; basalt is the most common. The primary mineral constituents in basalts are dark in color, and include dark-colored plagioclase, pyroxene, and olivine. Andesite, the fine-grained equivalent of diorite, is intermediate in color and composition. The light-colored silicic rhyolite is the fine-grained equivalent of granite.

Pyroclastics. Pyroclastic rocks are usually fine grained. The most common are volcanic ash, pumice, and tuff. Pyroclastic rocks usually are intermediate to highly silicic in composition, but can also be mafic (volcanic bombs). They often contain large amounts of volcanic glass, and are normally medium to light in color. Pyroclastics, much less common than flow materials, are carried and deposited by wind and water and often form layered sequences.

Igneous rocks are important economically because the fluids associated with them during formation contain high concentrations of valuable elements. For example, gold, silver, copper, and uranium occur in veins associated with igneous rocks, and rare metals, such as lithium and beryllium, commonly occur in pegmatite minerals.

COMPILER: J. Ehlen, USAETL.

References:

Turner, Francis J. and Verhoogen, John. *Igneous and Metamorphic Petrology,* 2nd edition. New York: Mc Graw-Hill Book Company, Inc., 1960, pp 1–449.

Pirsson, Louis V. *Rocks and Rock Minerals,* 3rd edition. Revised by Alfred Knopf. New York: John Wiley and Sons, Inc., 1956, pp 103–226.

TRANSPORTED -- AEOLIAN
LOESS (WINDBLOWN SILT)

Loess is an unconsolidated, or weakly consolidated, deposit of windblown soil that comes mostly from river flood plains. These deposits, which occur mostly in plain or plateau regions, range in thickness from a few centimeters to as much as 200 meters. Usually they are calcareous in nature (either calcium or magnesium carbonate) and consist mostly of angular grains of silt-sized particles (approximately 0.075 to 0.002 mm) with lesser amounts of very fine sand and clay. In general, the particle sizes decrease with increasing distance from the source. Most frequently the silt-size particles are quartz, i.e. quartz is common to all loessal deposits.

Debate continues as to the mode of emplacement, as well as the origin of loess. The prevailing view is that the sediment was produced by the grinding action of glaciers on underlying rocks. Later, the particles were deposited downstream from runoff from melting glaciers, and subsequently reworked and carried by the wind to be deposited on downwind upland surfaces.

Loess has a vertical microtubular structure which supports a capillary rise of as much as 9 m (30 feet), and which is responsible for forming the characteristic steep erosional faces. Loess that has not been deeply weathered has a high porosity (50–60%),[1] and an in-place dry density that ranges from 66–104 pounds per cubic foot.[2] It is usually well drained internally, with the vertical permeability being several times greater than the horizontal permeability. It is remarkably uniform in physical properties, easily eroded when exposed to running water, and forms a fertile soil.

Loessal deposits are distributed throughout the world. Within the United States loess can be found in Washington, Idaho, South Dakota, Nebraska, Iowa, Kansas, Illinois, Kentucky, Tennessee, Mississippi, Indiana, and Ohio. There are deposits in Europe that constitute an irregularly shaped rich farming belt through northeastern France, Belgium, Germany, Hungary, Poland, Czechoslovakia, Rumania, and into southeastern Russia. There are deposits in north China and throughout the basin of the Yalu River. In South America deposits can be found in Argentina, Paraguay, and to some extent Uruguay. There are also deposits in northern Africa, Israel, Australia, and New Zealand.

Engineering Characteristics and Problems. Although of low density, this material, when dry has a fairly high strength because of the clay binder. This strength can be lost because of wetting. Remolded loess has a greatly reduced permeability, is only moderately compressible, and has a low cohesive strength.[3] Road cuts, other than near vertical, will be unstable and gradually erode back to the stable steep configuration, unless preventative measures are taken. The supportive properties are usually good if the material is compacted properly. Once the vertical structure is destroyed, which is easy to do, the material takes on other characteristics, and presents the engineer with a different set of problems. For example, when dry, the material is loose, impossible to compact, and easily removed by wind; and when saturated, it can become quick. These latter characteristics are also of concern when considering problems associated with cross-country mobility.

COMPILER: J.N. Rinker, USAETL.

[1] Nyle C. Brady. 1974. *The Nature and Properties of Soils.* 8th ed., Macmillan Publishing Co., Inc., New York.

[2] J.B. Sheeler. 1968. "Summarization and Comparison of Engineering Properties of Loess in the United States." Highway Research Record No. 212, Conference on Loess: Design and Construction. Nat. Res. Council, Nat. Acad. of Sci. – Nat. Acad. of Engineering. Washington, DC, Pub. No. 1557.

[3] U.S. Dept. of Interior, Bureau of Reclamation. 1968. Earth Manual.

WATER DEPOSITS

Water-deposited materials are formed from sediments eroded and weathered from earth surface materials (rocks, soils, and other deposits). They cover a large portion of the world's land area and are important because they provide excellent sites for highways, airports, and other construction projects, and because of their economic value as sources for granular material. They range from minor deposits associated with the beds and banks of small streams to very large deposits such as the outwash plains formed from the erosion of adjacent mountains. The Great Plains of the United States are of this latter type. The depositing medium is flowing water, which has the ability to sort material by particle size as a function of the speed of the current. Furthermore, the telltale clues left by flowing water, i.e. ridges, channels, and current marks in the form of linear and curvilinear tone streaks are important indicators of these deposits.

These materials can become indurated, consolidated, or cemented, which alters both the structural characteristics of the mass, as well as the identifying surficial patterns. In many places, water-deposited materials of the Great Plains and the Coastal Plain of the U.S. have become rock-like through long periods of time, and no longer exhibit the surface patterns associated with water deposits. The air photo interpretation of water-deposited materials depends on relative age and erosional history; texture of the material and of the overburden; degree of induration, cementation, or consolidation; topographic position; climate; and the nature of the original topography covered by the material. There are several ways to classify water-deposited materials and we have elected to start on the one based on information in Frost (1953)[1] because it is oriented towards the use of air photo patterns.

- Alluvial Deposits
  - Fluviatile Plains
  - Intermontaine Basins
  - Stream Flood Plains
  - Stream Terraces
  - Deltas
- Marine Deposits
  - Coastal Plains (Estuarian Plains, Tidal Flats, Terraces)
  - Miscellaneous Shore Features
    - (Beaches, Spits, Bars, Tidal Marshes, Reefs, Barrier Beaches, Beach Ridges)
- Lacustrine Deposits (Nonglacial Lakebeds)
  - Tertiary
  - Pleistocene
  - Recent
- Glacio-Fluviatile Deposits

COMPILER: J.N. Rinker, USAETL.

