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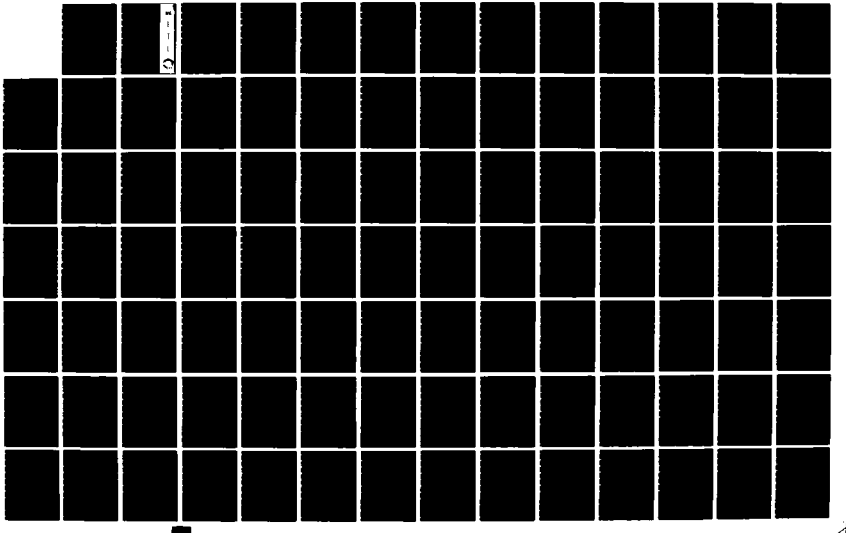

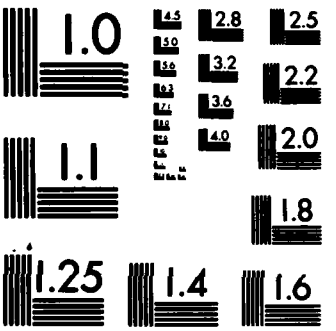

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Methodological preliminaries to the development of an expert system for aerial photo interpretation

Robert R. Hoffman

JANUARY 1984

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Prepared for

U.S. ARMY CORPS OF ENGINEERS
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This report describes an investigation of the psychological aspects that affect the reasoning of expert aerial photo interpreters. The purpose of the study is to help develop an artificial intelligence expert system to aid terrain analysis. Artificial intelligence offers tools for studying and representing expert knowledge and reasoning. This study examines four methods for extracting the expert's knowledge: the Standard Terrain Analysis Method, the Structured Interview Method, the Limited Information Task, and the Method of "Tough Cases." Criteria are presented for analyzing the four methods, and criteria that must pertain to aerial photo interpretation in order for expert systems tools to be applicable are described. This report discusses the structure of expert systems in general and the structure of an expert system for photo interpretation in particular.

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PREFACE

This report was prepared for the U.S. Army Engineer Topographic Laboratories (ETL), Fort Belvoir, Virginia, through Battelle Institute, Research Triangle, North Carolina, under the Army Research Office's *U.S. Army Summer Faculty Research and Engineering Program.*

The work was performed at the Engineer Topographic Laboratories by Mr. Robert R. Hoffman of Adelphi University, Garden City, New York, under the technical supervision of Mr. Olin W. Mintzer, ETL.

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SUMMARY

The research reported here represents a psychological investigation of the reasoning of expert aerial photo interpreters, as prolegomena to the development of an artificial intelligence expert system for assisting interpreters in the process of terrain analysis. The process of photo interpretation relies on psychological acts of perception and judgment and access to knowledge. Artificial intelligence offers tools for studying and representing expert knowledge and reasoning. This study examines four methods for extracting the expert's knowledge. The Standard Terrain Analysis Method involves the systematic analysis of landforms based on information from photos, maps, and other sources. The Structured Interview Method involves the analysis of detailed interpretation keys. In the Limited Information Task, the expert is constrained to interpret aerial photos without benefit of contextual information. The Method of "Tough Cases" involves studies of photos which are particularly difficult or challenging to the expert. The four methods yielded different amounts and kinds of information. Except for the Standard Terrain Analysis Method, which is very time-consuming, all the methods have the potential for efficiently yielding information about the expert's knowledge and reasoning rules. Criteria are presented for analyzing the methods, such as task simplicity, task validity, and task efficiency. Criteria which must apply to a given domain in order for expert systems tools to be applicable are also described, and it is concluded that they apply to the domain of aerial photo interpretation. The structure of expert systems is described and statements are made about the structure of an expert system for photo interpretation. Finally, some developmental phases of the system are outlined and research which remains to be done is described, including some recommended alterations in the experimental methods.

CONTENTS

Page

Preface....1

Summary....2

Tables....3

Illustration....3

Introduction - Purposes and Goals....5

Photo Interpretation from the Psychological Perspective....5

Study #1 - The Standard Photo Interpretation Method....10

Study #2 - The Structured Interview Method....16

Study #3 - The Limited Information Task....22

Study #4 - The Method of "Tough Cases"....27

Discussion of the Results and Comparison of Methods....31

Artificial Intelligence Considerations....38

Recommendations for Further Research....55

References....60

Appendix 1 - The Data Base Derived by the Structured Interview....62

Appendix 2 - Transcripts from the Limited Information Task....103

Appendix 3 - A Transcript from the Method of Tough Cases....113

Appendix 4 - A Prototype Data Base for Physiographic Regions....117

Appendix 5 - Instructions for Recording Analyses of Tough Cases....133

TABLES

NUMBER	TITLE	PAGE
1	A summary of the results of the limited information task	26
2	A demonstration of what it might be like to interact with an expert system for aerial photo interpretation	51
3	Developmental phases for an expert system for aerial photo interpretation	58

ILLUSTRATIONS

NUMBER	TITLE	PAGE
1	Overall architecture for an expert system for aerial photo interpretation	50

METHODOLOGICAL PRELIMINARIES TO THE DEVELOPMENT OF AN EXPERT SYSTEM FOR AERIAL PHOTO INTERPRETATION

INTRODUCTION -- PURPOSES AND GOALS

Aerial photography is an important tool in geology and mining, land resource management, mapmaking, agriculture and forestry, military applications, and many other domains. The research described in this report was conducted from the perspective of an experimental psychologist and focused on the reasoning processes that are used by expert aerial photo interpreters.

The major purpose of this study was to define methods for efficiently extracting the knowledge and reasoning of experts, for subsequent use in knowledge-based photo interpretation expert systems. In the following section, I describe the process of aerial photo interpretation from the psychological perspective. In each of the next four sections a particular method for disclosing experts' knowledge is investigated. After a comparison of the methods and the results they yielded, I consider what implications this research has for the development of an expert system.

PHOTO INTERPRETATION FROM THE PSYCHOLOGICAL PERSPECTIVE

For most skillful perceptual problems, experts are unusual, their relevant knowledge is extremely detailed and logically interconnected, and general understanding of the perceptual processes involved is limited. Research on the perceptual skills of experts, in any domain, affords an excellent opportunity for basic and practical psychological experimentation.

According to the Manual of Remote Sensing (Reeves, 1975), the process of aerial photo interpretation involves three separate psychological acts:

(1) Measurement or visual estimation of sizes, shapes, and dimensions,

(2) Identification of objects by means of various visual cues such as variations in tone, texture, pattern, and depth, and

(3) Problem-solving which uses the perceived information to derive knowledge about the area that is covered in the photos.

For example, in identifying an object as a barn, the interpreter would have estimated (or measured) sizes and proportions, studied the shapes of the roof surfaces, and attended to surrounding objects such as silos and animal pens. The process of aerial photo interpretation consists of collecting facts through observation and measurement of the image and of formulating hypotheses to explain the facts (Lobeck, 1939). The formulation of hypotheses relies on deductive and inductive reasoning. Once formulated, an hypothesis can suggest or imply other facts that should be observable--either to confirm correct hypotheses or to eliminate invalid ones.

The facts and hypotheses which the interpreter collects are not strictly about the photo, but about the landforms, soils, vegetation, and cultural conditions that are represented in the photos. Thus, the process of aerial photo interpretation is often referred to as terrain analysis in recognition of its reliance on principles of geomorphology and landforms. The visual pattern is systematically analyzed and information is extracted about the land and terrain, such as information on soil characteristics, water table, and past geomorphologic processes in the area. Landforms are land units that have resulted from constructional or destructional processes that when found under similar conditions (such as age, climate, and weathering) will exhibit a definable range of visual and physical characteristics (Frost, 1950; Mintzer

and Messmore, 1982). Each landform has separate and distinct characteristics of topography, rock, soil, and water conditions. The same landform, regardless of its location, will exhibit similar patterns if found under the same environmental conditions. Changes in the environmental conditions (e.g., erosion or weathering) will change the appearance and significance of pattern elements. The greater the number of different landforms in a given coverage, the greater the complexity of the area in terms of composition and structure. The more a landform type is repeated, either vertically or horizontally, the greater the likelihood of an orderly structure. Typical descriptions of landforms include such terms as flat plains, massive hills, steep-sided slopes, saw-tooth ridges, bold and dome-like hills, etc. Because of the reliance on geomorphological principles, a background in the earth sciences is important preparation for learning the process of aerial photo interpretation.

In recent years, a number of researchers in computer science and cognitive psychology have investigated domains of expert knowledge, for example, expert medical diagnosticians and expert physicists. This research has yielded a body of phychological principles which should apply to the domain of expertise in aerial photo interpretation. These principles and methods would then take the form of predictions or expectations about psychological aspects of the expert's reasoning and the form of expectations about workable methods for extracting the expert's knowledge.

Psychologists often distinguish between perceptual processes, learning processes, and knowledge. In any given domain, experts can be compared to novices in terms of their differences on each of the three factors. Almost by definition, an expert's perception differs from that of the novice. Through a process of le rning, r ceptionbecomes rapid and automatic. Perceptual

knowledge and strategies may be used without conscious awareness or decision-making. Thus, the process of disclosing expertise can be a process where the expert himself learns about his own knowledge. Experts search the available information efficiently and can combine information from different sources or representations. In terms of learning and knowledge, experts know the conditions under which principles apply, they understand the relations between principles, they can formulate realistic hypotheses, and they know how to search for additional information. Novices, in contrast, can be easily tricked by counterexamples.

All of these psychological facts apply to the domain of aerial photo interpretation. When examining an aerial stereo photo and accompanying photo mosaic and topographical map, the expert perceives things that are not visible to the novice. Is it a thick soil, or is it controlled by the underlying rock? Is the underlying bedrock a massive bed, or is it layered? Are the layers thick or thin, tilted or folded? The expert perceives the underlying geomorphological processes, and can answer such questions, questions that mystify the novice. Both novices and experts can perceive and measure the lakes in an aerial photo. However, the expert sees the shape of the lake in relation to its surround and the underlying bedrock; for example, when a lake lies along a fracture and has stream inlets that are parallel or perpendicular to one another, or when there are more streams on one side of the lake than the other, implying that the underlying bedrock might be tilted.

Another example is the expert who upon seeing a particular photo, announced that there were certain bacterial infections likely to occur in personnel who were sent into that area. Given that climate, the pattern to the ponds and vegetation suggested the presence of certain bacteria. The expert's understanding of the relations between soils and pathogens enabled

the expert to perceive the coverage in a way that the novice could not.

Experts can perceive information about objects (e.g., rain forest, broadleaf shrubland, interstate bridge, windblown silt soils), about composition (e.g., wooden bridges, sandstone hills, granite cliffs), about use and function (e.g., recreation forest, light manufacturing industry), about origins (e.g., volcanic basalt, glacial soils), and about conditions (e.g., unstable slopes, gypsy moth-infested forest). Their knowledge is extensive and complex. In order to be able to make the kinds of inferences the expert makes, the novice needs knowledge. He must undergo training involving hundreds of examples as well as training in geomorphology. The novice also needs to learn new perceptual skills. He must go beyond simple perceptual detection to an ability to identify and classify. At higher levels of experience, things can be identified without being detected (e.g., because of a forest canopy, soils cannot be detected, but can be identified by inference) (Rinker and Corl, 1984).

Given that psychological principles apply, the problem of extracting the expert aerial photo interpreter's knowledge becomes a psychological one of finding the proper experimental method or methods. The next four sections of this report explore the experimental methods issue. First, what sorts of perceptual and judgmental tasks do expert photo interpreters usually engage themselves in?

STUDY #1

THE STANDARD PHOTO INTERPRETATION METHOD

The standard methods that are used in the interpretation of aerial photos have been described in a number of sources (e.g., Gay, 1979; Mintzer and Messmore, 1982; Nikolayev, et al., 1977; Rinker and Corl, 1984; Way, 1978). Over the last several decades of research on photogrammetry and photo interpretation, a fairly standard procedure has evolved, which I refer to as the Standard Terrain Analysis Method or the Standard Photo Interpretation Method. While the methods described by various sources and experts vary slightly, they all share certain common features:

(1) All have the general goal of providing a complete, accurate terrain analysis.

(2) All are applicable to various specific goals, such as landuse mapping, tactical mapping, geological mapping, etc.

(3) All rely on black-and-white stereo aerial visible light photography as the primary source of information. Scales of 1:20,000, 1:30,000, and 1:40,000 are preferred.

(4) All recommend full use of all available contextual information, such as from topographical maps, geological maps, soils maps, road maps, radar imagery, infrared imagery, etc.

(5) All recommend the use of a photomosaic that includes the target coverage.

(6) All assume that the interpreter is already an expert. Except for the production of some overlays and the identification of certain cultural forms, novices are not capable of conducting a complete terrain analysis, although the terrain analysis method can be used as a teaching tool.

(7) All assume that the photo interpreter's abilities to infer and reason go well beyond an ability to detect or recognize things such as shape and size (e.g., roads, airports, vehicles, etc.)

(8) All rely on an analysis of photo pattern features into cues. For each feature, the following cues are described:

(a) shapes (outlines, forms),

(b) sizes (observed or measured),

(c) shadows (as cues to size and shape),

(d) patterns (spatial arrangements, as in orchards),

(e) photo grey tones (e.g., grain crops appear dark),

(f) texture (e.g., a dense pine forest versus a sparse shrubland),

(g) site and association (i.e., the location of objects relative to the terrain and to each other will have implications about their function).

(9) All rely on an analysis of the coverage into separate landform units (e.g., mountainous upland versus cultivated rolling plains versus streams and rivers).

(10) All rely on an analysis of features into categories:

(a) topography (relief, shape, slope),

(b) drainage patterns and gully characteristics (e.g., density of dissection and gully shapes as indicators of rock porosity and soil type),

(c) soils,

(d) vegetation and cultivation patterns,

(e) land use and cultural patterns.

(11) All rely on an analysis of the categories in terms of a specific landform classification scheme (e.g., mesas, buttes, and terraces are all plains, but are classified differently depending on elevation factors).

(12) All rely on the expert's knowledge and inference-making. Once the photo pattern elements are used to discriminate landform units and to categorize landforms, the terrain units must then be identified. The identification process relies on three methods:

(a) perceptual recognition based on the expert's knowledge and experience,

(b) matching of the descriptors of the landform with published interpretation keys,

(c) hypothesis-testing in which a likely identity of a landform is postulated. This in turn leads to searches for confirming or

disconfirming evidence (e.g., If it is a glacial outwash plain, it should have a flat to undulating basin--does it?). If a majority of the questions generate negative answers some other hypothesis is sought.

(13) All recommend the production of factor overlays:

(a) Direct (e.g., ridgelines, slopes, vegetation, land use, cultural features),

(b) Derived (e.g., geology, soils, subsurface water, population or economic changes).

(14) All result in the production of data records:

(a) factor overlays,

(b) categorical or feature descriptions,

(c) notes on the interpreter's inferences or hypotheses,

(d) notes on any special or unusual features,

(e) information about geobiological dynamics,

(f) information relevant to any specific goals of the analysis.

(15) All recommend reliance on standard published interpretation keys.

(16) All recognize that the terrain analysis method is labor-intensive and very time-consuming.

The Standard Method is highly systematic and reliable. Much time is spent producing records of the interpreter's identifications and descriptions. While expert photo interpreters, by virtue of their extensive experience, rely heavily on knowledge-based perceptual recognition and on sequences of

hypothesis tests, relatively little time is spent during a Standard Terrain Analysis making records of the interpreter's reasoning. It was therefore determined that this Standard Method would have to be altered in order to produce more records of the interpreter's reasoning.

The procedure for identifying and mapping landforms consists of airphoto interpretation/landform descriptor analysis and delineation of the landform map. The identity of the interpreted terrain units as landforms may be conducted by one of three methods. These are

1) descriptor matching,

2) hypothesis and descriptor matching analysis,

3) recognition of identity from experience.

The first method is to compare the set of descriptors prepared by the analyst for the unknown landform with a set of descriptors in a catalogue listing all known landforms. The analyst may search for matching or similar descriptors, i.e., topographic form, drainage system, gully characteristics, special features, etc. Once the descriptors of the unknown landform are matched with similar descriptors of a landform of known identity, the landform is identified. If the procedure does not satisfy, then landform identity method two is used.

The second method is to analyze the set of descriptors using the scientific method. The analyst hypothesizes the identity of the landform, basing his hypothesis on the landform's set of descriptors. With the hypothesis in mind, the photointerpreter then asks himself a question: e.g., if it is a glacial outwash plain, it would have a flat to undulating plain. Does it? He checks the table for a corresponding descriptor and finds that it does have a flat plain. Then he asks if it has an internal drainage pattern, and finds that the descriptor corresponds with the descriptor of an outwash

plain. The analyst continues this if-then questioning until all seven descriptors have been examined and matched. Finding a majority - say, 5 of 7 - matching descriptors, then the landform's identity matches the hypothesis. On the other hand, if the majority of questions generated negative responses, then the hypothesis is rejected and another landform-identity hypothesis is examined in a similar manner. This procedure is continued until the appropriate identity is found. This second method, rather than the first method, is more apt to be used by an expert photointerpreter.

The third method - the experienced analyst's method - is to recognize the landform's identity because it or a similar landform pattern has been observed on the ground or on airphotos, or both, prior to commencing the analysis.

The results of any one of the above procedures are field-checked as the final step of the landform mapping of the terrain.

Another important fact made salient by an examination of the literature on the Standard Terrain Analysis Method is that much of the logical foundation of aerial photo interpretation already appears in published texts and interpretation keys. It could be immediately concluded that a first pass at a description of expertise could be directly gleaned from the published sources. The second method to be studied capitalized on this fact.

STUDY #2

THE STRUCTURED INTERVIEW METHOD

The primary method used in the field of expert systems engineering in order to describe the knowledge of experts is the interview method. The field of expert systems engineering relies so heavily on this method that papers and texts on artificial intelligence systems make essentially no reference to the psychological-experimental problem of generating efficient methods for the extraction of experts' knowledge. Interviews with experts are exhaustive, exhausting, and time-consuming. Here is an illuminating passage from Duda and Gaschnig (1981):

> ". . . something must be done to shorten the time needed to interview experts and represent their special knowledge in the form of rules. This is often called the knowledge acquisition problem. Despite several concentrated efforts it remains a bottleneck. The development of a model containing a few hundred rules may take several months of the expert's time and even more of the system builder's" (p. 264).

Since it was anticipated that interviews with experts would be necessary, a means was sought for making those interviews as structured and efficient as possible. This problem was solved by capitalizing on the information available in the literature on terrain analysis. This information often takes the form of interpretation "keys." These are verbal, diagrammatic, or photographic descriptions or examples of the scenes and landforms one is

likely to encounter in aerial photos. Object keys describe common objects and easily recognized landforms (e.g., sand dunes, volcanic cinder cones). Inference keys describe typical landform patterns or situations. Catalog keys provide alternative choices for each thing to be identified (e.g., types of industries or types of landforms). Question-and-answer keys pose specific questions, each with several alternative answers. Each answer leads to further questions and the process continues until an identification is reached. The overlays that are produced in the Standard Photo Interpretation Method are also examples of keys. In the interpretation process, the overlays are compared to published keys (as well as to the interpreter's knowledge) to yield an identification or categorization.

One way in which expert photo interpreters analyze their own knowledge is through a process of reading and criticizing published interpretation keys or texts, those written by themselves or by other photo interpreters. Since they are familiar with this sort of analysis, it was decided that it would be used as the format for structuring the detailed interviews.

Most studies that use the interview method result in data in the form of verbal protocols -- a transcript of the expert's verbalized thoughts in response to questions or problems to solve. In order to analyze transcript data, the utterances must be broken up into phrases in the form of propositions or assertions. These can then be coded and classified. An advantage of using photo interpretation keys to structure the interview is that the raw data would already be in a coded form -- the expert's comments on the specific propositions in the key's list.

