APPENDIX C.

PHOTO INTERPRETATION LOGIC SHEETS

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P. I. LOGIC SHEETS

J. N. Rinker and P. A. Corl

These sheets contain a list of specific pattern elements associated with the factors of landform, drainage, erosion, deposition, vegetation, cultural, tones and texture, and special. For the present, work is concentrating on patterns associated with landform and drainage. For each pattern element, the dominant and supportive characteristics, or indicators, that are used to identify the pattern element are listed. As many as possible of these characteristics will be documented with Air Photo Indicator Sheets of the type shown in appendix B. In the column headed by the word "Indicator," there are entries in the form of numbers, letters, and combinations of the two. A four digit number refers to a completed Air Photo Indicator Sheet that illustrates the item in question. The letter groups indicate sources for and specific areas of photography. In these instances the sources are either U.S. Department of Agriculture, ASCS, or USGS. Specific information as to location, type, and designation of all Federal agency photography can be had. Symbols could also be added that relate a pattern element to specific data base items, such as in DLMS, TTPDB, etc. On this set of P.I. Logic Sheets, each dominant and supportive characteristic is judged in relation to its capability of being detected and identified by stereoscopic photography, monoscopic photography, interactive systems, and automatic procedures. A plus mark (+) indicates that it can be done. An L indicates a limitation, i.e. it can be done, but neither consistently nor reliably. A question mark indicates uncertainty, and a zero indicates that it cannot be done. The evaluation of the interactive column was dropped because it is redundant. If the interactive system uses stereo photos, then the symbols in the stereoscopic column apply. If the interactive system uses monoscopic viewing, then the symbols in the monoscopic column apply. In most instances the column identified as automatic will be filled in with zeros. At a later time the evaluation columns will be removed, which will provide more room for comments and for listing other information, such as applicable data base elements from DLMS, etc.

Because these sheets identify specific pattern elements, they can serve as guides to the development of the logic and questions associated with a knowledge-based system. Most of the questions in the sample knowledge-based system in appendix I were developed from the material in these P.I. Logic Sheets.

CLASS	PATTERN INDICATORS: DOMINANT	PATTERN INDICATORS: SUPPORTIVE	INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Flat surface								
A. Horizontal, or nearly so	Visual impression			+	0	0	0	Flat to the extent that the plain does not need other adjectives to describe it, i.e. relief variations are insignificant at the scale being considered
		Uniform tone throughout, no highlights or shadows		+	+			
		Uniform square road grid plus uniform square field patterns		+	+			This indicates only that if there is relief, it is not enough to force adjustment of the road net or cropland.
		Curvilinear and linear tone streaks	0043	+	+			Among the flatter surfaces available are the water deposited materials, e.g. flood plains, terraces, etc. An arcuate, or curvilinear tone pattern is frequently found on such deposits.
		Lack of a well-defined directional drainage pattern		+	L			
								NOTE: Basalt flows form plains (mesas, and plateaus). Surface is dark gray to black in photo tone, and sometimes speckled with light spots. Drainage is mostly internal. General absence of cultural patterns.
B. Tilted	Visual impression			+	0	0	0	
		Supportive elements above also apply here						Tilt might not be enough to alter road and cultural patterns.
		Parallel drainage pattern	0032	+	+			
II. Uneven surface								
A. Rolling								
1. Widely spaced elongate hills: straight, parallel, gently rounded ridges 30-40 miles long (50-65 km) and some 2 miles apart (about 3 km). They have a windswept, streamlined appearance.	Visual impression			+	0	0	0	To see the overall pattern, small scale imagery is needed, i.e. 1:60,000 and smaller, or a photomosaic. Suggestive of wind-deposited silts.
		Highlight and shadow, if present, will have diffuse gradients		+	+			Supportive patterns of road and field adjustment, etc., are seldom present. At times, in small scale imagery, there is a poorly defined streaked appearance to the landscape.
2. Closely spaced elongate hills: gently rounded, parallel, straight ridges which are usually less than 1 mile (1.65 km) in length, and closely spaced. One end is frequently more blunt and steeper than the other end.	Visual impression		0055	+	0	0	0	Probability of glacial action and the formation of drumlins, i.e. hills of compacted, nonsorted glacial till. Long axis of the hills is parallel to the direction of ice movement. Blunt ends faced the glacier.
		Highlight and shadow, if present, will have diffuse gradients		+	+			

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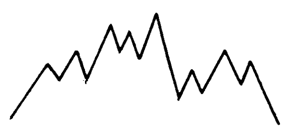
CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
II. Uneven surface	DOMINANT	SUPPORTIVE						
A. Rolling 2. Closely spaced elongate hills (Cont'd)		Long field patterns, in contrast to a uniform square road grid	0055	+	+			Relief not enough to require adjustment of the road net, but sufficient to cause adjustment of the fields.
		Some parallelism in the drainage pattern		+	L			
								NOTE: Old, stabilized, transverse dunes are also lineal and usually gently rolling. These ridge-like hills are usually curvilinear, interconnected, and form a ridge-like pattern.
III. Pitted surface A. Shallow, rounded, nonuniform, and frequently wandering depressions. These are usually nonsymmetrical, but frequently show some alignment.	Visual impression		Possible indicator counties: BFB BFI BFK BFP BFS BFT	+	0	0	0	Characteristic of a pitted glacial outwash plain, i.e. a flat to gently undulating terrain with a pitted appearance and showing elongated shallow depressions and elongated slight rises as remnants of old current marking. The pitted appearance is caused by the numerous slight depressions which are also referred to as infiltration basins. The depressions have an area about the size of a barn. Relief is not enough to cause adjustment of the vegetation or cultural patterns.
		Unconnected and poorly developed drainage pattern		+	L			Drainage is mostly by internal means. Streams with well-defined gully systems are seldom found.
		Light gray overall photo tone with a speckled appearance		+	+			The speckled characteristic is caused by the darker tones of the depression and current markings. The darker tones represent a moister and probably a finer grained soil.
B. More or less circular and symmetrical depressions. The depressions tend to be bowl-like, or funnel-like, and have different depths. Some can contain water. Alignment noticeable.	Visual impression		0019	+	0	0	0	Typical of a youthful limestone plain, showing an early development of sinkholes, many of which show obvious alignment with fractures. Such a surface is also referred to as a gently undulating surface.
		Discontinuous drainage pattern containing circular, point, or short lineal drains, and segments of branched drainage	0022	+	L			

CLASS	PATTERN INDICATORS: DOMINANT	PATTERN INDICATORS: SUPPORTIVE	INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
III. Pitted surface								
B. More or less circular and symmetrical depressions (Cont'd)		Highlight and shadow	0019	+	+			Only if the sinks are sufficient developed.
		Tone changes of dry, and water-filled depressions	0022	L	L			At times the water is shallow and so silt laden that its tones blend with the surrounding soil.
		Road adjustment		+	+			Occurs only where the sinkhole is too large to fill, and the road must therefore be curved around it.
		Vegetation pattern of isolated clumps of trees scattered throughout the fields		+	+			In farming areas, trees and shrubs can be left standing in the sinkholes, or growing around the sinkholes to serve as a barrier. If the land supports a closed canopy tree cover, the pitted characteristic can be missed, except for unusually large sinkholes.

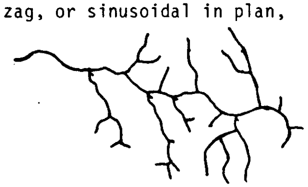
CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
A. Irregular in plan and elevation, no dominant or consistent arrangement, or symmetry,	Visual impression			+	0	0	0	Irregularity and lack of symmetry are more associated with igneous and metamorphic rocks than with sedimentary units.
		Highlight and shadow tones lack symmetry and are irregular		+	+	?	0	
hilltops not concordant, i.e., no carry-over of elevations between hilltops.	Visual impression			+	0	0	0	
1. Sharply angular, jagged profiles,	Visual impression		AXL	+	0	0	0	Sharp angularity is suggestive of a hard resistant material. Coupled to angularity, lack of symmetry, and lack of concordancy, it is indicative of extrusive, fine-grained igneous rocks, or metamorphic rocks of igneous origin.
		Highlight and shadow tones are contrasty, well-defined, and have sharp boundaries	AXL	+	+	?	0	
and contours.	Visual impression		AXL	+	L	0	0	
		Drainage plan shows angularity in entrances and in courses. Pattern tends to be dendritic.	AXL	+	L	?	0	
2. Rounded angularity in profile, with "lumpy" surfaces, and 	Visual impression		0024	+	0	0	0	Some angularity can be seen because of fracture faces. Most surfaces, however, show a roundedness, with a superposed "lumpy" look, as opposed to frequent sharp interruptions. This pattern is indicative of coarse-grained intrusive rocks. These usually have a light uniform photo tone.
rounded angularity to the contours,	Visual impression		0024	+	L	0	0	
and numerous vertical factures and some curvilinear joints.	Visual impression			+	+	?	0	
a. Pinnacles and needles common.	Visual impression		GSVE-4-43, 44	+	0	0	0	Equigranular granitic rock.
b. Without pinnacles or needles. Surface is blocky and choppy.	Visual impression		0025	+	0	0	0	Very coarse, nonequigranular granitic rock.
NOTE: In moist tropical areas, granitic rocks undergo a type of in-place weathering that can extend								

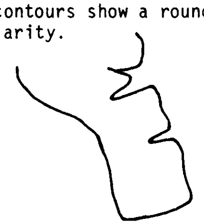
P.I. LOGIC FACTOR/CLASS VS. INDICATOR

FACTOR LANDFORM - HILLS AND MOUNTAINS

CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
many meters (25-30) into the rock. This material is soft, and does not develop hard, angular shapes.								
B. Some regularity in plan and elevation. Closely spaced peaks and branching ridges, with successively smaller ridges projecting from predecessors.	Visual impression		BOI	+	L	0	0	Branching ridge-like extensions are suggestive of sedimentary rocks. The branching, which can be dendritic-like, suggests homogeneity on an areal basis, as well as a lack of structural control. It would also indicate that the sedimentary beds are relatively horizontal.
		Highlight and shadow units become progressively smaller.	BOI	+	+	?	0	
Many ridge sections are concordant,	Visual impression		BOI	+	0	0	0	Concordancy is indicative of sedimentary units.
and have some symmetry to cross-section profiles.	Visual impression			+	0	0	0	Cross sectional symmetry that pertains through much of the length of a ridge is indicative of sedimentary rocks.
		Highlight and shadow tones on opposite sides of ridge have same approximate length.		+	+	?	0	
1. Sharply crested, with angularity in cross section profiles,	Visual impression		BOI	+	0	0	0	Sharp angularity can be indicative of a hard resistant material, or of a relatively soft and easily erodible material subjected to heavy seasonal rains. A fine, closely spaced network of ridge-like hills suggests the latter. Check drainage net for intensity of gully development. A fine or closely spaced net is indicative of an impermeable material that is easily eroded, such as clay shales, silty clay shales, etc.
		Highlight and shadows are well defined and have sharp boundaries.		+	+	?	0	
and in contours.	Visual impression		BOI	+	L	0	0	

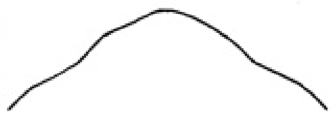
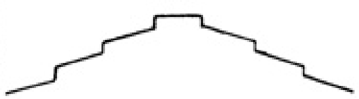
P.I. LOGIC FACTOR/CLASS VS. INDICATOR FACTOR LANDFORM - HILLS AND MOUNTAINS

CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
C. Branching ridges and finger-like extensions that are nonlineal, zig-zag, or sinusoidal in plan,	Visual impression			+	L			Ridges and branching extensions are characteristic of sedimentary rocks. The branching, dendritic-like pattern suggests that the beds are relatively flat-lying. Check for indicators of bedding.
		Highlight and shadow tones		+	+	?		
		Drainage plan outlines ridge development		+	L	?		
and with symmetrical cross section profiles that show concordancy to the ridge tops.	Visual impression			+	0			Both a symmetrical cross section and concordancy are suggestive of sedimentary rocks.
		Highlights and shadows on opposite side of ridges have same approximate length.		+	+			
1. Smooth side slopes	Visual impression			+	0			Smooth slopes are indicative of thinly bedded units.
		Smooth, uniform tone		+	+			
and uniform gradient. Sides of ridges have a relatively uniform gradient between the transition zones at the top and bottom. In length, it can range from being a significant part of the slope, to being an insignificant part of the slope.	Visual impression			+	0			The uniform, straight gradient is most associated with thinly bedded granular materials such as sandstone, silty sandstone, etc. These materials can be interbedded with clay shale to a certain extent and still retain this landform characteristic. In this case the beds would probably be fine sand, sandy silt, and silty clay. As the amount of cohesive material increases, i.e., clay, the ridgelines become more rounded, valley bottoms round out, and the length of the straight line gradients decreases.

CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected hills	DOMINANT	SUPPORTIVE						
C. Branching ridges 1. Smooth side slopes	Visual impression			+	0	0	0	Sharply rounded crests and contours are indicative of relatively hard units. The long, straight gradients of side slopes suggest the probability that the beds are sandstone. It is also possible for the hill to be made up of interbedded sandstone and shale, but with a landform as described here the shale would probably be a silty, sandy shale, and would not be present in large amounts.
a. Sharply rounded angularity to cross section profiles, i.e. ridges have sharply rounded crests, and bottoms of the V-shaped valleys are sharply rounded. Slopes have a long, straight gradient with little, or no change of slope near the bottom,	Visual impression		0070	+	0	0	0	
		Highlight and shadow tones are well defined, with straight boundaries where they fall on the mid-slopes		+	+			
								NOTE: If the sandstone is soft, or is calcareous, the contours become more rounded at junctures between tributaries and collectors. In very soft materials, the rounding is pronounced.
and contours show a rounded angularity. 	Visual impression			+	L	0	0	
b. Rounded profiles,	Visual impression			+	0			The roundedness is indicative that the ridges contain some fraction of a cohesive material in addition to the granular fraction.
		Highlight and shadow units do not have sharp edges and boundaries, i.e., edges are somewhat diffuse	(shaley part)	+	+			
with fairly gentle slopes that have at least some section of uniform straight gradient between the top and bottom transitions, 	Visual impression			+	0			The straight midsection slope is indicative of the presence of a granular component. Thus, this type of landform is frequently associated with a thinly interbedded series that contains shaley members, e.g., silty sandstone and silty shale. The rounded crests and lessening of the straight-line portion indicates that more clay is present than in the previous landform.

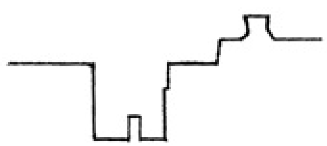
CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
C. Branching ridges 1. Smooth side slopes b. Rounded profiles (Cont'd)								
and rounded contours.	Visual impression		0060	+	L			The degree of roundedness of the contours can vary. The different levels of the hills are in response to variation in hardness of the beds.
c. Very gently rounded profiles,	Visual impression	Highlight and shadow tones have diffuse boundaries	0067	+	0			This degree of roundedness indicates the presence of a very soft and cohesive material, i.e., clay soils or soft clay shale beds.
and contours, with little or no straight mid-slope gradients. The top and bottom transition zones merge into each other, giving a saucer shape to the depressions between the hills.	Visual impression			+	0			

CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
C. Branching ridges (Cont'd)								
2. Smooth side slopes	Visual impression		0049	+	0			This is indicative that the interbedded units are composed of limestone and shale. The upper steeper portion of the slope represents in place rock. The lower and less steep slope is an accumulation of colluvial material over the rock units. This is a very subtle slope change, not easily perceived on the ground. It is apparent in stereoscopic imagery because of vertical exaggeration (six- to eight-inch focal length lenses).
with compound gradient. The hillsides are composed of two relatively straight sections of different slopes, which gives the appearance to the hill that it flares out in the bottom one-third to one-half. 	Visual impression			+	0			
Contour lines can have straight, curved, and arcuate, or scallop-like sections. Changes in direction are most frequently rounded.	Visual impression		RM, RN	+	L			The presence of limestone beds will cause a rounding to the contour intersections of tributaries and collectors. As the amount of limestone, or calcareous fraction, increases, the rounding becomes more pronounced, as would also be the case with soft, or calcareous sandstones. The contour can become arcuate, or scallop-like.