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[1]R.E. Frost, J.G. Johnstone, O.W. Mintzer, M. Parvis, P. Montano, R.D. Miles, and J.R. Shepard. 1953. *A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes.* School of Civil Engineering and Engineering Mechanics, Purdue University, West Lafayette, Indiana.

ORGANIC SOIL
PEAT AND MUCK

Organic soils are formed by the sequential deposition of vegetative remains on the bottoms of shallow ponds, bogs, marshes, and swamps, where they slowly undergo anaerobic decay. Structure of organic deposits is that of a layered system that varies in the nature of the original plant tissue and in the extent of decomposition. These layers can later become soil horizons. Organic soils are differentiated on the state of decomposition. Nondecayed and slightly decayed deposits are called peat, and those deposits that are fully decomposed or nearly so are called muck. In peat deposits one can identify plant parts and plant species. The texture of these soils ranges from fine to coarse as a function of the nature of the plant residue. In muck deposits plant parts cannot be identified and the soils are fine.

Organic soils are dark brown to black and are light in weight when dry, having about one-sixth the bulk density of a mineral soil. They have a high water holding capacity, holding three to four times their dry weight in moisture. Some slightly decomposed peats can hold 12–20 times their dry weights in water.[1] On the other hand, dry mineral soils can usually hold only one-fifth to two-fifths of their dry weights as water. Organic soils have a much larger surface area than even mineral soils such as clay, and consequently, they have a more pronounced colloidal nature. Plasticity, however, is low. In general, these soils are porous and easy to cultivate when dry; and if the structure has been destroyed, these soils are easily eroded by the wind. In dry seasons peat and muck deposits can burn for weeks if they catch fire, and such fires are difficult to extinguish. In addition to being valuable agricultural soils, these materials are used in greenhouses, in nurseries, on lawns, and as a fuel.

Although the organic soils are nowhere near as extensive as the mineral soils, they can be found throughout the world where conditions are favorable. A great portion of the world's deposits (60%) occur in Russia.[2] Within the U.S., these deposits are scattered throughout the country, although the vast majority are in glaciated areas. The Pleistocene glaciation set the stage for the development of shallow ponds, bogs, and swamps by leaving a suitable topography and by impeding, if not blocking, drainageways.

Engineering Characteristics and Problems. Because these soils are highly compressible, they should be avoided as foundation materials. If this cannot be done, compensatory techniques must be used, e.g. excavation and backfill, use of piles and bridges, or causing compaction by surcharging.[3]

COMPILER: J.N. Rinker, USAETL.

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[1]Nyle C. Brady. 1974. *The Nature and Properties of Soils, 8th Ed.* Macmillan Publishing Co., Inc., New York.

[2]"United States Mineral Resources," Geological Survey Professional Paper 820, 1973.

[3]R.E. Frost, J.G. Johnstone, O.W. Mintzer, M. Parvis, P. Montano, R.D. Miles, and J.R. Shepard. 1953. *A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes.* School of Civil Engineering and Engineering Mechanics, Purdue University, West Lafayette, Indiana.

SEDIMENTARY ROCKS
SANDSTONE — FLAT-LYING

Sandstone is composed of sand-sized particles cemented together. Most frequently the particles are quartz, and the cementing agent can be calcium carbonate, iron, or silica. The characteristics of sandstone depend on the origin of the sand and on the type of deposition, i.e. aeolian, alluvial, or marine. The beds can be massive or thin, and cross bedding is common. The relative strength and resistance to weathering of sandstone are determined by the mineral composition of the grains, the type of binder, and the thickness of the beds caused by depositional variation. For example, sandstone cemented by silica is resistant to erosion and weathering. Other sandstones can be so weakly cemented that they easily break apart into their component grains. Sandstones that are cemented with calcium carbonate develop deeper soil mantles than sandstones having a siliceous binder. As the calcium carbonate content increases, such rocks take on the patterns of limestone. On exposed sandstones with rough topography, surface water carries away many of the particles, resulting in a thin soil mantle. Because sandstones can be porous, they are important reservoirs of water. Although they usually occur interbedded with other sedimentary rocks, one can find massive units up to 130 meters (approx. 400 feet) thick.

Landform. The resultant landform depends on the climate, as well as the thickness of beds. In arid regions, sandstone is a mesa former and the landform is blocky, flat-topped with vertical sides, and contains box-like canyons and gullies with vertical walls. Pinnacle rock forms are common and talus piles are usually found at the base of cliffs. Wind abrasion can carve the blocks into unusual shapes. In humid regions, the landform associated with massive beds is slightly crested, with a vertical face and talus piles at the base of the face. Dense vegetation can cause a rounding or smoothing effect. Soft sandstones have sharply crested ridges and V-shaped valleys. Thinly bedded sandstones also tend towards this type of landform.

Drainage-Plan. Dendritic on a broad regional basis. The local pattern can vary in its arrangement from dendritic to rectangular with many right angle turns in the streams caused by jointing in the rock. The angles between gullies, tributaries, and major streams are relatively sharp, i.e. they are not rounded as in the case of limestone.

Drainage-Elevation. In cross section the gullies are long, straight, steep, and V-shaped, and the valleys containing them are V-shaped. Areas between closely spaced gullies are sharply crested. Gullies developed in a soil mantle on soft sandstone are sharply V-shaped. A residual soil of sand and clay produces U-shaped gullies, whereas one of silty clay produces broader and softer V shapes.

Erosion. By water, wind, and gravity. Sandstone is fairly resistant and not easily eroded by running water. Depending on the climate, sandstone weathers to blocky pieces which are slowly reduced to sand, or it weathers directly to sand. This sand is removed by running water or by wind action. Weathering is easier along joints and fractures, especially in arid climates, and can form a series of widened grooves on the surface. Wind erosion or, more accurately, sand blasting can cause an outcrop to appear "honey combed" or "moth eaten." Unless precautions are taken, shallow residual soils are easily erodible in farming areas. Talus accumulations attest to the gravitational influence.

Deposition. Usually in the form of talus slopes in both arid and humid regions. The eroded sand can be deposited as fans at gully mouths, as valley fill, or carried out to form deposits in a basin.

Vegetation. A forest cover in humid regions. Because sandstone is often a water-bearing rock, it will support some vegetation even in subhumid areas, and provides a basis for separating sandstone from other sedimentary units. In arid regions vegetation is sparse and is usually concentrated along drainageways and in joints.

Cultural. Orchards are common in humid areas. The shallow soils are not usually suitable for tillage. Where farming does occur contour plowing is frequently practiced as a means of reducing surface erosion.