METHOD

Subjects. The subject was an expert photo interpreter.

Materials. The background literature on terrain analysis was used to generate a detailed list of commonly held rules of photo interpretation, a compilation of all the photo interpretation keys. A version of this list appears in appendix 1. Every time a source mentioned a defining feature (e.g., a dome is a large rounded hill or mountain) or implication (e.g., steep gully slopes imply cohesive soils), then that item was entered into the list under the appropriate landform category. Different authors had different backgrounds of experience, so in most instances the keys differed only in detail and did not differ on matters of fact (for example, whether exposed basalt has a light or medium tone). In cases where there was disagreement, the contradictions were resolvable by taking other factors into consideration (for example, the color of exposed rock depends on the climate). One of the purposes of this study was to determine the degree to which experts might agree or disagree with each other.

The completed key was a catalog of inferences. It consisted of 243 major categories, 872 defining features, and 312 associated implications.

Procedure. The key was presented to the expert, who was given the following instructions:

> "This file is a relational data base for an expert system being designed to assist people in the process of aerial photo interpretation. Organizational headings are of two types: (1) Contextual information (such as climate, time-of-year, and available topographical information) and (2) Landform information (such as for

glacial forms, fluvial forms, etc.). Entries in the data base are of two general types: (1) Defining features (e.g., What is a hill?) and (2) Associated implications (e.g., a massive dome-like shape to a hill implies that it might be granite). Many of the headings will be incomplete and you may disagree with some of the specific entries. Your task in this study is to go through the list, reading each heading and entry in order to decide if you agree or disagree with it. If you disagree with it, you are to correct or qualify it in writing on your copy of the list. Qualify or alter it as much as you care to, until you feel that it is an accurate or acceptable statement. If facts or headings occur to you which are absent from this list, then you are to insert them. If you are hesitant to comment on a given entry, because of uncertainty or because of lack of experience with a particular landform, you are to insert that as a comment as well. You are encouraged to think out loud as you consider each entry and describe any thoughts or inferences you might have."

The expert photo interpreter and the examiner were seated opposite each other at a table in a quiet room. The expert read each entry out loud and then commented. The examiner made notes on his own copy of the list and occasionally asked the expert a probing question if the expert showed signs of implicit reasoning, for example, hesitations or facial expressions of puzzlement.

RESULTS AND DISCUSSION

It took about 10 hours for the complete analysis of the list. Of the 243 categories and subcategories, 20 (about 8 percent) were changed or reorganized, 13 (or about 5 percent) were deleted entirely, while 52 new ones were added (representing an increase of about 21 percent). Of the 872 defining features, 192 (or 22 percent) were changed or modified, 80 (or 9 percent) were deleted, and 96 new ones were added (representing an increase of about 11 percent). Of the 312 associated implications, which were usually references to climate, 73 (or 23 percent) were changed or modified, 53 (or 7 percent) were deleted, while 61 new ones were added (representing an increase of about 20 percent).

While all of the 1,427 listed propositions and categories came from published texts and keys, 431, or about 30 percent, were modified or deleted by this expert and 209 new ones were added (representing an increase of about 15 percent). The moral here is one that is fairly well known among expert photo interpreters: Don't trust the published keys. Many of the changes took the form of qualifications or modifications. For example, the key originally stated that alluvial fans have no distinct gully shape. However, this expert asserted that they usually have U-shaped gullies. As another example, the key originally stated that longitudinal dunes can occur in clusters; however, this expert asserted that they usually occur in clusters. These two examples are representative of the sorts of qualifications and changes that this expert proposed.

Many of the corrections and deletions involved differences between this expert's experiences and those that went into the generation of the source keys. The expert would comment that a particular listed feature or

implication did not go with that landform according to his experience. Often, the listed feature was deleted and some other feature was substituted for it. For example, for flat sandstone the feature "gently rolling plains" was rewritten as "rolling plain with gentle to strong relief." As another example, the feature of flat interbedded sandstone and shale, "terraced hill slopes," was rewritten as "occasional terraced hill slopes." Both these examples reflect changes in which the representativeness of a feature was judged relative to the expert's background of experience.

All of the suggested changes were incorporated into the list, and it is this revised list that actually appears as appendix 1. Examination of the list shows that it is a very detailed categorization of landforms and their associated patterns.

When the expert made no comment on a given heading or entry, he was in effect agreeing with it. In these cases, we have learned nothing new about the expert's reasoning. We have obtained confirmation of a previously known fact. Of the 1,427 entries, 787 (or 55 percent) were unchanged. Most of the items that the expert agreed with were simply read, acknowledged as correct, and passed over. Assuming (conservatively) that five seconds was spent on each such item, then about one hour of the total interview time was spent discussing these items. Assuming that nine of the ten hours were spent discussing the changed or deleted items, then approximately 45 seconds was spent on each one. In other words, this method produced about 1.2 new inference-related propositions per task minute.

STUDY #3

THE LIMITED INFORMATION TASK

If one can limit the information that is available to the expert, one can determine what information the expert seeks and in what order. From this knowledge, aspects of the reasoning process can be derived. As a class of tasks, "information acquisition tasks" involve presenting a series of decision tasks wherein the Subject must explicitly and actively search for information. Information can be hidden or withheld until the Subject requests it. Verbal protocol data can be collected and various measurements can be taken, such as of decision accuracy and latency.

In the Standard Terrain Analysis Method, information search is involved, but information access is not limited. In order to limit the information available, one will have to relax the constraint that the analysis be accurate, correct, and complete. It is an uncomfortable thing for expert photo interpreters to do when they are asked to analyze a stereo photo under conditions of limited information access. However, the goal of the task is not to determine how skillful or knowledgeable the expert is, since it is still assumed that the Subject is an expert. Rather, the goal of this task is to use a stimulus to evoke instances of reasoning -- to determine which features in a photo are easy to find, describe, and infer from, and which are hard.

Some sources (e.g., Frost, 1950; Rinker and Corl, 1984) that rely on the Standard Method also advocate a method in which stereo photos are examined without benefit of any contextual information. Some experts are very good at this task, being able to localize coverage even to within specific counties in the United States. Part of the challenge of this method is the goal of localizing the coverage, at least of identifying its physiographic province.

Such information is usually given in the Standard Method. Another goal of this method is to pinpoint judgments which are certain and which depend entirely on the photos at hand. If something can be identified with certainty only on the basis of the photos, then the identification is probably correct. This method also addresses a potential problem with the Standard Method. During the Standard procedure, the photo interpreter may overrely on topographical or other contextual information and may not carefully perceive the photos. What gets identified in the photos will usually be correct, but the photo interpreter may miss things. With novices, contextual information can have a definite biasing effect. If the novice is told that a particular photo covers an area that has a limestone bedrock, then the novice may perceive the associated features even when the area is not limestone, for example.

It seemed reasonable to develop a method in which information access is limited and which would not require a detailed terrain analysis or the production of factor overlays. Information would be limited in two ways:

(1) No background or contextual information would be provided, and

(2) The stereo pairs could be viewed for only one minute. It was anticipated that the information limits would be relatively efficient at making the expert's reasoning explicit.

METHOD

Subjects. Subjects were two expert photo interpreters.

Materials. The materials were five stereo pairs selected so as to be outside the domains that these experts were most familiar with. They were a scene from the Scottish Highlands, a mesa north of Fort Bliss, a region in the western portion of the Black Hills, a region in the western Berkshire Mountains, and a view of the Hudson River Valley near Newburg, New York.

Procedure. The expert photo interpreter and the examiner seated themselves opposite each other at a table equipped with a dual stereoscope that enabled both participants to view the photos in stereo at the same time. One of the stereo pairs was placed in the stereoscope and brought into proper alignment. Once the expert had the photos in focus, he had one minute in which to view the photos. The expert was given the following instructions:

> "I'll be showing you a stereo pair. We will get it into depth and focus and then you'll have some time in which to examine it. You will not have to say anything or describe anything at that point. Take the time to examine the photo and take in as much information as you can."

After the one-minute inspection period, the expert was given the following instructions:

> "Now I'm going to remove the photos from view. I want you to tell me everything you can about the coverage."

At that point, the examiner removed the photos and started a tape recorder. After the expert was allowed 10 minutes in which to describe the coverage, the photos were reintroduced and the expert and examiner discussed them for another five minutes.

RESULTS AND DISCUSSION

The recordings were transcribed and the transcriptions were coded into propositions. Each statement was identified as either (a) a proposition which expressed a description or defining feature of the coverage or (b) a proposition which expressed or related to an inference. For example, the statement "sharp ridges" was coded as a description whereas the statement "it's summer photography" reflected an inference. The statement "probably 10 to 15 inches of rain per year" reflected an inference whereas the statement "the rocks appear banded and stair-stepped" was coded as a description. The statement "the knobby area had basalt-like slopes" was coded as an inference whereas the statement "the tonal streaks are due to a slope break where there is talus and no vegetation" was coded as a description. Statements could be easily coded as belonging to one of the two types. Three representative transcripts are presented in appendix 2.

Both experts were hesitant to propose hypotheses or to reach conclusions about the coverage. When encouraged to speculate, however, both experts produced evidence about their reasoning. As an inspection of the transcripts reveals, the first few minutes of the sessions usually involved descriptive statements. Following these, the examiner often asked a question or two to probe the expert's reasoning. The remaining minutes of the sessions were usually taken up by inference trains once the expert began to speculate.

The results of the coding analysis are presented in table 1.

Since about 15 minutes of total time was spent studying each stereo pair, the efficiency or productivity of this method could be estimated by dividing the average number of inference-related propositions produced in that total time, resulting in a figure of about 1.9 for expert #1 and 2.9 for expert #2. Thus, this method can be expected to produce about one to three inference-related propositions per task minute.

Table 1. A summary of the results of the Limited Information Task

Propositions in the transcripts that reflected both descriptions and inferences were counted for each stimulus and averaged over Subjects. Transcripts appear in appendix 3 for those trials noted with an asterisk.

	Number of feature and description-related propositions	Number of inference-related propositions
EXPERT #1		
Stimulus #1 -		
Scottish Highlands*	36	16
Stimulus #2 -		
Fort Bliss, Texas*	26	52
Stimulus #3 -		
W. Black Hills	36	40
Stimulus #4 -		
W. Berkshires	41	25
Stimulus #5 -		
Hudson Valley	17	15
Average	31.2	29.6
EXPERT #2		
Stimulus #1 -		
Scottish Highlands*	18	28
Stimulus #2 -		
Hudson Valley	18	61
Average	18	44.5

STUDY #4

THE METHOD OF "TOUGH CASES"

Research on experts' reasoning encounters a special difficulty when it enters its later phases. By this time, much of the experts' basic knowledge and reasoning tools have been described, as in appendix 1. Many of the systematic methods of search, detection, and hypothesis testing have been described, as in study #1. The task that now faces the expert systems engineer is one of disclosing the more subtle and refined aspects of expert reasoning. These are manifested when the expert encounters a "tough case" or a case with unusual, novel, or challenging features. By definition, such cases are rare. Therefore, manifestations of the experts' highly refined reasoning are also rare. As a consequence of this situation, the researcher must adopt special methods of study. The problem from the perspective of the expert systems engineer is one of data flow or data density. Take the example of the Standard Method of terrain analysis. The general features of landforms which relate logically to rock types, soil types, etc. have been described in various keys and texts. Most of the information that appears in an actual analysis is information of this sort. Must the examiner lead the expert through the complete terrain analysis procedure in order to encounter only one or two instances of refined reasoning? If challenging or novel cases occur only rarely, then one may end up doing a lot of work with little return. This is the data density problem. We want to know something about the expert's reasoning that we do not already know.

Special methods are needed to generate novel or challenging cases or to make routine cases more challenging. Tough cases invariably are individual problems within a terrain analysis. For example, a tough case might involve identifying the bedrock in a particularly complex area. Many tough cases

encountered by terrain analysts involve cultural features. These were the focus of the present study.

METHOD

Subjects. The Subjects were one expert photo interpreter and one highly experienced photo interpreter who had a specialty in dealing with radar imagery.

Materials. Materials were radar images covering an area in the Atlantic Coastal Plain province of the United States. Also available were a radar mosaic, stereo aerial photos, topographical maps, and road maps. The focus of this study was three particular tough cases. All three involved cultural features, although in all three cases site and landform information was very important in the experts' analyses. The three cases were a small abandoned airfield, a small racetrack, and a small abandoned airfield that had been converted to other uses.

Procedure. One of the experts encountered the three tough cases while scanning and digitizing the radar mosaic. After checking the visible light coverage and the maps, this expert informed the examiner and the other expert that a tough case had indeed been encountered. The examiner and the two experts then examined the materials at a large table which could accommodate all the photos and maps as well as a stereoscope. While the two experts discussed the materials, the examiner recorded their conversation. The experts were instructed to think outloud about their reasoning and hypotheses and not to worry about the accuracy of their hunches.

Each tough case was examined for either 30 minutes or 60 minutes, and each was examined on a different day.

RESULTS AND DISCUSSION

The results consisted of the transcripts of the discussions and of notes taken by the participants. The first two tough cases served as pilot studies, and a detailed analysis will be presented only of case #3. As in the method for analyzing the results of the Limited Information Task, statements in the transcripts were coded as either description-related propositions or inference-related propositions.

Case #1 -- Small Abandoned Airfield. A small airfield for general aviation had been abandoned. Nearby buildings were in a state of disrepair, as was the tarmac. Since it was in a coastal region, there was more than one landing strip and the strips were oriented at different angles (to allow different approach paths depending on the wind direction). Therefore, a basic airfield pattern was present. However, vegetation had grown up through cracks in the tarmac. These patches of vegetation yielded bright returns on the radar image where there should have been a flat surface. Fallow fields and forests that were adjacent to the landing strips had not been tended and were encroaching upon the field. At the border between the airfield and the fallow fields and the border between the fallow fields and the forests there were sharp discontinuities in the height of the vegetation cover, resulting in very bright "halos" around the airfield in the radar image. The proximity of the vegetation to the airfield masked the basic airfield pattern. Finally, structural deterioration in the buildings (garages and small hangars) also masked the airfield pattern.

Discussion of this image for about 30 minutes eventually resulted in the above description. In the course of solving this problem, a number of alternative hypotheses were proposed and discarded. A major key to solving the problem was comparing the pattern to other nearby airfields. This

comparison revealed a common pattern due to the influence of coastal winds, which confirmed the fact that the target pattern was an airfield. It also revealed that new airfields had been constructed in the region. The hypothesis that it was an abandoned field explained the unusual features, such as the bright returns in what should have been a flat tarmac.

Data obtained from this case were subsequently used in generating demonstrations of the applicability of artificial intelligence methods. These demonstrations are discussed in section 10 (Artificial Intelligence Considerations).

Case #2 -- Small Private Racetrack. A small racetrack was difficult to identify because of problems associated with site, tone, and scale. There were numerous sports tracks and racetracks in the area, all of about the same scale. Most had access roads, grandstands, and parking facilities. The track of interest had no clear access and no adjacent buildings. The tones to the bare soil suggested that it had only recently been constructed, involving moving some earth near an adjacent drainage way. It was tentatively decided that this was a small private horse track, rather than one for small motorized vehicles, because of the lack of dirt paths in the area adjacent to the track.

Decisions about this case were never certain. Discussion of the image lasted about 30 minutes. In the course of the discussion many alternative hypotheses were discussed and tested.

Case #3 -- Small reconverted airfield. A small Naval coastal airfield, constructed at the beginning of World War II, was used at that time as a base for small Navy aircraft and for small dirigibles for coastal observation for submarines. It had a number of circular tethering pads and two large hangars. There were adjacent barracks, fields, fence rows, and controlled access roads. After WWII the base was sold to a company that built and tested

weather balloons. New construction covered areas of the old airfield, and a dock at the shoreline fell into disrepair. One of the hangars was converted into a light manufacturing facility (furniture).

As the discussion between the experts proceeded, it appeared that the radar imagery provided more information about what the area had been in the past and that the visible-light stereo photos provided more information about its present uses. Because of the influence of historical processes and events and because of factors related to scale, tone, and site, this case combined all the challenges of the first two cases, and so an analysis of it is presented in detail.

Part of the transcript from case #3 is presented in appendix 3. The discussion of this site continued on for some days after the initial session, coming to a resolution only after background research on the area was conducted. The full transcript contains 56 statements that reflect descriptions and 109 statements that reflect inferences or hypotheses. Thus, this method yielded about 1.8 inference-related propositions per task minute.

The transcript is laden with series of hypothesis tests. In these, an hypothesis was proposed and if true, it would suggest that certain predictable features should be present and that certain other contraindicative features should be absent. The experts then searched for those features.

DISCUSSION OF THE RESULTS AND COMPARISON OF THE METHODS

This project involved studies of four basic methods for generating evidence about the reasoning of photo interpreters: The Standard Terrain Analysis Method, the Structured Interview, The Limited Information Task, and the Method of Tough Cases. The purpose of this section is to compare the

methods and their results in order to make some statements about which method best fits the goal of efficiently extracting experts' knowledge. These methods and the results they produced can be compared according to many criteria. The following ones were used:

(1) TASK SIMPLICITY

Except for the Standard Method, which is quite complex, all the methods studied here involved very simple instructions and tasks. The Subjects needed no special training and did not need to be aware of the hypotheses the examiner was investigating.

(2) MATERIALS SIMPLICITY

The Standard Method and the Method of Tough Cases rely on stereo aerial photos, stereoscopes, mosaics, and maps. The Structured Interview relied on a prepared key that contained over 1,400 entries and took approximately 60 man-hours to be derived from the published sources. The Limited Information Task relied only on stereo photos and a stereoscope.

(3) TASK BREVITY

It was pointed out in study #1 that the field of expert systems engineering relies exclusively on interview methods and that interviews can take man-months to complete. This should be used as an overall baseline with which to compare the other methods. Ideally, one wants to disclose the expert's reasoning in as brief a time as possible. A Standard Terrain analysis can take at least ten hours. The Structured Interview conducted here took about ten hours, the Limited Information Task took 15 minutes for each stimulus, and the Method of Tough Cases resulted in 30- and 60-minute transcripts.

Use of the highly detailed key in the interview enabled the interview to be conducted in about 10 hours. Adding structure and detail to the interview apparently significantly reduces the time it can take to study experts through the interview method. Relative to the laborious interviews often conducted in studies of expert knowledge, all of the methods studied here involved briefer tasks, including the Standard Terrain Analysis Method.

(4) TASK FLEXIBILITY

Ideally, the task presented to experts should be adaptable to the preferences and styles of individual experts. Instructions may not have to be adapted, but the pacing of the task might. For some experts, information about reasoning can be readily evoked by the simplest of questions. For such experts, use of a tape recorder is absolutely necessary. For other experts, the verbalizations are less discursive and shorthand notes can suffice for recording data.

The Structured Interview Method was used on only one expert, so comparisons of individuals are not possible. Since the experience of reading and criticizing published keys is a common one to photo interpreters, this task should be easily adaptable to different experts' styles. The Limited Information Task evoked in the experts a feeling of hesitation, since no contextual information was provided and since time was limited. Judgments could not be given with certainty. Nevertheless, both experts adapted easily to this task and both produced abundant evidence about their reasoning processes. The Method of Tough Cases is the one for which task flexibility is a key issue. When dealing with the tough cases which usually occur in remote sensing, the expert is usually dealing with one particular form of imagery, say radar or panchromatic infrared photography. Some experts regard it as

important to be able to resolve the problem by considering only the information at hand; others prefer to collect all the available information and then do a systematic analysis. Because use of the Method of Tough Cases depends on the unpredictable discovery of a tough case, special recommendations are in order with regard to this method (to be discussed in section 11, Recommendations for Further Research).

(5) TASK VALIDITY

Ideally, the task presented to the expert should not differ to any great extent from what the expert usually does, in this case the Standard Terrain Analysis. The further a task departs from the usual problem-solving situation, the less it will be an indicator of the usual sequences of mental operations which the expert engages in. However, deliberate violation of selected aspects of the standard procedure can also expose the expert's reasoning.

The Structured Interview as conducted here is not all that different from the process of reading and criticizing a published key or text. The Limited Information Task relaxes the constraint of certainty and the constrairt of access to contextual information, but is otherwise not unlike a terrain analysis. The Method of Tough Cases relies on a common occurrence in photo interpretation labs, the discovery of a tough case. Although the Limited Information Task departs from the Standard Method, the results indicate that it is a valuable method in producing evidence about the expert's reasoning.