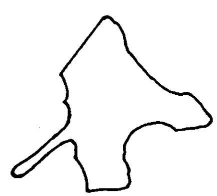
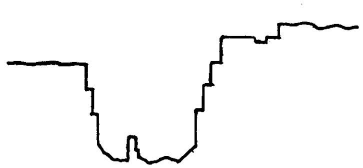
CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
C. Branching ridges (Cont'd) 3. Interrupted slopes a. Smooth slopes changes without steps, or vertical breaks,	Visual impression			+	0	0	0	Interbedded series of sedimentary rocks. Beds are thick enough to show slope changes that correspond to the different materials, but the materials are relatively soft, i.e., none are hard enough to support vertical faces. In places however, a single unit might be resistant enough to cause an abrupt slope change. Indicative of clay shale, soft sandstone, calcareous sandstone, soft limestone, etc.
 Profile across ridge		Contour-like banding of tones. No highlight and shadow tones that would indicate steep breaks.		+	+	+	0	The tones represent different rock types. Usually clay shales show as a darker tone, and limestones and sandstones as lighter tones. If some vegetation has developed, it will more frequently be associated with the sandy units than with the clays, or the limestones. Dense vegetation obscures both the slope changes and tone changes. The vegetation can show a banded appearance because of changes in species composition, height, etc.
and with rounded, arcuate, and at times, scallop-like contours.	Visual impression			+	0	0	0	The fact that the materials are soft, as indicated by the type of slope change, would also lead to the development of rounded contours.
		Rounded, and arcuate contour-like bands of tones.		+	+	+	0	
b. Stepped slope changes. The profile across a ridge shows sloping faces alternating with vertical faces.	Visual impression			+	0	0	0	Indicates that some units are hard and resistant to erosion, and can maintain a vertical face. The sloped areas indicate the presence of a softer material, a clay shale, soft sandstone, or soft limestone. The vertical faced units represent a more resistant material, such as a hard sandstone, or a hard limestone. Where thick beds are present, the terrain takes on a blocky appearance.
 Profile across ridge		Presence of sharply defined shadow tones.		+	+	+	0	

P.I. LOGIC FACTOR/CLASS VS. INDICATOR FACTOR LANDFORM - HILLS AND MOUNTAINS

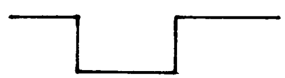
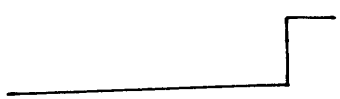
CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
C. Branching ridges 3. Interrupted slopes b. Stepped slope changes (Cont'd)								
In plan, the stepped units will have more angular contours than the units with gently sloping faces.	Visual impression			+	0	0	0	
4. Blocky, with some discontinuity. Blocks can be small and isolated, or extensive. Elevation difference between levels can be tens of meters.	Visual impression	Highlight and shadow tones are well defined		+	0			Indicative of massive beds of sedimentary rocks, usually sandstone and limestone. In some cases can be beds of columnar basalt.
a. Blocky profile with blocks and branches of different widths. Some branches are extensive, yet thin. Fin-like projections and pinnacles can also be found.	Visual impression		AIG	+	0			This landform is found in arid and subhumid regions and is associated with massive beds of sandstone and limestone. In dry areas it is more difficult to identify these components than it is in more humid regions where the beds tend to show characteristics of the pure material, especially the soluble nature of limestone. Surfaces of higher levels are carved, by ablation, into various shapes, including concave faces. The nature of the lowest level, being a drainageway, is also influenced by running water. Indications of bedding usually evident on slope faces. If sandstone, an accumulation of eroded material in the form of smooth-toned talus material can be found at the bases of many faces. This is a granular, or sandy, material than can spread far out into the flats (check for V-shaped gullies). Vegetation, if present, usually associated with sandstone.
		Highlights and shadow tones		+	+			
Slopes between levels range from steep through vertical, to concave.	Visual impression			+	0			
Surfaces of the different levels can be small or extensive.	Visual impression			+	+			
Larger surfaces usually show irregularities associated with dissection, i.e., erosion by running water.	Visual impression			+	0			
		Tones, highlights and shadow		+	+			

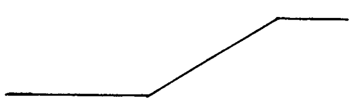


Profile

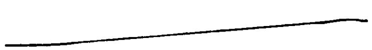
CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
C. Branching ridges 4. Blocky, with some discontinuity a. Blocky profile with blocks and branches of different widths.(Cont'd)								
Contours are irregular and contain sections that are linear, angular, rounded, arcuate, and scallop-like.  Contour	Visual impression		AIG	+	L			A function of composition and the forms of weathering and erosion. In sandstone, windborne sand particles can carve exposed faces into contorted shapes, including concave arcs, i.e., the curve of the arc goes inward. Although this might be found in limestone, it is more consistently associated with sandstone. Panchromatic photo tones of sandstone are very light.
b. Blocky profile, with box-like valleys and gullies. Limited branching. Terrain is a dissected plain. Rims are very sharp and angular, and walls are vertical. Top surfaces usually show a lineal pattern of roughness, which is rounded in cross section.	Visual impression		AAR	+	0			Typical of lava flows of basalt (columnar). Panchromatic photo tones are dark gray.
		Highlight and shadow		+	+			
A gentler slope is usually found along the base of cliffs.	Visual impression		AAR	+	0			Because of the structure of columnar basalt (resembles a packed bunch of hexagonal wooden pencils), exposed faces erode by columns falling to the base level, where they accumulate as a rough blocky talus.
Circular depressions are frequently found on flat surfaces.  Profile	Visual impression			+	0			Banding is usually evident where several flows have accumulated on top of each other, and with sufficient time between flows to weather the older surface.
		Highlight and shadow			L			

CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Connected Hills	DOMINANT	SUPPORTIVE						
C. Branching ridges 4. Blocky, with some discontinuity b. Blocky profile, with box-like valleys and gullies. (Cont'd)								
The plan view shows limited branching, although extensions and isolated remnants can be found. Contours are not as irregular as in the previous group, and show straight sections as well as rounded angularity and roundedness. The arcuate or scallop-like pattern is absent.	Visual impression		AAR	+	L			
		Highlight and shadow		+	+			
D. Complex interconnected ridges								
1. Plan view resembles a honeycomb structure. Cells can be relatively shallow depressions with gentle slopes, or very deep pits with vertical walls. Ridgetops can be rounded, sharp, and also knobby.	Visual impression		0019 0021	+	0			Indicative of massive beds of limestone in a moist region (temperate or tropic). The depressions, which are called sinkholes, result from the dissolution of the limestone along fractures and fracture intersections. In the youthful stage, the sinkholes appear as shallow depressions. With age the sinkholes become larger, and deeper, with the greatest relief being developed in moist tropical regions (in excess of 100 m).
		Highlight and shadow tones	0019 0021	+	+			
 Profile - youthful stage  Profile - mature stage								
Contours are usually rounded and arcuate.	Visual impression		0019 0021	+	L			

CLASS	PATTERN INDICATORS: DOMINANT	PATTERN INDICATORS: SUPPORTIVE	INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Flat Bottomed Gullies								
In general there are three basic gully cross sections that correspond to the three soil textural groups of granular soils, silty soils, and clayey soils. The shapes of the first two can be modified as a function of water flowing over the surface or of water flowing along a stratum and emerging lower down on the face.								
A. Vertical sides. Cross section profile is box-like, with a flat bottom and vertical sides.	Visual impression			+	0			Most frequently found in alluvial deposits and, at times, in loess. Is usually indicative of undercutting at the base and subsequent slumping. Can come about by draining a saturated soil that has a rapidly declining high water table caused by flooding, subsurface drainage along an impervious layer, and direct cutting by running water into a bank.
		Highlight and shadow		L	L			
 Profile								
Gradient is relatively long, gentle, and uniform, and ends in a vertical, or nearly vertical, headwall.	Visual impression			+	0			
 Gradient								
B. Steep sides. Cross section profile shows steep, but not vertical, sides.	Visual impression		0014	+	0			Characteristic of loess, i.e., wind-deposited silt. The gully walls have slopes of about 55-60°. In deeply weathered loess the upper part of the slopes tend to round off and grade smoothly into the flatland. Gullies in loessal material are also characterized by the presence of silt pinnacles, fin-like projections from the walls, and cat-steps, or terracettes.
 Profile								

CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
I. Flat Bottomed Gullies	DOMINANT	SUPPORTIVE						
B. Steep sides (Cont'd) Gully gradient is gentle, long, and ends in a steep headwall.  Gradient	Visual impression		0014					
II. V-Shaped Gullies A. Cross section profile is in the shape of the letter V.  Profile	Visual impression		0053 0054	+	0			Indicative of granular and semigranular, nonplastic, noncohesive soils, i.e., sand, gravel combinations. Semigranular indicates that silt and clay particles can be present to some extent. This gully shape can also be found in thinly bedded sandstones. NOTE: There might be a measurable relation between the width of the V, the depth of the V, and the gully length that is indicative of the particle size distribution. Not yet confirmed.
Gully gradient is short and steep.  Gradient	Visual impression		0053 0054	+	0			In purely granular material the gradient is very steep and the gully extends only a short distance. In the stereo image they tend to resemble knife-like notches. As the silt fraction increases, the gullies lose some steepness and become longer. The presence of clay fraction modifies the gradient even more. Fans can frequently be noticed at the mouths of gullies. The shorter and more humped the fan, the coarser the material in the source.

P.I. LOGIC FACTOR/CLASS VS. INDICATOR FACTOR DRAINAGE - ELEVATION (CROSS SECTION)

CLASS	PATTERN INDICATORS		INDICATOR	STEREO-SCOPIC	MONO-SCOPIC	INTER-ACTIVE	AUTO-MATIC	COMMENTS
III. Saucer Shaped Gullies	DOMINANT	SUPPORTIVE						
A. Cross section profiles are very broad with gentle side slopes that gradually and smoothly merge with the upland surface.  Profile	Visual impression		0010	+	0			Indicative of nongranular, plastic, and cohesive soils, i.e., clay, and silty clay. As the clay content increases the slopes become more gentle and the gradients longer. These gullies can be very broad in relation to the amount of water they carry.
The gradient is gentle, uniform, and long, extending well back into the upland.  Gradient	Visual impression			+	0			The gully can extend for miles, becoming less and less perceptible, until it can no longer be traced.

3

APPENDIX D.
SOIL CLASSIFICATION FOR REMOTE SENSING

A.E. Krusinger

SOIL CLASSIFICATION FOR REMOTE SENSING

Alan E. Krusinger

A draft report of the classification system and its symbology has been discussed and critiqued internally. This summary was prepared by J.N. Rinker and P.A. Corl from material extracted from the draft report.

The soils classification systems most frequently used are based on laboratory and field measurements; consequently, there has always been a problem in converting soils information derived from air photo analysis into the symbology of an existing system. Thus, there is a need for a classification system based solely on the pattern elements within stereo aerial photography, or other imagery.

Soils maps for engineering purposes are usually expressed in terms of the Unified Soil Classification System (USCS), the American Association of State Highway Officials (AASHO) system, or the Federal Aviation Administration (FAA) system. The Unified Soil Classification System was developed for the U.S. Army Corps of Engineers during World War II by Dr. Arthur Casagrande. In cooperation with the U.S. Bureau of Reclamation, this system was expanded to include embankments and foundations. The AASHO system was developed in 1931 as a Public Roads Administration soil classification system, was refined in 1942 and 1945, and then adopted by AASHO. It is the system that is most used in highway construction. The FAA system was developed in 1944 under the aegis of the Civil Aeronautics Administration (CAA), the predecessor of the FAA. This system classified soils in terms of their value as subgrade for airfield pavements. These systems are similar in that the soils are identified on the basis of (1) the percentage of gravels, fines, and sands; (2) the shape of the grain size distribution curve; and (3) the plasticity and compressibility. Another classification system used in this country is the 7th Approximation developed by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture (USDA). It is a geomorphological system that relates soil to parent material and is used in agricultural and land use planning. Although it relates plant species to soil species and is oriented towards profile development, classification is based on laboratory and field measurements (soil texture, soil moisture, parent material, pH, plasticity, etc.). Table 1 lists particle sizes and groupings of the systems.

With reference to photo interpretation procedures, the prediction of soil characteristics is an inferential process even when soil surfaces are bare and directly visible in the imagery. Pattern elements within the image enable one to deduce origin of the material; and from origin one can deduce probable properties and grain size distribution. Based upon these one can then assign a symbol. The pattern elements used for this determination are landform, drainage-plan, drainage-elevation, erosion, deposition, vegetation, cultural (land use), photo tone and texture, and special. From a sequential evaluation of these pattern elements one can deduce the probable structure, surficial geology, probable climate, and in turn, the probable soil texture that would be developed within or transported to an area. Soil texture is interpreted from origin, and origin is interpreted from an analysis of pattern elements in the image. Of these pattern elements, landform is the most important because it is directly related to the nature and origin of the materials. Soil texture and homogeneity of materials can be inferred directly from some landforms, e.g. sand dunes, terraces, glacial till plains, etc. Drainage patterns (plan and elevation) provide information about permeability and cohesiveness. The nature and density of vegetation can also provide information about the soil. The boundaries within a vegetation map frequently indicate changes in soil or soil-moisture relations, and consequently, these boundaries are often coincident with the boundaries in a soils map. Cultural patterns in the form of quarries, borrow pits, etc., can also provide clues about composition. Photo tones and texture patterns provide information about origin, i.e. transported versus residual, as well as information about homogeneity. Because detailed stereo aerial observation is necessary to deduce the nature of landform and drainage-elevation patterns, other imaging devices, such as LANDSAT, radar, imaging radiometers, etc., have but limited capability for this task.

Good classification schemes have some similar characteristic regardless of the nature of the objects being classified. Professor T.K. Liu of the University of Illinois has listed some basic requirements, which we tried to follow in our development of a classification scheme based on photo interpretation.[1] These are

1. Distinct properties as a basis for forming groups.
2. The scheme should be simple, concise, and logical.
3. Members within a group should have the same general properties.
4. Desirable terminology.
5. Descriptive symbols that are appropriate and easily learned.
6. Flexibility.
7. Ease of application.

[1]Thomas K. Liu. 1970. *A Review of Engineering Soil Classification Systems. Special Procedures for Testing Soil and Rock for Engineering Purposes,* American Society for Testing and Materials, 5th Ed., ASTM Special Technical Publication 479, pp. 361–381.

TABLE D1. U.S. Standard sieve sizes and corresponding soil separate size classification
This information was compiled from various sources by A.E. Krusinger and M.B. Satterwhite, ETL–RI–CRS. The sources include the *Soil Primer,* 1973, Portland Cement Assoc. (PCA), and the Arthur H. Thomas Co. scientific catalog.

U.S. SERIES DESIGNATION ALT.	U.S. SERIES DESIGNATION STD.	SIEVE OPENING (inches)	SIEVE OPENING (mm)	NOM. WIRE DIA. (mm)	TYLER SCREEN SCALE EQUIV. DESIG.	SOIL SEPARATE CLASSIFICATION USDA SYSTEM	SOIL SEPARATE CLASSIFICATION UNIFIED SOIL CLASS.
1"	25.4[1] mm	1.00	25.4	3.80	.742"	Coarse Gravel	Coarse Gravel
3/4	19.0	0.750	19.0	3.30	.624		
5/8	16.0[2]	0.625	16.0	3.00	.371		
1/2	12.7[1]	0.500	12.7	2.67			
3/8	9.51	0.375	9.51	2.27	2½ mesh		Fine Gravel
5/16	8.00[2]	0.312	8.00	2.07			
1/4	6.35[1]	0.250	6.35	1.82		Fine Gravel	
3½ mesh	5.66[2]	0.223	5.66	1.68	3½		
4	4.76	0.187	4.76	1.54	4		
5	4.00[2]	0.157	4.00	1.37	5		
6	3.36	0.132	3.36	1.23	6		Coarse Sand
7	2.83[2]	0.111	2.83	1.10	7		
8	2.38	0.0937	2.38	1.00	8		
10	2.00[2]	0.0787	2.00	.900	9		
12	1.68	0.0661	1.68	.810	10	Very Coarse Sand	
14	1.41[2]	0.0555	1.41	.725	12		
16	1.19	0.0469	1.19	.650	14		Medium Sand
18	1.00[2]	0.0394	1.00	.580	16		
20	841μ	0.0331	0.841	.510	20		
25	707[2]	0.0278	0.707	.450	24	Coarse Sand	
30	595	0.0234	0.595	.390	28		
35	500[2]	0.0197	0.500	.340	32		
40	420	0.0165	0.420	.290	35		
45	354[2]	0.0139	0.354	.247	42	Medium Sand	
50	297	0.0117	0.297	.215	48		
60	250[2]	0.0098	0.250	.180	60		
70	210	0.0083	0.210	.152	65		Fine Sand
80	177[2]	0.0070	0.177	.131	80	Fine Sand	
100	149	0.0059	0.149	.110	100		
120	125[2]	0.0049	0.125	.091	115		
140	105	0.0041	0.105	.076	150		
170	88[2]	0.0035	0.088	.064	170	Very Fine Sand	
200	74	0.0029	0.074	.053	200		
230	63[2]	0.0025	0.063	.044	250		Fines (Silts or Clays)
270	53	0.0021	0.053	.037	270		
325	44[2]	0.0017	0.044	.030	325	Silt & Clay	
400	37	0.0015	0.037	.025	400		

[1]These sieves are not in the fourth root of 2 series, but they have been included because they are in common use.

[2]These sieves correspond to those proposed as an International (ISO) Standard. It is recommended that, where possible, these sieves be included in all sieve analysis data or reports intended for international publication.

Classification systems share some common problems: there is seldom unanimity of thought as to how to classify things within a given subject; and there are at least several ways to do it. An added problem is that many terms are not rigorously defined, and different individuals have different meanings for them. Within the topic of soils, for example, are the terms transported, residual, sedimentation, and deposited. Although there is agreement in a general sense, there are always soils that someone would take out of one group and put into another, or create a different heading for them under the reasoning in one case that deposits are really a form of sedimentation, and on the other hand that deposits are different from sedimentation. The system proposed here (refer to table 2) suffers the same problem and will, no doubt, be modified at least once during the test by photo analysis. It will serve, however, as a start.

The system and symbols that evolved turned out to be similar to a system developed several years ago by Mr. Richard W. Galster of the Seattle District of the U.S. Army Corps of Engineers.[2,3] With a few minor changes, mostly in omitting qualifying symbols and adding symbols to modify the residual origin category, we have adopted the plan. The origin symbol consists of one or two upper case letters, e.g. G for glacial origin or RS for residual sedimentary origin. Following this, one can use a lower case qualifying symbol to describe further the origin, e.g. placing a t after the G to indicate a glacial till. The textural symbols are basically those of the USCS, but are used in the lower case form. Textures of the basic soil types are indicated by using as many symbols as needed to express the soil characteristics. The letters are arranged in sequence to the right to represent decreasing amounts. An area containing a clayey, silty glacial till would bear the symbols Gt/mc. Details of symbol format, i.e. separate symbols with hyphens or slashes can be worked out during test and evaluation.

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[2]R.W. Galster. 1975. "A System of Engineering Geology Mapping Symbols." *Assoc. of Engineering Geologists, Program and Abstracts,* 19th Annual Meeting, South Lake Tahoe, NV, p. 22.

[3]R.W. Galster. 1977. "A System of Engineering Geology Mapping Symbols." *Assoc. of Engineering Geologists Bulletin,* Vol. XIV, No. 1, pp. 39–47.

TABLE D2. **Proposed soil classification system based on photo patterns**

ORIGIN SYMBOLS		TEXTURAL SYMBOLS	
A	Alluvium	c	Clay
C	Colluvium	m	Silt
L	Lacustrine	s	Sand
M	Marine	g	Gravel
G	Glacial	k	Cobbles
E	Eolian	b	Boulders
V	Volcanic	r	Rock Rubble
F	Manmade Fill	e	Erratic Blocks
R	Residuum	f	Fines (Silt and Clay)
RS	Sedimentary	p	Organic Material/Peat
RI	Igneous		
RM	Metamorphic		

QUALIFYING SYMBOLS

For Glacial Deposits

(t)	Till
(o)	Outwash
(i)	Ice Contact Deposits or Ice Contact Stratified Drift

For Volcanic Deposits

(a)	Ash
(pu)	Pumice
(ci)	Cinders

For Colluvial Deposits

(ta)	Talus
(ls)	Landslide
(mf)	Mudflow

For Alluvial Deposits

(fp)	Flood Plain
(te)	Terrace
(d)	Delta
(f)	Alluvial Fan

APPENDIX E.
A PHYSIOGNOMIC VEGETATION CLASSIFICATION SYSTEM
FOR USE WITH
IMAGERY FOR MILITARY APPLICATIONS

M. Treiber and M.B. Satterwhite

A PHYSIOGNOMIC VEGETATION CLASSIFICATION SYSTEM FOR USE WITH IMAGERY FOR MILITARY APPLICATIONS

INTRODUCTION

Jack N. Rinker

The following is a proposed vegetation classification system developed within ETL. Of necessity, all such systems share some degree of commonality, with the variations arising mostly from differences in goals of the classifications and in the manner of expressing the information. We, of course, had a set of objectives that we thought a vegetation classification system should meet. We evaluated the systems that were available and decided that none met enough of our goals to warrant its selection for use. Consequently, we set about the task of tailoring a system to our needs. The goals that were established included:

1. The system must be directed toward Army needs. This is not as restrictive as some think because, for the most part, civil and military needs are the same. The objective was to make certain that where Army requirements would vary from the usual, either in content or expression, the classification format could handle it.