Tone and Texture. If not obscured by vegetation the tones of sandstone and residual sandy soils tend to be light. The tones tend to be slightly darker with increased clay and silt content.

COMPILERS: Robert E. Frost and J. Ponder Henley, USAETL, 1980.

SEDIMENTARY ROCKS
LIMESTONE — FLAT-LYING
HUMID, SUBHUMID AREAS

Limestone is made principally of calcium carbonate, a substance that is slightly soluble in the weak carbonic acid formed from atmospheric carbon dioxide and rainwater. In areas of sufficient rainfall, the slightly acid runoff trickles down through and along joints and fractures, slowly dissolving the limestone and gradually enlarging the cracks. Intersections of vertical fractures are gradually enlarged into sinkholes. Caves and passages can become so large that the rock roof collapses from its own weight. With time the sinkholes, voids, and passages become ever larger, and eventually coalesce to form interconnected solution valleys. As the limestone is dissolved away, particulate matter that settled out during the formation process is deposited as a residual soil.

Landform. Plain. In youth the landform is a sinkhole-studded plain with poorly developed sinkholes in early youth and well-developed ones later. Relief can be as much as 25 meters (refer to Indicator 0019). In maturity the form is a karst plain with large, deep sinkholes, collapse features, and vertically walled solution valleys that are usually flat-bottomed, and with relief ranging from 100 to 200 meters (refer to Indicator 0021). Tributaries to the main solution valley are short and stubby. In the plan view of youthful and mature forms, the intersections of drainageways are well rounded, appearing scalloped in places. In old age the landform is a mound-covered plain. The dome-shaped mounds are remnants of the former sinkhole divides. In tropical regions limestone frequently shows a knobby surface.

Drainage–Plan. Discontinuous in youth and maturity. Although some drainage occurs through the porous soil and into the joints and fractures, most of the drainage is by way of the sinkholes, which are circular in horizontal beds. If a sinkhole drainageway becomes clogged, a pond results. As the landscape matures and solution valleys merge, areas of connected drainage develop which are usually dendritic in pattern.

Drainage–Elevation. Surface gullies rarely exist. Sinkholes are gently rounded depressions in youthful terrain, and gradually evolve into deep, steep-sided, funnel-shaped holes.

Erosion. Degradation occurs by chemical solutioning, scouring by running water, and gravitational collapse.

Deposition. Other than the accumulation of the residual soil, depositional patterns are not developed.

Vegetation. A closed forest canopy in humid regions. In cleared areas of the youthful landform trees are frequently left in many of the sinkholes.

Cultural. The residual soil that accumulates is a very good soil and can support a variety of agricultural practices, topography permitting. Quarries are frequently evident.

Tone and Texture. The rock color usually ranges from a light to a dark gray, and the soil color from yellowish-brown to red. In humid areas vegetation obscures both the soil and the rock. In less humid or cleared areas the soil shows as a light photo tone with darker circles or spots for the sinkholes.

Special. Fractures and joints are apparent on aerial photography as surficial line traces, as segments of drainage, and as flat walls of sinks and collapse features. Sinkholes tend to aline with the fracture pattern.

Engineering Characteristics and Problems. The weathering of limestone can produce a relatively deep residual soil mantle. In humid areas a typical soil profile would show a top horizon consisting of a yellowish-brown silty soil of some 50 cm (2 feet) thickness; a relatively thick bright red B horizon of clay and silty clay; and a rather whitish C horizon of plastic clay containing limestone fragments. The more important engineering problems are associated with road cuts, the need to avoid or fill sinkholes, the possibility of subsurface voids, and varying subgrade conditions. Even though the top horizon soils are well drained internally, they become poorly drained when their structure is destroyed by compaction.

COMPILERS: Jack N. Rinker and Robert E. Frost, USAETL.

SEDIMENTARY ROCKS
LIMESTONES AND SHALES
FLAT-LYING — HUMID

In many places sedimentary rocks exist as alternating beds of limestone and shale. Differential weathering of interbedded hard resistant limestones and soft shales can develop several patterns, depending on the thickness of the beds. If the beds are thin, the slopes tend to be smooth. Thicker beds can show as slope changes, as well as tone changes that are in the form of contour-like bands that outline the hills. In 1:20,000 scale aerial photography slopes appear relatively smooth where the beds are less than half a meter in thickness. The combination of weathering, erosion, impervious and hard limestone, and impervious and soft shale units, tends to develop a compound slope with the upper section steeper than the lower. The lower slope is mantled with a colluvium of limestone fragments embedded in plastic clay. This mantle, which becomes thicker towards the toe, tends to protect the in-place rock from further degradation.

Landform. A flat-topped dissected plain with softly rounded slopes in both plan and elevation. In humid areas angularity is absent. Hill slopes are not uniform but are steeper in the top one-half to two-thirds and flare out in the bottom portion. The upper, steeper slope represents rock in place; the lower, gentler slope represents colluvial material; and the break in slope marks the transition. Spurs, uniform in height and general slope, extend out from the upland areas. The contour that represents the base of the hills is rounded, arcuate, and in places, scallop-like.

Drainage–Plan. Although the overall regional pattern appears dendritic in form, a close examination will usually reveal the influence of joints and fractures. Larger streams and whole valleys tend to meander. The upland surface can show tones, and sometimes depressions, associated with sinkholes. On the hill slopes many straight parallel gullies can be found on the colluvium. These cannot be detected if there is much vegetation. The angles between gullies and tributaries are rounded.

Drainage–Elevation. Large gullies that are tributary to important collector valleys have a cross section profile that resembles a broad, open, and rounded "V." In humid regions, gully shapes are difficult to observe because of vegetation.

Erosion. By abrasive scouring, weathering, and gravity. Landslides can occur in the colluvial material.

Deposition. None.

Vegetation. In humid areas such a region will be tree covered or cleared for farming. In semiarid regions it will usually be grass covered.

Cultural. Farming in humid regions and grazing in semiarid locations. In arid regions the soils are usually too thin for crops. Contour farming practices are frequently followed. Highway alinement usually follows ridges or valley bottoms where possible. Because colluvium is an unstable material, landslides are a constant problem to construction and engineering efforts.

Tone and Texture. In humid regions vegetation masks the tones and color of the underlying material. In arid regions, and if the beds are thick enough, a contour-like banding can be seen. The lighter banding marks the limestone beds, and the darker banding indicates the shale layers.

Special. The flaring out of the lower slopes in what is known to be a series of sedimentary rocks is an indicator that points to the likely presence of interbedded limestone and shale. This is also a direct clue to the existence of colluvial material and to the engineering problems associated with its instability.