(6) DATA RECORDS

The method used for studying expert knowledge should produce records that contain evidence about the expert's reasoning and inferences as well as

evidence about what features in the photos the expert describes. All of the methods studied here produce records about descriptions of features and about what the expert deduces or infers. The Standard Method produces overlays and analyses of landforms and soils, but produces no or few explicit statements about the expert's reasoning sequences (except for the expert's final conclusions). The Structured Interview produced refinements in the detailed key, again representing final conclusions and deductions rather than reasoning sequences. Only those two methods that involved tape recordings of discussions produced evidence about reasoning processes as well as evidence about final deductions and conclusions.

(7) INSTANTIATION OF THE DATA

The method used to study expert knowledge should produce data in a format that is suitable for entry into an associative data base (such as the one in appendix 1). The analysis of the transcripts into propositions which reflect either descriptions or inferences is an example of how verbal protocol data can be instantiated in a computer format. The expert's verbalized sentences, whether long or short, can represent either predications (e.g., "The hills have sharp ridges") or inferences (e.g., "I would expect to see more ponds if the area were glaciated"). While the transcribing of tape recordings is a time-consuming process (taking approximately two minutes for each minute of tape), the propositional recoding is a straightforward task and is not very time-consuming (taking about five minutes per page of transcript). The recoding is not error-free, since a given sentence might contain more than one proposition which could be broken up and counted as more than one item. However, it is known that such propositional recoding processes generally result in intercoder reliabilities of 80 percent or more.

Except for the Structured Interview Method, all the methods studied here involved data that require recoding into a propositional format.

(8) EFFICIENCY

The most important criterion to be applied is that of overall efficiency. The method should evoke lots of inferences and lots of inferences that represent information that is not already known to the examiner or to the data base. In other words, the method should produce new knowledge and not just knowledge. For example, the Standard Terrain Analysis produces much data, such as a detailed gully overlay, and it takes much time collecting such data. However, the analysis may produce one or two new insights into the photo interpreter's reasoning.

The efficiency of a method can be assessed by comparing the total number of propositions produced to the total number of propositions that represent new knowledge. Such an assessment can be computed for the results from the Structured Interview. About 30 percent of the entries were modified or deleted and the pool of items was increased by about 15 percent. This is felt to be a reasonable return on the investment of time, since a standard interview can involve days or even months of effort.

Efficiency can also be measured by determining the rate at which inferences were produced. This can be calculated for the methods studied here. The Structured Interview yielded about 1.2 inference-related propositions per task minute, the Limited Information Task produced between two and three inference-related propositions per task minute, and the Method of Tough Cases yielded about 1.8 inference-related propositions per task minute. All of these figures would certainly be larger than that produced by the Standard Terrain Analysis Method, in which much time is taken in analyzing

maps and in preparing overlays and relatively little time is spent making records of the expert's reasoning processes.

In most studies of expert knowledge, it has been found that the Interview Method yields about one or two sentences or propositions per task minute. Therefore, all of the methods studied here, with the exception of the Standard Method, are relatively efficient at producing evidence about expert reasoning.

SUMMARY

The Structured Interview, Limited Information Task, and Method of Tough Cases are all approximately equal in terms of task simplicity, with the Limited Information Task being simplest in terms of materials. None of the tasks departs to a great extent from the sorts of tasks that expert photo interpreters usually engage in, with the possible exception of the Limited Information Task, which deliberately relaxes the constraints on the Standard Method in order to evoke evidence about reasoning. While the Structured Interview was the most time-consuming task, it yielded a great deal of specific data of a form suitable for entry into a data base. While the Limited Information Task was not time-consuming, recoding of the data did take some time. Once coded, the data revealed considerable evidence about reasoning processes. The Method of Tough Cases can be time-consuming, just as a Standard Terrain Analysis can be. However, it produces more evidence about reasoning processes. More evidence about reasoning was collected from those methods that involved tape recording of the expert's verbalizations.

ARTIFICIAL INTELLIGENCE CONSIDERATIONS

Having conducted these preliminary studies of expert photo interpreters, we are now in a position to consider the following three questions:

(1) What are artificial intelligence expert systems like?

(2) Is the domain of aerial photo interpretation one to which the expert systems tools apply?

(3) Given the research conducted here, what statements can be made about what an expert system for aerial photo interpretation would be like?

I consider these three questions in order.

WHAT ARE EXPERT SYSTEMS LIKE?

As expert system is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field. The knowledge of an expert system consists of facts and heuristics. The facts constitute a body of information that is widely shared, publicly available, and generally agreed upon by the experts. The heuristics are mostly private, little-discussed rules of good judgment (rules of plausible reasoning, rules of good guessing) that characterize expert-level decision making in the field. The performance level of an expert system is primarily a function of the size and quality of the knowledge base that it possesses (Feigenbaum, 1982).

Research on expert systems has not produced models of basic psychological processes such as decision making or perception. However, it has yielded models for detailed analysis of knowledge. This was impossible in past psychologies. About 25 expert systems exist now for tasks in medicine, chemistry, geology, and electronics. An expert system is basically a plan for making symbolic inferences. Any expert system will have a number of components, including:

(1) A general knowledge data base or taxonomy of types and patterns. Even for simple domains (e.g., chess playing), 50,000 or more patterns, concepts, and relations will have to be explicitly represented. This is roughly equivalent to the vocabulary of a young adult. The largest expert system, one for medical diagnosis of over 500 diseases, requires more than 100,000 entries in the data base.

(2) An inference engine or rule interpreter which operates on the entries in the data base in order to produce descriptions of the input.

(3) A working memory in which the system keeps track of its analysis of the input information.

Separation of these components enables one to refine the inference rules and to add onto the data base without altering the basic structure of the system.

While specific data base and inference engine systems differ in structural detail, the commonality of all expert systems is the explicit representation of detailed knowledge in the form of "if-then" rules. If certain antecedent conditions obtain, then certain actions are possible. Two examples from actual expert systems are

THE MYCIN SYSTEM (Medical Diagnosis)

IF: (1) the site of the culture is blood and

(2) the identity of the organism is not known with certainty and

(3) the stain of the organism is gram-negative and

(4) the morphology of the organism is rod and

(5) the patient has been seriously burned,

THEN: There is weak but suggestive evidence that the identity of the organism is pseudomonas.

THE PROSPECTOR SYSTEM (For Mineral Exploration)

IF: There is hornblende pervasively altered to biotite,

THEN: There is strong evidence for potassic zone alteration.

In the actual computer entries, the rules are stated as n-tuples of the form:

IF $\langle a_1 \rangle$ $\langle a_2 \rangle$ . . . . . $\langle a_n \rangle$

THEN $\langle c_1 \rangle$ $\langle c_2 \rangle$ . . . . . $\langle c_n \rangle$

where the symbols for antecedents and consequents would each represent propositions, as in the above examples. The antecedents are patterns to be matched against the data base; the consequents are conclusions that can be reached. The consequents can cause the system: (1) to alter the contents of working memory, (2) to generate further questions for the user, (3) to enable other rules, or (4) to disable other rules.

A basic operation which the inference engine must perform is to search the rules and the data base. There are two general search methods used in the rule interpretation process. One is the data-driven or forward-chaining method, the other is the goal-driven or backward-chaining method. In data-driven searches, the rules are scanned until a match is found between the input data and the rule antecedents. The rule is then applied and these two steps are repeated until a goal is reached. In goal-driven searches, principles and hypotheses guide the search for details. The rules are scanned until one is found whose consequent actions achieve the desired goal. Each such rule is tried until one is found that matches the input in terms of antecedents. Goal-driven reasoning operates by pruning solutions which cannot apply. Exhaustive searches are avoided since each alternative need not be evaluated completely. Many expert systems combine goal-driven and data-driven search processes. Refined systems also use negative inferences and inferences with degrees of certainty.

DO EXPERT SYSTEMS TOOLS APPLY TO THE DOMAIN OF AERIAL PHOTO INTERPRETATION?

Photo interpretation is a diagnosis problem. Patterns are perceived, identified, classified, and interpreted for their significance on the basis of possibly uncertain information. Attempts have been made to get machines (computers) to perform such acts as perception and identification. Such systems are limited in terms of the information they can accept and analyze (e.g., limited to spectral data) and they cannot take full advantage of the image characteristics. The human interpreter can observe and analyze all forms and patterns with little effort, while this is a major undertaking for machines. Attempts to get machines to recognize various photo pattern

elements (such as landforms or cultural features) have not met with much success, in part because the patterns which experts perceive are not invariant or logically independent of one another. Artificial intelligence techniques involve the attempt to substitute knowledge and judgment for multivariate statistical recognition functions. In other words, the emphasis shifts from the problem of perceptual identification to the problem of reasoning.

Artificial intelligence techniques have already been applied to various aspects of the aerial photo interpretation process and photogrammetry. For example, in digital image analysis systems, digitized imagery can be analyzed by means of superimposed polygons that describe various factors such as relief and drainage gullies. The system assists the user in a classification of patterns by allowing the user to edit the display by specifying the position and shapes of features. Another example is the CALAP (Computer Assisted Landform Analysis) program developed by Leighty (1983). This program specializes in the Atlantic Coastal Plain physiographic province. Users who have imagery covering areas in that province can access CALAP, which presents the user with a series of questions about the coverage, including landforms, drainage systems, and the like. The user answers each question in turn, and the final result is a terrain analysis not unlike those produced by the Standard Terrain Analysis Method.

There are certain minimal criteria which must obtain in order for expert systems concepts to apply:

(1) There must be at least one available human expert who is acknowledged to perform the task well.

(2) The primary source of the expert's performance must be special knowledge,

perceptual skills, and experience.

(3) The expert must be able to explain his knowledge and experience and the methods that are used to apply them to particular problems.

(4) Comprehension of the basic problem-solving task should not require much more than common sense.

(5) The task should take the expert a few minutes to a few hours to complete.

All of these criteria certainly obtain for the domain of aerial photo interpretation.

The labor-intensive task of photo interpretation could definitely benefit from the use of an interactive expert system. Less skilled individuals could be guided through a sequence of reasoning like that which experts would follow. As an example, consider the problem discussed in the Method of Tough Cases, that of recognizing small abandoned airfields in which the basic airfield pattern may be partially masked.

An artificial intelligence system could incorporate the reasoning shown by the experts:

(1) The basic landing strip shape would appear as a linear segment wider than adjacent roads.

(2) In a coastal region, there would be more than one landing strip, and the strips would be oriented in different directions.

(3) There would be adjacent forms - dirt roads, access roads, fallow fields, small buildings, small hangers, parked planes.

If the field has been abandoned, the above basic airfield features would be modified:

(1) The tree and grass cover would encroach upon the landing strips.

(2) No parked planes would be visible.

(3) The tarmac would be cracked and partitioned by vegetation.

(4) Access roads would be overgrown.

(5) Adjacent buildings should show signs of deterioration.

(6) There would be other airfields in use in the adjacent area.

In the course of conducting these investigations, I have encountered numerous principles of the psychology of expert knowledge and of expert systems engineering and can say without hesitation or qualification that the known psychological principles of expert knowledge and perception apply to the domain of aerial photo interpretation. In fact, the domain represents a "textbook case" for the application of expert systems tools.

WHAT WOULD AN EXPERT SYSTEM FOR AERIAL PHOTO INTERPRETATION BE LIKE?

An expert system for aerial photo interpretation would have the following characteristics:

(1) It must be interactive. Users must be able to query the system about the reasons for a particular decision.

(2) The system must be usable in various tasks or interactive modes:

USER AS CLIENT. The system must aid experts in conducting standard terrain analyses.

USER AS TUTOR. The system must be expandable. The system editor should allow the user to enter new data entries and new rules and to modify old entries without altering the basic structure of the system.

USER AS STUDENT. The system must aid novices in learning the process of aerial photo interpretation. The system should be able to diagnose students' errors to allow the student to improve with experience. The nonexpert can be led through the reasoning sequence by a series of if-then questions which would lead to conclusions about the coverage akin to those an expert would reach. The system would direct the user's attention to certain pattern elements by posing such questions as "Are the hills of uniform slope?" or "Are the gully walls steep?" which would be answered by the user following an examination of the photos.

(3) The system must be user-friendly and able to conduct dialogues in natural language. For example, the computer system called ROSIE, which was designed to assist in the production of large data bases, accepts statements which involve class membership (e.g., "The rock is granite"), predication (e.g., "The rock is tilted"), intransitive verbs (e.g., "The rock erodes"), transitive verbs (e.g., "The rock forms gullies"), and predicate compliments

(e.g., "The rock is partially exfoliated"). It accepts past, present, and future tenses and existential quantifiers (some, a, an, any, all, the).

(4) The system must be able to retrieve information based on symbolic names and descriptions.

(5) The symbolic names and descriptions in the data base should have a natural hierarchical organization in a form not far removed from the language that experts ordinarily use. The scheme for coding types of landforms, vegetation, soils, etc., should have certain characteristics:

(a) Use of distinct attributes, as few as possible, for defining groups or categories.

(b) The terms and categories should convey meaningful descriptive information about the character of the objects or landforms. Symbolic codes that have meaning only to experts should be avoided.

(c) The terminology should be clear, simple, and easily remembered so that different users, even relatively unskilled ones, can obtain the same results.

(d) The terminology should be based on data that can be acquired from photo imagery and other cartographic representations.

(e) The terms should permit worldwide comparisons.

(f) The terms should relate to common mapping units or categories and should provide for easy cartographic representation.

(g) The organization scheme should be flexible and capable of being augmented or altered.

(h) The terminology should convey information pertinent to the Army.

(6) The system should permit on-line display of the contents of the working memory.

(7) The system should accept contextual information from various imagery sources (e.g., radar, color infrared photos) and from various cartographic sources. Presumably, the system would begin a given analysis by querying the user about the nature of the available contextual information, such as climate, time of year, and available maps.

(8) The representation of contextual information should permit detail even to the level of individual physiographic provinces and regions. In theory, each physiographic region could be represented in the data base and used to assist in the terrain analysis procedure. If for a given image the analyst does not know the physiograhic region that is covered, the system could access the physiographic regions files to generate candidate locations for the imagery. If the physiographic region is known, that information could be accepted as part of the context.

In order to demonstrate the feasibility of including the earth's physiographic regions in a data base for photo interpretation, a prototype file was created which focused on the continental United States. This file appears in appendix 4. In it, each physiograhic province and section is given a symbolic description which approximates its geographic location and a description of its major landform and soils features. The detail in this file can be expanded considerably and it can be included in the eventual expert system data base.

(9) The system must be able to integrate map data and image data using either semantic or cartographic decriptions. For example, a bridge can be defined as a landmark, a long rectangular polygon, a linear segment, or a set of geodetic points.

(10) The system must rely on existing photogrammetric tools for data acquisition, such as the Standard Terrain Analysis Method.

(11) The system should include the capability of on-line display of digitized images which exemplify each listed landform category.

(12) The system must deal with spatial information and be able to accept coordinates, topographical data, geometrical patterns, and relations (such as "contains" and "is adjacent to").

(13) There must be a mechanism for resolving ambiguities and for knowing when enough information has been obtained for a decision to be made.

(14) Search processes should be efficient and systematic. The system should discard candidate hypotheses only when the evidence rules them out and it should avoid discarding good solutions that are based on weak evidence. There should be a consistent and well-defined structure to the subproblems.

(15) The system must be able to deal with inconsistent, incomplete, or uncertain information. The approach commonly taken in artificial intelligence systems is to associate with each rule a probability value that reflects the generality of the rule or the degree of belief in the evidence. The

abilities come from the judgments of experts and enter into the deduction process by limiting the range or likelihood of inferences. A problem with this approach is that probability-based inferences are difficult to explain to system users, as opposed to inferences that are based on reasons or assumptions. Anotner problem with this approach is that experts do not reason using probabilities and they do not like to commit themselves to specific subjective probability values. When experts encounter an uncertain or problematic case, as the study of the Method of Tough Cases revealed, they usually reason in terms of specific (albeit atypical) instances which they have encountered and which conflict with the general rule. Even probability-based systems are refined by the study of specific cases. Specific instances can, of course, be included in the system as another way of dealing with uncertainty. Any system user could access a program whereby new entries or rules could be added as qualifications to other (general) rules (e.g., if X, then Y, unless Z, then Q). An advantage of such a solution would be that the history of data base changes would be explicit in the data base itself. This argument is similar to one made by Doyle (1983).

(16) The system must yield consistent, complete, and correct analysis.

The overall architecture of an expert system for photo interpretation might look like that represented in figure 1. A demonstration was prepared of what it might be like to interact with such a system. The demonstration was modeled after Leighty's (1983) CALAP program and is presented in table 2.

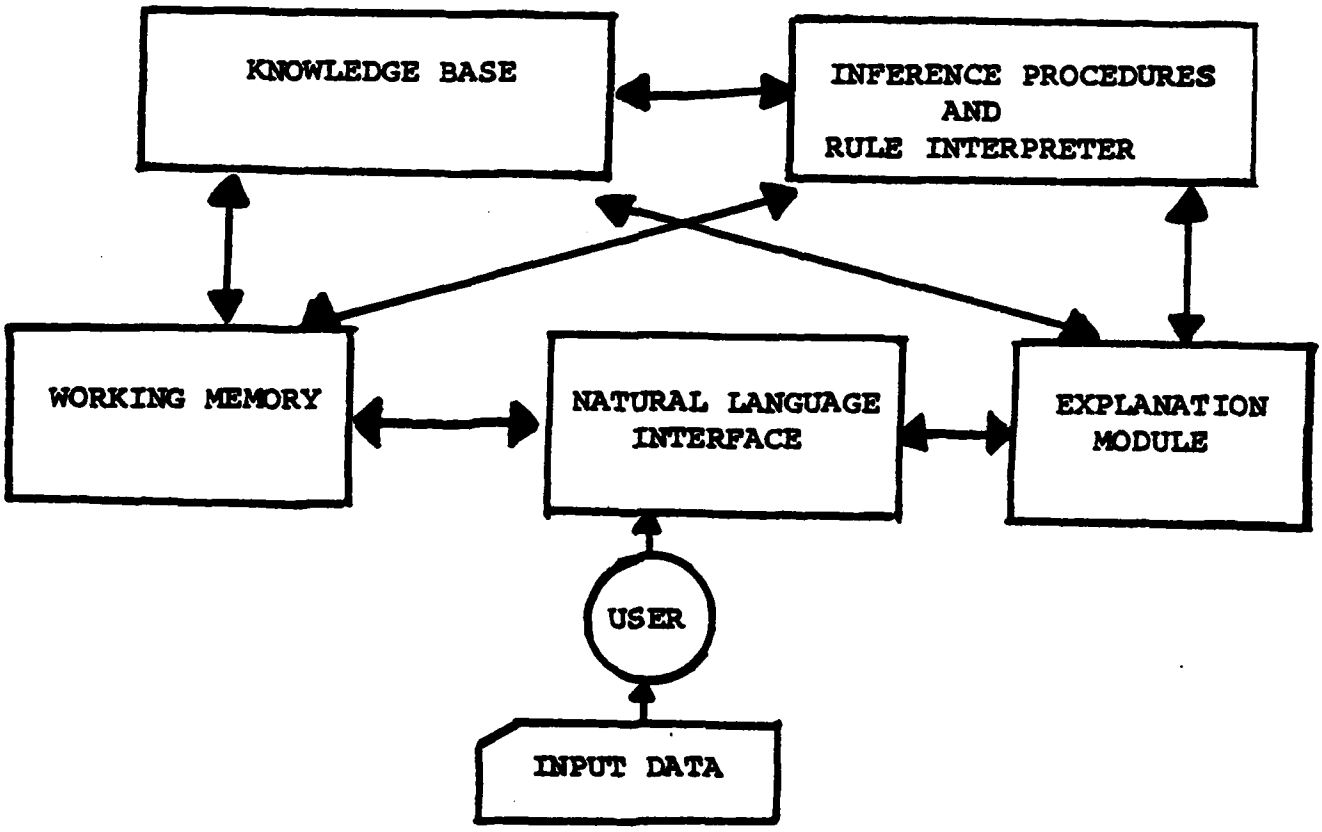

Figure 1. Overall architecture for an expert system for aerial photo interpretation.

A demonstration of what it might be like to interact with an expert system for aerial photo interpretation. The system poses questions to the user who must seek answers in the photos. The system builds up an internal model of the area and checks the model against rules in its data base in order to reach conclusions.

System On

Q: Do you know the physiographic region?

A: No.

Q: Do you know the location?

A: Yes. Pennsylvania.

SYSTEM STATUS: Coverage may involve any physiographic region in Pennsylvania. Humid climate.

Q: Do you have a topographic map available?

A: No.

INPUT: rugged topography

dendritic drainage pattern

long parallel ridges and valleys

SYSTEM STATUS: Forward chaining. If (rugged topography) and (dendritic drainage) and (long parallel ridges and valleys), then (tilted interbedded sedimentary rock).