2. At least the lower levels of the classification must be obtainable from air photo analaysis.

3. The system must be able to absorb information of ever increasing detail as well as information from other sources without the need of altering the classification structure or the symbology. Other sources refer to field data, published material, personal knowledge, etc. In other words, one can go as far into the classification scheme as resources permit.

4. The entry levels should be based on patterns that can be recognized by individuals with a minimum of training.

The classification system that resulted was critiqued at ETL, in the Center for Remote Sensing (CRS), tested by Dr. Miklos Treiber via a photo analysis of the Accotink Bay Wildlife Refuge and Nature Study Area, Fort Belvoir, Virginia. Copies were also provided to Mr. Robert E. Frost, ETL, for use in three air photo analysis courses that he gave to Corps of Engineers personnel. Since that time, the system as presented here has been modified by Mr. Melvin B. Satterwhite, CRS, ETL, for use in the remote sensing course presented by ETL in Latin America under the auspices of the Inter-American Geodetic Survey (IAGS). As results from these various efforts are accumulated, are evaluated, and are tested by CRS, there will be a number of modifications made to the basic scheme.

A PHYSIOGNOMIC VEGETATION CLASSIFICATION SYSTEM FOR USE WITH IMAGERY FOR MILITARY APPLICATIONS

Miklos Treiber and Melvin B. Satterwhite

Vegetation is a factor that influences the appearance and general character of most land surfaces. Because much of the earth's surface is mantled at least in part by some kind of vegetation cover, the signature recorded by a remote sensor is that of the foliar surface, plus that portion of the land surface detected through holes in the vegetative cover.

The term "vegetation" is used to designate the total plant cover of a region, area, or place. The vegetation of any area comprises one or more plant communities, or aggregations of plants, usually forming a mosaic. Variations in plant cover, or the pattern of vegetation in any area, are the results of a complex interrelation between the physical characteristics of the terrain and environment (geographic location, topographic position, geology, and climate), and the nature and frequency of natural and man-induced disturbances (cultural characteristics). This implies that vegetation consists of more or less distinct mappable units and that these units reflect variations in the physical and cultural characteristics of an area.

Although numerous vegetation classification systems have been proposed for a variety of purposes, there is not one designed for military applications and for use with remote sensor imagery – particularly aerial photography. Thus, there exists a need to develop a workable vegetation classification system that can be used by analysts to characterize these properties in map form. The objective of this study is to provide the basis for a physiognomic vegetation classification system, based on the characteristics of the vegetation itself.

PRINCIPLES AND CHARACTERISTICS OF VEGETATION CLASSIFICATION

The objectives of classifying vegetation are to facilitate recording of information in a systematic manner, to aid in the storage and retrieval of the information, and to aid in the communication of the information easily and unambiguously.

Vegetation mapping is done in terms of units that can be used to characterize and designate areas that are outlined on a map, photo, or image. Taken together, these areas form patterns, or a mosaic. The mapping units representing different features or factors can be compared, and the information can be portrayed graphically to facilitate communication about the variation in the vegetation mosaic.

There are many systems of vegetation classification (see selected bibliography) serving different purposes and interests. The more ambitious systems, e.g. United Nations Educational, Scientific, and Cultural Organization (UNESCO), Fosberg, and Waterways Experiment Station (WES), attempt to classify the world's vegetation; whereas others, such as Küchler, Braun-Blanquet, and Anderson, espouse more limited objectives, i.e. classifying vegetation of a country or region. Most of the vegetation classification schemes fall into one of four categories: (1) physiognomic, (2) ecological, (3) floristic, or (4) some combination of these systems. Using combinations does not necessarily improve the system. In fact, it is apt to make the scheme more complex, and it introduces greater variability and ambiguity. Therefore, this kind of system is excluded from the present discussion. Table 1 compares the three main types of classification systems to the requirements for a practical procedure of classifying vegetation. These requirements include:

1. clearly defined mapping units or categories.
2. a terminology that conveys information about the character of the vegetation.
3. mapping units, or categories, that impart information pertinent to the field Army.
4. structure and internal logic that are clear and simple so that different investigators can use it and produce the same results.
5. the classification must be based on data that can be acquired from imagery.
6. the system must be adaptable to various mapping and photographic scales.
7. the symbols and categories used should permit worldwide comparisons.
8. the system must provide for easy cartographic representation.

A physiognomic system is based primarily on the form and structure of the vegetation. Ecological systems are based not only on the features of the vegetation but also on various factors of the environment, such as climate, ground water, and edaphic characteristics. Floristic systems are based on taxonomic criteria, i.e. species composition (floristics) or plant classification schemes. Of the three categories of classification systems compared in table 1, the physiognomic type best satisfies the established requirements of a vegetation classification system for use with imagery for military applications. The advantages and disadvantages of using a physiognomic classification are listed in table 2.

TABLE E1. Comparison of vegetation classification systems with resp[illegible] to stated requirements and for use with imagery*

REQUIREMENTS	PHYSIOGNOMIC SYSTEM	ECOLOGICAL SYSTEM	FLORISTIC SYSTEM
Clearly defined mapping units or categories	+ e.g., trees, needleleaf 75% cover	± e.g., forest, savanna, scrub	± e.g., hardwood (oak-hickory, maple-beech)
Terminology must convey information about the character of the vegetation	+ Form and structure of vegetation	– Appearance and physical environment	– Taxonomy and plant classification
Mapping units or categories must convey information pertinent to the Field Army	+ Directly interpretable	± Often requires special training or additional data	– Requires special training
Structure and internal logic must be clear, simple, and the results reproducible	+	– Special training	– Special training
The primary basis for classification must be data that can be acquired from aerial photography or imagery	+ Direct observations	± Direct observation and inference	– Rarely possible
Adaptable to ALL mapping and photographic scales	± Restricted at very small scales	± Restricted at medium and small scales	– Applicable only at very large sclaes
Permit worldwide comparisons	+ Universal	± Regional or local	+ Regional or local
Easy cartographic representation	+	±	±

*Symbols are defined as follows: (+) satisfactory, (±) satisfactory with restriction, and (–) unsatisfactory.

TABLE E2. Advantages and Disadvantages of a Physiognomic Vegetation Classification Approach

Advantages

1. Direct observations and measurements can be used as a basis for classification.

2. Permits worldwide comparisons.

3. Cartographic representation is simplified and universal.

4. Adaptable to all map scales, but with limitations at very small scales.

5. Floristic and taxonomic terms are avoided, reducing the training required for use of the system.

Disadvantages

1. Does not identify species or community types; classification is descriptive.

2. Scale and quality of imagery are very important. The detail and accuracy with which the vegetation is characterized increases as scale becomes larger and decreases as scale becomes smaller.

SIGNIFICANT VALUES OF VEGETATION ELEMENTS IN RELATION TO MILITARY PERSONNEL AND CLASSES OF MATERIEL

A literature review was conducted to learn what physiognomic values are significant for a classification of vegetation for military purposes, the manner in which military operations are conducted, and the physical dimensions and operational characteristics of selected items of materiel. The sources of these data were Tyson (1964), Griffiths (1964), Peltier (1966), McCormick (1967), Blackman and Randolph (1968), Blackman and Stoll (1968), Ben, et al. (1969), McLeary (1972), Robinson and Viletto (1974), and Chrostowski and Gaines (1976). The significant values of vegetation elements in relation to military personnel and classes of materiel are presented in table 3.

PROPOSED PHYSIOGNOMIC VEGETATION CLASSIFICATION SYSTEM

The proposed vegetation classification system is a physiognomic one based on the characteristics of the vegetation itself. Thus, the categories and elements of this system are descriptors used to categorize the vegetation. Four categories are proposed: life form, height, coverage (canopy closure), and seasonality. The elements of the categories are summarized in table 4. These categories and the elements within these categories can be used to describe vegetation worldwide. The classification hierarchy, structural descriptors, and symbols for the classification system are presented in table 5.

The classification of vegetation relies on letter symbols, and letter and number combinations to designate the various types of vegetation. The life form elements are indicated by capital letters, and the structural categories are signified by lower case letters and numbers. The capital letters, together with their associated lower case letters and numbers, enable the analyst to describe the vegetation in great detail, scale permitting, because the number of letter/number combinations is large.

VEGETATED CATEGORIES (I)

The vegetation of the earth can be divided into two groups: woody and herbaceous (nonwoody) plants. Although the special life form categories can also be classified as either woody or herbaceous, they are treated separately and therefore are not discussed here. Woody plants (W), as defined here, are those plants having persistent (perennial), aboveground stems greater than 2 meters tall. By definition the category woody plants includes trees and shrubs. Herbaceous plants (H) are those plants that produce annually, aboveground parts with or without underground stems. The aboveground stems of herbaceous plants rarely exceed 2 meters, and their tissues are generally soft. These definitions are not in strictly accord with accepted botanical terminology, but have been altered in order to clarify the categories and elements used in this classification system. For example, technically the banana tree (*Musa sapientum*) is herbaceous. In this classification however, it is considered to be a woody plant. This is justified by the fact that, from a military applications point of view, the shape of a banana tree is more like that of a woody plant than an herbaceous one.

TABLE E3. Significant values of vegetation elements in relation to military personnel and classes of materiel[1]

	FACTOR	SIGNIFICANT VALUES	COMMENTS
I.	MILITARY PERSONNEL:		
	A. Vegetation height	1.5–2 m	Variable seasonally; deciduous vs evergreen; annual vs perennial.
	B. Canopy closure	50%	< 50% poor concealment.
II.	WHEEL AND TRACKED VEHICLES AND ORDNANCE:		
	A. Height of vegetation (trees)	5.0 m	Function of vehicle height.
	B. Height to first branching (trees)	3.0 m	Function of vehicle height.
	C. Spacing of tree trunk	5.0 m	Minimum tree and shrub clump spacing a function of 1.5 x vehicle width.
	D. Diameter (dbh) of tree trunk	25 cm	Diameter sufficient to interdict movement.
	E. Fallen logs	9.5 m	Function of ground clearance and maximum step negotiable.
III.	SURFACE–TO–SURFACE MISSILES, TRANSPORT MODE: (same measures as for II), and		
	E. Diameter of canopy opening	100–500 m	Suggested canopy opening for unrestricted field of launch.
IV.	LAND–MOBILE SURFACE–TO–AIR WEAPONS, TRANSPORT MODE: (same measures as for II), and		
	E. Diameter of canopy opening	50–100 m	Suggested canopy opening for unrestricted field of launch.
V.	AIR CUSHION VEHICLES:		
	A. Height of vegetation	0.5 m	Function of hover height.

TABLE E3. (Continued)

VI. HELICOPTERS		
A. Diameter of canopy opening	12.5 m 25.50 m	Small and medium models. Twice the rotor diameter or 1.5 x overall length.
B. Height of vegetation for landing	0.5 m	Fuselage clearance.
C. Height of vegetation for hovering	3 m 15 m	Height of rotors. Based on rappelling from hovering aircraft; height and density of vegetation.
D. Litter	type, volume, and configuration	Impedes motor efficiency, damages motor and other parts, and impedes pilot vision.
VII. STOL AIRCRAFT:		
A. Length of canopy opening	250, 500, and 1000 m	Based on landing (stall) speed and length of takeoff run (attaining 15 m altitude) for aircraft with three payload configurations.
B. Width of canopy opening	20, 35, and 50 m	Based on aircraft wingspan.
C. Height of vegetation	0.5 m	Fuselage clearance; landing gear cannot negotiate woody vegetation.
D. Litter	type, volume, and configuration	Impedes motor efficiency, damages motor and other parts, and impedes pilot vision.

[1] M.S. Chrostowski and J.F. Gaines. *Study of Classification and Nomenclature of Vegetation.* U.S. Army Engineer Topographic Laboratories, ETL–0058, June 1976, AD–A028 984.

Source: modified table from Chrostowski and Gaines.

TABLE E4. Categories and Elements for Developing a Physiognomic Vegetation Classification System

Primary Categories and Elements

A. **Life Form**
Woody Plants (4 types)
Herbaceous Plants (3 types)
Special Life Forms (5 types)

B. **Height**
> 35 m
25–35 m
15–25 m
5–15 m
2–5 m
< 2 m

C. **Coverage (Canopy Closure)**
Closed ($> 75\%$)
Interrupted (50–75%)
Parklike, scattered (25–50%)
Sparse ($< 25\%$)

Secondary Categories and Elements

D. **Seasonality (Foliage Duration)**
Evergreen
Deciduous
Mixed

E. **Leaf Type**
Broadleaf
Needleleaf/Scaleleaf

TABLE E5. Summary of the Classification Hierarchy, Structural Descriptors, and Symbols for the Proposed Vegetation Classification

CLASSIFICATION HIERARCHY

CATEGORY	SYMBOL
I. Vegetated	I
A. Woody plants	W
1. Broadleaf	B
a. deciduous	BD
b. evergreen	BE
c. semideciduous	BS
2. Needleleaf-Scaleleaf	N
a. deciduous	ND
b. evergreen	NE
c. semideciduous	NS
3. Aphyllous	A
4. Mixed	M
B. Herbaceous plants	H
1. Graminoids	G
2. Forbs	F
3. Lichens and Mosses	L
C. Special Life Forms	S
1. Stem succulents	K
2. Tuft plants	T
3. Bamboos	V
4. Epiphytes	X
5. Climbers (lianas)	C
II. Nonvegetated	II
A. Water	IIA
B. Bare Soil	IIB
C. Rock	IIC
D. Built-up Area	IID
E. Snow and Ice	IIE

STRUCTURAL DESCRIPTORS
STRATIFICATION CLASSES
(Height in m)

SYMBOL	HEIGHT CLASS
1	< 2 m
2	2–5 m
3	5–15 m
4	15–25 m
5	25–35 m
6	> 35 m

COVERAGE CLASSES
(Canopy Closure, %)

SYMBOL		COVERAGE CLASS
r	(rare or sparse)	< 25%
p	(scattered or park like)	25–50%
i	(interrupted)	50–75%
c	(continuous)	> 75%

Woody vegetation is conspicuous and varied in its appearance, and more significant to military applications than nonwoody, or herbaceous, plants. In accordance with physiognomy as the guiding principle, the woody vegetation is characterized on the basis of leaf characteristics, i.e. whether it is evergreen or deciduous, broadleaf, needleleaf, or without leaves (aphyllous). Four life form elements of woody plants are recognized.

Broadleaf (B) Woody Plants. These plants have broad leaves in contrast to needle or scale leaves. Three elements are recognized under the category broadleaf woody plants based on seasonality or foliage duration: broadleaf deciduous (BD), broadleaf evergreen (BE), and broadleaf semideciduous (BS).

A vegetation mapping unit is characterized as being broadleaf deciduous (BD) if the plants have broad leaves and defoliate periodically so that they bear no green leaves during a part of the year. Examples of broadleaf deciduous trees are white oak (*Quercus alba*) in Virginia, paper birch (*Betula papyrifira*) in Quebec, and the kapok tree (*Bambax malabaricum*) in Indonesia.

Plants that are broadleaf evergreen (BE), in contrast to broadleaf deciduous, are not bare or without green leaves at any season. Broadleaf evergreen plants include magnolia (*Magnolia grandiflora*) of the Southeastern United States, black mangrove (*Rhizophora mangle*) of tropical tidal flats, the Australian eucalyptus trees (*Eucalyptus* sp.), and big sagebrush (*Artemisia tridentata*) of the Western United States.

The element broadleaf semideciduous (BS) is used here to characterize vegetation that includes both broadleaf evergreen and broadleaf deciduous woody plants when each of these elements comprises at least 25 percent of the mapping unit. This element occurs, primarily, in tropical and semitropical areas of the world where the broadleaf evergreen forests (BE) of the humid tropics merge gradually with the broadleaf deciduous (BD) forests of the drier and cooler regions.

Determining foliage duration when mapping vegetation on imagery is difficult, particularly in the absence of ancillary information. In such cases, the vegetation should be characterized as it appears at the time the imagery is acquired. The analyst must be aware of the fact that deciduousness is a complex character. The season and length of time that trees are bare can vary greatly. In addition, some plants may lose their leaves at different times than other plants of the same species. The analyst must remember in all such cases that he maps variations in the vegetation and not individual plants. He is, therefore, guided by the general appearance of the vegetation in making his decisions.

Where the degree of deciduousness of a given forest varies with individual strata (canopy layers) the mapper or analyst can describe each stratum separately and so attain a high degree of accuracy. For example, the "seasonal evergreen forest" of the American tropics is entirely evergreen except the uppermost stratum of emergent trees that are approximately 25 percent deciduous.[1]

Needleleaf-Scaleleaf (N) Woody Plants. The term "needleleaf" is defined here to apply to the typically needle-shaped leaves of such trees as the loblolly pine (*Pinus taeda*), the hemlock (*Tsuga canadensis*), and the true cedars (*Cedrus libani*). It also applies to leaves that are scale-like in appearance, as the leaves of arborvitae (*Thuja occidentalis*) and the junipers (*Juniperus* sp.). As in the category broadleaf plants (B), three elements are recognized in the category needleleaf-scaleleaf plants (N): needleleaf-scaleleaf deciduous (ND), needleleaf-scaleleaf evergreen (NE), and needleleaf-scaleleaf semideciduous (NS).

The three elements of needleleaf-scaleleaf woody plants are defined by foliage duration as were the elements for broadleaf plants. Deciduous needleleaf plants (ND) are characterized by the periodic absence of leaves. Examples of plants that shed their needles seasonally are species of larch (*Larix* sp.) of northeastern North America and eastern Siberia, and the bald cypress (*Taxodium distichum*) of the Southeastern United States. Evergreen needleleaf plants (NE) bear functional leaves at all times. Examples of this type are *Pinus taeda, Tsuga canadensis, Cedrus libani,* and *Thuja occidentalis.* The semideciduous needleleaf element (NS) is used to describe vegetation comprised of needleleaf evergreen and deciduous trees, where each component constitutes at least 25 percent of the vegetative cover.

The limitations and problems in determining seasonality from imagery discussed under broadleaf plants (B) apply equally here.

Aphyllous (A) Woody Plants. This is a composite category and is intended to be used to describe woody vegetation with no apparent leaves.