Engineering Characteristics and Problems. Insofar as construction operations are concerned, several problems are associated with this type of area. Usually these problems are in terms of drainage, compaction, subgrade conditions, and landslides. The colluvial mantle can become unstable from excess water, cutting the toe, loading the surface, etc., any of which can induce landslide activity.

COMPILERS: Robert E. Frost and Jack N. Rinker, USAETL.

SEDIMENTARY ROCKS
SHALE — FLAT-LYING

Shales are fine-grained (less than 0.005 mm) clastic sedimentary rocks produced by the compaction and induration of silt and clay-sized particles. They are the most common and widely distributed sedimentary rocks. Shale has a wide range in chemical composition as a function of the clay minerals within it. In terms of particle size distribution it can also include a wide range of nonclay components. For example, there are argillaceous (clay) shales, arenaceous (sandy or siliceous) shales, calcareous (limey) shales, ferruginous (iron-rich) shales, and carbonaceous (organic) shales. The structure is of the bedded type, with the beds ranging from very thin to thick. Shales are usually fissile, that is, they are easily split into thin layers parallel to the original bedding planes. In general, shales are not as durable as sandstone and limestone. Because shale is made of an impermeable material, intergranular cementation does not occur, and as a result it readily succumbs to simple mechanical weathering. Clay shales absorb water and have a tendency to expand and shrink as they become wet or dry.

Landform. Because there are many varieties of shale, there are many varieties of landform. Climate is also an important factor. In general, shales occupy troughs, or can be maturely dissected to form a softly rounded topography in humid climates; or rugged, severely dissected terrain in arid regions that have few, but torrential, rainstorms. Hard shales will have steeper slopes, but retain a rounded aspect. These landforms are not as controlled by geologic structure as are those developed on other sedimentary rocks.

Drainage-Plan. Dendritic. If the shales are soft, the intersections of branches and gullies will be rounded. Only when the shales are relatively hard will angularity appear in the plan view. In general, the finer the drainage net, i.e. the closer the spacing of the gullies, the finer the particle size distribution of the material. Thus, clay shales usually have a relatively dense or closely spaced drainage net. The basic pattern is modified by climatic conditions. In an area subjected to bursts of intense rainfall and flash flooding the drainage pattern is denser than for a similar clay shale in a region where the rain is more uniformly distributed throughout the year.

Drainage-Elevation. In cross section the gullies are rounded, almost saucer-shaped, and have long, uniform gradients. In sandy shales the gullies tend to have a cross section that is more of a broad V shape. In arid regions the slopes can be angular and steep because of scouring caused by flash flooding.

Erosion. By water primarily. The fine texture and lack of cementing agents make shale susceptible to mechanical weathering and erosion by running water. It is easily eroded in arid regions because of the lack of vegetation and the flash flooding.

Deposition. In addition to forming a residual soil mantle, the silt and clay particles weathered from shales can be transported from the immediate area and redeposited elsewhere as alluvial or lacustrine sediments. Because of their small particle sizes, they do not form fans at gully mouths.

Vegetation. In humid climates, shales will support a dense vegetative cover if the residual soil is deep enough. Side slopes too steep for cultivation or with soil too shallow for agriculture will be forested. The uplands can be cultivated. In arid climates the land is barren or very sparsely vegetated with shrubs or grass if a soil is developed.

Cultural. The primary economic pursuit is agricultural, which is climate dependent. High quality shale is used in making fired clay products and in making cement; therefore, quarrying operations and kilns are frequently present.

Tone and Texture. In arid regions the coloring is usually of a yellowish-brown, which gives a light photo tone in panchromatic imagery. In flat lands where gullying has not occurred the depressions are dark and the highs are light. In humid regions tones are usually obscured by vegetation.

Engineering Characteristics and Problems. The residual soil mantle over a clay shale is plastic, cohesive, and has little or no dry strength. In general, the problems associated with clay shales are poor subgrade support, pumping, and poor natural drainage. Subgrade support and compaction of shale for fill present problems because of the expansive nature of clay shales when wet. Because of the poor natural drainage and the fissile nature, shales can also become a problem in stability. For example, ground water can collect on a shale's impervious surface, especially if located below an aquifer, and if this bed is dipping, this lubricated surface can cause sliding and slumping of the material above it.

COMPILERS: J. Ponder Henley, Jack N. Rinker, and Robert E. Frost, USAETL.

IGNEOUS ROCKS

Of the three groups of rocks, igneous, metamorphic, and sedimentary, only the igneous rocks can be considered "original," for they are formed from the cooling of molten material. Igneous rocks are divided into two groups: extrusive rocks, which solidify on or near the surface of the earth, and intrusive rocks, which solidify deeper within the earth's crust. Chemical composition in both types of igneous rocks ranges from silicic to mafic, i.e. from rocks composed of light-colored minerals containing large amounts of silica to those composed of dark-colored minerals containing less silica and enriched in iron, magnesium, and calcium. The mafic rocks tend to be mechanically stronger than the silicic rocks because of their composition. Because their mineral components react more readily with water than do the mineral components of the silicic rock, the mafic rocks are less resistant to weathering in climates where water is abundant. In short, the mode of emplacement, the chemical properties, climate, weathering, and tectonic activity determine the characteristics of the photo patterns found on igneous rocks.

Landform. The air photo pattern produced by igneous rocks is more complex than the patterns of sedimentary and some metamorphic rocks because of the greater range in igneous rock composition and the tendency of such rocks to form random patterns. With the exception of such landforms as lava flows, the topography in areas of exposed igneous rocks tends to be that of rugged mountains and hills; escarpments and plains, however, are common. Depressions such as calderas and craters are characteristic of volcanic igneous landforms.

Drainage–Plan. The most common drainage patterns on igneous rocks are dendritic, indicating homogeneous composition over large areas, and radial, indicating the shape of the typical hill or mountain landform. Stream alinements usually are highly irregular, and straight stream segments are short. Stream density is generally low.

Drainage–Elevation. Stream channels in igneous rocks usually are V-shaped and quite deep, providing the high relief typical of igneous terrains. Waterfalls are common.

Erosion. Mechanical weathering of igneous rock predominates, but is often accompanied by chemical weathering, particularly in humid climates. Weathering in hot arid regions is almost exclusively mechanical. Erosion is concentrated along fractures.

Deposition. Areas of igneous rocks (excluding pyroclastics) usually form highlands, and are not, therefore, areas of deposition; most eroded material is carried out of the igneous region.

Vegetation. Vegetative cover on igneous rocks is more sparse than on metamorphic or sedimentary rocks in the same area; the less weathered and younger the surface exposure, the sparser will be the vegetation.