Hypothesis: Tilted interbedded sedimentary rock.

Backward chaining:

Hypothesis: If (sandstone) then (rounded ridges).

Hypothesis: If (limestone) then (sinkholes).

Q: Are the hills rounded or sawtooth?

A: Rounded.

Q: Are there sinkholes?

A: No. Explain last two questions.

SYSTEM ANSWER: Tilted sandstone implies sawtooth ridges, but in an arid climate. We know this is a humid climate. Rounded ridges occur for sandstone in humid climates, but the same holds for limestone. The lack of sinkholes rules out limestone.

SYSTEM STATUS: Hypothesis: If (sandstone) and (blocky hills) then (beds are thick).

Q: Are there blocky hills?

A: Yes.

SYSTEM STATUS: Hypothesis: If (sandstone) and (thick beds) and (tilted beds), then (narrow valleys) and (slope asymmetry) and V-shaped gullies).

Q: Are there narrow valleys?

A: Yes.

Q: Are there V-shaped gullies?

A: Yes.

Q: Is there slope asymmetry?

A: Yes.

SYSTEM STATUS: Hypothesis confirmed. Coverage would be in the Kanawah region or the Allegheny Mountain region of the Appalachian Valley Province.

OUTPUT FINAL HYPOTHESIS.

RECOMMENDATIONS FOR FURTHER STUDY

In past research on expert systems, attempts to speed the knowledge-acquisition process have focused exclusively on the development of smart editors on working systems. The data for starting up a system comes exclusively from extensive interviews. The present report has focused on the development of tasks that involve perception and judgment and induce experts to expose the details of their skills and knowledge. The present data suggest a number of conclusions about further research and research methods.

With regard to the Structured Interview Method, it is recommended that the method be employed with two more experts from one of the Engineer Topographic Laboratories (ETL) and two more experts from outside of that laboratory (such as at NASA-Goddard or a university), in each case leading to refinements in the data base. The method should be altered to include the use of a tape recorder to record evidence about the expert's reasoning which does not appear in the written comments on the data base. Also, the examiner should frequently probe the expert with the question "How do you know that?" whenever the expert seems to have drawn an inference or tapped into knowledge. This method can also be adapted to other forms of data bases, such as the physiographic regions file that appears in appendix 4. The list can also be transformed into a set of questions (e.g., "Are sinkholes a feature of limestone topographies?) and foil questions (e.g., "Are sharp ridges a feature of glacial landforms?) which can be presented to experts.

With regard to the Limited Information Task, it is recommended that this task be used to explore selected aspects of photo interpreter logic. For example, if one sought information about expert logic with regard to basalt landforms in a humid climate, photos covering such landforms could be collected and studied using this method. Use of this method would allow one

to avoid having to deal with information or reasoning that is tangential to the desired information, and the task produces abundant evidence about reasoning, including the discussion period when the photos are reintroduced. It is recommended that the method be altered slightly -- the expert should be allowed to examine the photos for one minute prior to putting them under the stereoscope for the one-minute stereo inspection period.

The Method of Tough Cases raises both interesting possibilities and difficult problems. Tough cases occur only when an expert encounters one. Yet, when they do occur they afford a special opportunity to study expert reasoning. Expertise is rare. So, too, are situations where the expert is faced with a challenging or novel case. Neither expertise nor manifestations of refined reasoning should be wasted. Wherever possible, recordings of some form should be made of events in which experts manifest refined reasoning. It is recommended that all experts and expert teams be provided a small portable tape recorder and that they be asked to record all instances of discussions that involve tough cases. The instructions for the experts are presented in appendix 5.

Of critical importance in the development of the inference and explanation components will be a formalization of the principles of geobiological dynamics. Ultimately, every aspect of terrain is explained in terms of historical geological and climatological events. It will be important in this regard to use the Limited Information Task to reveal the reasoning used for specific landforms and to analyze texts on physiography and geology.

In studies of expert knowledge, the first body of knowledge usually extracted from experts is terms, facts, standard procedures, etc., such as one might find in texts. The present report represents such a first step. In the cycle of constructing an expert system, the information must be instantiated

n a system, which must then be tested against further data. A complex expert system is likely to take as long as 10 man-years to complete. With this in mind, the development of an expert system for aerial photo interpretation would take phases such as those described in table 3.

It is concluded that the domain of aerial photo interpretation meets all of the criteria for the application of expert systems techniques. It is concluded that there are enough different methods available to extract expert knowledge in this domain. It should be possible to have a prototype expert system instantiated following three man-years of effort.

Table 3. Developmental phases for an expert system for aerial photo interpretation

PHASE	TIMETABLE
(1) Initial feasibility study, development of methods for examining expert logic, initial development of data base.	Previous work at ETL and this report
(2) Refinement of data base and of methods for examining expert logic.	3 man-months; will require additional experts
(3) Initial formulation of geodynamical principles (from texts and data collected in phases 1 and 2) for the inference component.	3 man-months
(4) Refinement of inference component using methods for examining expert logic.	3 man-months; will require an expert
(5) Programming for the working memory, interface, and explanation components.	6 to 8 man-months; will require the efforts of an expert in A.I.

(6)	Integration of data base, memory, explanation, interface, and inference components.	6 to 8 man-months; will require the efforts of an expert in A.I.
(7)	Testing and refinement of instantiated system.	6 to 8 man-months; same comment as above
(8)	Evaluation of performance in a prototype environment.	Same as above
(9)	Development of maintenance plans.	4 to 6 man-months

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APPENDIXES

Appendix 1 — The Data Base Derived by the Structured Interview.

Appendix 2 — Transcripts from the Limited Information Task.

Appendix 3 — A Transcript from the Method of Tough Cases.

Appendix 4 — A Prototype Data Base for Physiographic Regions.

Appendix 5 — Instructions for Recording Analyses of Tough Cases.

APPENDIX 1

THE DATA BASE DERIVED BY THE STRUCTURED INTERVIEW

Version: August, 1983
Earth 1.2

Robert R. Hoffman
Artificial Intelligence Center
Engineer Topographic Laboratory

EARTH-1

****
****

WELCOME TO THE PLANET EARTH. THIS FILE IS CALLED EARTH 1.
IT IS A FIRST-PASS AT A SEMI-INTELLIGENT RELATIONAL DATA
BASE FOR AN EXPERT KNOWLEDGE SYSTEM WHICH IS BEING DESIGNED
TO ASSIST PEOPLE IN THE PROCESS OF AERIAL PHOTO INTERPRETATION.

THIS FILE CONSISTS OF TWO PARTS:
(1) SHORT FORM - AN OUTLINE OF THE DATA BASE

(2) LONG FORM - THE DETAILED DATA BASE ITSELF

ORGANIZATIONAL HEADINGS ARE OF TWO GENERAL TYPES:
(1) CONTEXTUAL INFORMATION, SUCH AS TIME-OF-YEAR, CLIMATE, MAJOR PHYSIOGRAPHIC REGIONS, AND AVAILABLE TOPOGRAPHICAL INFORMATION

(2) LANDFORM INFORMATION, SUCH AS GLACIAL FORMS, FLUVIAL FORMS, ETC.

ENTRIES IN THE DATA BASE ARE OF TWO GENERAL TYPES:
(1) DEFINING FEATURES (e.g., WHAT IS A "HILL?")

(2) ASSOCIATED IMPLICATIONS (e.g., A MASSIVE DOME-LIKE SHAPE TO A HILL IMPLIES THAT IT MIGHT BE GRANITE)

NOTE: MANY OF THE SUB-FILES INCLUDED HERE ARE NOT COMPLETE

NOTE: SOIL TYPES AS IMPLIED BY LANDFORMS ARE NOT YET INDICATED

********** DATA BASE OUTLINE **********
****
****

Context 1 Climate
- c1.1 Tropical
- c1.2 Arctic
- c1.3 Arid
- c1.4 Humid

Context 2 Time of year
- c2.1 Spring
- c2.2 Summer
- c2.3 Autumn
- c2.4 Winter

Context 3 Physiographic regions (NOTE: This sub-file has yet to be produced)

Context 4 Topographical information (Note: This sub-file has yet to be produced)
- c4.1 topographical maps
- c4.2 road maps
- c4.3 geological maps
- c4.5 soils maps

Context 5 Available spectral information (NOTE: This sub-file has yet to be produced)
- c5.1 Radar
- c5.2 Infra-red

Rock Forms 1 Hills, mountains
Rock Forms 2 Displacements
- rf2.1 Faults
- rf2.2 Lineaments
- rf2.3 Troughs
- rf2.4 Joints
- rf2.5 Escarpments
- rf2.6 Gorges
- rf2.7 Folds

Rock Forms 3 Domes
Rock Forms 4 Canyons
Rock Forms 5 Basins
Rock Forms 6 Plateaus
Rock Forms 7 Terraces
Rock Forms 8 Steppes
Rock Forms 9 Mass wasting
- rf9.1 Landslides
- rf9.2 Soil slump
- rf9.3 Soil/rock creep
- rf9.4 Avalanches
- rf9.5 Talus
- rf9.6 Soil erosion

Rock Forms 10 Plains
Rock Forms 11 Pinnacles
Rock Forms 12 Ridges
- rf12.1 Hogback ridges
- rf13.2 Saddles

Rock Forms 13 Ridges
Rock Forms 14 Bluffs
Rock Forms 15 Sinkholes

Rock Type 1 Flat sedimentary rocks
- rt1.1 Shale
  - rt1.1.1 humid climate
  - rt1.1.2 arid climate
- rt1.2 Limestone
  - rt1.2.1 humid climate
  - rt1.2.2 arid climate
  - rt1.2.3 tropical climate
- rt1.3 Sandstone
  - rt1.3.1 humid climate
  - rt1.3.2 arid climate
- rt1.4 Sandy shale
  - rt1.4.1 humid climate
  - rt1.4.2 arid climate

Rock Type 2 Flat interbedded sedimentary rocks
- rt2.1 Shale/limestone
  - rt2.1.1 humid climate
  - rt2.1.2 arid climate
- rt2.2 Sandstone/shale
  - rt2.2.1 Thick beds, humid climate
  - rt2.2.2 Thick beds, arid climate

rt2.2.3 Thin beds, humid climate
rt2.2.4 Thin beds, arid climate
Rock Type 3 Tilted interbedded sedimentary rocks
rt3.1 Tilted interbedded sandstone/shale
rt3.1.1 humid climate
rt3.1.2 arid climate
rt3.2 Tilted interbedded limestone/shale
rt3.2.1 humid climate
rt3.2.2 arid climate
rt3.3 Tilted interbedded sandstone/limestone/shale
rt3.3.1 humid climate
rt3.3.2 arid climate
rt3.4 Tilted interbedded sedimentary rock - Shale predominates
rt3.4.1 humid climate
rt3.4.2 arid climate
rt3.5 Tilted interbedded sedimentary rock - Limestone predominates
rt3.5.1 humid climate
rt3.5.2 arid climate
rt3.6 Tilted interbedded sedimentary rock - Sandstone predominates
rt3.6.1 humid climate
rt3 6.2 arid climate
Rock Type 4 Igneous Rocks
rt4.1 Serpentine
rt4.2 Quartzite
rt4.3 Granite
rt4.3.1 Dome granite
rt4.3.1.1 humid climate
rt4.3.1.2 arid climate
rt4.3.2 Rugged granite
rt4.3.2.1 humid climate
rt4.3.2.2 arid climate
rt4.3.3 Rose-shaped granite
rt4.3.3.1 humid climate
rt4.3.3.2 arid climate
rt4.4 Basalt (includes lava flows)
rt4.4.1 humid climate
rt4.4.2 arid climate
rt4.4.3 young
rt4.4.4 Old
rt4.5 Volcano
rt4.5.1 humid climate
rt4.5.2 Old
rt4.5.3 cinder cone
rt4.6 Volcanic tuff
rt4.6.1 humid climate
rt4.6.2 arid climate
Rock Type 5 Metamorphic rock
rt5.1 Gneiss
rt5.2 Slate
rt5.2.1 humid climate
rt5.2.2 arid climate
rt5.3 Schist
rt5.3.1 humid climate
rt5.3.2 arid climate
rt5.4 Marble

Soil Type 1 General dynamical principles
st1.1 tone
st1.1.1 desert varnish tone
Soil Type 2 Silt
Soil Type 3 Peat, muck
Soil Type 4 Sand
Soil Type 5 Gravel

st5.1 arid climate
Soil Type 6 Lean clay
Soil Type 7 Silty clay
Soil Type 8 Heavy clay
Soil Type 9 Silt/clay/sand
Soil Type 10 Loam

Landforms 1 Glacial forms
- lf1.1 Alpine glacier
- lf1.2 Glacial lakebed
- lf1.3 Outwash plain
  - lf1.3.1 humid climate
  - lf1.3.2 arid climate
- lf1.4 Till plain
  - lf1.4.1 humid climate
  - lf1.4.2 young, thin
  - lf1.4.3 young, thick
  - lf1.4.4 old, thin
  - lf1.4.5 old, thick
- lf1.5 Kame
  - lf1.5.1 humid climate
  - lf1.5.2 arid climate
- lf1.6 Eskers
  - lf1.6.1 humid climate
  - lf1.6.2 arid climate
- lf1.7 Drumlins
  - lf1.7.1 humid climate
  - lf1.7.2 arid climate
- lf1.8 Terminal (end) moraine
  - lf1.8.1 humid climate
  - lf1.8.2 fine soils
  - lf1.8.3 coarse soils

Landforms 2 Fluvial landforms
- lf2.1 Estuaries
- lf2.2 Bays
- lf2.3 Reservoirs
- lf2.4 Lake
- lf2.5 Canals (see Cultural Forms section)
- lf2.6 Depressions
  - lf2.6.1 Ponds
  - lf2.6.2 Bog, marsh
- lf2.7 Levees
- lf2.8 Swamps
- lf2.9 Continental plains
- lf2.10 Floodplains
- lf2.11 Deltas
  - lf2.11.1 Arcuate delta
  - lf2.11.2 Estuarine delta
  - lf2.11.3 Birdsfoot delta
- lf2.12 Coastal plain
  - lf2.12.1 Young
  - lf2.12.2 Old
- lf2.13 Valley fills
  - lf2.13.1 humid climate
  - lf2.13.2 arid climate
- lf2.14 Alluvial fans
- lf2.15 Mud flats
- lf2.16 Stream system
  - lf2.16.1 Young
  - lf2.16.2 Mature
  - lf2.16.3 Old
  - lf2.16.4 humid climate
  - lf2.16.5 arid climate

lf2.16.6 tropical climate
lf2.17 Playas
lf2.18 Terraces
lf2.19 Beach ridges
lf2.19.1 humid climate
lf2.20 Tidal flats
lf2.20.1 Marsh
lf2.20.2 Mud
lf2.20.3 Sand
lf2.21 Carolina bays

Landforms 3 Aeolian Landforms
lf3.1 Deserts
lf3.2 Dunes
lf3.2.1 Beach dunes
lf3.2.1.1 humid climate
lf3.2.2 U-dunes (Wind-drift dunes)
lf3.2.2.1 humid climate
lf3.2.3 Star dunes
lf3.2.3.1 humid climate
lf3.2.4 Longitudinal dunes
lf3.2.4.1 humid climate
lf3.2.5 Transverse dunes
lf3.2.5.1 humid climate
lf3.2.5.2 arid climate
lf3.2.6 Barchan dunes
lf3.2.6.1 humid climate
lf3.3 Loess plain
lf3.3.1 Young
lf3.3.2 Old
lf3.3.3 humid climate

Landforms 4 Tundra landforms
lf4.1 Perennial snow fields
lf4.2 Permafrost region
lf4.3 Bare ground tundra

Drainage Patterns 1 General dynamical principles
dp1.1 Fine textur
dp1.2 Medium texture
dp1.3 Coarse texture

Drainage patterns 2 Drainage pattern types
dp2.1 Annular drainage
dp2.2 Dendritic drainag
dp2.3 Rectangular drainage (angulate drainage)
dp2.4 Discontinuous drainage (karst)
dp2.5 Thermokarst drainage
dp2.6 Elongated bay drainage
dp2.7 Yazoo drainage
dp2.8 Anastomotic drainage
dp2.9 Internal drainage
dp2.10 Braided drainage
dp2.11 Deranged drainag
dp2.12 Parallel drainage
dp2.13 Pinnate drainage
dp2.14 Radial drainage
dp2.14.1 centrifugal pattern
dp2.14.2 centripetal pattern
dp2.15 Trellis drainage
dp2.16 Dichotomic drainage
dp2.17 Infiltration basin

Drainage patterns 3 Drainage gully shapes
dp3.1 Box gullies
dp3.2 U-gullies

dp3.3 Saucer gullies
dp3.4 V-gullies
dp3.5 Trapezoid gullies

Vegetation Type 1 Forest
vt1.1 Conifers
vt1.2 Deciduous
vt1.2.1 spring, summer
vt1.2.2 autumn, winter
vt1.3 Mixed forest
Vegetation Type 2 Tundra
vt2.1 Herbaceous tundra
vt2.2 Shrub and brush tundra
vt2.3 Wet tundra
vt2.4 Mixed tundra
Vegetation type 3 Rangeland
vt3.1 Grassland
vt3.2 Shrub/brush rangelend
vt3.3 Herbaceous rangelend
vt3.4 Mixed rangeland
Vegetation Type 4 Agriculture
vt4.1 Row crops
vt4.1.1 field tiles
vt4.1.2 irrigation ditches
vt4.1.3 autumn, winter
vt4.1.4 spring, summer
vt4.3 Vineyards
vt4.4 Orchards
vt4.5 Fallow fields
vt4.6 Pastures
vt4.7 Tree nurseries
vt4.8 Livestock
Vegetation Type 5 Crop diseases

Cultural Forms 1 Land engineering
cf1.1 Landfill
cf1.2 Quarries
cf1.3 Strip mines
cf1.4 Tailings
Cultural Forms 2 Water engineering
cf2.1 Reservoirs
cf2.2 Dams
Cultural Forms 2 Recreation
cf2.1 Marinas
cf2.2 Parks
Cultural Forms 3 Transportation
cf3.1 Two-lane roads
cf3.2 Expressways
cf3.3 Dirt roads
cf3.4 Bridges
cf3.5 Railroads
cf3.6 Airport
cf3.7 Canals
cf3.8 Locks
Cultural Forms 4 Utilities
cf4.1 Sewage treatment facilities
cf4.1.1 sewage infiltration basins
Cultural Forms 5 Communications
cf5.1 Broadcast towers
Cultural Forms 6 Rights-of-way
cf6.1 Power lines
cf6.2 Pipelines
cf6.3 Firebreaks

cf6.4 Hedgerows
Cultural Forms 7 Residential areas
Cultural Forms 8 Heavy industry
Cultural Forms 9 Light industry
Cultural Forms 10 Commercial area/service industries

********** DETAILED DATA BASE **********

CONTEXT

Context 1 Climate

c1.1 Tropical climate
- very rugged topography
- lush vegetation growth
- highly eroded in derforeste areas
- little agriculture in areas of low population density
- deep soils except on slopes

c1.2 Arctic climate
- little free moisture
- sparse vegetation
- rock talus by cliffs, especially on south-facing slopes

c1.3 Arid climate
- rugged topography
- thin soils
- mottled tones
- rapid erosion
- evaporation causes surficial mineral deposits
- mechanical decomposition

c1.4 Humid climate
- subdued topography
- deep soils except on slopes
- lush vegetation
- intense agriculture

Context 2 Time of year

c2.1 Spring
- sharp field pattern
- distinct soil moisture content
- lighter soils at higher elevations
- definite mottled tones

c2.2 Summer
- dark tones imply mature crops
- grey tones to bare soil
- field patterns not sharp

c2.3 Autumn
- distinct field patterns
- light tones to fields
- light tones to trees

c2.4 Winter
- dull tones

no mottling except for snow cover
dark tones to bare soil
low sun angle implies shadows by gullies and long shadows to trees

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Context 3 Physiographic regions

Context 4 Available topographic information
- c4.1 topographic map
- c4.2 road map
- c4.3 geological map
- c4.4 soils map

Context 5 Available spectral information
- c5.1 Radar
- c5.2 Infra-red

ROCK FORMS

Rock Forms 1 Hills, mountains
- relief of less than 300 meters implies hill
- relief of more than 300 meters implies mountain
- implies rock is more durable than surrounding rock
- rounded crests imply less resistant rock
- peaked crests imply more resistant rock
- tone banding implies stratification of soil or rock
- slope differences imply tilted rocks
- symmetrical slopes imply no tilting

Rock Forms 2 Displacements

rf2.1 Faults
- long, wide
- implies displacement of rock
- possible differences in topography and drainage on the two sides
- presence of talus
- possible presence of folds
- offset beds
- offset streams
- linear vegetation patterns in arid regions, possibly perpendicular to drainage gullies
- texture, tone and elevation changes across the boundary

rf2.2 Lineaments
- faults and folds along a line
- can occur in parallel clusters

rf2.3 Troughs
- linear traces extending beyond a depression
- implies faulting

rf2.4 Joints

narrow short cracks

rf2.5 Escarpments
long, steep ridge between landforms
implies resistant rock

rf2.6 Gorges

rf2.7 Folds

Rock Forms 3 Domes
raised rock defined by closed topogrraphy
can be small or very broad
can be circular, linear or ellipsoid in shape
can be compound
can be clustered
structural disturbances at flanks tilted beds, faulted beds, hogbacks, rugged mountains
can have radiating fractures
radial drainage, annular at base
undissectd implies young
can be composed of salt, gypsum, intrusive bedrock (e.g., intrusive granite of other igneous rocks, intrusive metamorphic rocks, etc.)