True aphyllous plants do not have leaves; they have chlorophyll in their stems, branches, and twigs, which are frequently succulent. The *Casuarina* forest of Australia and some oceanic islands and the *Euphorbia* forests of Ethiopia are examples.

This category can also include other woody vegetation elements. When mapping from small-scale imagery, in the absence of ancillary information or prior knowledge of the vegetation by the analyst of the particular area being studied, the broadleaf deciduous element (BD) and the needleleaf deciduous element (ND) in the leafless condition can be classified as aphyllous (A).

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[1] J.S. Beard. "The Classification of Tropical American Vegetation Types." *Ecology.* 36:89-90, 94-96. 1955.

Mixed (M). Unless the natural vegetation consists of a pure stand, all plant communities are mixed. The term "mixed," however, is employed here in a much more restricted way to denote a mixture of needleleaf or scaleleaf evergreen (NE), and broadleaf deciduous (BD) elements. Furthermore, the (M) element should only be used when each of the two components occupy at least 25 percent of the area. If either (NE) or (BD) does not cover at least 25 percent of the vegetation unit, the two letters are recorded or described separately in the formulae.

Representative vegetation units that would be classified as mixed (M) occur in Michigan (hemlock–maple forests), Georgia (pine--oak–hickory forests), and Europe (birch–pine forests).

HERBACEOUS VEGETATION CATEGORIES (H)

The second life form category is that of nonwoody, or herbaceous, vegetation. As defined earlier, this includes all vegetation producing soft, aboveground stems annually, less than 2 meters in height, with or without underground perennial stems. Herbaceous plants are therefore seasonal in character. Herbaceous vegetation should be shown on maps and overlays as it appears in the landscape. The analyst must be aware, however, that the aspect of herbaceous vegetation is highly variable seasonally and, therefore, the date of the imagery on which the vegetation is being analyzed is important and should be indicated. As in the case of woody vegetation, plants of the herbaceous life form category are divided according to their appearance of physiognomy into three elements: graminoids, forbs, and lichens and mosses (byroids).

Graminoids (G). This term includes all herbaceous grasses. To these are added all plants that are grasslike in appearance even though they are not grasses in a taxonomic sense, such as sedges (*Carex*), reeds (*Phragmites*), cattails (*Typha*), and others. The bamboos, although taxonomically grasses, are excluded from this element because they are "woody" and generally exceed 2 meters in height. Common herbaceous graminoids (G) are little bluestem (*Andropogon scoparius*) of the North American prairie, rushes like *Juncus roemerianus* of the Southeastern United States, and species of *Imperata* of the tropical savannas, and others. Examples of vegetation types composed primarily of graminoid plants are the Argentine pampas, the Russian steppes, the North American prairie, and the African savannas.

Forbs (F). The term "forb" is applied to broadleaf herbaceous plants, in contrast to the narrowleaf graminoids. This term also includes all terrestrial ferns except tree ferns. Forbs (F) are common as an understory in many broadleaf deciduous forests, especially when the canopy closure is < 75 percent and in areas where the annual precipitation exceeds 1,000 mm per year. This category is also common in many arid and semiarid regions where forbs are referred to as ephemerals because their life cycle is very brief.

Lichens and Mosses (byroids) (L). This category includes all mosses and lichens that grow on the ground, whether on soil or on rock outcrops; however, epiphytic lichens and mosses are excluded because they are classified in the present system as a special life form element (epiphytes). Lichens (e.g. *Cladonia* spp.) may cover large areas, especially in higher latitudes as in the forest tundra and the tundra of North America and Eurasia. Mosses can be equally important, for example, the *Sphagum* of the Irish blanket bogs. Algae are included in this category if aquatic vegetation is to be mapped.

SPECIAL LIFE FORM CATEGORIES (S)

The basic life form categories of woody and herbaceous plants described above can be used to characterize the majority of the world's vegetation. There are, however, vegetation elements that are very distinctive in the landscape with unique characteristics that are not adequately described by the seven life form elements enumerated above. These elements, referred to here as special life forms, are epiphytes, climbers (lianas), stem succulents, bamboos, and tuft plants/palms. The special life forms should not be included on maps or on vegetation overlays unless they are a conspicuous element in the landscape and affect the general appearance of the vegetation. The introduction of special life forms is subjective; however, these categories help to describe further the basic life form categories of woody and herbaceous plants, and their presence or absence in a given vegetation type is often highly significant.

Climbers or Lianas (C). The terms "climber" and "liana" are used for all woody plants that have a climbing habit. Lianas are most common in tropical rain forests (e.g *Paullinia cupana*), but are frequently found in many flood plain forests as well, such as the fox grape (*vitis vulpina*). Note that lianas are difficult to detect, and thus the analyst must take care in designating this element.

Stem Succulents (K). Stem succulents are plants without leaves or with very reduced leaves, and with stems serving as photosynthetic organs. These striking life forms of great variety are concentrated in arid or semiarid regions of the world. Where they grow in appreciable numbers, the general physiognomy of the vegetation is profoundly affected. Many stem succulents are armed, bearing spines or thorns. The barrel cactus (*Echinocactus grandis*) of the Southwestern United States and Mexico is a well-known example.

Tuft Plants/Palms (T). These plants have in common the characteristic that they consist of a trunk (often unbranched) that carries at its apex a tuft of leaves. Examples of well-known tuft plants are the palms of some oceanic islands and Indomalaysia and the *Mauritia* savannas of northern South America. Cycads and tree ferns (e.g *Alsophila camerunensis*) of the wet tropics are also included in this element. The special life form element of tuft plants/palms is comprised of taxonomically unrelated plants; however, physiognomically they are similar.

Bamboos (V). These plants are grasses, taxonomically, but because they are woody, large in size, and unique in aspect, they are classified as a special life form. Bamboo groves usually consist of individual clumps of plants with tall slender trunks and feathery texture. Examples of bamboos are the tree-like *Gigantochloa maxima* in Java and *Chusquea quila* in southern Chile where this species forms inpenetrable thickets as an understory in temperate rain forests.

Epiphytes (X). Epiphytes are a group of taxonomically diverse plants that are characterized by their common habit or growth form. Epiphytes are plants that grow upon other plants, for instance, mistletoe *(Phoradendron)* on apple trees in New England or Spanish moss (*Tillandsia usneoides*) on live oaks in Florida. Although these plants are not alike in appearance, only in growth habit, they do introduce a new physiognomic element into the life form of their host plants, and it is this changed physical appearance of the host plant that is significant.

NONVEGETATED CATEGORIES (II)

Although the primary objective of this paper is the classification of vegetation, five nonvegetated categories are included, which are Water (IIA), Bare Soil (IIB), Rock (IIC), Built-up Area (IID), and Snow and Ice (IIE). No attempt has been made to elaborate on the variations in the nonvegetated categories. These terms are included to enable the analyst to (1) classify areas that are devoid of vegetation and (2) provide information about the terrain that can be important to the understanding of the characteristics of the vegetation in areas that are sparsely vegetated or in areas where the vegetation is interrupted by nonvegetated zones.

Water (IIA). This term is used to designate any water body, i.e. lakes, bays, reservoirs, rivers, or oceans, and to indicate vegetated areas in which water is a significant component (marshes, swamps, estuaries, etc.). In such areas, the vegetation is classified as in any other vegetated area, but the Water term (IIA) is included.

Bare Soil (IIB). The Bare Soil symbol (IIB) is used to designate areas devoid of vegetation. It also designates areas that do contain some vegetation, but the soil surface is the significant component of the landscape. Examples of the former include plowed fields, mud or tidal flats, and sand dunes. Examples of the latter can be found in many deserts where the vegetation, though present, is sparse. Indeed, at scales of 1:50,000 and smaller the vegetation might not be apparent; this is particularly true of satellite imagery.

Rock (IIC). This term is used to indicate rock bodies, i.e. lava flows, coral reefs, granite domes, etc., and to describe vegetated areas in which outcrops occur.

Built-up Area (IID). This category is used to denote landscapes influenced by cultural activity. Used by itself it indicates that vegetation is absent or is insignificant compared to the cultural features, i.e. urban areas, airports, buildings, etc. When used in conjunction with a vegetation descriptor, it indicates that cultural characteristics are evident.

Snow and Ice (IIE). This term is used to designate areas covered with some form of ice or snow, e.g. glaciers, sea ice, icebergs, permanent and non-permanent snow. If vegetation is apparent beneath the snow, this term is used in conjunction with the vegetation classification.

STRUCTURAL CATEGORIES

The life forms enumerated above can be further characterized by plant height and coverage or canopy closure. These parameters can often be evaluated and sometimes measured with reasonable accuracy on imagery. Applied to the individual strata or canopy layers, these elements permit the analyst to describe the structure of the vegetation in detail, especially on large-scale imagery. On small-scale imagery, the mapper or analyst can show only the uppermost stratum and describe it in general terms.

Height. The height classes in this vegetation classification have been designed to reflect the significant values of vegetation elements described above, in relation to military personnel and classes of materiel. Six height classes are proposed: (1) < 2m, (2) 2–5m, (3) 5–15m, (4) 15–25m, (5) 25–35m, and (6) > 35m.

The height of the vegetation is measured from the ground upward to the surface of the average height of the upper limits of a stratum. The height classes are expressed by numbers (table 5). All life form categories should be described by height classes. If height is not designated, the height of the vegetation unit is assumed to be less than 2 meters class 1. Note that vegetation height is a dynamic character, varying in time. Herbaceous vegetation is especially subject to strong variations in height during each year. When imagery is the only source of data, the herbaceous vegetation should be described as it appears on the imagery being analyzed: a note should be made, however, of the possible variability in height and cover for such plants.

Coverage or Canopy Closure. This element refers to the spacing of plants in the landscape and expresses the density by indicating the percentage of the ground covered by each life form category, assuming that they project vertically to the ground. Four coverage classes with their symbols are described below.

Continuous, > 75 Percent Cover (c). This implies a near continuous or continuous growth with plant canopies touching one another.

Interrupted, 50–75 Percent Cover (i). The vegetation is interrupted when the spacing of the individual plants is such that they do not touch. These stands will often have small openings among the dominant life forms. The analyst must not confuse coverage with the distances between the individual stems. For example, spruces (*Picea*) need not be far apart before large gaps between plants are evident; whereas, many broadleaf trees can be much more widely spaced before the canopy is broken at all. Among herbaceous plants, the element (i) can be especially useful in differentiating between bunched and nonbunched grasses and in describing the growth habit of woody plants that are clumped (shrubs).

Scattered or Parklike, 25–50 Percent Cover (p). When this element is used in connection with woody vegetation, it signifies that the plants are scattered either singly or in small groves as in the so-called parklands and in savannas. In the case of herbaceous vegetation, this element signifies discontinuous patches.

Sparse, < 25 Percent Cover (r). This applies to areas supporting a paucity of vegetation. This category is also used to describe one life form associated with another that is either continuous (c) or interrupted (i). For example, widely spaced palms can grow in an otherwise continuous cover of grass.

FORMULAE FOR CARTOGRAPHIC REPRESENTATION

The guiding principle in presenting a vegetation map or overlay is to show it in such a way that the reader can visualize the vegetation. In other words, the vegetation must be presented on the map in symbols that can be readily translated into appearance in the landscape. The technique and symbology are directed not so much at classifying vegetation but rather at describing it, and the symbols are a form of shorthand for lengthy descriptions.

The symbols are used in a prescribed sequence. First, the life form is shown by its capital letter(s). The height class is given second, and the coverage is shown last. The sequence should always be the same: LIFE FORM – HEIGHT – COVERAGE (canopy closure). This sequence applies to each recorded life form individually. Thus, BE4iNE4r (refer to table 5) describes vegetation that is primarily broadleaf evergreen (BE), with trees 15 to 25 meters in height (4), and with a coverage (canopy closure) 50 to 75 percent (i); interspersed within this vegetation unit are needleleaf-scaleleaf evergreen trees (NE), 15 to 25 meters tall (4), and with coverage of less than 25 percent (r). Figure 1 illustrates a hypothetical vegetation unit showing the prescribed use and order of the symbols.

I. Vegetated I
- A. Woody Plants . . . . W
  - 1. Broadleaf. . . . . .B
    - a. deciduous . . . . BD
    - b. evergreen . . . . .BE
    - c. semideciduous . . . . .BS
  - 2. Needleleaf--Scaleleaf . . . . N
    - a. deciduous . . . . ND
    - b. evergreen . . . . NE
    - c. semideciduous . . . . .NS
  - 3. Aphyllous . . . . A
  - 4. Mixed . . . . M
- B. Herbaceous Plants . . . . H
  - 1. Graminoids . . . . G
  - 2. Forbs .F
  - 3. Lichens and Mosses L

BD4iG1p

STRATIFICATION CLASSES (m)

SYMBOL	HEIGHT CLASS
1	< 2 m
2	2 – 5 m
3	5 – 15 m
4	15 -- 25 m
5	25 -- 35 m
6	> 35 m

COVERAGE CLASSES (Canopy Closure, %)

SYMBOL	COVERAGE CLASS
r	< 25%
p	25 -- 50%
i	50 -- 75%
c	> 75%

FIGURE E1. Hypothetical vegetation unit – BD4iGlp: (BD) broadleaf deciduous; (4) height of woody plants is 15–25 m; (i) canopy closure of the woody plants is 50–75%; (G) graminoid vegetation is present; (1) the height of the graminoid layer is < 2 m; (p) with a cover value of 25–50%.

The most conspicuous feature of the vegetation is placed at the beginning of the sequence. For example, BDG is a forest of broadleaf deciduous trees (BD) with a layer of grass (G) underneath the trees. The trees are the most conspicuous feature and, therefore, are mentioned first. If, on the other hand, the vegetation consists of a grassland with sparse trees (r), then the order is reversed because the grass is more prominent than the trees. The sequence would read GBDr. The choice of which vegetation element is most conspicuous or important is based on the objectives of the study. For example, a range manager is interested in the grass component; whereas a task commander would be more interested in the woody vegetation.

The small letters are used to qualify the capital letters. Each capital letter (life form) has its own small letter or number that follows it. If there is more than one life form to be described, each will have its small letter or descriptor independent of the other. Exceptions to this occur when the scale of the imagery is so small that height and cover cannot be measured or estimated, when the objectives of the study do not require such information, or when the vegetation is to be described in terms of general composition. As an example of the latter exception to the rule, a broadleaf deciduous forest (BD), 25 to 35 meters in height (5), with scattered or parklike coverage of 25 to 50 percent (p) and a graminoid (G) layer less than 2 meters in height (1) has the following descriptor: BD5pG1. This descriptor can be made more general by omitting some of the categories. For example, if the height term of the graminoid layer is not needed, then the symbol would read BD5pG, or if presence of the graminoid layer is unimportant, it would read BD5p. If a vegetation mapper or analyst must generalize his data, he should do so in such a manner that the purposes of his mission or objectives are served best.

Thus, in some cases the level of detail required may only be to differentiate between areas that are vegetated (I) and nonvegetated (II), or area covered by woody plants (W) and nonwoody, herbaceous, plants (H). In other cases, the level of detail required is greater. When using large scale imagery the descriptor unit would be very detailed, e.g. IIDBD4pNE3rBElrGp (see table 5). By including IID (built-up areas), we are indicating that cultural characteristics are evident within the mapping unit. This sequence of symbols describes a wooded residential community.

The number of letters used depends on the available information, the scale of imagery, the skill of the interpreter, and the scale of the map that is to be prepared. The analyst, however, should describe the vegetation in as much detail as the scale and type of imagery being used will allow. This will enable the analyst or cartographer to have a complete record that can be manipulated to suit the scale and the purpose of the maps or overlays to be produced. The analyst, or mapper, should not hesitate to use long descriptors because the completeness of the information is often of significance in some stages of map preparation, even though some of this information may not be used on the final map product. In all cases where symbols or symbol sequences are used on a map or overlay, even if only in the legend, there must be a key, printed along with the legend, in which the individual symbols are defined.

Vegetation Analysis. Vegetation mapping is based on careful observation and detailed analysis of vegetation in the field coupled to an analysis of vegetation patterns on the imagery. A simple form has been devised to facilitate the recording of physiognomy and structure of vegetation. This form is the Vegetation Analysis Data Sheet, shown in table 6. The analyst should use this form to record the characteristics of the vegetation for each mappable vegetation unit recognized or delimited. These data sheets can then be used to prepare map products as well as to document the analysis for a geographic area. Although the vegetation descriptors of the mapping units may be generalized to suit the objectives of the study, one still has the more detailed vegetation description for future use. These data sheets can also be used for comparing and documenting temporal changes in the vegetation for a particular geographic area.

DISCUSSION AND CONCLUSIONS

There continues to be a need for a vegetation classification system based on the characteristics of the vegetation that can be used either with remote sensing imagery or directly in the field and that contains information elements required by the military. The scheme described here meets these needs. If such a system is widely accepted and used, the information now presented in diverse fashion will become available in comparable forms, making utilization of such data more effective. It will also facilitate the comparison of vegetation maps to other kinds of maps, e.g. climate, soil, environmental, etc.

TABLE E6. Vegetation Analysis Data Sheet

SITE CHARACTERISTICS

LOCATION: ____________ DATE: ____________ ANALYST: ____________

SITE DESCRIPTION: ____________ BASE MAP: ____________ DATE: ____________

PROJECT NAME: ____________

Summary of the Classification Hierarchy, Structural Descriptors, and Symbols for the Proposed Vegetation Classification

CLASSIFICATION HIERARCHY

CATEGORY	SYMBOL
I. Vegetated	I
A. Woody plants	W
1. Broadleaf	B
a. deciduous	BD
b. evergreen	BE
c. semideciduous	BS
2. Needleleaf-Scaleleaf	N
a. deciduous	ND
b. evergreen	NE
c. semideciduous	NS
3. Aphyllous	A
4. Mixed	M
B. Herbaceous plants	H
1. Graminoids	G
2. Forbs	F
3. Lichens and Mosses	L
C. Special Life Forms	S
1. Stem succulents	K
2. Tuft plants	T
3. Bamboos	V
4. Epiphytes	X
5. Climbers (lianas)	C
II. Nonvegetated	II
A. Water	IIA
B. Bare Soil	IIB
C. Rock	IIC
D. Built-up Area	IID
E. Snow and Ice	IIE

STRUCTURAL DESCRIPTORS STRATIFICATION CLASSES (Height in m)

SYMBOL	HEIGHT CLASS
1	< 2 m
2	2–5 m
3	5–15 m
4	15–25 m
5	25–35 m
6	> 35 m

COVERAGE CLASSES (Canopy Closure, %)

SYMBOL	COVERAGE CLASS
r (rare or sparse)	< 25%
p (scattered or park like)	25–50%
i (interrupted)	50–75%
c (continuous)	> 75%

VEGETATION MAPPING	PHOTO #'S	COMMENTS

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APPENDIX F.
EVALUATION OF LAND COVER/LAND USE
CLASSIFICATION SYSTEMS FOR ARMY MGI APPLICATIONS

P.B. McCracken

EVALUATION OF LAND COVER/LAND USE CLASSIFICATION SYSTEMS FOR ARMY MGI APPLICATIONS

INTRODUCTION

J.N. Rinker and P.A. Corl

Developing, critiquing, and using classification systems of any sort involves judgment, and judgments differ greatly among different people. Consequently, one should not expect universality from any system. All systems have goals, especially those that deal with land cover and land use information. Perusing the literature and participating in discussions reveals an added difficulty in that there is much disagreement about terms, even as to the meaning of land cover/land use. To some, the term "land use" applies to cultural patterns, and the term "land cover" applies to natural patterns. To some, the term "land use" is nearly all encompassing in that the land is used to grow trees or that it is used to support a building, a road, etc. To others, the term "land cover" is nearly all encompassing in that the land is covered with trees, it is covered with buildings, it is covered with roads, it is covered with water, etc. Some say that an area covered with trees should be classified with the land cover term "forest." Others say not so, because the term "forest" implies a planting and is, therefore, a land use term. One man's rangeland is another's grassland, is another's savanna, is another's barren land. The arguments become tedious.