Cultural. Areas of igneous rocks are usually culturally unexploited, except where plains are formed. In these areas, agriculture is commonly the major activity. The most common use of other igneous terrain is for recreation.

Tone and Texture. Dark-colored rocks are composed of low silica minerals enriched in iron, magnesium, and calcium and appear dark gray to black in photo tone on panchromatic aerial photography. Light-colored rocks are high in silica and sodium and, as a result, appear light gray to white in photo tone on panchromatic aerial photography. Photo texture is related to grain size: the coarser grained the rock, the rougher and blockier the texture. Texture is also related to the density, direction, and attitude of joints.

Special. Almost all igneous rocks are jointed. Certain types of joints are characteristic of certain types of rocks, i.e. columnar joints are characteristic of basalt, and curvilinear sheeting joints are characteristic of granite.

COMPILER: Judy Ehlen, USAETL.

IGNEOUS ROCKS
PYROCLASTICS

Pyroclastic igneous rocks are formed from particles ejected from the crater of a volcano or a fissure. Particles range in size from silt (ash fragments) to boulders (volcanic bombs) that can be more than 4 meters in some dimension. The photo patterns of pyroclastic rocks are therefore distinctly different from those formed on flow materials.

Landform. Pyroclastics usually form low, rounded hills and plains. Two types of volcanos are formed of pyroclastic material: cinder cones and spatter cones. Cinder cones are small- to medium-sized volcanos formed of cinders (lava with a high gas content). Lava flows often extrude from the bases and sides of cinder cones. Spatter cones are small hills usually less than 20 meters (65 feet) high, and are formed of basaltic material with a low gas content. This material is ejected over short distances as small globs that stick together upon landing. Cinder cones and spatter cones often form lines along the fissure from which they are derived. Resistant pyroclastic rocks, such as tuff and welded tuff (tuff hardened by heat and/or pressure) cap the hills. In addition, welded tuff sometimes occurs in rings called maars, which are formed by underwater eruptions. Extensive fairly flat areas covered with pumice to a depth of at least several inches are relatively common near volcanos that have a history of violent explosive eruptions. Such plains are called pumice plains. Pumice is a highly silicic, glassy lava.

Drainage–Plan. Excluding the fine-grained ash deposits, drainage patterns on pyroclastics are usually subdendritic, rectangular, or radial. Surficial drainage is usually absent on the more porous pyroclastic materials, such as pumice, particularly when they are relatively young. The very dense dendritic drainage patterns on ash deposits are similar to those formed on fine-grained sedimentary rocks (e.g. shale), making differentiation between ash and shale difficult on aerial photography unless there are other volcanic features in the area. Radial patterns develop on cinder cones and spatter cones.

Drainage–Elevation. Stream channels in the finer-grained pyroclastics are often steep-sided and V-shaped, whereas in the more resistant pyroclastic materials, such as welded tuff, they are more irregular and angular, without the sharp V-shaped cross section.

Erosion. Fine-grained volcanic material that has been deposited by wind or water will erode in a pattern similar to that of any fine-grained sedimentary material. Because of the softness of such materials, they are easily eroded. Consequently, badlands-type topography is common. Material that has been welded is more resistant to erosion and will develop vertical slopes, often with pinnacles and fins (narrow, sharp ridges). Although water is the primary agent of erosion, it is possible that the wind plays some role in the formation of fins and pinnacles.

Deposition. Pyroclastic materials are either deposited near their source by gravity or are carried some distance by the wind. The average distance that fine-grained volcanic ash is carried is usually measured in kilometers, whereas volcanic bombs are usually deposited within a few meters of the vent. They are subsequently moved downslope by running water.

Tone and Texture. Pyroclastic material is usually silicic in composition, and is light in color and photo tone. Tuffs, ash deposits, and pumice are highly variable in color, ranging from pink, green, and buff, to gray and white. Volcanic bombs, which are basaltic in composition, are dark in photo tone, as are cinder cones and spatter cones. The textures of pyroclastic materials differ greatly. The most common pyroclastics are tuff and ash deposits, which appear smooth on aerial photography. Welded tuff appears coarse in texture because smaller particles have been welded together to form large, blocky aggregates. Cinder cones and spatter cones are usually rough and blocky in photo texture.

COMPILER: Judy Ehlen, USAETL.

IGNEOUS ROCKS
VOLCANIC ROCKS (FLOW MATERIALS)

Because basalt is the most common volcanic rock, the comments below refer to basaltic rocks except where indicated otherwise.

Landform. These fine-textured igneous rocks produce more rugged, higher relief topography than any other type of igneous rock. Two types of volcanos formed of flow materials are common features of the volcanic landscape. The large shield volcanos are formed of basaltic lava. Composite cones (cone-shaped hills) are formed of layers of basalt and/or andesite and pyroclastic material. Individual basalt flows, usually extruding from the sides and base, are commonly associated with volcanos. The surface pattern of lava flows is often ropey. Lava flows can remain as caps upon other rock materials, forming flat-topped mesas and buttes. In addition, basalt forms extensive flat plains where sequences of very thin, very fluid lava flows that may be thousands of feet in total thickness have extruded from fissures (plateau basalts).

Drainage–Plan. Surface drainage on basalt flows is poorly developed because of columnar jointing and the porous nature of the rock. On volcanos the drainage pattern is usually radial. Lava flows and plateau basalts show little if any surface drainage.

Drainage–Elevation. In plateau basalts, valley sides tend to be steep, sometimes nearly vertical, and form deep canyons and gorges. V-shaped cross sections are more common on other volcanic features.

Erosion. Weathering is mainly mechanical. Mountains and hills formed of flow materials tend to erode to form sharp-crested, rugged, blocky terrains.

Deposition. Because of their rugged topography, volcanic terrains are not areas of deposition. Colluvial materials are common on the sides of volcanos, but very little depositional material is associated with basalt flows.

Vegetation. Soils that develop on volcanic rocks are usually nutrient-rich and a dense vegetative cover develops in temperate and tropical humid climates. Vegetation is relatively sparse on volcanic rocks in arid climates. Generally speaking, vegetation density on volcanic features provides relative age information: the sparser the vegetation, the younger the features.

Cultural. There are no unique cultural patterns that indicate the presence of volcanic rocks. In temperate and humid climates, flow materials weather to form soils suited for agriculture where terrain conditions permit. Weathering in arid climates proceeds slowly, as does soil development, and agriculture is limited. Basalts are often used as aggregate for construction.