Rock Forms 4 Canyons

Rock Forms 5 Basins

Rock Forms 6 Plateaus
high elevated plain
associated with excarpments

Rock Forms 7 Terraces

Rock Forms 8 Steppes
implies stratified rock

Rock Forms 9 Mass wasting
rf9.1 Landslides
rf9.2 Soil Slump
rf9.3 Soil/Rock creep
rf9.4 Avalanches
rf9.5 Talus
rf9.6 Soil Erosion

Rock Forms 10 Plains

Rock Forms 11 Pinnacles
sharp peak
broader base

Rock Forms 12 Ridges
rf12.1 Hogback Ridges
rf12.2 Saddles

Rock Forms 13 Bluffs

Rock Forms 14 Sinkholes
imply humid climate
abrupt edges
can occur at intersections of lineations, fractures
vegetation at bottom
rubble at bottom
water at bottom
circular shape implies flat beds
elongate implies tilted beds
deep sinks imply massive beds
roads and fields curve around sink holes
can be clustered
large sinkholes imply massive beds

ROCK TYPES

Rock Type 1 Flat sedimentary rocks

rt1.1 Flat shale
gently rolling, irregular plains
rounded contours
symmetrical finger ridges
branching rounded hills with saddles
usually lowlands
uniform gradients imply homogeneous rock
uniform gradients imply uniform erosion
tonal bands imply bedding
compound slope gradient implies thick bedding
flared at base implies thick bedding
scalloped hill bases
V-, U-gullies
landslides
escarpments, very sharp ridges, steep pinnacles, steep slopes, V-gullies, and a medium to fine drainage net imply sandy shale

rt1.1.1 humid climate implies valleys, rounded hills
humid climate implies dendritic drainage,
humid climate implies fine net, ponds and meanders, especially if bedded
humid climate implies forested,

dense on hill slopes
humid climate implies tonal bands
humid climate implies row crops in rectangular arrays
humid climate implies intense agriculture

rt1.1.2 arid climate implies steep, rounded hills and ridges
arid climate implies intermittent drainage
arid climate implies asymmetrical slopes
arid climate implies steep gullies
arid climate implies shrub land, barren land
arid climate implies light tones or mottled tones

rt1.2 Flat limestone
gently rolling plains, pockmarked
little surface drainage
discontinuous drainage, acute angles to gully intersections
isolated tree clumps
hills, ridges imply massive beds
symmetrical, branching finger ridges
knobby hills
steep slopes
few surface gullies
hill tonal bands, stairsteps, or compound slopes imply bedding
concave hills, flare at base, imply thin bedding
sinkholes, ponds, and depressions
gullies lead into sinkholes

rt1.2.1 humid climate implies valleys
humid climate implies mottled tones
humid climate implies agriculture, irregular field pattern
humid climate implies forested on ridges and hills
humid climate implies sinkholes

rt1.2.2 arid climate implies blocky hills and ridges
arid climate implies flat table rocks
arid climate implies light to medium tones
arid climate implies discontinuous drainage, locally dendritic
arid climate implies barren land

rt1.2.3 tropical climate implies rounded topography
tropical climate implies conical, steep-sided hills
tropical climate implies large depressions and sinkholes
tropical climate implies internal drainage
tropical climate implies dark tones (vegetation)

tropical climate implies heavy
forestation
tropical climate implies cultivation
on lower hills and plain

rt1.3 Flat sandstone
rolling plains with gentle to strong relief
hills and valleys
symmetrical, branching, peaked, short ridges
blocky, knobby hills imply thick beds
sharp ridges, steep slopes, escarpments
light tones
tonal banding implies bedding
uniform hill slope implies thin bedding
coarse dendritic drainage, especially if bedded
often with parallel joints
V-gullies
angular field patterns
talus deposits, landslides

rt1.3.1 humid climate implies contour plowing
humid climate implies orchards
humid climate implies forested
humid climate implies knobby hills

rt1.3.2 arid climate implies barren land,
grassland, shrubland
arid climate implies flat table rocks
of equal elevation
arid climate implies blocky hills with
a joint pattern

rt1.4 Sandy shale
shale predominates, mixed with sand
no bedding
hill tops either very flat or very sharp
unequal elevations
scalloped hill slopes
minor terraces
pinnacles
parallel ridge lines
deep gorges
V-gullies
coarse dendritic drainage

rt1.4.1 humid climate

rt1.4.2 arid climate
arid climate implies very rugged
topography
arid climate implies shurbland,
grassland at lower elevations
arid climate implies light tones

Rock Type 2 Flat interbedded sedimentary rock

rt2.1 Flat interbedded shale/limestone
terraced hill slopes
limestone hilltops with round sinkholes
uniform slopes imply thin interbedding
dendritic drainage
medium tones

rt2.1.1 humid climate implies cultivation, follows drainage

rt2.1.2 arid climate implies barren land

rt2.2 Flat interbedded sandstone/shale
uniform slopes imply thin bedding
steep-sloped, knobby ridges imply sandstone predominates
sandstone cap rocks
occasional terraced hill slopes
river gorges
dendritic drainage
U-gullies if shale predominates
V-gullies if sandstone predominates
light to medium tones

rt2.2.1 Thick bedding, humid climate
rugged topography
terraced hillsides
hilltops at the same elevation
tonal bands on hilsides or to the vegetation
dendritic drainage
Saucer gullies
cultivated uplands
forested hill slopes
medium tones
dark tones if sandstone predominates

rt2.2.2 Thick bedding, arid climate
rugged topography
terraced hill slopes
steep escarpments
hilltops at the same elevation
tonal banding to hill slopes
talus on slopes
coarse dendritic drainage
V-gullies
barren, shrubland or grassland
light tones

rt2.2.3 Thin bedding, humid climate
rounded topography
hilltops at the same elevation
curvilinear valleys and ridge lines
uniform slopes
forested hill slopes
cultivated uplands
fine dendritic drainage
Saucer gullies
medium tones

rt2.2.4 Thin bedding, arid climated
rugged topography
minor terracing
uniform slopes
talus on slopes
narrow bedding lines
banded vegetation
fine dendritic drainage, few

gullies
scrubland, grasland

Rock type 3 Tilted interbedded sedimentary rocks

rt3.1 Tilted interbedded sandstone/shale
ridges and valleys
sandstone predominates on ridges
shale predominates in valleys
tonal banding

rt3.1.1 humid climate implies agriculture in valleys

rt3.1.2 arid climate

rt3.2 Tilted interbedded limestone/shale
shale predominates on hills
slope asymmetry
tonal banding

rt3.2.1 humid climate implies agriculture in valleys and on slopes

rt3.2.2 arid climate

rt3.3 Tilted interbedded sandstone/limestone/shale
sharp, thick, angular, dissected ridges
tonal bands to rock
flat valleys
faults, folds, fractures
trellis drainage on slopes and ridges
dendritic drainage in valleys
sinkholes
quarries in limestone valleys
crops in slopes and on valleys with shale
forested ridges and slopes in sandstone or limestone
light to medium tones to cultivated valleys and slopes

rt3.3.1 humid climate implies rounded, parallel, sawtooth ridges
humid climate implies flat too undulating topography
humid climate implies rounded hills
humid climate implies trellis and dendritic drainage
humid climate implies light tones to rock

rt3.3.2 arid climate implies sharp, sawtooth ridges
arid climate implies undulating lowlands
arid climate implies banded tones to rock
arid climate implies barren land, grassland, shrubland on hill slopes
arid climate implies few roads, highways, or railroaailroads
arid climate implies grassland,

shrubland
arid climate implies some agriculture
in valleys

rt3.4 Tilted interbedded sedimentary rock -
Shale predominates
rounded topography
faults, folds, stairsteps
long, parallel ridges and valleys
ridges have flared bottom and slope asymmetry
smooth slopes imply thin beds
large streams
sawtooth ridges
dendritic drainage, meanders, long gullies
steep, V-gullies
banded tones
smooth texture

rt3.4.1 humid climate implies low, conical,
rounded hills
humid climate implies dark tones

rt3.4.2 arid climate

rt3.5 Tilted interbedded sedimentary rock -
Limestone predominates
long, parallel, rounded ridges and valleys
slope asymmetry
flared bottom to ridges
sinkholes, often elliptical or elongate rather
than circular
fractures
smooth slopes imply no bedding
angular, dendritic, discontinuous drainage
Box-, Trapezoid gullies

rt3.5.1 humid climate implies rounded hills

rt3.5.2 arid climate implies stairsteps

rt3.6 Tilted interbedded sedimentary rock -
Sandstone predominates
very rugged topography
rough, knobby texture
massive hills, rounded crests
blocky hills imply thick beds
long, parallel ridges and valleys
slope asymmetry, long gradients
straight midsection to slope
sawtooth ridges
narrow valleys
talus at hill base
dendritic, rectangular drainage
V-gullies

rt3.6.1 humid climate implies rounded ridges
humid climate implies dark tomedi
medium tones
humid climate implies forested

rt3.6.2 arid climate implies stairsteps,
blocky hills
arid climate implies sharp ridges

arid climate implies light to medium tones

Rock Type 4 Igneous rock

rt4.1 Serpentine
- winding, smooth, curved ridges
- conical, rounded, scalloped, elongate hills
- landslides
- smooth texture
- dendritic or radial drainage
- numerous, short, steep gullies
- dull tones
- sparse vegetation

rt4.2 Quartzite
- strong relief
- narow, rounded crests
- coarse texture
- light tones
- angular drainage
- steep gullies

rt4.3 Granite

rt4.3.1 Dome granite
- dome hills imply curvilinear sheets
- massive domes imply widely spaced joints
- exfoliated domes imply steep sides and thin beds
- irregular, rounded hill topes
- boulder piles
- light tones to bare rock
- steep slopes
- escarpments
- waterfalls
- locally dendritic drainage, radial on domes
- coarse texture
- curved sheets
- rounded terraces

rt4.3.1.1 humid climate implies:
- massive, bold dome hills
- rounded tops
- steep slopes
- boulders and talus at hill bases
- V-gullies
- medium to dark tones
- forested, cultivated

rt4.3.1.2 arid climate implies:
- rounded hills
- few V-gullies
- light tones
- dark tones to fractures
- barren land, grassland
- vegetation in fractures

rt4.3.2 Rugged granite
- lumpy, jointed hills

rugged, asymmetrical mountains
irregular, rounded hill tops
steep slopes
escarpments
waterfalls
coarse texture
jagged needles and pinnacles imply vertical fractures
rectangular drainage
boulder piles
light tones to bare rock

rt4.3.2.1 humid climate implies:
V-gullies

rt4.3.2.2 arid climate implies:
dissected, parallel, straight, blocky ridges
sharp crests, steep slopes
rectangular drainage
few V-gullies
light tones
dark tones to fractures
barren land, grassland

rt4.3.3 Rose-shaped granite
annular drainage

rt4.3.3.1 humid climate

rt4.3.3.2 arid climate

rt4.4 Basalt (includes lava flows)
rugged, asymmetric, dissected mountains
occasional jagged sawtooth ridges
vertical columnar escarpments
narrow parallel ridges
terraced hill slopes, canyon walls, gorges
talus at hill bases
ropey, blocky, jagged profile implies lava flows
scattered mesas, buttes, and plateaus of equal elevation
curved sheet joints
convex slopes
stratified layers
waterfalls
steppes
tonal bands
parallel or dendritic drainage
radial drainage locally by buttes or curvilinear ridges
U-, V-, and a few trapezoid gullies
medium tones
light toned gullies
grassland, shrubland

rt4.4.1 humid climate implies cultivation
humid climate implies waterfalls

rt4.4.2 arid climate implies barren land or shrubland

rt4.4.3 Young
broad, level plains
cultivation in a rectangular net

rt4.4.4 Old
mesas, plateaus, domes
vertical escarpments
columnar joints
parallel drainage, few gullies
dark tones to rock
barren land

rt4.5 Volcanoes
craters, calderas, or vents on top of a hill
symmetrical, circular hill, dish-shaped interior
concave slope
knife-edged crater
ropey, lobate lava flows at slope base
cinder cones nearby
can be heavly vegetated by forest or scrub
light tones to ash
dark to medium tones to rock and lava flows
radial or dendritic drainage at slope base
V-gullies

rt4.5.1 Old
low, rounded profile

rt4.5.2 humid climate implies low, rounded profile

rt4.5.3 Cinder cone
various sizes
vertical upper slope
broad slope at base
usually in clusters
occasionally along fissures

rt4.6 Volcanic tuff
pitted texture
knife-sharp ridges
steep slopes
hill tops at different elevations
fine dendritic drainage
light tones

rt.6.1 humid climate implies forested or grassland

rt4.6.2 arid climate

Rock Type 5 Metamorphic rock

rt5.1 Gneiss
rolling topography
highly dissected
narrow, parallel, sharp, steep, jagged ridges
hill elevations vary
angular dendritic drainage
few, evenly spaced, broad U-gullies,
medium tones
knobby, rounded hills imply glaciation

rt5.1.1 humid climate implies forested, grassland, and agriculture

rt5.1.2 arid climate implies scrubland

rt5.2 Slate
rolling, irregular topography
many steep, locally parallel ridges and small narrow valleys
many small, rounded, steep hills form a scalloped pattern
locally, hill tops at same elevation
fine trellis or rectangular drainage
parallel V-gullies
medium to light tones
linearity of roads controlled by hill and valley conditions

rt5.2.1 humid climate implies forested, crops in the valleys

rt5.2.2 arid climate implies barren land or grassland

rt5.3 Schist
irregular, rolling topography
smooth knobby hills and ridges
smooth texture
parallel ridges and valleys
tonal variations to rock, light tones
rectangular or dendritic drainage
long, deep, parallel U-, or V-gullies, with light, banded tones

rt5.3.1 humid climate implies low, rounded ridges, steep slopes
humid climate implies forested slopes, cr crops on the hill tops

rt5.3.2 arid climate implies distinct tonal bands to rock, light tones
arid climate implies fine rectangular drainage
arid climate implies barren land, grassland

rt6.3 Marble
massive, rounded ridges
sink holes
smooth texture
light to medium tones

SOIL TYPES

Soil type 1 General dynamical principles
terrain type implies soil type
vegetation boundaries imply soil boundaries

st1.1 tone
tone implies moisture

light tone implies dry
dark tone implies moist
mottled tone implies moisture variances
mottled tone implies irregular drainage
tone implies vegetation
tone implies soil color

st1.1.1 desert varnish tone

Soil type 2 Silt
light tones
silky texture
high water-holding capacity
U-gullies
highly erodable
less permeable than sand
water causes instability

Soil type 3 Peat, muck
biological residual from vegetation
usually in low-lying areas amid higher ground, but can extend into uplands
no natural surface drainage
highly porous
very dark tones to soil, light tones to grass cover
dense tree cover in adjacent swamp lands
layered
implies glaciated area

Soil type 4 Sand
usually quartz
forms dunes
forms sand plains
low water-holding capacity
highly porous
V-gullies
shrubs, grasses
oak (deciduous) or pine (conifer) trees on dunes

Soil type 5 Gravel
igneous, metamorphic or sedimentary rock fragments
usually with some sand, mixed and layered
V-gullies

st5.1 arid climate implies shrubland or grassland
arid climate implies desert varnish tone

Soil type 6 Lean clay
plastic when moist
cohesive
Saucer gullies
expands when wet

Soil Type 7 Silty clay

Soil Type 8 Heavy clay
highly plastic when moist

Soil Type 9 Silt/clay/sand
elastic

Soil Type 1Ø Loam

LANDFORMS

Landforms 1 Glacial forms

1f1.1 Glacier
- scalloped edges of rocks and slopes
- tarns (steep-sided small lake)
- parallel ridges
- hanging valleys
- cirques (amphitheater valleys)
- gouge curvature opposite to direction of ice flow
- parallel "finger" lakes
- moraines at glacier edge
- braided drainage
- U-shaped valleys
- light tones to ice

1f1.2 Glacial lakebed
- large, flat, broad plain
- can be in uplands
- can contain beach ridges
- artificial drainage, including ditches and field tiles
- swamps, ponds at edge
- saucer gullies
- a few broad meanders
- uniform medium tones
- fine texture
- trees along ditches
- intensely cultivated
- crops, pasture
- scattered forests at edge

1f1.3 Outwash plain
- can be within a valley
- can be a terrace
- associated with kames
- associated with fluvial fans
- stratified graded silt, sand, gravel
- occur at the borders of glacial forms
- braiding scars and sand streaks
- light tones
- ponds
- meanders along the edge
- infiltration basins (dark tones) in the ponded and pitted areas
- sand and gravel quarries
- internal drainage
- pitted
- rectangular road grid controlled by cultivation pattern

orchards

1f1.3.1 humid climate implies cultivation

1f1.3.2 arid climate implies grassland, grain crops, irrigation dictnes

1f1.4 Till plain
broad, flat plain
shallow, rounded, nonuniform, elongated depressions
occurs as low, rolling prarie
mixed sand, gravel, silt, clay, boulders
channel scars
undeveloped, discontinuous, deranged, or dendritic drainage
a few saucer gullies
light tones with dark streaks, or mottled tones

1f1.4.1 humid climate implies cultivated, forested

1f1.4.2 Young, thin
flat, undulating topography implies young
topography controlled by underlying rock
drainage controlled by underlying rock
light tones; slight mottling
field tiles and drainage ditches

1f1.4.3 Young, thick
flat, undulating topography implies young
flat plain
slight undulation
deranged drainage, few gullies
depressions and swamps
mottled tones
sharp mottling to tones implies changes in soil coarseness
arid climate implies grassland
humid climate implies agriculture
rectangular road grid
rectangular field grid
field tiles and drainage ditches

1f1.4.4 Old, thin
flat, dissected topography implies old
topography controlled by underlying rock
drainage controlled by underlying rock
U-gullies
medium tones
irregular field shapes
humid climate implies trees by drainage gullies

1f1.4.5 Old, thick
flat, dissected topography implies old
dissected plains
dendritic drainage
U-gullies, fringed or light-toned

light tones
arid climate implies grass land, scrubland
humid climate implies cultivation
rectangular fields and road grid

1f1.5 Kame
associated with till plains and outwash plains
steep-sided, knobby or conical or rounded mounds, isolated or clustered within a rolling prarie
mounds are less than 400 feet in length or width, less than 50 feet in elevation
mounds can be elongated or hook-shaped
small sharp ridges
usually unstratified gravel and sand
sand, gravel pits
marsh or wetland at base
internal drainage
few, short V-gullies at base, especially if arid climate
light tones on hills, medium tones on terrace

1f1.5.1 humid climate implies some cultivation, scattered forests, pasture, orchards

1f1.5.2 arid climate implies grassland

1f1.6 Eskers
associated with till plains
usually within a rolling topography
long, snake-like narrow ridge
elevation varies
steep slope
may cut across till plains, lake beds, drumlins, streams, or lakes (where they may take the form of small peninsulas
usually less than one mile long, less than 200 feet wide, less than 100 feet high
can be discontinuous ("beaded")
can be meandering and interconnected
stratified sand and gravel
sand and gravel pits
marsh or wetland at base
internal drainage
few V-gullies along the crest
light tones at crest, dark tones at base
roads along crest line

1f1.6.1 humid climate implies scattered forest, or orchards, grazing

1f1.6.2 arid climate implies grasland

1f1.7 Drumlins
usually in a rolling prarie
smooth, long, oval, rounded, cigar- or teardrop-shaped low-lying hills
always occur in clusters, usually parallel
flat or rounded top, steep sides
usually less than one mile long and less than 250 feet high and less than 1500 feet wide
axes parallel to glacial movement
one end is steep and rough, the other is gentle

and smooth
head (large end) usually points north
smooth, broad slope implies fine soils
steep, narrow slope implies course soils
wet or marshy at base
no drainage pattern
few, short, steep gullies
light tones on crests