The Army needs a variety of information for many different purposes; and maps that show land cover/land use characteristics, and topography, can meet many of these needs. Augmented with other information such as geological structure, lithology, etc., they have even a broader range of application. How to identify and classify this information is the problem. Ideally, the classification system must meet Army needs, be usable throughout the world, be able to classify all areas (i.e. no holes in the map), be applicable to imagery analysis, and be able to be used by lower skilled individuals, at least at the entry levels. As yet no such system exists. Although there are several classification systems available, they all fall short in one or more respects. There are numerous reasons for these inadequacies, and near the top of the list must appear the element of haste, in terms of rapid response to expediency and pressure, rather than the slow, deliberate, tested evolution of a concept. What seems reasonable at a committee meeting frequently proves otherwise after careful thought and debate. Next are lack of a rigorous critique and evaluation of the stated needs and lack of a rigorous critique and testing of any resulting system.

Although the details of any land cover/land use classification system tend to be based on the goals of the analysis, there are some practical generalities that should be kept in mind. First, it is usually easier to identify land cover patterns in imagery than it is land use; second, accurate land cover descriptors can provide much of the information needs; and third, grouped categories, or lumped-together categories, should be avoided because they set the stage for information loss.

The fact that land cover is usually easier to identify than land use does not support the notion that all first level entries should be land cover. Some land use patterns are just as easy to identify, e.g. transportation patterns (roads, highways, airports, etc.), and these can, and should, be noted at the first level of the classification system. The first level should contain the most readily identified patterns, be they land cover or land use. There is an element of circularity to this procedure, at least for some applications. The imagery of the terrain is analyzed and converted into mapped notations of some classification system, which the map reader analyzes and converts into a mental image of the terrain.

Terrain surfaces can be covered with vegetation, soil, rock, water, snow, ice, or manmade materials and, of course, various mixtures of these. Granted that with certain photo emulsions at certain scales, times, seasons, and places, it is difficult to tell bare soil from grassland. One can, however, make most of the distinctions most of the time. The vegetation units can be classified into more detailed land cover units, such as closed tree canopy, open tree cover, brush, grassland, or mixes (refer to appendix E). Each of these land cover descriptors carries information that is useful to the Army with respect to mobility, cover and concealment, cross-country movement, etc., and does so independent of any use of the land. It might well be that some of the grasslands, or mixes of grass, brush, and trees, are used as rangeland, and if this land use practise is known, then one could infer that the area probably contains some sort of grazing stock. If these units were classified on the basis of land use only, however, and lumped together under the heading of rangeland, the inference about probable grazing stock would still exist, but the rest of the information would be lost, i.e. one would not know if the area was a grassland, a brushland, a savanna, a mixture, or what. From the standpoint of military operations, the latter elements are more pertinent to need than is the fact that the area is a rangeland.

Statements in the literature notwithstanding, none of the classification systems (going back to our Project Sanguine work in the late 60's)[1] are particularly applicable to data base development via imagery analysis procedures, once the obvious patterns have been completed. At times, one can bound areas on the imagery but cannot with any certainty identify them beyond rather vague and general terms. This is especially true for land use characteristics, and it becomes more of a problem when working with small scale imagery, monoscopic photography, radar imagery, or Landsat scenes. If one has access to other information, such as maps, or can visit the region, then one can match the areas in question to mapped boundaries, or to field observations, and assign classification labels. The resulting product is not an image that has been analyzed, but an image that has been annotated, and the bulk of the classification information may well have come not from the remote sensor, but from other sources. When the goal is some type of map, and this is usually the case, then obviously one uses all information that can be found, and a remote sensor might not even enter into it. But, if one is trying to evaluate a procedure, or a system, then another approach is needed. The only way to honestly evaluate the practical limits of an analysis procedure and the utility of some form of remote sensor imagery is to consider the worst possible case. How much information can an analyst obtain from the imagery alone, i.e. without auxiliary sources? A group should do fairly well in analyzing imagery of the area in which they live. How well will that group do in analyzing imagery of an area when they do not even know where the area is? How are the results of the analysis to be expressed, and does the system used convey to the map reader the characteristics of the terrain that are of concern to him? These are some of the issues being studies by CRS, and the following section summarizes the findings of one aspect of this work.

[1]Photographic Interpretation Research Division, 1969. An air photo analysis of a portion of Wisconsin and Michigan, for Project Sanguine, USACRREL, Hanover, NH.

EVALUATION OF LAND COVER/LAND USE CLASSIFICATION SYSTEMS FOR ARMY MGI APPLICATIONS

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This summary, prepared by J.N. Rinker and P.A. Corl, contains material extracted from the draft report prepared by Paul B. McCracken.

The Army depends to a significant extent on aerial photography and other remote sensor systems to provide up-to-date Military Geographic Information (MGI) about the terrain on and over which it must operate. Other sources for such information are maps, documents, intelligence reports, and interrogational reports. In order to use the results of an image analysis, it is necessary to find out what elements of information are needed, to evaluate the usefulness of remote sensor systems to obtain those elements, and to develop techniques and classification schemes for transferring the information into a practical data base. Consequently, this research has followed three paths: (1) a continuing review of Army documents to determine what items of terrain information are stated as needed by the Army; (2) a review of reports and internal research results that evaluate the uses of remote sensing to obtain terrain information; and (3) an evaluation of existing land cover/land use classification systems to find out if they meet Army needs and if they are applicable to remote sensing procedures.

1. **Determination of Information Needs.** Over the past several years, the Center for Remote Sensing, ETL, has reviewed a number of Army manuals and other documents to learn what kinds of terrain information the Army needs. Table 1 lists the material that has been reviewed to date. With reference to MGI information, FM 30–10 is the most comprehensive source. In terms of clarity, consistency, and exactness of expression, many of these items are not well written, and, in some instances, the older manuals are superior to the new. Because the manuals serve as basic sources of information, they should be examples of unequivocal writing.

TABLE F1. **Army Documents Reviewed that Contain Terrain Data Requirements.**

NUMBER	DATE	TITLE
*FM 5–30	Sep 67	Engineer Intelligence
*FM 5–36	Jan 70	Route Reconnaissance and Classification
*FM 21–26	Jan 69	Map Reading
*FM 30–5	Oct 73	Combat Intelligence
*FM 30–10	Mar 72	Military Geographic Intelligence (Terrain)
*FM 30–20	Apr 69	Aerial Surveillance and Reconnaissance – Field Army
*FM 31–60	Mar 72	River Crossing Operations
*FM 55–8	Mar 70	Transportation Intelligence
*FM 90–10	Aug 79	Military Operations on Urbanized Terrain (MOUT)
FM 101–5	Jul 72	Staff Officer's Field Manual – Staff Organization and Procedure
*TM 5–330	Sep 68	Planning and Design of Roads, Airbases, and Heliports in the Field of Operations
*TM 5–332	Dec 67	Pits and Quarries
*TM 5–545	Aug 67	Geology

Gunther, A.C. *A system for Topographic Inquiry – No. 3, Alpha-numeric Subsystem Data Base Listing.* USAETL, Ft. Belvoir, VA, ETL–0004, Mar 75, AD–A007 739.

Grubbs, J.B., Gunther, A.C., and Orsinger, R.J. *The Army Terrain Information System (ARTINS), Report No. 1, Data Base Storage Requirements.* USAETL, Ft. Belvoir, VA, ETL–0050, Mar 76, AD–A024 554.

Defense Mapping Agency Aerospace Center, Product Specifications for Digital Land Mass System (DLMS) Data Base. DMAAC, St. Louis, MO, July 77.

Defense Mapping Agency, Land Combat Data Base (LCDB). DMA, Washington, DC, year unknown.

*Assistant Chief of Staff, G2, 9th Infantry Division, 9th Infantry Division Manual for the Intelligence Preparation of the Urban Battlefield (IPUB). 9th Infantry Division, Ft. Lewis, WA, Apr 79.

Support Division, Topographic Department, DMAH/TC, Memorandum for Record, 12 Mar 81, subject: "Information Content – Proposed: Tactical Terrain Product Data Base (TTPDB)."

*Document includes collection methods.

There is also an obvious need to clarify and standardize concepts and terms that are associated with terrain information. For example, with respect to classifying urban patterns there are variances between FM 30–10 (1972) and FM 90–10 (1979). FM 30–10 is more comprehensive, straightforward, and clearer than FM 90–10, even though it was published several years earlier. FM 30–10 describes urban patterns in terms of seven functional divisions, eleven categories of building types and construction materials, four levels of density, six basic street arrangements, and four types of block arrangement. When combined, these provide a rather diversified descriptive capability. The manual does not, however, provide a list of symbols and a formal system for classifying such patterns. It refers to appended maps as examples. FM 90–10 combines information about function, street pattern, building arrangement and, to a certain extent, density into five basic patterns under a category heading of "Form." A second category entitled "Types of Buildings and Their Tactical Significance" contains nine classes. Although a list of letter symbols is provided for the Form category, a similar list is not given for the second category. One might assume that the associated numbers can be used. Other than the list of symbols for the one group, a classification hierarchy is not provided.

Another example can be found by comparing FM 30–10 to FM 30–5. Both manuals refer to the five military aspects of the terrain. In FM 30–10 these are listed as follows: key terrain features, observation in fields of fire, concealment and cover, obstacles, and avenues of approach. The acronym KOCOA is associated with these five aspects to serve as a memory cue, as well as a convenient abbreviation for communication purposes. In FM 30–5 these five aspects are altered in their order of presentation in that key terrain is placed between obstacles and avenues of approach, and no acronym is provided. If one was, it would be OCOKA. Interestingly, this acronym is used in association with these five aspects in an unpublished document entitled "9th Infantry Division Manual for the Intelligence Preparation of the Urban Battlefield (IPBM)" dated 24 April 1979. For the above manuals, the most recent editions as well as the earlier ones were reviewed. In all cases the discussion of the military aspects of the terrain was as stated above. For some reason, consistency in the discussions of this subject was never established.

Although FM 90–10 is intended for universal application, the examples are from western Europe, and these pattern relations are not necessarily usable elsewhere. The manual states that "With minor modification it is applicable to other urban areas throughout the world."[2] The manual does not provide any information about the modifications, and it is our opinion that in most cases the modifications would be greater than "minor."

[2] *Military Operations on Urbanized Terrain (MOUT).* August 1979. FM 90–10.

2. **Evaluation of Remote Sensing Systems.** Although airborne remote sensing imagery cannot provide all MGI information needs, it can provide more than is perhaps realized. Over the past several years, studies have been done at ETL in which remote sensor systems were evaluated for their capabilities to meet Army terrain information needs. These reports are listed in table 2. Of the items in table 2, ETL Reports TR--72-6, 0054, and 0081 address the issue by itemizing specific elements of information and evaluating the remote sensors against them. The number of terrain data elements listed in the three ETL reports were 80, 1765, and 313, respectively. In all cases these were derived from much larger groups of elements by deleting redundancies, combining similar elements, and removing items that were not applicable.

The results of these evaluations show that much of the needed terrain information can be obtained and that the level of detail varies as a function of the type of sensor system as well as of the skill of the interpreter. The studies also point out that some terrain information requested by the Army cannot be obtained by remote sensing procedures. One of these reports, ETL--0081, included the methods by which data are obtained from aerial photography, i.e. by direct observation, measurement, or inference. Tallying the results in this study, it seems that about two-thirds of the needed data elements can be obtained directly from 1:20,000 scale stereo panchromatic photography, and approximately one-half of them can be obtained from 1:100,000 scale stereo panchromatic photography.

The documents listed in table 2 were generated as a result of research projects, and the MGI data elements in them came from DA and DOD sources, published and unpublished. The data elements in the basic DA and DOD documents were not organized in any consistent manner. In addition, several methods for obtaining these data elements were given, but the guidelines specifying which methods are optimal for obtaining terrain information are weak. Attempts to strengthen these guidelines are a part of the research program within CRS. An effort has been directed towards providing more complete information as to the kinds and details of MGI data elements that can be reasonably obtained by various remote sensor systems, particularly aerial photography. Part of this effort includes developing discipline-oriented classification systems that are designed to be used with aerial photography as a preliminary data source. Two tentative systems, vegetation and soils, have been designed and are included in appendixes D and E. A similar system is needed to handle the cultural patterns of the landscape. Realistically, the system should combine all of the elements into a land cover/land use type of classification.

TABLE F2. ETL Reports Associated with the Evaluation of Remote Sensing Imagery for Terrain Analysis

1. Lind, Aulis O. *An Evaluation of Multiband and Color Aerial Photography for Selected Military Geographic Intelligence in a Subtropical Desert Evironment.* Technical Report 54–TR, USAETL, January 1970, AD–707 429.

2. Reed, R.K. and Rinker, J.N. *Evaluation of Color Test Photography for Military Geographic Analysis – A Literature Review.* USAETL, ETL–TR–70–6, July 1970, AD–884 356L.

3. Orr, Donald G. *Project SAND (Phase III): Analysis of Remote Sensor Imagery of Selected Areas in the Mississippi Delta.* USAETL, ETL–TR–71–3, September 1971, AD–892 579L.

4. Vogel, T.C., *et al. A Matrix Evaluation of Remote Sensor Capabilities for Military Geographic Information (MGI).* USAETL, ETL–TR–72–6, July 1972, AD–751 192.

5. *Advanced Radar Topographic Application.* Raytheon Co., Autometric Division, USAETL, ETL–CR–73–2, February 1973, AD–908 394L.

6. Vogel, T.C., Brooke, Robert K., Jr., and Schwarz, Gunther. *Military Applications of Multiband Aerial Photography.* USAETL, ETL–0030, September 1975, AD–B008 114L.

7. Vogel, T.C. *Remote Sensor Image Capabilities for Acquisition of Terrain Information.* USAETL, ETL–0054, June 1976, AD–A026 592.

8. Rinker, J.N., *et al. Capabilities of Remote Sensors to Determine Environmental Information for Combat.* USAETL, ETL–0081, November 1976, AD–A035 139.

9. Stellar, David, *et al. Radar, Thermal Infrared and Panchromatic Image Interpretation.* USAETL, ETL–0208, December 1979, AD–A086 332.

3. **Evaluation of Existing Land Cover/Land Use Classification Systems for MGI.** Although the term "land cover/land use" is not common in Army terminology, it is descriptive of the kinds of terrain information that are wanted. Basically, the Army needs to know what is covering the land in terms such as trees, brush, grasses, structures (buildings, towers, etc.), water, bare rock, etc., and the uses of the land in terms such as transportation, communication, agriculture, recreation, industrial, residential, etc. A practical and carefully thought out land cover/land use classification system designed for use with remote sensors, at least at the first two levels, and which can incorporate information from other data sources, would be of benefit to the Army in several ways.

1. It would facilitate communication between Army units by providing standard MGI terrain data elements.

2. It would serve as a guideline to terrain analysts for determining which information elements could be obtained from air photos and which could not.

3. A land cover/land use map or overlay would serve as a unifying document concerning the general nature of the terrain and to which more detailed discipline overlays could be added as needed.

4. A land cover/land use overlay containing generalized information can be produced quickly from small-scale photography by analysts from the lower skill group.

In 1976, the U.S. Geological Survey (USGS) published Professional Paper 964, entitled, "A Land Use and Land Cover Classification System for Use with Remote Sensor Data." This system is being used by USGS in producing nationwide land use and land cover maps at a scale of 1:250,000. The report claims that this system was developed to meet the needs of Federal and State agencies for up-to-date information about land use and land cover throughout the country on a basis that was uniform in categorization at least at the first and second levels and which could be used with data from satellite and aircraft remote sensors. A follow-on statement claims that it uses the features of existing and widely used classification systems that are amenable to data derived from remote sensing sources.

This land use and land cover classification system was developed for an important purpose, i.e. a need to standardize the recording of this kind of information. Because every agency had its own classification scheme and mapping scale, it was difficult to compare data and to communicate between agencies. Through standardization of terminology and mapping scales, it was intended to eliminate the duplication of effort between various local, state, and federal agencies and to provide a better basis for comparison and communication. As of October 1982, approximately 75 percent of the land use and land cover mapping for the continental United States had been accomplished.

At first reading of the USGS classification system, the categories of land use and land cover seemed to match many of the Army's terrain information needs. Consequently, rather than trying to design a classification system from scratch, it was decided to evaluate this one with respect to its usefulness to the Army and its compatibility with remote sensor information. Even though we knew that this system would not provide anything but coarse land cover/land use detail, we thought it could serve as the first step in better defining the basic structure of an Army system, and in helping to define what terrain data can be obtained with remote sensors as the primary sources. The evaluation was done by means of an air photo analysis and mapping the units according to the USGS system. This system, as it appears in USGS Professional Paper 964, is at the end of this section.

The geographic area selected for the evaluation is located within Baltimore County, Maryland, extends into the northern part of the city of Baltimore, and contains an area that is approximately 270 square miles. The land cover and land use patterns were mapped from U.S. Department of Agriculture aerial photographic prints (panchromatic, 9 inches by 9 inches format, 1:20,000 scale, October 1971). These photos were studied stereoscopically on an uncontrolled mosaic constructed from one-half of each stereopair. Mapping of land cover/land use boundaries was done on a clear acetate sheet overlaying the photography. A more regional overview of the area was obtained by examining smaller scale USGS stereo aerial photography (panchromatic, 9 inches by 9 inches format, 1:76,000 scale, April 1974). A daylong field check was also done.