Tone and Texture. Basalts range from dark gray to black in color and photo tone. Andesitic rocks, intermediate in composition and color (such as pink, gray, or medium brown), are medium gray in photo tone. The silicic rhyolites, which range from light brown, buff, and pink to gray or white in color, are light gray to white in photo tone. Sun angle, however, can cause tone reversals. Lava flows appear rough and jagged, ropey, or blocky on aerial photography. These textures correspond to the types of lava, aa, pahoehoe, and block, respectively. The various sized blocks of rock on the surfaces of the flows augment the normal rough texture of lava flows.

Special. Columnar joints, deep joints perpendicular to the surface of a lava flow that result from contraction during cooling, are very common in massive lava flows. They produce distinctive columns on cliff faces. Springs and waterfalls are common on valley sides in areas of multiple basaltic lava flows. Water percolates through porous surface lavas and interflow material, flowing horizontally when a denser, relatively impermeable layer is reached, producing lines of springs on cliff faces. Hot springs and associated features are common in areas of recent or incipient volcanism.

COMPILER: Judy Ehlen, USAETL.

IGNEOUS ROCKS
PLUTONIC (GRANITIC) ROCKS

As used here, the term "granitic" rocks refers to all silicic, medium- and coarse-grained plutonic igneous rocks.

Landform. Granitic rocks usually occur in large, relatively homogeneous masses that are rounded in overall form. Granite terrains may at first appear to be very rugged, blocky, and angular, but close observation reveals the characteristic roundedness that is apparent at scales as small as 1:120,000. Predominance of vertical joints tends to produce a more blocky landscape. The extreme form of such terrain is one dominated by pinnacles and needles. Where horizontal sheeting joints predominate, rounded, dome-like shapes are more common. Where vertical and curvilinear sheeting joints occur in approximately equal amounts, large pillow-shaped bodies called woolsacks will develop. Plutonic rocks generally lack a linear arrangement or control in topographic features.

Drainage–Plan. Drainage patterns on granitic rocks are usually subdendritic, subrectangular, or radial. Rectangular drainage will predominate where vertical joints are moderately developed to well-developed and where the intersection between the joints approaches a right angle. Where horizontal sheeting joints predominate, a distinct drainage pattern is usually absent. Regional radial drainage results from the dome shape common to large granitic bodies. Drainage density is usually medium to coarse and there are few tributary streams. Stream paths are very irregular.

Drainage–Elevation. Drainageway cross sections in granitic rocks are usually roughly V-shaped. Because of the coarse grain of the rock and the pervasive jointing, side slopes have a rounded block appearance.

Erosion. In temperate, subhumid regions the weathering of granitic rocks is primarily by mechanical means, and is concentrated along the fractures, resulting in the characteristic rounded, lumpy shapes. Chemical weathering of granites is most common in humid, tropical regions, and the primary weathering product is clay.

Deposition. Granitic terrains are usually not areas of alluvial deposition. Talus and other colluvial deposits are common, but most weathered material is removed from the area.

Vegetation. Granitic rocks are usually sparsely vegetated in temperate and arid climates, but a denser vegetation cover will develop in the tropics.

Tone and Texture. The photo tones of granitic rocks vary, but generally, are light gray to white on panchromatic aerial photography as a result of their silicic composition. Granitic rocks appear coarse textured on aerial photography as a result of the rough, blocky texture produced by weathering along closely spaced vertical joints.

Special. Jointing is a characteristic feature of granitic rocks and is apparent on all photo scales at least as small as 1:120,000. Vertical joints occur in almost all igneous rocks, but curvilinear sheeting joints are peculiar to granitic rocks; such joints are caused by the release of pressure that occurs when the material above the pluton is removed. Vertical joints are tensional features.

COMPILER: **Judy Ehlen, USAETL.**

TRANSPORTED MATERIALS – AEOLIAN SAND

Aeolian sands are wind-reworked, sand-sized particles from granular material associated with glacial and alluvial depositions, and are most frequently found in arid regions and beach areas. The chief constituent is quartz. Other materials can be encountered in dunes, such as dunes formed of volcanic particles, and the dunes of White Sands National Monument, New Mexico, that are formed of gypsum. Aeolian sand grains are usually smooth and well rounded. Compared to water-laid sand, the grains show a small range in size. Grains smaller than about 0.08 mm (1/300 inch) are borne away as dust. Grains larger than about 2.5 mm (1/10 inch) are seldom moved by the wind. Within a dune, the vast majority of the grains fall within an even narrower range. Windblown sands tend to form hills (sand dunes) that can have one of several typical shapes depending on the environment, and which are frequently grouped together in some type of chain, belt, or colony. They are depositional forms superposed on other landforms and, unless stabilized, can be moved over the ground by wind action. Because of the continual reworking of the sand, the dune accumulates material by sequential deposition that in cross section shows a well-developed pattern of cross bedding.

Landform. Hills. The shape of a sand dune depends on the constancy of wind speed and direction and the source of the supply of sand. As a result, many different hill shapes can be formed, ranging from regular to very irregular. Dunes can occur as individuals, as an ordered array, or as a jumble of merging forms. A constancy of wind direction and speed tends towards the development of forms and arrangements that are orderly. Of all shapes, the more common are barchan and lineal. Barchan dunes are crescent shape in plan and asymmetrical in cross section with the steeper slopes on the downwind side and the gentler slopes facing upwind. The steepest slope of the downwind face has the angle of repose of dry sand, i.e. about 30°. Although the horns of the crescent frequently point downwind, they can point upwind as well. These dunes frequently form in clusters that extend for several miles. Within the cluster the axes of the dunes will be parallel unless a secondary system develops because of a wind shift. Lineal dunes can form perpendicular to the wind direction. This ridge type dune is long, narrow, sharply crested, can extend for several miles, and can occur as a cluster of parallel ridges. Such dunes tend to develop when the wind is moderate, and constant in direction. A strong wind that can move all the grains arranges the sand into longitudinal ridges parallel with the wind direction. These ridges can be hundreds of miles long, several hundreds of feet wide, several hundreds of feet high, and have smaller dunal features on their surfaces. This type of dune is called a seif.

Drainage. Internal. Because of the relatively small areal extent of the individual dune, and because of the porosity of the material, water that falls on the dune drains immediately into the interior and does not run over the surface to develop a drainage pattern.

Erosion. By wind principally. Because of the internal drainage, water does not flow over the surface and scour out channels. If present, these can result from a cloudburst that saturates the outer reaches of the dune. The gullies will have a sharp V-shape and a steep, short gulley gradient.

Deposition. By wind. Active dunes are formed, and progress across the landscape, by a combination of erosion and deposition. Particles are tumbled up the wind-packed windward slope and deposited on the downwind side.