1f1.7.1 humid climate implies, forested, cultivated
rare orchards
contour plowing on steeper slopes

1f1.7.2 arid climate implies grassland

1f1.8 Terminal (end) moraine
usually within a rolling prarie
undulating linear bands of hills
small, concentric knobs, ridges, and depressions
smooth, rounded slopes
hills and depressions have various elevations
distinct boundary with adjacent landforms
formed at glacier edge resulting from material pushed ahead of glacier
many ponds, swamps, and hedgerows
usually unsorted, unstratified soils
deranged drainage
narrow and deep V-gullies
landslides
curvilinear roads

1f1.8.1 humid climate implies forested, swamps, orchards
humid climate implies some cultivation

1f1.8.2 round, undulating hills, distinct drainage net, saucer gullies, cultivation, and forests imply fine soils

1f1.8.3 rounded, steep ridges, light tones, saucer to V-gullies, forests imply coarse soils

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Landforms 2 Fluvial landforms

1f2.1 Estuaries

1f2.2 Bays

1f2.3 Reservoirs (see Cultural Forms section)

1f2.4 Lakes

1f2.5 Canals, drainage ditches (see Cultural Forms section and Agriculture section)

1f2.6 Depressions

1f2.6.1 Ponds
imply peat, muck soils

imply blocked drainage system
indistinct boundaries in swamps

1f2.6.2 Bog, marsh
depressions of various shapes and sizes
grass, shrub cover
flat topography
dense vegetation
dark tone soils
few surface drainage features
few streams
occasional rectangular, artificial drainage channels

1f2.7 Levees

1f2.8 Swamps
indistinct boundaries
discontinuous drainage
ponds, with various shapes and sizes
meanders
imply blocked drainage system
imply peat, muck soils
tree and shrub cover
occur in deltas, floodplains, outwash plains, terraces, tidal flats, Carolina bays

1f2.9 Continental Plains"(alluvium)
flat horizontal plain
formed by sedimentation and deposition
uniform rectangular road grid and field pattern
roads and fields curve around depressions
road net aligned with field boundaries
curvilinear tone streaks
occasional random surficial drainage
few saucer and U-gullies
medium to light tones
occasional slight mottled tones
curvilinear tone streaks in the cultivation pattern and around depressions
occasional badland erosion features at edges
small, circular flat-bottomed depressions ("buffalo wallows")
grain crops
occasional alkaline deposits (salt flats)

1f2.10 Floodplains
large,broad, flat, gently-sloping plain
rolling, undulating, streaked, dissected
arcuate sandstreaks, which follow drainage contours
deep soils
bounded by rolling uplands
bounded by terraces
traversed by streams, meanders and oxbows
anastamotic, internal or dendritic drainage
few V-, U- or Saucer gullies
levees
contains depressions, ponds and swamps
scattered forests
intensive agriculture
orchards
field irrigation ditches
irregular field patterns

contour plowing
trees by water channels
mottled tones
light tones imply dry soils
light tones imply sand
dark tones imply poorly drained areas and moist soils

1f2.11 Deltas
flat
where stream or river enters calm water (ocean or lake)
even, perfect outline implies lake
dichotomic drainage
Saucer, U-gullies
numerous stream channels
can include marshes, ponds, lagoons
can include marinas

1f2.11.1 Arcuate deltas
fan-shaped plain
convex edge faces water body
many shallow channels which radiate out from main feeder stream
dichotomic drainage
locally braided
V-gullies
coarse soils

1f2.11.2 Estuarine delta
in the uplands surrounding the river mouth
narrow and flat
coarse braided drainage
many islands and inlets
swamps, ponds
clay to gravel

1f2.11.3 Birdsfoot delta
stream enters quiet water
a few large, stable channels radiate from main channel
fine drainage net
natural levees
offshore deposits of fine soils
swamps
large, broad, flat plain

1f2.12 Coastal plain
gentle slope toward the ocean
undulating and rolling, with depressions
often with linear shoreline features, such as beach ridges
includes Carolina Bays (see 1f2.21)

1f2.12.1 Young
flat, gently rolling
linear relief in the uplands parallel to shore
lowland drainage ditches
coarse dendritic or parallel drainage
wide U-gullies
mottled tones

depressions and swamps
cultivated uplands
irregular field patterns
contour plowing
forested lowlands

1f2.12.2 Old
highly dissected and rugged
major channels follow broad valleys
moderately steep slopes
dendritic drainage, fine net,
locally parallel
U-, V-gullies
forested, especially on hillsides
and in gullies
agriculture in the uplands
occasional contour plowing

1f2.13 Valley fills
plain
may be large (broad) or small
in valleys or basins
adjacent to alluvial fans
gradual slope from uplands
a few rock outcroppings in the valley
may contain playas
many parallel, braided, inactive streams
V-gullies
light tones
scrub by the drainage channels

1f2.14 Alluvial fans
fan-shape deposits
gentle slope from the fan apex down into a valley
often form at the mouth of large V-gullies
stream discharge from mountainous uplands
bounded on upstream side by rugged mountainous
topography
fan blends into valley bottom
course soils at gulley mouth
fine soils at the fan edge
high arch to the slope implies coarser material
shorter fan implies coarser material
radial or braided drainage, locally parallel
Box, V-gullies with steep gradients
light to medium tones
usually in an arid region
brush near the channels and the fan fringe
scrubland, grassland

1f2.15 Mud flats
usually in a coastal plain or tidal basin
alluvial mud deposits
in or near a river or stream
deposited at points of low water velocit
light tones relative to the water
marshes or scrub growth

1f2.16 Stream systems
rapids produced by underlying rock
braided drainage implies quick changes in water
load
indistinct boundaries in swamps

offset stream implies rock faulting

1f2.16.1 Young
steep gradients
coarse drainage
no meanders
occur in steep, V-shaped valleys
streams at valley bottom
rapids, waterfalls
water filled depressions
lakes
swamps in the large depressions

1f2.16.2 Mature
occur in moderate slope topography
well-integrated drainage
dissected topography
some meandering
narrow floodplains in valleys

1f2.16.3 Old
occur in extensive floodplain
flat or undulating topography
occasional isolated hills
gentle gradients
stream scars
meanders, oxbow lakes, yazoos

1f2.16.4 humid climate implies rolling topography

1f2.16.5 arid climate implies broad, flat pl in
arid climate implies deflation hol.ws

1f2.16.6 tropical climate implies savanna
tropical climate implies dome-like hills

1f2.17 Playas
dry, low relief lakebeds in arid regions
very flat surfaces in region of valley
scrabbled surface implies alkaline deposits
can include beach ridges
few drainage features
no vegetation, unless scattered scrub
irrigation and intense cultivation
rectangular field grid
includes salt flats

1f2.18 Terraces
lie between floodplain and uplands
slope defines the borders
can be more than one per region, implies stages of river downcutting
usually uniform, smooth topography
often lie adjacent to a river bed
smooth terraces imply glaciation (common)
consists of silt, sand, and gravel
vertical cliff faces imply gravel
rolling surfaces and slopes imply fines
internal drainage
V-gullies at edges
fans at gully exits

gravel excavations
linear, curvilinear tone streaks
light to medium tones
occasionally forested

1f2.19 Beach ridges
long, narrow, inland ridges parallel to coastline
same elevation
constructed by wave action
can be in glacial lakebeds, playas
separated by troughs ("swales") of swampy organic matter
flat ridge tops can have dwellings, roads, trees
steeper slopes to seaward side
scalloped slopes on landward side
sharp ridges imply gravel
rounded ridges imply sand
light tones
internal drainage
few V-gullies
scattered trees, marshland

1f2.19.1 humid climate implies dense forest

1f2.20 Tidal flats
flat area near ocean coast
near some type of barrier to wave action
near sandbars, lagoons, small islands
can include beach ridges
intricate dendritic drainage
wide, wandering channels
can include artificial dikes, drainage ditches
dense vegetation

1f2.20.1 Marsh
flat
dense marsh grasses
drainage ditches common
medium to dark tones

1f2.20.2 Mud
no vegetation
many hair-like meandering channels
medium tones

1f2.20.3 Sand
near tidal inlets
no vegetation
few, parallel channels
light tones

1f2.21 Carolina bays
in Atlantic Coastal Plain physiographic region (see the Physiographic file)
inland ponds or covered with swampy vegetation
elliptical shape
parallel NW/SE axis
narrower at southern end
flat bottom
swampy

1f3.1 Deserts
sand and gravel soils
usually arid climate
desert varnish tones
occasional silt soils
usually with dunes

1f3.2 Dunes

1f3.2.1 Beach dunes
hummocky shape
varying wind directions
gradual windward slopes
steep leeward slopes
usually 30 to 100 meters in relief
internal drainage
light tones
vegetation cover and an indistinct boundary with surrounding landforms implies it is stabilized
barren implies active

1f3.2.1.1 hum'd climate implies grasses, shrubs, trees

1f3.2.2 U-dunes (Wind-drift dunes)
U to V shape
blowout from other dunes
strong winds, one direction
areas of little sand
narow ridges and horns
the horns point opposite the wind direction
horn apex is upwind
gradual windward slopes
steep lee slopes
usually 30 to 100 meters in relief
vegetation cover and an indistinct boundary with surrounding landforms implies it is stabilized
light tones
internal drainage
barren implies it is active
inland implies grass, forest

1f3.2.2.1 humid climate implies grass, grass, forest and shrubs

1f3.2.3 Star dunes
many-pointed star shape
varying wind direction
gradual windward slopes
steep lee slopes
usually 30 to 100 meters in relief
areas of little sand
vegetation cover and an indistinct boundary with surrounding landforms implies it is stabilized
light tones
internal drainage
barren implies it is active

1f3.2.3.1 humid climate implies grass, forest, and shrubs

1f3.2.4 Longitudinal dunes
very long, narrow, parallel ridges
sharp crests
usually in clusters
strong winds
parallel to wind
usually 3Ø to 6Ø meters in relief
occur in areas of little sand
equal side slopes
internal drainage
V-gullies
no vegetation
vegetation cover implies it is stabilized
barren implies it is active

1f3.2.4.1 humid climate implies grassland

1f3.2.5 Transverse dunes
thin, elongate, closely spaced, parallel ridges
wave-like shapes
pockmarked, scalloped
usually 3Ø to 1ØØ meters in relief
perpendicular to winds
one major wind diraction
gentle winds
in areas of abundant sand
fine soils
internal drainage
light tones
barren implies it is active

1f3.2.5.1 humid climate implies grassland, forested

1f3.2.5.2 arid climate implies barren

1f3.2.6 Barchan dunes
distinct crescent shapes
asymmetrical slopes
broad ridges and horns
horns and the steeper slope point downwind
usually clustered
parallel axes
gradual windward slopes, steep lee slopes
usually 3Ø to 1ØØ meters in relief
in areas of flat topography
in areas of little sand
strong to moderate winds, one major direction
internal drainage
few V-gullies
light tones
vegetation on horns
smooth leeward slope implies it is stabilized
inland implies grassland, forested

AD-A139 899 METHODOLOGICAL PRELIMINARIES TO THE DEVELOPMENT OF AN EXPERT SYSTEM FOR AERIAL PHOTO INTERPRETATION(U) ARMY ENGINEER TOPOGRAPHIC LABS FORT BELVOIR VA R R HOFFMAN

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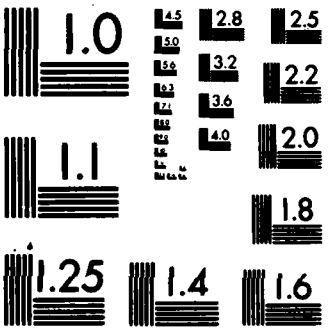

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

barren implies it is active

1f3.2.6.1 humid climate implies grassland, forested

1f3.3 Loess plain
can be plains, ridges, or dissected plateaus
gentle, rolling topography
irregular repeated hills with parallel ridges
covers extensive areas
rolling prarie surrounded by hills and ridges
easily eroded windblown silt
silt sources are lakebeds, outwash plains, deserts, alluvial plains
occur near to glacial features, plains, or alluvial deserts
vertical to very steep bluffs, cliffs and road-cuts
pinnate or dendritic drainage
Trapezoid-, Box-, or U-gullies
close, steep, short gullies
terracettes, fins and pinnacles in gullies
no alluvial fans
light to medium tones
rangeland, grassland, grain crops
intense cultivation, with contour plowing
fence rows

1f3.3.1 Young
parallel, smooth hills
deep soils
fine dendritic drainage
Box gullies
uniform light tones
intensely cultivated

1f3.3.2 Old
dissected, especially near major streams
rugged, steep hills
steppes and terracettes
fine pinnate drainage
Box gullies
light to medium tones
grassland, shrubland

1f3.3.3 humid climate implies densely forested

Landforms 4 Tundra landforms

1f4.1 Perennial snow fields

1f4.2 Permafrost regions
depressions imply silt/ice mixture, subsurface ice
discontinuous drainage
thermokarst drainage
beaded ponds along streams
polygonal frost wedges

1f 4.3 Bare ground tundra

Drainage Patterns 1 General dynamical principles
cross-linked patterns imply rapid water flow
light tone streaks imply drainage
dark streaks imply blocked drainage
tone fringe to gullies implies erosion and fine soils

dp1.1 Fine drainage texture
implies much runoff
implies impervious bedrock
implies low permeability soils

dp1.2 Medium drainage texture
implies mixed soils
implies much runoff

dp1.3 Coarse drainage texture
implies permeable bedrock
implies permeable soils
implies internal drainage

Drainage patterns 2 Drainage pattern types

dp2.1 Annular drainage
central-point symmetry
annulus (ring) structure
right-angle tributaries connect the annuli
implies fractures and joints
implies two directions of flow: radial and and concentric
implies domes, basins
implies sedimentary rock
implies igneous rock

dp2.2 Dendritic drainage
tree-like shape
acute angles
in uniform slope topography
curved major streams
barbed or spurred appearance implies tectonic disruptions
implies ies old, dissected coastal plains
implies old, thick glacial till
implies area originally flat
implies low permeability soils
implies uniform material
implies intrusive volcanic tuff
implies soft, flat sedimentary rock
implies sandstone

dp2.3 Rectangular drainage (angulate drainage)
implies basic dendritic pattern
implies fractures, joints and faults
sharp angular bends in streams
tributaries at right-angles with streams
straight segments
implies two or more directions of water flow
stronger pattern implies thinner soils

implies metamorphic rock
parallel joints imply sandstone
acute angles imply uplifted bedrock

dp2.4 Discontinuous drainage (karst)
very small ponds
short irregular gullies
acute angle gully intersections
discontinuous gullies
few gullies and streams
implies limestone beds
implies permafrost
implies glaciated terrain

dp2.5 Thermokarst drainage
gullies form polygons and hexagons
polygons linked by meandering streams
streams link small depressions ("beads on a string")
implies permafrost

dp2.6 Elongated bay drainage (see Carolina Bays in Fluvial Landforms section)
parallel elliptical depressions
linked by streams
oriented NW/SE
swampy
implies Atlantic coastal plain (see Physiographic Regions file)

dp2.7 Yazoo drainage
stream has significant meander appearance
channel scars by stream
gullies and tributaries at right angles with major stream
gullies at acute angles with tributaries
implies resistance to flow during river flooding

dp2.8 Anastomotic drainage
gullies have significant meandering
gullies at right-angles with streams
oxbow lakes
implies floodplains and deltas

dp2.9 Internal drainage
surface erosional scars or tone changes
may be gullies at the edge, not branched
implies porous rock (e.g., lava)
implies permeabble soils
implies sand, gravel
implies infiltration basins
implies alluvial soils
implies beaches
implies sand dunes

dp2.10 Braided drainage
occurs in flat stream valleys
implies rapid water flow
curvilinear gullies tending in one general direction
gullies cross and intersect frequently

implies coarse deposits (e.g., sand, gravel)
implies heavily loaded stream
implies alluvial fans
implies arid climate

dp2.11 Deranged drainage
discontinuous streams
short, discontinuous, small gullies
gullies cluster
subsurface drainage
flat or undulating topography
implies high water table
implies swamps, ponds, marshes, lakes
implies floodplains, moraines, till plains

dp2.12 Parallel drainage
flat, uniformly inclined topography
parallel gullies
acute angle tributaries
gullies intersect stream at acute angle
stream may lie on a fault or fracture
as landform slope increases, acuteness of angles
implies one direction of flow
implies tilted plain
implies coastal plains
implies basalt flows
implies homogenous soil
implies alluvial fans
implies tilted sedimentary rock
implies loess soil

dp2.13 Pinnate drainage
feather-like pattern
many minor gullies connect to major gullies
short, uniform angle gullies
major gullies at a right-angle to stream
implies loess soils, floodplain
implies high silt content soil

dp2.14 Radial drainage
gullies radiate from a central depression or dome-like elevation
gullies are parallel
gullies arranged in a circle
implies domes, depressions, hills, volcanoes
implies granite

dp2.14.1 centrifugal pattern implies dome or central elevation
gullies feed into stream which lies around the e base of the elevation

dp2.14.2 centripetal pattern implies basins or sinks
gullies lead into the depressions

dp2.15 Trellis drainage
parallel streams
straight tributaries
gullies at right angles
minor gullies are short, evenly spaced
implies two directions of flow, one direction having more flow than the other
implies bedrock control of drainage
implies folded rock
implies interbedded rock
implies tilted interbedded sedimentary rock, edges exposed
gullies go with the direction of bedding
if this pattern occurs on both sides of a divide (fault, fracture), implies vertical bedding

dp2.16 Dichotomic drainage
fan shape
locally braided
implies alluvial landforms

dp2.17 Infiltration basin

Drainage patterns 3 Drainage gully shapes

dp3.1 Box gullies
steep side slopes
flat bottom of channel
implies silt soil
implies alluvial deposition
implies loess soil
implies sand/clay mixtures

dp3.2 U-gullies
moderately steep side slope
curved channel bottom
implies loess soil

dp3.3 Saucer gullies
gentle curved slope to gulley wall
can extend far
light tones at bottom
implies fine, cohesive plastic soils (e.g., clay, silt)
implies glacial lakebed
implies nongranular soil
gentler slope implies more clay

dp3.4 V-gullies
short, steep gradients
narrow channel bottom
implies noncohesive soils
implies grannular soils (e.g., sand, gravel
flattening at gulley bottom implies silt soil deposits
steep sides imply aeolian deposits
short steep sides imply coarse soil
often have alluvial fans at major stream or gully mouth

dp3.5 Trapezoid gullies
moderately steep side slopes
wide, flat gully bottom (inverted trapezoid)
upper slope can round off into the flat land
implies silt soils (aeolian deposition)
implies loess soil

Vegetation and Forestry

Vegetation Type 1 Forest

vt1.1 Conifers
pine trees
dark tones
crown shape
conical shape
elongated shadows
pointed tops
wheel-spoke shapes
star-like shapes
layered branches
usually in sandy soils
dark tones year round

vt1.2 Deciduous forest
rounded, clump-like shapes
large masses of foliage
usually in loam or clay soils

vt1.2.1 spring, summer implies dark tones

vt1.2.2 autumn implies light tones

vt1.2.3 winter implies bare branches
winter implies visible ground

vt1.3 Mixed forest
stands of conifers
groves of deciduous

Vegetation Type 2 Tundra (also see Tundra in Landforms section)

vt2.1 Herbaceous tundra

vt2.2 Shrub and brush tundra

vt2.3 Wet tundra

vt2.4 Mixed tundra

Vegetation type 3 Rangeland

vt3.1 Grassland
rectangular drainage implies organic soils
rectangular drainage implies repeated flooding

vt3.2 Shrub/brush rangeleland

closed or open canopy

vt3.3 Herbaceous rangelend
soft stem plants
annual growth
plants less than 2 meters in height

vt3.4 Mixed rangeland

Vegetation Type 4 Agriculture

vt4.1 Row crops
tone stripes
nonrectangular fields imply edges follow drainage pattern
nonrectangular fields imply edges follow topographical contours (e.g., rolling plain)
rectangular field pattern implies flat topography
rectangular light toned pattern within fields imply field tiles
road net often aligned with field boundaries
tone contours plus uneven topography imply contour plowing
banded tones imply poor drainage. high water table
terraces imply rice
field tone alternation implies fallow ground alternates with cultivated ground
grain farming implies fine soil
no houses nearby plus large buildings clustered amid many fields imply industrial farming

vt4.1.1 field tiles

vt4.1.2 irrigation ditches
lineal dark tones
light tone hillocks on both sides
occasional well pumping stations
drainage into adjacent fields
dark tones and closer to ditches

vt4.1.2 autumn, winter and light tones to vegetation implies grain crops

vt4.1.3 spring, summer and dark tones to vegetation implies grain crops

vt4.3 Vineyards
linear pattern to vegetation
often on south slopes
cannot be far in north latitude
often near lakes
often on hilly terrain

vt4.4 Orchards

lattice pattern
repeated uniform rows
porous soils, well drained soils
level terrain plus trees arranged in a rectangular pattern imply nuts, citrus
rolling, uneven terrain plus trees arranged in a contour pattern ("fingerprints") imply fruits, peaches, apples

vt4.5 Fallow fields

vt4.6 Pastures

vt4.7 Tree nurseries

vt4.8 Livestock

CULTURAL FORMS

Cultural Forms 1 Land engineering

cf1.1 Landfill

cf1.2 Quarries

cf1.3 Strip mines

cf1.4 Tailings

Cultural Forms 2 Water engineering (see also Transportation, cf3)

cf2.1 Reservoirs

cf2.2 Dams

Cultural Forms 2 Recreation

cf2.1 Marinas

cf2.2 Parks
scattered trees
grassland
baseball, football fields

Cultural Forms 3 Transportation

cf3.1 Two-lane roads
vertical hill cuts imply loess soils

cf3.2 Expressways
vertical road cuts imply loess soils

cf3.3 Dirt roads

cf3.4 Bridges

cf3.5 Railroads

cf3.6 Airports

cf3.7 Canals

cf3.8 Locks

Cultural Forms 4 Utilities

cf4.1 Sewage treatment facilities

cf4.1.1 sewage infiltration basins
orderly array of ponds
nearby physical plant
gravel, sand soils
pipe system

Cultural Forms 5 Communications

cf5.1 Broadcast towers
adjacent small buildings for transmitter
towers often in clusters

Cultural Forms 6 Rights-of-way

cf6.1 Power lines
long, relatively thin rectangular swath
through vegetation
light tone relative to surround
power line towers

cf6.2 Pipelines

cf6.3 Firebreaks
narrow swath cut through a forest
light tone relative to surround
cuts across topographical changes
can fall on property lines

cf6.4 Hedgerows
follow drainage patterns
can fall on property lines

Cultural Forms 7 Residential areas

Cultural Forms 8 Heavy industry

Cultural Forms 9 Light industry

Cultural Forms 10 Commercial area/service industries

END OF THE EARTH 1 FILE

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APPENDIX 2

TRANSCRIPTS FROM THE LIMITED INFORMATION TASK

EXPERT #1, STIMULUS #1 - SCOTTISH HIGHLANDS

EXAMINER: Tell me as much as you can.