The USGS system contains two levels of detail. Level I, the most general in character, has nine classes, seven of which are land cover and two, land use. Level II is still quite general but is concerned with the more specific types of land cover or type of land use associated with a given land cover. The details of the analysis and mapping are at the end of this section.

The results show that the USGS system is limited in value to the Army for recording and portraying military geographic information. One drawback of this system is the aggregation of several distinct terrain features into one category or into an "Other" category. For example, consider the following Level II classes: Transportation, Communications, and Utilities; Cropland and Pasture; Bays and Estuaries; and Strip Mines, Quarries, and Gravel Pits (part of the Level I Barren Land class). In most cases each separate item of these classes can be detected and identified on imagery, and each of them conveys different information about the environment in terms of soils, engineering materials, mobility, cover and concealment, etc. Because of the classification system and the lumping of different things under a similar numerical code, much of this information is disguised or lost and cannot appear on the final map. Furthermore, this classification system is not as amenable to remote sensing techniques as it implies. As brought out earlier, the USGS land cover/land use classification system was evaluated initially because it stated that it was for use with remote sensor data and it was already in operational use within the Federal Government. The results of the evaluation show that however useful for economic analysis and State needs, the USGS classification system does not meet Army requirements. Furthermore, it has some inconsistencies in internal logic and is not particularly useful with remote sensor imagery. Because of these results, it was decided to evaluate other classification systems. A review of the literature relevant to this subject, and contact with others in the field, produced 18 more land cover/land use classification systems. One of these was published in 1950, and the others were developed in the 1960's and '70's. Some are based on USGS's classification system, at least for the first two levels. The majority of them claim to be designed for use with airborne remote sensor imagery, primarily photography.

Because of time constraints, these 18 systems were not tested by photo analysis. Instead, a matrix was compiled in which the types of terrain data supplied by these 18 systems were compared to the types of data specified in the DMA Tactical Terrain Product Data Base (TTPDB). The data elements included in the TTPDB are virtually the same specified in FM 30–10 and other DA documents, but with minor variations in terms and groupings. The groupings in this data base are: vegetation, surface materials, surface drainage, transportation, obstacles, aerial obstructions, and special features. The terrain data elements for built-up areas have not been defined as of this time. Those included in FM 30–10 were added into this matrix so as to provide a more complete picture of needed information.

Table 3 lists the 18 land cover/land use classification systems that were evaluated. The USGS system, which was evaluated by photo analysis, is included in order to compare it to the other 18. This table summarizes the types of land cover and land use associated with these systems, as well as indicating the number of levels of information, the number of categories per level, the type of data provided, and the method of category coding. Table 4 lists the sources of the classification systems presented in table 3. Table 5 is a matrix displaying the types of terrain information specified by the TTPDB and by FM 30–10. Note that many of the categories require quantitative data and, as can be seen, none of these land cover/land use classification systems are of help in supplying this kind of information, although some do so on a minimal basis. The letter "T" used in the matrix signifies that the indicated classification system provides the information specified by the TTPDB or the FM 30–10 category for which it applies and that it is expressed in the terminology of the TTPDB or of FM 30–10. Very few T's appear in the matrix, three in the TTPDB section, and eight under the FM 30–10 category of Urban Areas. As can be seen, most of the classification systems provide some qualitative data (signified by the letter "P") for the TTPDB and Urban Areas category of FM 30–10. Most of the classification systems supply some information with respect to the type of vegetation or transportation feature specified in the TTPDB. Although some of the data elements in the TTPDB Vegetation category can be translated directly into land cover classes of the USGS system, the reverse is not necessarily true.

TABLE F3. Characteristics of the land cover/land use classifications systems that were tested and evaluated for use with remote sensor imagery and for applicability to Army needs. The classification by Anderson contains two schemes. These we have designated as No. 1 and No. 2. The sources of these classification systems are listed in Table F4.

LAND COVER/LAND USE CLASSIFICATION SYSTEM	COVER					USE								LEVELS					
	Structures	Vegetation	Bare Ground	Water	Snow/Ice	Built-up Areas	Transportation	Agriculture	Silviculture	Extraction Act.	Recreation	Water	Bare Ground	1	2	3	4	TYPE OF DATA	CODING SYMBOLS
Anderson, J.R., 1971 (No. 1)	X	X		X				X	X	X	X	X		7	16	10	0	QL	AN
Anderson, J.R., 1971 (No. 2)	X	X		X			X	X		X				9	0	0	0	QL	N
Anderson, J.R., et., 1972 USGS Circ. 671	X	X	X	X	X	X		X		X		X		9	34	0	0	QL	N
Anderson, J.R., et. al., 1976 USGS Prof. Paper 964	X	X	X	X	X	X		X		X		X		9	37	0	0	QL	N
Drake, B., 1977	X	X	X	X	X	X	X	X		X		X		112	47	0	0	QL	N
Gwynn, A.P., 1968	X	X				X	X	X		X	X			2	8	33	0	QL	AN
Jenks, G., 1968	X	X	X	X	X			X						8	0	0	0	QL	N
MacConnell, W.P., 1974	X	X				X	X	X		X	X			65	0	0	0	QL	A
McNair, A.J., 1970	X	X	X	X		X		X	X	X	X	X		175	0	0	0	QL QN	AN
Mower, R.D., 1971	X	X	X	X				X						10	0	0	0	AL	A
Pascucci, R., et al., 1969	X	X		X		X	X	X		X	X	X		8	46	48	34	QL QN	N
Ryerson, R.A., 1980	X	X	X	X		X		X		X				7	19	0	0	QL	A
State of Florida, 1976	X	X	X	X		X	X	X	X	X	X	X	X	7	40	131	YES	QL	N
State of Maryland, 1978	X	X	X	X		X	X	X		X	X	X		23	47	8	0	QL	N
State of New Hampshire, 1975	X	X	X			X	X	X		X	X			132	0	0	0	QL	A
Swanson, R.A., 1969	X	X	X	X		X	X	X	X	X	X	X		115	0	0	0	QL	A
Bur/Public Roads, Wash,DC, 1969 Standard Land Use Coding Manual	X			X		X	X							9	67	0	0	QL	N
Van Valkenburg, S., 1950	X	X						X						9	0	0	0	QL	N
Walton, J.M., et. al., 1979	X	X	X	X	X	X		X		X	X	X		9	31	63	28	QL	N

LEGEND: QL -- Qualitative; QN -- Quantitative; A -- Letters; N -- Numbers;
AN -- Alphanumeric; X -- Subject Areas Addressed.

TABLE F4. Sources of the Classification Systems Listed in Table F3.

Anderson, J.R. 1971. "Land Use Classification Schemes." *Photogrammetric Engineering* 37:379–387. (No. 1 and No. 2).

Anderson, J.R., Hardy, E.E., and Roach, J.T. 1972. *A Land Use Classification System for Use with Remote Sensor Data.* U.S. Geological Survey Circular 671.

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E. 1976. *A Land Use and Land Cover Classification System for Use With Remote Sensor Data.* U.S. Geological Survey Professional Paper 964.

Drake, Ben. 1977. "Necessity to Adapt Land Use and Land Cover Classification Systems to Readily Accept Radar Data." *Proceedings, 11th International Symposium on Remote Sensing* 3:993--1000.

Gwynn, A.P. 1968. *Aerial Photographic Interpretation and Land Use Classification.* Regional Planning Council, Baltimore, MD.

Jenks, George. 1968. Refer to report by Mower, 1971.

MacConnell, William P. 1974. *Rhode Island Map Down – Land Use and Vegetative Cover Mapping Classification Manual.* Cooperative Extension Service, Univ. of Rhode Island, U.S. Dept. of Agriculture, and County Extension Services Cooperative, Circular No. 169.

McNair, Arthur J. 1970. *Colorado Land Use and Natural Resource Inventory.* Colorado School of Mines Research Proposal CSM No. 335.

Mower, Roland D. 1971. *The Discrimination of Tropical Land Use in Puerto Rico: An Analysis Using Multispectral Imagery.* Center for Research Inc., Univ. of Kansas, Lawrence, KS. Technical Report 133–25.

Pascucci, R.F., North, G.W., Albrizio, R.A., and Shelkin, B.D. 1969. *Geograhic Analysis of Multiple Sensor Data from the NASA/USGS Earth Resources Program.* Autometric Operation, Raytheon Co., Alexandria, VA.

Ryerson, Robert A. 1980. *Land Use Information from Remotely Sensed Data.* Canada Centre for Remote Sensing, User's Manual 80–1.

TABLE F4. (Continued)

State of Florida. 1976. *The Florida Land Use and Cover Classification System: A Technical Report.* Dept. of Administration, Div. of State Planning, Bur. of Comprehensive Planning Report DSP--BCP--17–76.

State of Maryland. 1978. *Maryland Land Use Classification Scheme to be Used With County Land Use Maps.* Maryland Dept. of State Planning, 301 W. Preston St., Baltimore, MD 21201.

State of New Hampshire. 1975. *New Hampshire Data Base Pilot Study.* State of New Hampshire, Office of Comprehensive Planning, Concord, NH.

Swanson, Roger A. 1969. *The Land Use and Natural Resource Inventory of New York State.* New York State, Office of Planning Coordination, 488 Broadway, Albany, NY 12207.

U.S. Department of Transportation. 1969. *Standard Land Use Coding Manual.* Federal Highway Admin., Bur. of Public Roads, Washington, D.C.

Van Valkenburg, S. 1950. "The World Land Use Survey." *Economic Geography* 26: 1–5.

Walton, J.M., Olson, C.E., and Limoges, E. 1979. "Mapping Land–Use from Existing Air Photos." *Proceedings, 40th Annual Meeting of the American Society of Photogrammetry,* 290--300.

TABLE F5. Results of the evaluation of the land cover/land use classification systems listed in Table F3. The headings along the top are information elements taken from the TTPDB or FM 30–10. The letters and symbols within the columns indicate the capability of a classification system for obtaining the listed information. A blank space indicates that the classification system cannot provide the information. The symbols are explained below.

ARMY MGI REQUIREMENTS	TACTICAL TERRAIN PRODUCT DATA BASE OVERLAYS																																															FM 30 -- 10						
	VEGETATION									SURFACE MATERIAL						SURFACE DRAINAGE								TRANSPORTATION																				OB STA-CLES		AER IAL-OBST		URBAN AREAS						
LAND COVER/LAND USE CLASSIFICATION SYSTEMS	TYPE	CANOPY CLOSURE	HEIGHT	STEM DIAMETER	STEM SPACING	ROUGHNESS	UNDERGROWTH	CROWN DIAMETER	HEIGHT LOW BRANCH	TYPE – U.S.C.	QUALIFIER	STATE OF GROUND	DEPTH – SURF. MAT.	ROUGHNESS	DEPTH – BEDROCK	TYPE	GAP WIDTH	BOTTOM MATERIAL	HEIGHT – BANK	SLOPE – BANK	WATER VELOCITY	WATER DEPTH	BANK VEGETATION	TYPE	CONDITION	QUALIFIER	LENGTH	AVERAGE WIDTH	SURFACE	HIGHWAY TYPE	RAILROAD TYPE	PAS TRK, SID, YDS	BRIDGE TYPE	MOVEMENT	OVERHEAD CLEARANCE	HORIZONTAL CLEAR.	UNDER CLEARANCE	BYPASS CONDITION	CONST. MATERIAL	CLASSIFICATION	SPANS -- NO.	SPANS -- LENGTH	TUNNELS – HEIGHT	TYPE	HEIGHT	TYPE	HEIGHT	FUNCTIONAL DIVISION	BUILDING TYPE	BLDG. CONST. MATERIALS	BUILDING HEIGHT	STREET PATTERN	BUILDING ARRANGMT	DENSITY
Anderson, J.R., 1971 (No. 1)	M																							P																						P								
Anderson, J.R., 1971 (No. 2)	M																																																					
Anderson, J.R., et al., 1972 USGS Circ. 671	P	M^{x}								M	M																																	M*				P						
Anderson, J.R., et al., 1976 USGS Prof. Paper 964	P	M^{x}								M	M					P							M*																					M*				P						
Drake, B., 1977	P	M*								M	M					P							M*	P																				M*		M*		P						
Gwynn, A.P., 1968	P																							P																								P	M					
Jenks, G., 1968	P															M																																						
MacConnell, W.P., 1974	P	M^{x}								M	M													P						M		P												P*		M*		P	M					P
McNair, A.J., 1974	P		M							P	M					P							M*	P					M		M													P		M		T						
Mower, R.D., 1971	P																																																					
Pascucci, R., et al., 1969	P	T^{+}	T^{+}																					T					P		P													M*		P*		T	M					P
Ryerson, R.A., 1980	P									M	M																																	M*				P						M
State of Florida, 1976	P	M^{x}								M	P					P							P*	P	M							M														M*		T						P
State of Maryland, 1978	P									M	M					P								P								M												M*		M*		T						P
State of New Hampshire, 1975	P*	P								M	M					P*							M*	P						M	M	M												M*		M*		T	M					P
Swanson, R.A., 1969	P									M							M							P	M				M			P												M*		P*		T						M
Bur/Public Roads, Wash., DC, 1969 Standard Land Use Coding Manual	M															M								P																				M		M		P						P
Van Valkenburg, S., 1950	M																																																					
Walton, J.M., et al., 1979	P	P								M	M					P							M*	P								M												M*		M*		T						M

LEGEND: T = Total. The classification system contains the category specified and it is expressed in the terminology of the TTPDB or FM 30–10. P = Partial. This indicates that the information meets a substantial number of the requirements. M = Minimal. That is, only very few items, such as one or two, on the list can be met. * = Might be provided in another category. + = No specific ranges.
x = A threshold percentage is defined for distinguishing forest land from other land.

For all practical purposes, these classification systems have little to offer the Army except generalized land cover and land use information similar to that found in the USGS system. Those schemes that have three and four levels of detail do provide additional specifics, some of it quantitative, but not in the same format as that of the TTPDB. They also provide some specifics not requested by the TTPDB. As a result, these systems are considered to be of limited value to the Army in supplying military geographic information. Therefore, ETL is designing a system specifically for the Army, which is to be used with remote sensor imagery as the primary source of information.

The USGS Land Cover/Land Use Classification System (USGS Professional Paper 964)

LEVEL I		LEVEL II	
1	Urban or Built-up Land	11	Residential
		12	Commercial and Services
		13	Industrial
		14	Transportation, Communications, and Utilities
		15	Industrial and Commercial Complexes
		16	Mixed Urban or Built-up Land
		17	Other Urban or Built-up Land
2	Agricultural Land	21	Cropland and Pasture
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
		23	Confined Feeding Operations
		24	Other Agricultural Land
3	Rangeland	31	Herbaceous Rangeland
		32	Shrub and Brush Rangeland
		33	Mixed Rangeland
4	Forest Land	41	Deciduous Forest Land
		42	Evergreen Forest Land
		43	Mixed Forest Land
5	Water	51	Streams and Canals
		52	Lakes
		53	Reservoirs
		54	Bays and Estuaries
6	Wetland	61	Forested Wetland
		62	Nonforested Wetland
7	Barren Land	71	Dry Salt Flats
		72	Beaches
		73	Sandy Areas other than Beaches
		74	Bare Exposed Rock
		75	Strip Mines, Quarries, and Gravel Pits
		76	Transitional Areas
		77	Mixed Barren Land

LEVEL I	LEVEL II
8 Tundra	81 Shrub and Brush Tundra 82 Herbaceous Tundra 83 Bare Ground Tundra 84 Wet Tundra 85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields 92 Glaciers

A summarized description of the mapping of this study area follows. The order of discussion is according to the hierarchy of the USGS classification system, i.e. beginning with Urban or Built-up Land and ending with Perennial Snow or Ice.

First, land features were classified by the type of cover they provided on the ground's surface. Cover types were identified by their visual appearance in terms of size, shape in three dimensions, tone, location, and relation to surrounding objects. In addition, knowledge as to how the above factors related to each other in forming various recognizable patterns was an important factor. Where mapped, gross land use was inferred based upon knowledge of various physical characteristics within each cover type. The smallest mapping unit used was approximately 2 square millimeters, which is equivalent to a little less than one-half of an acre on the ground at the 1:20,000 scale. Mapping units this small were infrequent; they generally ranged from three or four times, to many times, larger than the stated minimum. Consequently, most features that were very small and isolated were included in a category that was more extensive. If such features were observed in sufficient numbers to create a larger pattern, they were classified separately. For example, isolated small buildings were generally incorporated into a more dominant land cover and not mapped; whereas, a cluster of such buildings was mapped and classified.

Within the study area there were two general land cover groups, land with structures on it and land with vegetation on it. Most of the structure-covered land occupies the southern portion of the study area. This cover type was mapped at Level II, that is, according to its general use function. Most of the structures were identified as residences. Land devoted to commerce, industry, transportation, communications, and utilities was also identified and mapped. Some land was labeled as "Other Urban or Built-up Land." For the most part, uses included within this category were golf courses and cemeteries.

Most of the land that was not classified under Urban or Built-up Land was classified either as Agricultural Land or Forest Land. Agricultural Land was mapped at Level II, whereas Forest Land was not. Most agricultural land was classified as Cropland and Pasture. A few orchards and one nursery were identified, and these were so labeled collectively, according to the Level II category. Some agricultural land was classified as "Other Agricultural Land." This land contained either small farm ponds or racetracks judged to be related to horse-raising activities. As indicated previously, land with tree cover was not classified at Level II. Level II requires that a distinction be made between deciduous and evergreen trees. To do this requires a person skilled in forestry patterns.

The categories of "Shrub and Brush Rangeland" or "Mixed Rangeland" were used for areas that appeared to be abandoned cropland that was reverting back to forest cover.

The area also contained several water bodies. All of these were classified at Level II, "Streams and Canals, Lakes, Reservoirs, and Bays and Estuaries."

Land without some form of cover was present, and these areas were classified at Level II as either "Quarries" or "Transitional Areas" under the Level I "Barren Land" category.

The remaining two categories, "Tundra" and "Perennial Snow and Ice," were not applicable to this study area.

APPENDIX G.
PHOTO PATTERNS ASSOCIATED WITH IGNEOUS AND METAMORPHIC ROCKS

J. Ehlen

PHOTO PATTERNS ASSOCIATED WITH IGNEOUS AND METAMORPHIC ROCKS

Judy Ehlen

Attempts to relate air photo patterns to specific types of rocks began in the 1930's. Since then pattern element descriptions of the common sedimentary rocks, and some of the igneous and metamorphic rocks, have been developed. Most of these descriptions exist as results from photo analyses of specific areas for engineering purposes. Examples of these include Frost (1950a and 1950b) and Gaskin (1970). Frost et al. (1953) provides a more general discussion of photo patterns associated with rock and soil types. Several workers have presented these criteria in list formats so that the pattern elements of particular rock types are presented in the form of a key. Because the photo patterns of the rocks vary with climate, separate listings are sometimes provided for the rocks as they appear in different climates. If separate climatic listings are not used, climatic restrictions on particular characteristics are occasionally included within the general descriptions.