Vegetation. Vegetation is not present on the dunes in areas of active dune formation and movement. As available moisture increases, vegetation begins to take hold, which, in turn, can stabilize the dune. With sufficient moisture, the dunes will develop a grass cover, and can even serve as pasture. In certain areas, orchards and melon patches are not uncommon. In areas that are no longer dry, very old dunes can be covered by brush and trees.

Cultural. In general, these soils are too drouthy to be associated with manmade features. In humid and subhumid regions, dunal areas can contain pastures, orchards, melon patches, etc.

Tone and Texture. Light gray to white on panchromatic photography, and light brown to a light yellowish tan on color photography. Gypsum dunes will show as white, and those made of volcanic particles will be dark. In arid regions there is very little color or tone contrast between the sand dune and the surrounding soils. In more humid areas, because of increased moisture and the added factor of some vegetation on the surrounding soils, the dune can show strong tone and color contrasts in relation to its background.

Special. The most readily identifiable patterns that suggest sand dunes are the hill shapes, particularly that of the barchan.

Engineering Characteristics and Problems. Dune sand is very fine and usually ranges from the No. 70 to the No. 200 sieve size. In general, sand dune areas offer little or no engineering difficulties. The soils are well drained internally and they offer excellent subgrade support. In areas of high winds, shifting sands can cause drift problems.. With reference to cross-country mobility, the less steep windward facing slopes are wind compacted. The downwind slopes are loose and are obstacles to movement.

COMPILERS: J.N. Rinker and R.E. Frost, USAETL.

TRANSPORTED MATERIALS — AEOLIAN
LOESS (WINDBLOWN SILT)

Loess is an unconsolidated, or weakly consolidated, deposit of windblown soil that comes mostly from river flood plains and which can be found in many parts of the world. These deposits, which occur mostly on plains or plateau regions, range in thickness from a few centimeters to as much as 200 meters. Usually, they are calcareous in nature and consist mostly of angular grains of silt, with lesser amounts of very fine sand and clay. Although the mineral composition varies, depending on the nature of the source material, there is usually present an appreciable amount of calcium carbonate, or calcium magnesium carbonate. Loess has a vertical microtubular structure which supports a capillary rise of as much as 30 ft. (9 meters) and which is responsible for forming the characteristic steep erosional faces. Loess is usually well drained internally, with the vertical permeability being several times greater than the horizontal permeability. It is easily eroded when exposed to running water, and forms a fertile soil.

Landform. Variable. Ranging from fairly rugged hills adjacent to the source of the silt, through moderately hilly terrain, rolling plains, and gently undulating plains. The slight ridges on the latter can be 30 to 40 miles long (about 50–65 kilometers), and some 2 miles apart (about 3 kilometers). Within the U.S., the dominant pattern is a repetition of similar hills forming a sequence of parallel ridges. Hills and ridges have a general windswept, or streamlined, appearance. Because of the uniformity of the material, weathering and erosional processes form very similar slopes on all sides of hills.

Drainage–Plan. Pinnate on a local basis.[1] Short, stubby, lateral gullies enter the collecting gully at right angles, or nearly so. These short gullies are so closely spaced and have such uniformity in length, that they present a featherlike, or pinnate, pattern, which is a unique characteristic of loess. Although the regional drainage pattern can vary from parallel, through angular, to subdendritic, the individual gullies will show the pinnate feature. In shallow deposits of loess, the pinnate pattern does not usually develop. Shallow deposits can also develop "phantom drainage" at the extension of gully tips. These drainageways have dark-toned centers, but no visible erosional scouring. In aerial photography of humid regions where tree cover is continuous, the pinnate pattern is seldom visible. In some cleared areas, the gully system can be outlined by the residual vegetation left standing in the gully.

Drainage–Elevation. In cross section, the bottoms of the gullies are flat. The sides are relatively steep ($45^\circ - 60^\circ$).[2] The side slopes are frequently uniform, although in stages of early development the upper slopes can tend to roundedness. In regions of heavy seasonal rains the gully cross section becomes more box-like, with uniformly steeper side walls. Renewed downcutting in the gully bottoms produces a cross section that is very rectangular. Undercutting by fast-moving water, such as along a river bank, can produce near vertical faces. Box-like gullies can be found also in the sand-clay mix-

[1]Indicator 0015
[2]Indicator 0014

tures of the eastern coastal plain of the United States, but these soils are readily differentiated from loess on the basis of other pattern elements. Gully cross section can be modified by vegetative cover, agricultural practices, erosion control procedures, and the carbonate component of the material. Gully gradient is gentle and uniform, except for the short steeper section at the head end. Gully walls frequently develop a series of small steps called "terracettes."

Erosion. By water principally. With enough rainfall, loessal deposits become heavily dissected. Erosion is by headward means. Slumping, slabbing, and creep can occur on walls of gullies and road cuts. Erosional remnants can occur in the form of isolated columns, pinnacles, or finlike projections from gully walls. In some areas, vertical walled holes, or depressions, can occur (natural wells, loess wells, gash sinks). If the vertical structure of this soil is broken on the surface (plowing, traffic, etc.), the material is easily eroded by the wind.

Deposition. Loess is a wind-deposited material. When eroded by the wind, it is redeposited downwind. Because of the fineness of the grains, water erosion carries the material out of the system, i.e. fans do not form at gully exits.

Vegetation. The types and amounts of vegetative cover on loessal deposits depend on the amount of moisture. With sufficient rainfall a dense forest cover will develop. Drier areas will support a grass cover. Many loessal regions are devoted to wheat farming.

Cultural. Because of the small grain size and the consequent high ratio of surface to volume, the minerals in loess are more readily available to plants, via water solution, than are minerals in coarse-grained deposits such as sand and gravel. This, coupled to its excellent water retention capability, puts loess among the more valuable of the agricultural soils. Much of the world distribution of loess coincides with the wheat producing belts. Areas associated with active crop farming can produce patterns of contour plowing, erosion control plantings, and fallow field practices. Erosion control procedures can destroy the box-shaped characteristic. Road cuts show vertical, or near vertical, faces.

Tone and Texture. In color, loess ranges through gray, yellowish gray, tan, yellowish brown, and brown. Yellow to yellowish brown are more common. On panchromatic photography, the tones are light to medium gray with soft gradations. Topographic highs are usually lighter in tone than lows, but tone change is gradual. High tonal contrasts (not shadow/highlight) seldom occur.

COMPILERS: J.N. Rinker and Robert E. Frost, USAETL.