PHOTO INTERPRETER: Sharp ridges, at least two different directions to the ridges. The slopes are generally constant in one relief condition and in the second relief condition. The stream valleys are flat and the slopes come right down . . . almost like a trapezoidal shape. Most of the area is forest covered. It is summer photography.

E: How do you know that?

PI: The tree cover is leafed out.

There are a few manmade features like the roads over the hills. There are probably roads in the valleys, but the tones on the roads in the valleys merge with the tones in the valley itself, so it was hard to tell. It looked like fairly dry country. The stream valleys didn't seem to have a lot of water in them. The stream surface didn't fill the valley. I only have a faint recollection of whether or not there were streams. A few of the areas were cleared, but not very much. Now, there are at least two different landforms there. One was ridges and the other was alluvial-filled valleys. I didn't really catch if there were terraces, but I didn't note that specifically.

E: Can you deduce whether or not there would be terraces?

PI: Well, it's not likely because the bedrock tended to come right down into the valleys. There were some breaks in slope, but they tended to be one general condition . . . hill to valley. In fact, those ridges reminded me of granites rather than any other kind.

E: How would you be certain of that?

PI: I'd have to draw a drainage pattern.

E: Could you do that?

PI: Well, there was one major valley. There weren't many fine-grained drainage systems; it was a coarse drainage system with some parallelism because the ridges had some parallelism. It looked like granites from the steepness of the slopes. I'd look for dome-shaped ridges, but I didn't see many of those. Or, I'd look for fractured surfaces by variations in tonality. In the fracture would be one tone and adjacent features would be another tone. Just about the time I was thinking it was granite, the time was up.

E: What else can you tell me?

PI: I have some feeling it is in California because it looks like chaparral on the slopes . . . low brush cover and not tall trees. Chaparral does tend to cover slopes completely in areas of California. I didn't see

any campsites or horse trails. Very little land use.

E: You were able to describe the topography, the major drainage pattern. You could make a stab at the rock type and the soils. You were able to describe the vegetation and the major cultural features. What interests me is that for the judgments you couldn't make with certainty, you were able to say what you would have to look for in order to make those judgments more certain, and that's what I really wanted to find out with this method.

PI: What do you know about this area?

E: It's the Scottish Highlands . . . which does look like some areas of California in exactly the way you described it. I deliberately picked scenes you wouldn't be familiar with. Here, you have partial information because you have limited time, so you can only go so far. When you reach a point where you can't say anything further, you know enough on the basis of what you have seen to tell what additional information you would have to look for in order to clarify your hypotheses. It is possible to get at your knowledge without doing a complete landform analysis. In this region, the ridges are parallel, there are some dome-like hills, there is very little land use, the streams are dry. There is scattered, low bush.

EXPERT #1, STIMULUS #2 - AREA OF FORT BLISS

E: What did you see in this pair?

PI: Well, there are at least three terrain situations. No major stream valleys. There are two sets of vegetation conditions. On the higher slopes is denser vegetation and more open vegetation on the lower slopes. There is some knobbiness and there are some sharp ridges. There are some rounded knob ridges as well as some sharp angular ridges. It approaches high altitudes, between 6,000 and 12,000 feet above sea level, but there is no snow on them, so it is probably a warm or tropical climate. There doesn't seem to be much vegetation, though. The vegetation is not tall. The canopy is quite thick, though, on the higher elevations. Lots of good cover for military situations. But also there would be lots of difficulty getting around. The canopy cover is heavy and that would be a dense undergrowth. There are a number of rock types, not just one or two. The softly rounded knobby stuff would be one rock type and the sharp stuff would be another rock type. The vegetation change which occurs . . . dense to more open as you go down the slope . . . is probably due to a difference of rainfall. There is a greater rainfall on the higher slopes than on the lower slopes.

E: Is there any way you could check that hypothesis to be sure of that if you still had the photos in view?

PI: The rainfall account of the vegetation change is one possible hypothesis. Another possibility is that there is a difference of rock types. A thicker soil may support a thicker vegetation, whereas downslope there is less of a chance for it . . . the rock type doesn't offer a thick soil. I'd check that by seeing if the slopes are steeper. I didn't get a good look to see if the thicker vegetation was on a less-steep slope. But I do know that thicker vegetation can grow at higher altitudes based upon better soil conditions or based upon more rainfall, or both. Vegetation might have had a better chance for survival on the less-steep slopes, so I would need to check to see if there was a steeper slope at the lower elevations as part of the cause for that difference. It being a more tropical situation, the rock types are not that clear-cut to me.

E: You can assume that this is in the continental U.S.

PI: We do have some near-tropical areas, but that would have to be Alabama or Oregon. But it can't be Oregon because it would have to have tall trees. My feeling about this area is that the trees weren't that tall.

E: No tall trees implies it isn't Oregon.

PI: Yes. I would look for that kind of climate - supports lush vegetation.

E: What about the drainage patterns?

PI: Well, they are really mixed up. That's generally true of changes from one rock type to another. There wasn't time enough to draw drainage patterns in my mind. But before I'd make a detemination of the separate rock types, I'd draw the drainage patterns. They would suggest the changes. Slope changes and rugged-to-softly-rounded ridges and drainage changes all indicate changes in rock type. So where the rocks are of one type it will have a homogeneous drainage pattern, except where the rock type changes even within a pattern. I had some notion that there are some volcanics in this area because there were some cinder cones or conical ridges, even though the vegetation subdued it. So I'd look in more detail for that.

E: So you'd suspect some of the rock would be basalt?

PI: Yes. There is a chance of some metamorphics in this area too. There is some parallelism, subtle ridges that tended to look like tilted-up rocks. The drainage pattern would have to verify that for me. One section of the photo had that parallelism, which would be similar to gneiss or schist.

E: What about tonal variations?

PI: There were some tonal variations in that same general area. Maybe some breaks in the slope which were created perhaps by landslides or faulting. There are some linear features. That was one of the areas I didn't have time to see.

E: Would you look for the faults as evidence of volcanism or as evidence for metamorphic rocks?

PI: Both.

E: Would there be different fault patterns?

PI: Yes. Now, the elevations may not be as high as I said. I don't understand why we don't have tall trees. We might not have ruled out the northern segments of the Appalachians. There is the possibility of Vermont or New Hampshire-type terrain. But we wouldn't have the volcanics or basalts. That would be Oregon, Washington, Nevada, even Idaho. But I rule out Idaho and Nevada because they are too dry.

E: This is a mesa north of Fort Bliss in Texas.

PI: There are some patterned criss-crossed lineal features all over the place that looked like dirt bike trails or even animal tracks or possibly Indian gardens. But they may be tank tracks.

E: There is lots of vegetation, but not Oregon or California. You ruled those out.

PI: The patchy change in vegetation may be related to fires at the lower elevations. It is more sparse and lighter toned. The knobby area had basalt-like shapes. The tonal streakiness is due to a slope break where there is talus and no vegetation. That sort of slope looks like

basalt. The deep fractures look like uplifted granites. Some of the streaks were off the stereo view . . . without the stereo you can't be sure if they are fissures or small ridges, or even faults in the film.

EXPERT #2, STIMULUS #3 - THE HUDSON RIVER VALLEY

E: O.K., tell me what you saw.

PI: It's similar in climate to the first one we saw. I saw a closed forest canopy. It was about a quarter urban, less than a fifth was agriculture, and the rest was essentially natural terrain with some recreational development on it, a set of ski slopes. The landform had fairly angular tops to the ridge lines and hill tops. Fairly smooth gradients. The dissection is pretty deep with indications of fracture control. Some of the soils and terrace cuts and deposits would be indicative of granular material, sand for example in some places. The tones in the fields made one think of a granular material down to silt rather than a clay soil. There are a number of possibilities that the landform suggests, but I don't want to propose those on just that much evidence.

E: You're allowed to speculate. What seems likely?

PI: Well, the terraces at the bottom that have been deposited and then cut have strong sides and uniform tones. One possibility would be granular material, sands. There must be a source for these. The land slopes

certainly are compatible with a sedimentary sequence . . . interbedded. There is some flair to the bottom of the slope, which can be associated with a number of things. It can be colluvial material, associated with interbedded limestone and shale. It could also have some sandstone beds in it. It could be a weathering surface with different degrees of weathering from a previous time . . . not colluvial, but at that point perhaps thousands of years ago under other conditions of water flow, and we're seeing the remnants of that. It could be a number of things.

E: What would you look for to tack down any of those hypotheses?

PI: I'd go back and draw out the landforms. What are the slopes? There were some fairly smooth gradients and some compound gradients. It may well be that there is a boundary. The material is being eroded without much difficulty. A big mass has come out of that valley. Although it is fracture controlled and that set the stage, it is somewhat easy to remove. I'd want to go back to look for bedding and for dip, if there is bedding. Or, are there indications that are more consistent with igneous and metamorphic?. . . although at first glance it doesn't seem to be that way.

E: What would those indications be if they were there?

PI: I'd want to see other photos and do a ridge-line analysis to look for concordance. In basalts there is concordance, but not with slopes of this type. Metamorphics are a problem because they can be of many

different origins. They can be completely reworked and so highly fractured that they could be here. I'd tend to interpret this area as sedimentary, interbedded, not too thick. Soils are sand and gravel deposits, some silt. I saw some tone changes that indicate subsurface weathering, which could be remnants of solution; it could be deposits in local lows giving you wet spots. There is little I can say economically. The agriculture base is not big enough to support the town. So it must have either a larger agricultural area or some combination of that and tourism, sports, recreation. I'd be inclined to put this in a temperate climate. Sort of humid. Plenty of water. I'd assume it's someplace in the midwest. I certainly would not associate it with Texas or Louisiana. We don't like to know where it is. If you show someone a photo and say it's Kentucky, they'll see limestone whether it's there or not. We like the photo to lead you. Sooner or later the cues will tell the story. Until you draw and isolate the patterns, you might miss significant things, things you'll miss at a glance . . . slight variations in drainage patterns or gully cross sections might imply different soils, for example. The drawings make us focus and concentrate our attention on one thing at a time, rather than wandering off. That's why it's a ritual, although we note unusual things that catch our attention. It takes a lot of practice to see the subtle changes.

APPENDIX 3

A PORTION OF THE TRANSCRIPT FROM CASE #3 OF THE METHOD OF TOUGH CASES

PI_1: It looks like an airport on radar, but it has some unusual features. According to the map it's an air base. We want to think about it in terms of an abandoned air base. There appear to be some buildings still standing. My first impression of those particular round things, knowing that it was possibly an air base, is that they were for storage, munitions, or petrol. The area nearby could be a park because it is fenced in. The road goes around it. Could be for recreation by the shoreline. Here, they seem to lead into a hangar. In the aerial photography we don't see the runways as clearly as we did on radar. It doesn't really look like an airport. It looks like some sort of industrial complex. The whole character of it has changed. It may have been an airbase back in 1940, but now it looks completely different. Some kind of storage depot, a large facility.

PI_2: The photos are the same date as the radar, but the map is older by six years.

PI_1: On the photos it loses its significance as an air base. The radar shows things that haven't been used for some time.

PI_2: Well, there is a straight patch corresponding to the landing strip on the radar. It's been cleared . . . a smooth surface. The surface doesn't have as much significance in the photos. There are some

buildings, possibly water surfaces in the cleared area.

PI_1: There are definite roads.

PI_2: Long buildings and short ones. These circular areas, they aren't high structures. Not clear that it is or was an air field. The landing surface doesn't extend down . . . that corresponds with the radar. Let's look at the radar mosaic.

PI_1: There are two very large buildings. But you can still see remnants of some type of runway. The circles look like round gas tanks.

PI_2: Stereo shows they don't have tanks on them, but they could have been pads for tanks at one time when it was an operational air base. There's a large balloon-like hangar . . . a quonset hut-type structure. The curved sides would not give much radar return, so it's not so clear on radar. Straight taxiway-type feature at one end of it. The round shapes are no longer in use.

PI_1: It's not just been abandoned, but it's been reconverted into something else. It's no longer an airport, unless it's now for helicopters or VTL craft.

PI_2: The airstrip does parallel those of this nearby airport. Their orientation is right. There is a large cleared area . . . it's still being cut. Let's look at the larger-scale photos. Where are the shadows? North goes this way. It's afternoon sun when the pictures

were taken. It's dark on the east side of this building. The building has a dark streak down the middle . . . an air vent. It's a hangar-like building. A road goes around it . . . part of it is hiding in the woods. It's good that we're working with three media -- maps, photos, and radar.

PI_1: But I don't want to cheat. The point is to tell from the radar without looking at maps or other stuff and without any biased impressions. But in water, breakwaters can look like piers. What can we get out of radar? Is it dependable?

PI_2: It's always best to work with more than one medium.

PI_1: But if you're going to have computers doing the interpretation for you, you will not have access to other media.

PI_2: On the larger-scale photos in stereo, the road access is like a park would be, but there is no beach, no campsites, no parking lots. This is a real challenge. The building is very tall. The other one is less rounded; it has sloping sides. The circular things are platforms . . . no verticality to them. Only one has a prepared surface, like concrete.

PI_1: Or, they vary in age and use.

PI_2: There is some parking . . . a lot of vehicles. One hypothesis is a test facility of some kind. These buildings are very interesting.

The grassy plot could be used as a runway, but it is not in use now. The larger grassy plot is nearly circular. It's mowed and kept open.

PI_1: How do you know they are doing some type of testing?

PI_2: The cleared area over here looks like a dumping ground for refuse, not testing.

PI_1: There is a tower of some sort, and railroads.

PI_2: A couple of the railroad lines go right into the buildings. So they are bringing something into the buildings. That means it's a heavy industry. It could be a vehicle test facility.

PI_1: There are a lot of things stacked up on the ground.

PI_2: Several railroad cars are there . . . freight cars, not tankers or flatbeds.

APPENDIX 4

A PROTOTYPE DATA BASE FOR PHYSIOGRAPHIC REGIONS

File Name: pr

Physiographic Regions Context Sub-file

Version: July 29, 1983

Prepared by Robert R. Hoffman
Artificial Intelligence Center
US Army Engineer Topographic Laboratory

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NOTE: AS OF THIS DATE, THIS FILE INCLUDES ONLY THE CONTINENTAL UNITED STATES

NOTE: THIS FILE DOES NOT YET INCLUDE DETAILS ABOUT SOIL TYPES AND ROCK TYPES

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SYMBOL KEY:

**************** - separates the physiographic divisions
_____ - separates the physiographic provinces within divisions

N = North
S = South
E = East
W = West

plus NE, NW, SE, SW combinations

Middle = the middle sector of a State
Extreme = the extreme sector of a region within a State

Hypothetical Example Region:

SE (except extreme E) Kentucky
Middle (NE to SW) Tennessee

So, this hypothetical example region includes the SE corner of Kentucky except for the extreme E and extends into middle Tennessee going from the NE corner down to the SW corner.

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DATA BASE OUTLINE

****
pr1 North America
****
pr1.1 Laurentian Upland Division
pr1.1.1 Superior Upland Province
****
pr1.2 Atlantic Plain Division
pr1.2.1 Atlantic Coastal Plain Province
    pr1.2.1.1 Embayed Region
    pr1.2.1.2 Sea Island Region
    pr1.2.1.3 Floridian Region
    pr1.2.1.4 East Gulf Coastal Plain Region

pr1.2.1.5 Mississippi River Alluvial Plain Region
pr1.2.1.6 West Gulf Coastal Plain Region
****
pr1.3 Appalachian Highlands Division
pr1.3.1 Piedmont Province
pr1.3.1.1 Piedmont Uplands Region
pr1.3.1.2 Piedmont Lowlands Region

pr1.3.2 Blue Ridge Province
pr1.3.2.1 Northern Blue Ridge Region
pr1.3.2.2 Southern Blue Ridge Region

pr1.3.3 Valley and Ridge Province
pr1.3.3.1 Tennessee Region
pr1.3.3.2 Middle Region
pr1.3.3.3 Hudson Valley Region

pr1.3.4 St. Lawrence Valley Province
pr1.3.4.1 Champlain Region
pr1.3.4.2 Northern Region

pr1.3.5 Appalachian Plateau Province
pr1.3.5.1 Mohawk Section
pr1.3.5.2 Catskill Region
pr1.3.5.3 Southern New York Region
pr1.3.5.4 Allegheny Mountain Region
pr1.3.5.5 Kanawah Region
pr1.3.5.6 Cumberland Plateau Region
pr1.3.5.7 Cumberland Mountian Section

pr1.3.6 New England Province
pr1.3.6.1 Seaboard Lowland Region
pr1.3.6.2 New England Upland Region
pr1.3.6.3 White Mountain Region
pr1.3.6.4 Green Mountain Region
pr1.3.6.5 Taconic Region

pr1.3.7 Adirondack Province
****
pr1.4 Interior Plains Division
pr1.4.1 Interior Low Plateau Province
pr1.4.1.1 Highland Rim Region
pr1.4.1.2 Lexington Plain Region
pr1.4.1.3 Nashville Basin Region

pr1.4.2 Central Lowland Province
pr1.4.2.1 Eastern Lakes Region
pr1.4.2.2 Western Lakes Region
pr1.4.2.3 Wisconsin Driftless Region
pr1.4.2.4 Till Plains Region
pr1.4.2.5 Dissected Till Plains Region
pr1.4.2.6 Osage Plains Region

pr1.4.3 Great Plains Province
pr1.4.3.1 Glaciated Missouri Pleteau Region
pr1.4.3.2 Unglaciated Missouri Plateau Region
pr1.4.3.3 Black Hills Region
pr1.4.3.4 High Plains Region
pr1.4.3.5 Plains Boarder Region
pr1.4.3.6 Colorado Piedmont Region
pr1.4.3.7 Raton Region
pr1.4.3.8 Pecos Valley Region
pr1.4.3.9 Edwards Plateau Region

pr1.4.3.10 Central Texas Region
****
pr1.5 Interior Highlands Division
pr1.5.1 Ozark Plateaus Province
pr1.5.1.1 Springfield-Salem Plateaus Region
pr1.5.1.2 Boston "Mountains" Region

pr1.5.2 Ouachita Province
pr1.5.2.1 Arkansas Valley Region
pr1.5.2.2 Ouachita Mountains Region
****
pr1.6 Rocky Mountain System Division
pr1.6.1 Southern Rocky Mountains Province

pr1.6.2 Wyoming Basin Province

pr1.6.3 Middle Rocky Mountains Province

pr1.6.4 Northern Rocky Mountains Province
****
pr1.7 Intermontane Plateaus Division
pr1.7.1 Columbia Plateaus Province
pr1.7.1.1 Walla Walla Plateau Region
pr1.7.1.2 Blue Mountain Region
pr1.7.1.3 Payette Region
pr1.7.1.4 Snake River Plain Region
pr1.7.1.5 Harney Region

pr1.7.2 Colorado Plateaus Province
pr1.7.2.1 High Plateaus of Utah Region
pr1.7.2.2 Uinta Basin Region
pr1.7.2.3 Canyon Lands Region
pr1.7.2.4 Navajo Region
pr1.7.2.5 Grand Canyon Region
pr1.7.2.6 Datil Region

pr1.7.3 Basin and Range Province
pr1.7.3.1 Great Basin Region
pr1.7.3.2 Sonora Desert Region
pr1.7.3.3 Salton Trough Region
pr1.7.3.4 Mexican Highlands Region
pr1.7.3.5 Sacramento Region
****
pr1.8 Pacific Mountain System Division
pr1.8.1 Cascade-Sierra Mountains Province
pr1.8.1.1 Northern Cascade Mountains Region
pr1.8.1.2 Middle Cascade Mountains Region
pr1.8.1.3 Southern Cascade Mountains Region
pr1.8.1.4 Sierra-Nevada Mountains Region

pr1.8.2 Pacific Border Province
pr1.8.2.1 Puget Trough Region
pr1.8.2.2 Olympic Mountains Region
pr1.8.2.3 Oregon Coast Range Region
pr1.8.2.4 Klamath Mountains Region
pr1.8.2.5 California Trough Region
pr1.8.2.6 California Coast Range Region
pr1.8.2.7 Los Angeles Range Region

pr1.8.3 Lower California Province

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pr1 North America

****

pr1.1 Laurentian Upland Division

pr1.1.1 Superior Upland Province
dissected, glaciated rolling plains
isolated hills