The first table is a compilation of identification criteria for many common rocks in arid environments. As indicated in the footnote, both published and unpublished criteria are included. Published criteria from Belcher et al. (1951), von Bandat (1962), and Way (1973) are shown in bold type. Criteria developed within CRS and its predecessor organizations are shown in italics. Results from recent work on some of these patterns have been published (Ehlen, 1981). Continuing field work and photo analysis by CRS personnel have shown that some of the published criteria are not correct, or are so restricted as to be of no practical use. Remaining uncertainties are being studied. The status of questionable criteria is shown on the table by question marks, brackets, and x's, which are explained in the footnote.

The proposed classification for igneous rocks (table 2) is based on work in south-central New Mexico (Ehlen, 1981 and unpublished data). As work progresses, the table will be expanded to include the patterns of igneous rocks in other climates. Photo tone, which corresponds indirectly to rock composition, and photo texture, to grain size, forms the basis for the classification. The work in New Mexico has shown that landform and drainage patterns are less reliable in terms of accurate predictions than photo tone and photo texture patterns.

During a photo analysis, the first classification step is to assign the rocks to one of the general groups, e.g. igneous, sedimentary, or metamorphic. Once the rocks are identified as igneous, they can be separated into broad tonal groups that correlate with the three general compositional categories of igneous rocks: light toned with felsic compositions, medium toned with intermediate compositions, and dark toned with mafic compositions. Each of these groups can be separated into two classes based on grain size predictions, with a coarse texture indicating large grain size and a fine texture indicating a small grain size. The grain size groups can be further subdivided according to small variations in photo tone, if they exist, within each grain size group. It must be remembered, however, that unless there are tonal variations within the photo texture or grain size groups, only general names such as granitic can be applied to the rock units.

Table 3 lists the published photo pattern element descriptions or identification criteria for metamorphic rocks, based on Belcher et al. (1951), von Bandat (1962), and Way (1973). The authors do not indicate whether or not the criteria are restricted to certain climates, or are intended for use in all climates. Although uncertainties exist in relation to many of these criteria, none are indicated on the table because work has just begun on their evaluation in temperate climates; no work has yet been done in other climates. Internal inconsistencies within the published criteria, particularly in reference to landforms, have been noted and are presently being investigated.

The published criteria of table 1 emphasize landform and drainage-plan patterns for all rock types addressed. As a result, more complete pattern element descriptions are needed, both for the rocks included in the table, as well as for other rocks. The photo pattern element descriptions shown in table 4 are the first step in an attempt to develop new criteria for igneous rocks other than basalt and granite in arid regions. The descriptions are based on recent work in south-central New Mexico (Ehlen, unpublished data), and refer only to the specified rock types in that location. These rock types are underlined on table 2. These preliminary identification criteria require evaluation in other localities. Table 5 shows preliminary criteria for some types of metamorphic rocks in temperate climates and is based on work in New England (Ehlen, 1983).

Obviously, many items concerning the classification scheme, and rock type identification criteria in general, remain to be addressed. Specific items for which work in arid and semi-arid climates is planned include (1) testing the criteria for granite; (2) investigating the igneous rocks not previously studied; (3) investigating all igneous rock types in multiple locations; (4) reevaluating and refining landform and drainage criteria for all rock types; and (5) developing reliable photo tone and photo texture criteria for all igneous rock types. The evaluation of identification criteria for metamorphic rocks in temperate climates is continuing.

TABLE G1. Rock Type Identification Criteria on Aerial Photography for Arid Regions.*

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Texture
Gneiss	Irregular boundaries (x) Steep-sided, sharp-crested ridges, often parallel Steep-sided, sharp-crested hills *Long slopes* *No talus* *High relief; rugged*	Angular dendritic Fine-to-medium texture Abrupt angular bends 90° intersections (?)	[U-shaped cross section] *Narrow, V-shaped cross section* *Steep gradients*	Light (?) Banding not apparent *Can be dark owing to desert varnish*	*Rough* *Uneven* *Knobby*
Schist	Parallel laminations(?) Moderate relief Fairly rugged topography Usually steep attitude Low ridges, shallow depressions *Slightly rounded ridge crests*	Angular dendritic, rectangular, *or trellis* Fine texture Gullies parallel	Narrow, deep gullies with few branches Steep-sided [U-shaped cross section] *Open, V-shaped cross section*	Light (?) [Often faintly banded] Uniform	
Slate	Boundaries irregular and transitional (?) Rounded, steep-sided hills, usually small (x) Sharp-crested, steep-sided ridges, usually alined Elevations repeat (x) Highly eroded	Rectangular to rectangular dendritic *or trellis* Very fine texture	Deeply incised Steep-walled [U-shaped cross section] *Narrow, V-shaped cross section*	Light (?) Hilltops darker, valleys lighter (?) *Light to dark gray as a function of origin*	

*Identification criteria, derived from the published literature (excluding those by R. E. Frost) are shown in this type. *Criteria that have been developed by R. E. Frost and those working with him over the years at Purdue University (1942–56), U.S. Army Snow, Ice, and Permafrost Research Extablishment (1956-60), U.S. Army Cold Regions Research and Engineering Laboratory (1960-70), and U.S. Army Engineer Topographic Laboratories (1970-present), are shown in this type.* [] indicates an item is incorrect, ? that it is being questioned, and x that it is unknown.

TABLE G1. Rock Type Identification Criteria on Aerial Photography for Arid Regions. (Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Texture
Marble	Massive, rounded *Smooth ridge crests*			Light (?) *Light to dark gray*	*Fine, smooth*
Serpentine	Smoothly curving boundaries Winding ridges between elongate, cone-shaped hills (x) Hills quite rounded Easily eroded	Dendritic or radial Coarse texture	Steep gradient (x)	Dull, even gray	
Quartzite	*Highly resistant to erosion* *High relief* *Moderately jointed* *Narrow, but slightly rounded ridge crests*	*Angular*	*Steep-sided gullies*	*Light to dark gray as a function of origin* *Can be banded*	*Medium to coarse* *Uneven to rough*
Granite	Tors and boulder piles Boundaries smoothly curving Highly resistant to erosion Rounded, convex surfaces - whalebacks and woolsacks Bold, massive dome-like hills Steep slopes A-shaped hills (?) *Summit elevations not repeated* *Random arrangement; lack of linearity*	Well-integrated dendritic, rectangular locally (?), radial regionally; *angular* Sickle-or hook-shaped *(pincer-shaped)* in headwater areas Stream intersections near 90° or slightly acute upstream (?)	Few gullies Steep, *uneven* gradients *Steep-sided, uneven V-shaped cross section* *Straight-sided on major portions of side-slopes (?)*	Light [Banded] *Uniform*	Choppy surface *Rounded and lumpy* *Coarse*

TABLE G1. Rock Type Identification Criteria on Aerial Photography for Arid Regions. (Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Texture
	Heavily jointed -- *vertical and curvlinear sheeting joints* Pinnacles, *needles and spires* in highly *vertically* jointed rock				
Basalt	Jagged, *well-defined* boundaries Level or gently sloping plains, mesas, and plateaus; *forms caprock* Shield-shaped hills Ridges with pear-shaped appendages and narrow connections (x) Talus at base of slopes Vertical escarpments Stepped (terraced) canyon walls As ejecta, cone-shaped hills *Flowmarks* *Flows can be lobate in shape*	Parallel regionally on flows Poorly developed, mainly (?) internal on flows Coarse texture on flows Radial on volcanos Fine texture on volcanos	Few to no gullies Cross section varies *Box-shaped cross section*	Very dark gray to black, *fre-quently* with light spots Banded where flows interlay-ered (?)	Ropey; *blocky and angular; rough and jagged*
	Columnar joints *Highly vertically jointed*				

TABLE G1. Rock Type Identification Criteria on Aerial Photography for Arid Regions. (Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Texture
Andesite	*Stepped canyon walls* *Talus* *Steep slopes* *Conical hills, plateaus*	*Dendritic*	*V-shaped cross section*	*Medium to dark gray*	*Rough to blocky*
Limestone	Transitional boundaries (x) Moderate to steep slopes Layered Forms caprock Sinkholes -- *solution features can be found, but are not characteristic of limestone development in an arid environment* *High relief* *Angular, sharp, narrow ridge crests in tilted rock* *Very resistant to erosion* *Rounded, lobate, or scalloped hills in plan view in flat-lying or gently dipping rocks* *Highly fractured*	Well-developed angular dendritic, discontinuous, *and rectangular* Fine-to-medium texture	Flat-bottomed gullies *Steep sides on gullies* *Box-shaped cross section*	Uniform, light gray Can be white Banded	*Angular to blocky*

TABLE G1. Rock Type Identification Criteria on Aerial Photography for Arid Regions. (Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Texture
Shale	Rugged topography (badlands) Steep-sided, rounded hills Rounded ridge crests Highly dissected *Easily eroded* Layered	Dendritic Very fine texture and high density Meandering *or wiggly* on valley floors Long gullies *Many high-order tributaries*	Steep-sided, sag and swale (?) Flat, open, V-shaped cross section Steep gradients (?) *Low gradient*	Uniform (?) Light (?) Dull Faintly banded *Light to dark gray as a function of origin*	*Soft, smooth, velvety, and fine*
Sandstone	Distinct linear boundaries (?) Resistant to erosion Bold, massive hills Forms caprock; elevations repeat Layered Streamlined shapes *Broad, gently rounded ridge crests* *Narrow,* steep-sided valleys *often near-vertical slopes* Jointed -- usually two sets at 90° -- *vertical joints* *Often very heavily jointed*	Angular dendritic to rectangular Medium-to-coarse texture *Joint-controlled* *Long, straight, stream segments*	No gullies (?) Incised V-shaped cross section *Even gradient*	Light-to-*medium-gray*	*Rough, uneven, and slightly knobby*

TABLE G1. Rock Type Identification Criteria on Aerial Photography for Arid Regions. (Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Texture
Interbedded Sedimentary Rocks (flat-lying)	Terraced hillsides (stair-step topography: [beds must be 25 feet thick or more] – *beds must be more than 1 m thick* Terracing follows contours Shale forms gradual slopes; limestone and sandstones, steep slopes Steep well-rounded hills where thin-bedded No solution cavities in limestones – *depends on climate during formation* *Knobs* *Blocky plateaus* *Rounded, lobate, scalloped hills in plan view*	Dendritic, can be angular *or rectangular* Fine-to-medium texture, if thin-bedded; fine texture, if thick-bedded	Few gullies (?) *Blocky, modified U-shaped cross section*	Banded, may be faint Gullies light where limestone present Sandstone darker than limestone	Texture of main rock type will predominate if thin-bedded *Generally blocky*

TABLE G1. Rock Type Identification Criteria on Aerial Photography for Arid Regions. (Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Texture
Interbedded Sedimentary Rocks (tilted)	Sharp, saw-tooth ridge crests -- V's between teeth point down dip Shale forms low, conical hills Straight, parallel, assymetric ridges *Stair-step topography where gently dipping* *Rugged topography* *Hogbacks, cuestas* *[Sandstone the ridge former,] shale the valley former, and [limestone is in between] – limestone is the ridge former where present* *Rounded, lobate, scalloped hills in plan view if gently dipping*	Trellis, can show parallelism Fine texture *Often meandering*	Few gullies (?)	Banded Ridges usually lighter toned than valleys	Texture of main rock type will predominate if thin-bedded

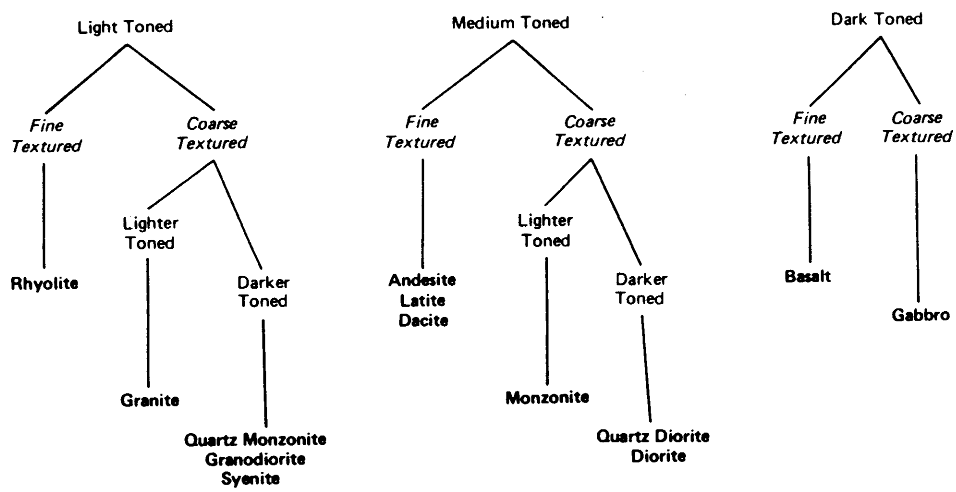

TABLE G2. Proposed Air Photo Classification for Igneous Rocks.

TABLE G3. Published Photo Pattern Element Descriptions for Metamorprhic Rocks.

Rock Type	Landform	Drainage: Plan	Drainage: Cross Section and Gradient	Photo Tone	Photo Texture
Gneiss	Steep, sharp-crested ridges and hills (b, v, w)*; ridge crests may be rounded where glaciated (w) Knobby, rounded hills (v) Highly dissected (b) Rugged topography (w) Slopes generally too steep for cultivation (b, w) Often nearly parallel, low ridges and shallow depressions formed by differential erosion along bands or foliation (v) Erodes uniformly (v) Very similar to granite landforms (b, v, w)	Distinct, angular dendritic (b, v, w) -- can be modified to trellis by parallelism of ridges and shallow depressions (b) Intersections at nearly right angles (b) Abrupt bends (uncommon in other rocks of similar pattern) (b) Drainage lines gently curved (v) Well-developed, dense (b) to widely spaced (v) Fine to medium texture (w) Princerlike headwater areas (v)	U-shaped cross sections (w)	Light tone predominates (v, b, w) No mottling or banding (b) Often obscured by by heavy tree cover (b)	Knobby (v) Rounded (v)
Schist	Low ridges, shallow depressions (v, w); riges may razor sharp where glaciated or in arid regions (v) Ridges steep-sided in humid climates (v, w) Smooth, rounded hilltops (b, v, w) Undulating terrain (v, w) Rugged topography, more or less rough (b, v) Minutely dissected (b) Steep attitude characteristic (v)	Angular dendritic (v) to rectangular (b) Closely-spaced, parallel qullies (b, w) Gullies have few branches (v, w) Well-integrated (b) Fine to medium texture (w) Structural control common (v)	U-shaped cross sections (w) Long, steep gradients (b, w)	Light, uniform grey (b, w) Gullies dark-toned (w)	Smooth (b)

TABLE G3. Published Photo Pattern Element Descriptions for Metamorprhic Rocks.(Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Cross Section and Gradient	Photo Tone	Photo Texture
	Convex slopes (v) Slopes steepest at bases of hills (b) Moderate relief where glaciated (b) Banding scattered and irregular or absent (b) Moderately susceptible to erosion and weathering (v)				
Slate	Parallel ridge and valleys (w); small rounded hills (v), sharp ridges (w) Hills all about the same height (b, v, w) Rugged topography (b, v, w) Very steep slopes (b, v, w) Relief constant throughout area (b) Highly eroded (b) Well-developed jointing (b) Sharp, irregular linear boundary or narrow transitional band (b)	Tight rectangular (b, w, v) Gullies generally parallel and short (b, v, w) Fine texture (w)	Deep, steep-sided gullies with steep gradients (b)	Varies, but generally light uniform grey (b, v, w)	
Serpentine	Long winding ridges connecting elongated conical hills in large exposures; smoothly rounded hills with convex slopes in small exposures (b, v) Occurs as roundish or olenticular bodies (b, v) with smoothly curving, scalloped outlines (v)	Straight, radial gullies around small exposures (b, v) Dendritic in large exposures (b, v) Numerous, short gullies (b, v) Widely spaces (b, v)	Steep gradients (b, v)	Dull, medium grey (b, v) Light tone where vegetation is sparse (b)	Smooth (b)

TABLE G3. Published Photo Pattern Element Descriptions for Metamorprhic Rocks. (Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Cross Section and Gradient	Photo Tone	Photo Texture
	Often forms low terrain with valleys when associated with rocks of greater resistance (v) Erodes uniformly (v) and easily weathered (b, v) Landslides common (b) Bare outcrop common; vegetation usually absent or sparse (b, v)				
Marble	Forms lowlands and valleys (w) Massive, with smooth, rounded forms (v) Sinkholes may occur (b) Easily weathered (w)			Light to dark grey, similar to limestone (v)	

*b = Belcher, and others, 1951
v = von Bandat, 1962
w = Way, 1973

TABLE G4. Photo Patterns for Quartz Monzonite, Monzonite, Quartz Diorite, and Rhyolite.

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Photo Texture
Quartz Monzonite	Peaks and ridges; peaks more common Ridge and spur crests slightly rounded Conical hills with slightly convex slopes Summit elevations do not repeat Steep, long slopes High relief Irregular, gently curving boundaries Outcrop mainly on peaks Moderately vertically jointed	Dendritic Fine to medium density Streams straight and long 2nd order tributaries vary in length; 3rd order short	Moderate gradient Steep-sided, V--shaped cross sections	Light, but not as light as granite	Rounded and lumpy
Monzonite	Symmetrical ridges, low control hills with slightly convex slopes, or rounded peaks; ridges most common Outcrop on some ridge crest forms pinnacles Smooth, steep slopes of medium length Moderate relief Talus Very gently curving boundaries Outcrop slightly rounded Moderately vertically jointed	Radial Fine to medium density Straight streams with some rill-type drainage Few to no tributaries	Gradient variable, generally moderate V--shaped cross sections	Intermediate between light and medium	Rounded and lumpy

TABLE G4. Photo Patterns for Quartz Monzonite, Monzonite, Quartz Diorite, and Rhyolite.(Continued)

Rock Type	Landform	Drainage: Plan	Drainage: Gradient and Cross Section	Photo Tone (Pan)	Photo Texture
Quartz Diorite	Ridges more common than hills or peaks: hills semi-conical Summit elevations do not repeat Moderate to steep slopes Talus Rounded outcrop Heavily vertically jointed	Radial Fine to medium density	Moderate to steep gradients Open, V--shaped cross sections	Medium, but not as dark as diorite	Rounded and lumpy, but rougher than granite, monzonite, diorite, or quartz monzonite
Rhyolite	Ridges and peaks symmetrical and rounded at the crests Gentle to moderate slopes Resistant to erosion Flows lobate in shape and generally smaller than basalt flows Flowmarks Boundaries lobate or gently curving, usually distinct Columnar jointing	Dendritic Fine to medium density Streams evenly spaced Streams incised	Even, low to moderate gradients Steep-sided, V--shaped cross sections	Light to white	Fine, smooth, even; may be rough and jagged if a recent flow

TABLE G5. Proposed Identification Criteria for Metamorphic Rocks in a Temperate Climate.