TRANSPORTED MATERIALS — ALLUVIAL DELTAS

A delta is an alluvial deposit built outward from the shoreline by the deposition of sediment carried by streams. They are recent deposits in the geologic sense. The kind of deltaic formation that develops depends on the type and amount of sediment carried by the stream and the nature of the water body receiving the stream discharge. There are three general types: arcuate deltas, which are deposits of coarse sediments; estuarine deltas, which form where the mouth of the stream is below the main body of water and which have soil textures ranging from clays to gravels; and bird-foot deltas, which are formed by streams depositing fine-textured soils into protected or quiet bodies of water. Deltas can be so large that they can be considered as subdivisions of a physiographic province.

Landform. Arcuate delta: a flat, gently sloping, fan-shaped plain with the curved edge toward the water body. The surface is broken by many channels. The pure fan shape develops only when the deposits are not confined. Estuarine delta: a confined, broad, flat floor of a trough. Because the stream mouth is submerged, the stream load is deposited in low areas on the inland side of the mouth, and the deposits do not spread out. If the deposits are coarse textured, an intricate braided pattern will be present on the surface. If the deposits are fine, a series of swamps and ponds will develop. Bird-foot delta (also called lobate): a broad, flat surface extending out into the body of water and with the stream concentrated in a few large channels that carry the sediment load. Sediments are distributed locally on both sides of the channel by levee action.

Drainage–Plan. Arcuate deltas: although shallow, braided channels are evident, much of the drainage is by internal means. The locations of the channels change frequently during high water. Estuarine deltas: if the deposits are coarse, a series of shallow, braided channels will be developed as on arcuate deltas. If the deposits are fine textured, a series of marshes and small ponds will form instead of defined channels. Bird-foot deltas: a few large, relatively stable channels carry the water load.

Drainage–Elevation. Because the surfaces are relatively flat, very little erosion occurs and gully cross section is not an important pattern element. Channel locations shift during high water in a sequence of constant erosion and deposition.

Erosion. See above (Drainage–Elevation).

Deposition. The deltas are deposits. In bird-foot deltas deposition occurs in the form of levees along the channel banks, and at the mouths of tributaries.

Vegetation. Vegetation cover ranges from barren through cropland to tree cover, depending on climate and age of the delta.

Cultural. In favorable climates deltas can be fertile areas. Large deltas can, and do, support sizeable populations. Granular deltas are good sites for construction, as well as for sources of materials for aggregate. The soils of recent deposits are usually too soft and wet to support loads.

Tone and Texture. Because deltas can be made of nearly any range of granular and fine-grained materials and frequently have high water tables, the tones are variable and range from light to dark.

COMPILERS: **Jack N. Rinker and Robert E. Frost, USAETL.**

TRANSPORTED MATERIALS — ALLUVIAL
STREAM TERRACES

Terraces occur in most of the major stream valleys of the world and can be so large that they are difficult to identify on air photos. They are composed of some combination of silt, sand, and gravel and are located between the flood plain and the upland. They are formed by the downcutting of former flood plains by stream action.

Landform. The shape is that of a relatively flat bench or shelf between the flood plain and the upland. In many cases there are several levels of terraces within a valley. They can also exist as an isolated remnant cut off from the upland. Granular terraces that are of poorly sorted material and have a sizeable content of gravel show very steep, near-vertical faces. Terraces with less coarse material tend to develop more gentle slopes. As the soils become finer textured the surfaces become more rolling and the terrace face is more rounded and dissected.

Drainage–Plan. A drainage net does not develop on granular terraces because water falling onto the surface drains down internally. If the terrace is large and composed of finer textured soils, a semblance of a drainage pattern can be noted. A deep granular terrace can show evidence of infiltration basins.

Drainage–Elevation. The gullies are V-shaped with short, steep, uniform gradients. These occur along the edges of the terrace face and do not extend very far back. If the terrace is composed of fine-textured soils, the gully cross sections will be more of a deep saucer shape and extend a considerable distance.

Deposition. Alluvial fans usually form at gully exits, being a rounded hump for coarse deposits and having a flatter and more extended shape for finer material.

Vegetation. Tree cover in humid areas unless cleared for cultivation.

Cultural. The most frequent patterns are those of farming and gravel extractions from excavations.

Tone and Texture. Terrace surfaces frequently show linear and curvilinear marks caused by flowing water from a river in flood stage. The lighter tone streaks are slightly higher in relief and represent well-drained soils. The darker streaks mark the various recessional stages of the flood waters, are slightly lower in elevation, and contain less porous soils, that is, an accumulation of silts and clays. Frequently in well-drained terraces an overall mottled pattern can be seen.

Engineering Characteristics and Problems. In general the suface layer is composed of silty clay. Granular terraces can vary from poorly sorted or dirty gravel to clean, well-sorted gravel. With depth, the sands and gravels usually become layered and are fairly well graded. Terraces are excellent sources of construction materials.

COMPILERS: **Jack N. Rinker and Robert E. Frost, USAETL.**

DEPOSITED MATERIALS
PEAT AND MUCK

Peat and muck deposits result from the accumulation of vegetation in low-lying areas, such as ponds, small lakes, estuaries, etc. Peat is a spongy mass of partly decayed vegetation, and vegetal structures can be identified within the deposit. When a deposit has decayed to the extent that such remains cannot be identified, it is called muck. Peat soils range in texture from fine to coarse. Muck soils tend to be fine textured.

Landform. Flat plains. Because these deposits result from the gradual filling in of low places, ponds, lakes, etc., the surface is very flat. In uplands, and in the interior away from the coast, peat and muck deposits are flat plains surrounded by higher ground and usually show the outlines of the earlier pond or lake.

Drainage-Plan. None. There is little or no indication of surficial drainage. In large peat and muck deposits that have filled in old channels in coastal areas, one can find narrow streams flowing through the mass. Drainage ditches can be found in areas where the peat and muck are being used for some economic purpose.

Drainage-Elevation. Gullies are not formed in these deposits.

Erosion. When dry, muck soils are subject to wind erosion.

Deposition. Not applicable.

Vegetation. In upland regions and glaciated areas the filled-in ponds support a very dense tree cover. In other regions the ground cover can be typical of the herbaceous material that filled in the pond.

Cultural. Peat and muck deposits are valuable economic resources. The areas frequently are drained and cultivated for a large variety of crops such as peppermint, onions, celery, potatoes, etc. Peat is also used as a fuel, and it is used extensively in nurseries and greenhouses.

Tone and Texture. All of these deposits are very dark, ranging from a dark reddish-brown to black. On panchromatic photography the tones range from a dark gray to black.

COMPILER: J.N. Rinker, USAETL.