N (except extreme NE) Wisconsin
NE Minesota
W Superior Michigan
Lake Superior
SW Ontario

****

pr1.2 Atlantic Plain Division

pr1.2.1 Atlantic Coastal Plain Province
broad plain rising inland
estuaries, marshes, tidal inlets, mud flats
inland ridges parallel to coast
altitudes less than 500 feet

pr1.2.1.1 Embayed Region
dissected, terraced coastal plain

S New Jersey
Long Island
Delaware
E Maryland
E Virginia
NE North Carolina

pr1.2.1.2 Sea Island Region
terraced coastal plain

SE North Carolina
E South Carolina
SE South Carolina
SE Georgia
extreme NE Florida

pr1.2.1.3 Floridian Region
marine plain
limestone bluffs
sand hills
swamps, sinks, lakes

Florida Peninsula

pr1.2.1.4 East Gulf Coastal Plain Region
belted coastal plain
coastal plain

SW Georgia
W Florida
S Alabama
Middle (W) Alabama

Mississippi (except extreme W)
W Tennessee (except extreme W)
extreme W Kentucky
extreme SE Louisana

pr1.2.1.5 Mississippi River Alluvial Plain Region
flood plain
includes the Mississippi river delta

Mississippi river valley (N to Illinois south border)
extreme W Mississippi
E Louisana
E Arkansas
W Tennessee
extreme SE Missouri

pr1.2.1.6 West Gulf Coastal Plain Region
coastal plain

W Louisana
extreme SE Oklahoma
SW Arkansas
E Texas
S Texas

****

pr1.3 Appalachian Highlands Division

pr1.3.1 Piedmont Province
rolling upland
altitudes mostly 5## to 1### feet in the south
surface slopes northeast (like the Coastal Plain Province)
altitudes below 5## feet in the north

pr1.3.1.1 Piedmont Upland Region
dissected plain
isolated, rolling hills

Middle (NE to S) Virginia
Middle (NE to S) North Carolina
W South Carolina
N Georgia (except extreme N and extreme NE)
Middle (E) Alabama

pr1.3.1.2 Piedmont Lowland Region
plain
isolated ridges

NE to Middle (W) New Jersey
SE Pennsylvania
Middle (N to S) Maryland

---

pr1.3.2 Blue Ridge Province
easternmost ridge of the Appalachian highlands
maximum altitudes above 5### feet

pr1.3.2.1 Northern Blue Ridge Region
dissected mountains

Middle (NE to SW, except extreme SW) Virginia
Middle (N to S, west of pr1.3.1.2) Maryland

pr1.3.2.2 Southern Blue Ridge Region

subdued mountains

Middle (SW) Virginia
W North Carolina
extreme E Tennessee
extreme NE Georgia

---

pr1.3.3 Valley and Ridge Province
parallel valleys and mountainous ridges
altitudes mostly between 1### and 3### feet, lower in the south
in the south is like the Coastal Plain and Piedmont Prov

pr1.3.3.1 Tennessee Region
even-crested stratified mountains
belts of valleys

extreme SW Virginia
NE to S (except extreme E) Tennessee
NW Georgia
Middle (NE) Alabama

pr1.3.3.2 Middle Region
even-crested stratified mountains
belts of valleys

S New York
extreme NW New Jersey
Middle (E to S) Pennsylvania
W (except extreme W) Maryland
W (except extreme SW) Virginia
E West Virginia

pr1.3.3.3 Hudson Valley Region
glaciated plain
folded strata

Hudson River valley
Middle (E) New York

---

pr1.3.4 St. Lawrence Valley Province
rolling lowland
altitudes below 5## feet

pr1.3.4.1 Champlain Section
glaciated rolling upland
glacial plain

extreme NW Vermont
extreme N New York

pr1.3.4.2 Northern Region
plain
isolated rock hills

S St. Lawrence river valley
SE Ontario
NE New York

---

pr1.3.5 Appalachian Plateau Province
plateau
mostly 2### to 3### feet
slopes west

deeply incised by winding stream valleys
considerable local relief
steep hillsides

pr1.3.5.1 Mohawk Region
dissected glaciated plateau
rolling topography

Middle (NW to Middle) New York

pr1 3.5.2 Catskill Region
glaciated mountainous plateau

Middle (S) New York

pr1 3.5.3 Southern New York Region
glaciated plateau
moderate relief

S New York
NE Pennsylvania
NW Pennsylvania
NE Ohio

pr1.3.5.4 Allegheny Mountain Region
plateau
strong relief
open folds
some mountains

Middle (NE to SW) Pennsylvania
NE West Virginia

pr1.3.5.5 Kanawha Region
mature plateau
strong relief

Middle (N) to SW Pennsylvania
SE Ohio
W West Virginia
E (except extreme SE) Kentucky

pr1.3.5.6 Cumberland Plateau Region
dissected plateau
moderate relief

Middle (SE) Kentucky
Middle (N to S) Tennessee
N (except extreme NW) Alabama

pr1.3.5.7 Cumberland Mountain Region
high plateau
high mountain ridges
eroded open folds

extreme SE Kentucky

---

pr1.3.6 New England Province
mostly hilly upland
altitudes below 1500 feet
locally mountainous with altitudes above 5000 feet
irregular and rocky coast

pr1.3.6.1 Seaboard Lowland Region
eroded glaciated plains
isolated hills

Maine coast
extreme SE New Hampshire
E Massachusetts

pr1.3.6.2 New England Upland Region
dissected glaciated plain
isolated hills

N Maine
NE to SW Maine
S New Hampshire
E Vermont
W (except extreme W) Massachusetts
Connecticut
Rhode Island
extreme SE New York
N New Jersey

pr1.3.6.3 White Mountain Region
glaciated mountains

SW Maine
N New Hampshire

pr1.3.6.4 Green Mountain Region
glaciated mountains
linear ranges
subdued plateaus

Middle (N to S) Vermont

pr1.3.6.5 Taconic Region
dissected glaciated mountains
folded strata

SW Vermont
extreme W Massachusetts

---

pr1.3.7 Adirondack Province
mountains rising to more than 5000 feet
subdued mountains
dissectd glaciated plain

NE New York

****

pr1.4 Interior Plains Division

pr1.4.1 Interior Low Plateau Province
plateaus
less than 1000 feet
rolling uplands with moderate relief

pr1.4.1.1 Highland Rim Region
moderate relief plain

Middle (S) Kentucky
W Kentucky

Middle (N to S) Tennessee
Middle (S) Indiana

pr1.4.1.2 Lexington Plain Region
uplifted moderately dissected plain

Middle (N) Kentucky

pr1.4.1.3 Nashville Basin Region
uplifted moderately dissected plain

Middle Tennessee (Nashville area)

---

pr1.4.2 Central Lowland Province
vast plain
elevations 5## to 2### feet
intensive agriculture

pr1.4.2.1 Eastern Lake Region
dissected, glaciated plain
hills with asymmetrical slopes
moraines, lakes

S Ontario
Lake Ontario, Lake Erie, Lake Huron, Lake Michigan, Georgian Bay
E Wisconsin
Michigan (all but the W portion of Superior Michigan)
NE Ohio
N Indiana
NE Illinois

pr1.4.2.2 Western Lake Region
glaciated plain
moraines, lakes

E North Dakota
Middle (N) North Dakota
Minnesota (except NE and extreme SE)
E South Dakota
Middle (N) Iowa

pr1.4.2.3 Wisconsin Driftless Region
dissected plateau and lowland
glacial outwash

extreme SE Minnesota
extreme NE Iowa
Middle (W) Wisconsin

pr1.4.2.4 Till Plains Region
till plains

Middle (N) Ohio
W Ohio
Middle (E to W) Indiana
SE Indiana
SW Indiana
Illinois (except extreme NE and extreme NW)
extreme Middle (S) Wisconsin

pr1.4.2.5 Dissected Till Plains Region

dissected till plain

Iowa (except Middle (N))
N Missouri
extreme E Nebraska
NE Kansas

pr1.4.2.6 Osage Plains Region
rolling plains
large streams

Middle (W) Missouri
SE Kansas
Middle (S) Kansas
Middle (N) Oklahoma
Middle (NE to SW) Oklahoma
Middle (N) Texas

---

pr1.4.3 Great Plains Province
western extension of the Central Lowlands Province
rises westward from 2000 to 5000 feet

pr1.4.3.1 Glaciated Missouri Plateau Region
glaciated plateau
isolated mountains

Middle (N to S) South Dakota
NW to Middle (S) North Dakota
NE Montana
Middle (N) Montana

pr1.4.3.2 Unglaciated Missouri Plateau Region
terraced plateau
local badlands
isolated mountains

SW North Dakota
W South Dakota
extreme NW Nebraska
NE Wyoming
SE Montana

pr1.4.3.3 Black Hills Region
dissected dome mountains

Middle (SW) South Dakota
extreme NE Wyoming

pr1.4.3.4 High Plains Region
broad plains

Nebraska (except extreme Middle (S) and extreme NW)
SE Wyoming
extreme E Colorado
W Kansas
W Oklahoma ("panhandle")
Middle (NW) Texas
extreme E New Mexico

pr1.4.3.5 Plains Border Region
dissected plateau

Middle (extreme S) Nebraska
Middle (N to S) Kansas

pr1.4.3.6 Colorado Piedmont Region
elevated plateau

E (except SE and extreme E) Colorado

pr1.4.3.7 Raton Region
trenched plain
bordered by dissected, lava-capped plateaus and buttes

SE (except extreme E) Colorado
NE (except extreme E) New Mexico

pr1.4.3.8 Pecos Valley Region
plain

E (except extreme E and extreme NE) New Mexico
Pecos River valley
Middle (W) Texas

pr1.4.3.9 Edwards Plateau Region
moderate relief plateau

Middle (SW) Texas

pr1.4.3.10 Central Texas Region
eroded plateau

Middle Texas

****

pr1.5 Interior Highlands Division

pr1.5.1 Ozark Plateaus Province
rolling upland
mostly above 1000 feet

pr1.5.1.1 Springfield-Salem Plateaus Region
plateau

S (except extreme SE) Missouri
extreme N Arkansas
NE Oklahoma

pr1.5.1.2 Boston "Mountains" Region
plateau
strong relief

Middle (NW) Arkansas

---

pr1.5.2 Ouachita Province
like the Valley and Ridge Province
altitudes 500 to 2000 feet

pr1.5.2.1 Arkansas Valley Region
plain
residual ridges

Middle (NW) Arkansas

Middle (E) Oklahoma

pr1.5.2.2 Ouachita Mountains Region
mountains
folded strata

Middle (SW) Arkansas
SE (except extreme SE) Oklahoma

****

pr1.6 Rocky Mountain System Division

pr1.6.1 Southern Rocky Mountains Province
Series of mountain ranges and intermontane basins
ranges trend north
includes higher parts of the continental divide
altitudes of 5### to more than 14,### feet

Middle (SE) (except extreme SE) Wyoming
Middle (N to S) Colorado
Middle (N) New Mexico

---

pr1.6.2 Wyoming Basin Province
elevated plains
isolated low mountains
elevated semiarid basins
altitudes mostly between 5### and 7### feet

SW (except extreme SW) Wyoming
NW Colorado

---

pr1.6.3 Middle Rocky Mountains Province
complex mountains and intermontane basins
altitudes mostly 5### to 12,### feet

extreme Middle (S) Montana
NW Wyoming
extreme W Wyoming
extreme SE Idaho
NE Utah
Middle (N) Utah

---

pr1.6.4 Northern Rocky Mountains Province
dissected, linear, blocky moutnains
long, straight valleys
altitudes mostly between 4### and 1#,### feet

Rocky Mountain Trench
W Montana
NE Washington
N (except extreme W) Idaho

****

pr1.7 Intermontane Plateaus Division

pr1.7.1 Columbia Plateaus Province
plateaus of lava flow
altitudes below 5### feet
semiarid
includes the Columbia and Snake Rivers

pr1.7.1.1 Walla Walla Plateau Region
rocky plateau

incised valleys

SE Washington
extreme Middle (NW) Idaho
Middle (N) Oregon

pr1.7.1.2 Blue Mountain Region
complex mountains
dissected volcanic plateaus

NE Oregon

pr1.7.1.3 Payette Region
plateaus
broad alluvial terraces

SE Oregon
SW Idaho
extreme Middle (N) Nevada

pr1.7.1.4 Snake River Plain Region
lava plateau

E (except extreme E) to Middle (S) Idaho
extreme NE Nevada

pr1.7.1.5 Harney Region
lava plateau
recent volcanism

Middle Oregon

---

pr1.7.2 Colorado Plateaus Province
highest plateaus on the continent
altitudes above 5### feet and up to 11,### feet
deep canyons
includes the Colorado River

pr1.7.2.1 High Plateaus of Utah Region
high, blocky, terraced plateaus
lava capped

NE (except extreme NE) Utah

pr1.7.2.2 Uinta Basin Region
dissected plateaus
strong relief

Middle (NE) Utah
Middle (NW) Colorado

pr1.7.2.3 Canyon Lands Region
canyoned plateaus

SE Utah
SW Colorado

pr1.7.2.4 Navajo Region
plateaus
little relief

NW New Mexico

NE Arizona

pr1.7.2.5 Grand Canyon Region
high blocky plateaus

Grand Canyon Trench
NW to Middle Arizona

pr1.7.2.6 Datil Region
lava flows
volcanic necks

Middle (W) New Mexico
Middle (E) Arizona

---

pr1.7.3 Basin and Range Province
elongate blocky mountains
trending north
desert basins
pattern more irregular in the south
altitudes from below sea level (Death Valley) to more than 12,### feet
relief between mountains and adjoining basins generally no more than about 5### feet
most basins to the north are without visible drainage patterns

pr1.7.3.1 Great Basin Region
isolated ranges of dissected block mountains
desert plains

SE (except extreme E) Idaho
W Utah
Nevada (except extreme NE and extreme S)
Middle (E) California
NE California
Middle (S) Oregon

pr1.7.3.2 Sonoran Desert Region
widely separated short mountain ranges
desert plains

SE California
SW Arizona

pr1.7.3.3 Salton Trough Region
desert alluvial slopes and delta plains

Gulf of California
Middle (S) California

pr1.7.3.4 Mexican Highlands Region
isolated ranges of dissected block moutnains
desert plains

SE to Middle (W) Arizona
SW to Middle New Mexico

pr1.7.3.5 Sacramento Region
block mountains
tilted strata
block plateaus

Middle (S) New Mexico

extreme W Texas

****

8 Pacific Mountain System Division

pr1.8.1 Cascade-Sierra Mountain Province
northerly trending mountains
Cascades are a series of volcanos
Sierra-Nevadas are a blocky mass of granite with steep eastern slope and a long gentle western slope
some altitudes more than 14,000 feet
humid western slopes
arid eastern slopes

pr1.8.1.1 Northern Cascade Mountain Region
alpine summits, same elevation
high volcanic cones

Middle (N) Washington

pr1.8.1.2 Middle Cascade Mountain Region
alpine summits, same elevations
high volcanic cones

Middle (S) Washington
Middle (NE to SW) Oregon

pr1.8.1.3 Southern Cascade Mountain Region
eroded volcanic mountains
no distinct ranges

Middle (N) California

pr1.8.1.4 Sierra-Nevada Region
blocky mountain range, tilted west
alpine peaks, same elevation
alpine peaks near the east side of the range

Middle (N to S) California

---

pr1.8.2 Pacific Border Province
coastal mountain ranges
altitudes mostly below 2000 feet
separated from the high Cascade-Sierra Province by troughs less than 500 feet in altitude

pr1.8.2.1 Puget Trough Region
coastal lowlands

Middle (NW to SW) Washington
Middle (NE) Oregon

pr1.8.2.2 Olympic Mountain Region
local alpine peaks, equal elevation

extreme NW Washington

pr1.8.2.3 Oregon Coast Range Region
uplifted dissected plain
isolated igneous hills

SW Washington

extreme W Oregon

pr1.8.2.4 Klamath Mountains Region
uplifted dissected plain
extensive ranges of hills

extreme SW Oregon
NW California

pr1.8.2.5 California Trough Region
low fluvial plains

Middle (NW to SW) California

pr1.8.2.6 California Coast Range Region
parallel ranges and valleys
faulted rounded crests

extreme W (except NW and extreme SW) California

pr1.8.2.7 Los Angeles Range Region
narrow ranges
broad fault blocks
alluvial lowlands

SW California

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pr1.8.3 Lower California Province
dissected, westward sloping granite uplands
northern end of the granite ridge forming the Baja California peninsula

extreme SW California

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END OF FILE

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APPENDIX 5

INSTRUCTIONS FOR RECORDING ANALYSES OF TOUGH CASES

We would like your help on a project that is aimed at describing the photo interpreter's reasoning processes. We are especially interested in the reasoning that is applied to "tough cases," where a terrain analysis is especially challenging or difficult, or where terrain shows novel or unusual features. A case may be especially difficult because its coverage falls outside your areas of experience or expertise. It may be difficult because it is especially complex or because it involves a challenging set of landforms or cultural features. Whatever the situation, we hope to understand how photo interpreters reason in dealing with problems they have to solve.

Expertise in any domain is not something that should be wasted. We hope that you and your colleagues will assist us by recording any discussions you may have in which reasoning is manifested. If you encounter a challenging or tough case, please record your deliberations. You should analyze the imagery at hand according to your usual procedure, but think out loud as you do it. Describe what you see and what you deduce, what hypotheses you formulate, and the things you look for to confirm or contradict the hypotheses. Simply conduct your usual analytical procedure while thinking out loud.

If you are analyzing imagery in the context of a group discussion, please conduct the discussion as you ordinarily would.

When you encounter a tough case during an analysis or discussion, simply start the tape recorder and continue your analysis as you ordinarily would. Try not to break the flow of your curiosity.

At the end of your analysis or discussion, indicate on the tape:

(1) the nature of the target (e.g., radar, photos, etc.),

(2) the location or physiography of the region, if known,

(3) the nature of the contextual information available (e.g., topographic maps, geological maps, etc.),

(4) The initials of each person involved in the discussion and each one's degree of expertise (Experienced, Highly Experienced, or Expert),

(5) The date and time.

All data will be regarded as strictly confidential. The transcripts will be coded in terms of logical-propositional content for comparison with other data and for entry into a data base. However, all individuals involved will remain anonymous. After the tapes have been transcribed, they will be erased. In order to analyze the data, we may request access to the imagery that you were studying.

Please ask us if you have any questions about the procedure.

Thank you very much for your help.

END

FILMED

5-84

DTIC