ROCK TYPE	LANDFORM	DRAINAGE: PLAN	DRAINAGE: CROSS SECTION AND GRADIENT	PHOTO TEXTURE
Marble	Low, gently rolling, small hills Forms lowlands and valleys Smooth ridge crests Low or gentle slopes Low relief Low resistance to erosion Outcrop as ledges not uncommon Sinkholes may be present	Dendritic with some structural control Second and third order tributaries with little branching Moderate density Main streams in large valleys can be wiggly or gently curving to scalloped	Saucer- or box-shaped cross sections; very soft appearing Very low gradients	Fine Smooth Soft
Slate	Linear hills with narrow valleys between Hills are rounded Ridges are generally symmetrical Ridge crests are narrow, but slightly rounded Ridgelines fairly straight and continuous Moderate to steep slopes Moderate relief Low to moderate resistance to erosion	Dendritic to trellis; if dendritic, very linear High order tributaries, up to fourth order, are common Low density Low to moderate branching Tributaries generally short to medium in length and generally curved, rarely straight	V-shaped, often deep and steep-sided, cross sections; stream bottoms flatten out and nick point is slightly rounded Moderate to steep gradients	Slightly rough and uneven
Phyllite	Long, continuous ridges Very broad, flattish ridge crests ranging to sharp, but slightly rounded, narrow ridge crests Ridges asymmetrical Forms hummocky terrain Moderate to steep slopes Moderate to high relief Low to moderate resistance to erosion Massive appearing	Dendritic with no structural control Tributaries primarily second order Low to medium density Main streams curved or wiggly; tributaries curved	Open, V-shaped cross sections Moderate to steep gradients	Uneven, but slightly rounded

Schist	Often forms low-lying areas surrounded by higher areas of different composition Forms hills and ridges Hill and ridge crests usually rounded, but vary in width from narrow to broad Steep slopes Moderate to high relief Moderate resistance to erosion	Dendritic Low density Widely spaced Tributaries short and straight	V-shaped cross sections Long, steep gradients	
Amphibolite	Small hills and ridges; generally randomly arranged Forms valleys and hummocky terrain Ridge crests and hill tops broadly rounded Often low-lying Low to moderate slopes Low to moderate relief Low to moderate resistance to erosion	Dendritic but very linear, e.g. much structural control Second and third order tributaries common; medium in length and straight Low to medium density	V- to box-shaped cross sections; fairly open Moderate gradients	Uneven Irregular
Gneiss	Steep-sided ridges with continuous crests Knobby, rounded hills Ridge crests narrow but rounded Very steep slopes Moderate to high relief High resistance to erosion Very massive appearing	Dendritic Primarily second order tributaries, but third order often present Tributaries short and straight with few branches Low to medium density Evenly spaced	Broad, open, V-shaped cross sections; often deep Main streams have low gradients; tributaries have medium to steep gradients	Knobby, uneven Rounded Hard appearing
Quartzite	Rounded, steep-sided hills High resistance to erosion	Streams short with little to no branching	Steep gradients	Moderately rough and uneven Knobby

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APPENDIX H.
SPECTROPHOTOMETRIC DATA SHEET
M.B. Satterwhite

SPECTROPHOTOMETRIC DATA SHEET

REFLECTANCE
VEGETATION/SOIL

1. SAMPLES: Marigold and Dusty Miller
Light–toned Soil
(gravelly medium sand)
2. LOCATION: ETL Test Facility

High reflectance contrast between vegetation and soil is important for monitoring vegetative cover or evaluating crop vigor from panchromatic, color, color infrared, and LANDSAT imagery. Where the spectral reflectances of the soil and vegetation are similar, differentiation between vegetation and soil is impossible or severely limited. The reflectance curves for a light-toned sand soil, green vegetation (marigold), and a gray vegetation (dusty miller) show the spectral regions that have the large reflectance contrasts and which can be used for separating these vegetation types from sand soil (figure 1). On panchromatic photography of these materials the brightest tone would be bare soil and the darkest tone, the vegetation. This relation is predicted from the inverse relations between cover and total reflectance in the visible region, shown in figure 2 for the 450, 550, and 680 nm bandpasses. Although the reflectance contrast in the infrared region (850 nm bandpass) is not large, it varies directly with percent vegetation, i.e. the brighter photo tones indicate denser cover. For LANDSAT imagery the percent cover varies inversely with total reflectance in Bands 4 (500–600 nm) and 5 (600–700 nm), but varies directly with total reflectance in Bands 6 (700–800 nm) and 7 (800–1100 nm) (figure 3). The reflectance contrast between soil and vegetation can explain why some desert and semidesert plants are not readily detected on panchromatic, color, color infrared, or LANDSAT imagery, whereas other species are easily detected.

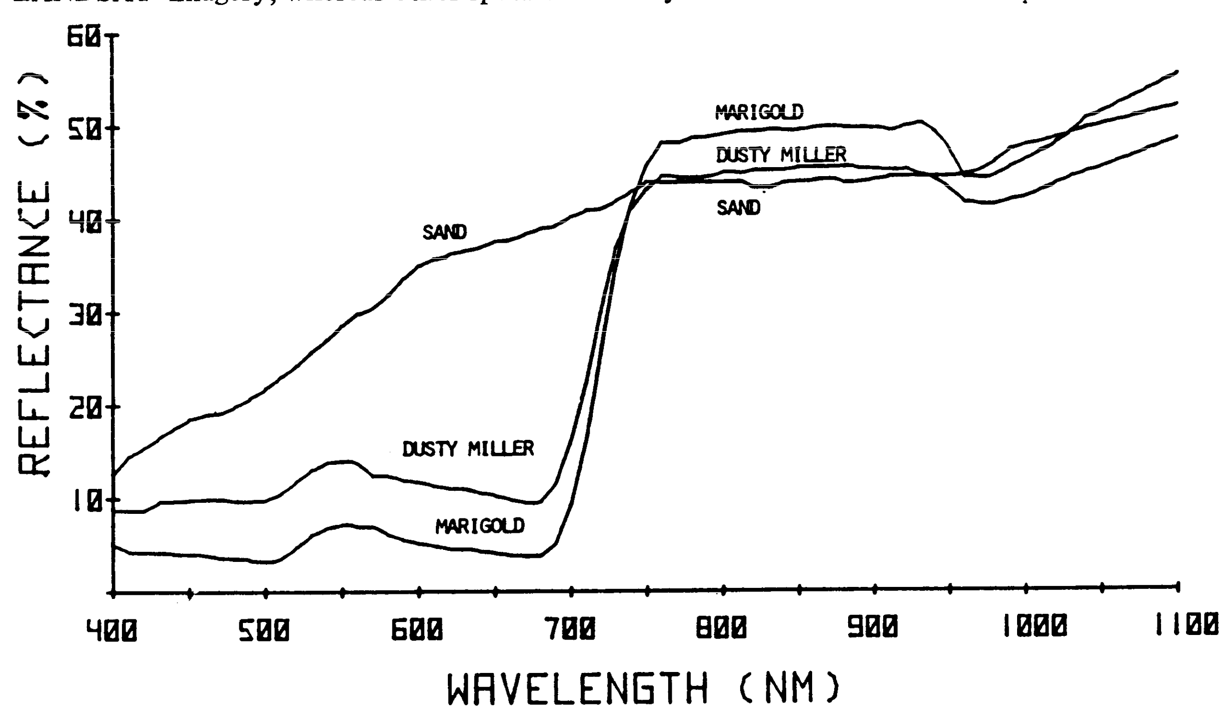


FIGURE 1 Measured Reflectance Curves for Sand Soil, Marigold, and Dusty Miller.

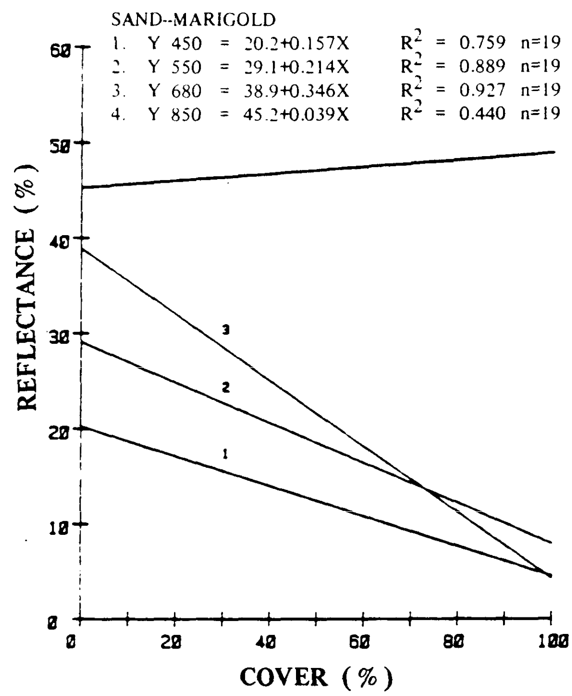


FIGURE 2. Regression Curves for Reflectance at 450, 550, 680, and 850 nm and Percent Cover of Sand-Marigold Targets.

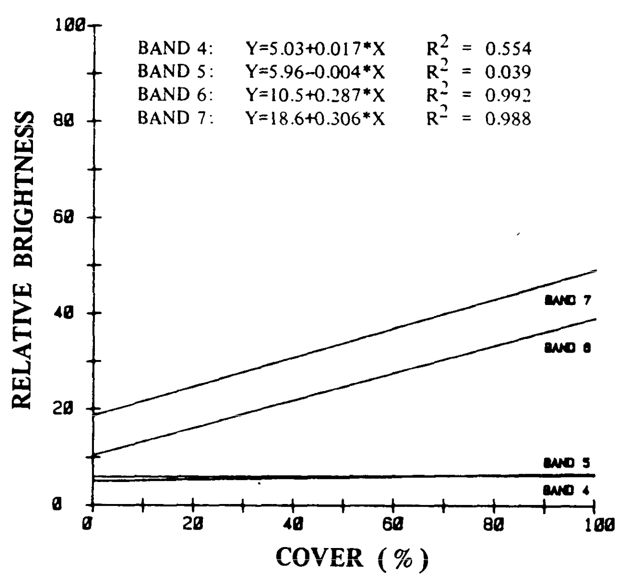


FIGURE 3. Regression Curves of the Percent Cover in the Sand-Marigold Targets Against Total Reflectance in LANDSAT Bands 4, 5, 6, and 7.

COMPILER: M.B. Satterwhite, USAETL.

APPENDIX I.
AN EXAMPLE OF A KNOWLEDGE-BASE PHOTO ANALYSIS SEQUENCE

J.N. Rinker and P.A. Corl

AN EXAMPLE OF A KNOWLEDGE--BASE PHOTO ANALYSIS SEQUENCE

J.N. Rinker and P.A. Corl

The image analysis procedure and photo interpretation logic discussed in this report have been successfully applied to a variety of engineering and environmental analysis projects throughout the world and taught over many years, both within the United States and abroad. Because it can be taught, it follows that it must be possible to document the procedure, at least to some extent, in the form of a question/answer sequence and groups of statements or rules. It does not follow that this task will be either easy or short.

First, the rules must be established for various types of rocks, soils, vegetation, etc., under different conditions of location, orientation, and climate. In most instances the rules are a restatement of the dominant and supportive pattern indicators listed in the P.I. Logic Sheets (appendix C). Then, questions plus explanatory text must be formed to guide the analyst down a path of reasoning, selected as a result of the answers to the questions, to arrive at a series of the most probable conclusions. The Photo Indicator Sheets of the type in appendix B and schematic drawings support the conclusions as reference material. For example, to the question "Are the hill slopes steeper at the top than at the bottom?" an added note would tell the analyst to compare his image pattern to those shown in Indicator Sheets X, Y, Z, etc. At present, the available effort is directed towards selecting and testing photo indicator patterns for the P.I. Logic Sheets and then developing some sort of organizational structure for the so-called rules. One source of complexity is that few indicators are associated with but one type of material or object. The pattern element "arcuate, scallop-like contours" is a useful indicator, but as a pattern it can be found in association with a variety of materials, including soft sandstone, calcareous sandstone, limestone, interbedded limestone and shale, and some shale beds. In a modified form it can also be observed in some lava flows. Therefore, the rules and questions must be so arranged that as the various pattern elements are considered, a gradual accumulation of positive responses in one file which exceeds those in other files can be recognized and, thereby, that file selected as the most probable answer in terms of materials, conditions, identities, etc.

Question sets must be developed for specific patterns within each factor and within specific climatic zones. These blocks of questions must be so interconnected that the program can be keyed to shift from block to block, and from the general to the specific and back again, as the analysis progresses. Flag questions must be made so that as a contradiction arises, the analysis drops back to an earlier point or to a subset of more detailed questions. Aside from developing a knowledge-base system, the framing of the rules and questions forces the pattern elements and the reasoning to be subjected to a hard, practical, and somewhat skeptical, evaluation.

The following is a short and oversimplified example of how these questions and rules can be used to establish a knowledge-base system. For this example, we have assumed that the analyst has had enough training so that he is familiar with the terminology and can map many landform boundaries, drainage, and other patterns. In this instance, the individual has drawn the boundaries around the various landform units, has completed the drainage mapping, and has noted other characteristics associated with tone, culture, vegetation, etc. To start the analysis, the individual has selected a general landform routine, and as he is able to properly identify some of the landform units, he can select subroutines under the appropriate heading. It would be possible, of course, to design yes/no questions that could help the individual determine the landform type.

Figure 1 is a reduced copy of the stereotriplet set used to test this sequence. Figure 2 is a reduced copy of the landform overlay. Table 1 shows some of the landform rules pertinent to the analysis and, in effect, also contains some of the material that is later cited as conclusions. As a minimum, an analysis sequence must contain a list of the landform rules and a question/answer sequence. Conclusions must be included somewhere in the program, either as part of the rules or as a separate data set, and it may well be that both approaches will be needed. The question/answer sequence gets information from the analyst in such a way that various combinations of answers automatically cite the appropriate rules, which, in turn, leads to conclusions from within themselves, or from a separate set of conclusions. The sets used here are incomplete and are used only for illustration. Unless the question is serving as a flag to reveal inconsistencies or contradictions, each has at least two answers, and in many cases, three. The answers are yes, no, and a question mark; the latter being used to indicate uncertainty about the question or lack of enough information to answer the question. With each question providing at least two branches, and each of these two more branches, it is not possible to portray much of an example in this form. The questions, therefore, flow along the "correct" path for this analysis. Following the question/answer sequence is a schematic of the logic behind these questions. Within this schematic, alternate sets of questions are indicated. This set of questions serves only as an example, and does not form a complete analysis. Obviously, sets of questions must be developed for a variety of landforms, as well as for the factors of drainage-elevation and plan, erosion, deposition, tone and texture, vegetation, and cultural.

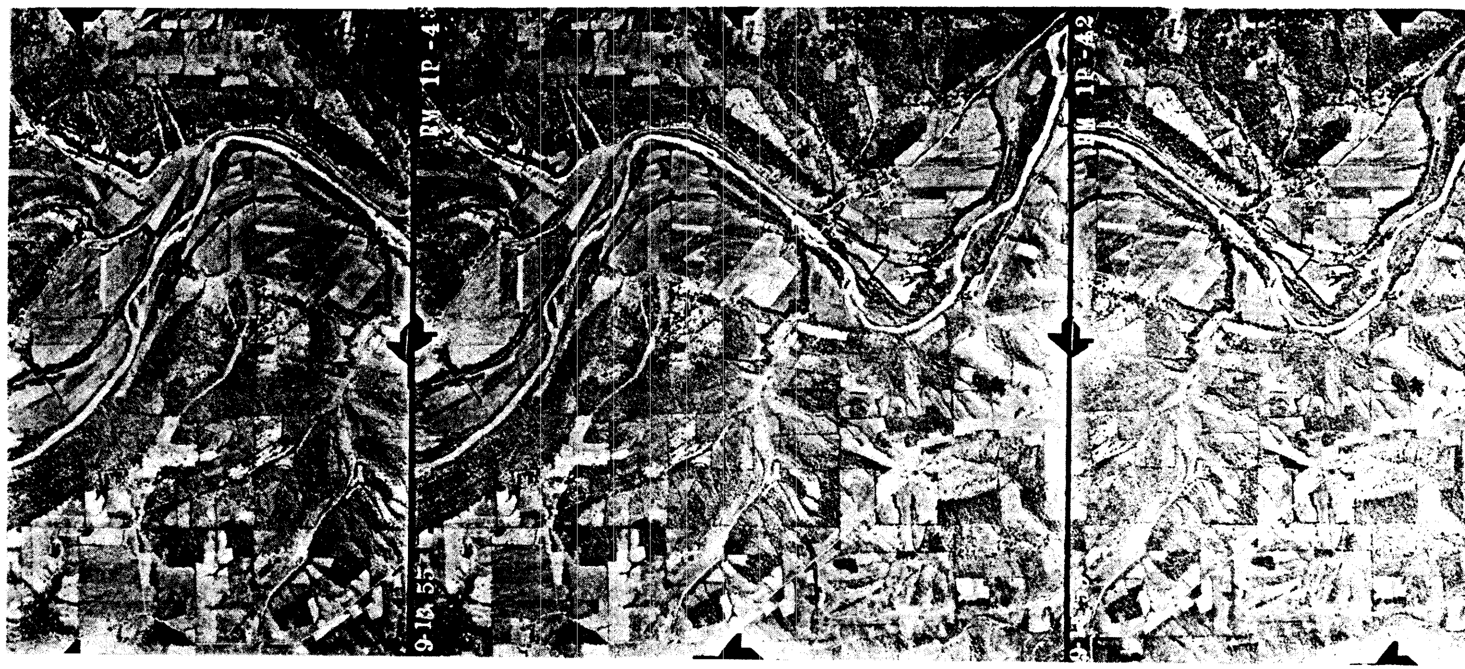


FIGURE I1. A reduced copy of the stereotriplet used for this example analysis. ASCS photography, Franklin Co., Indiana (RM), 13 Sep 1955. Original scale 1:20,000; scale of this reproduction is about 1:50,000. This stereotriplet has been reduced in scale so that it can be viewed in stereo directly, or with a pocket-type stereoscope.

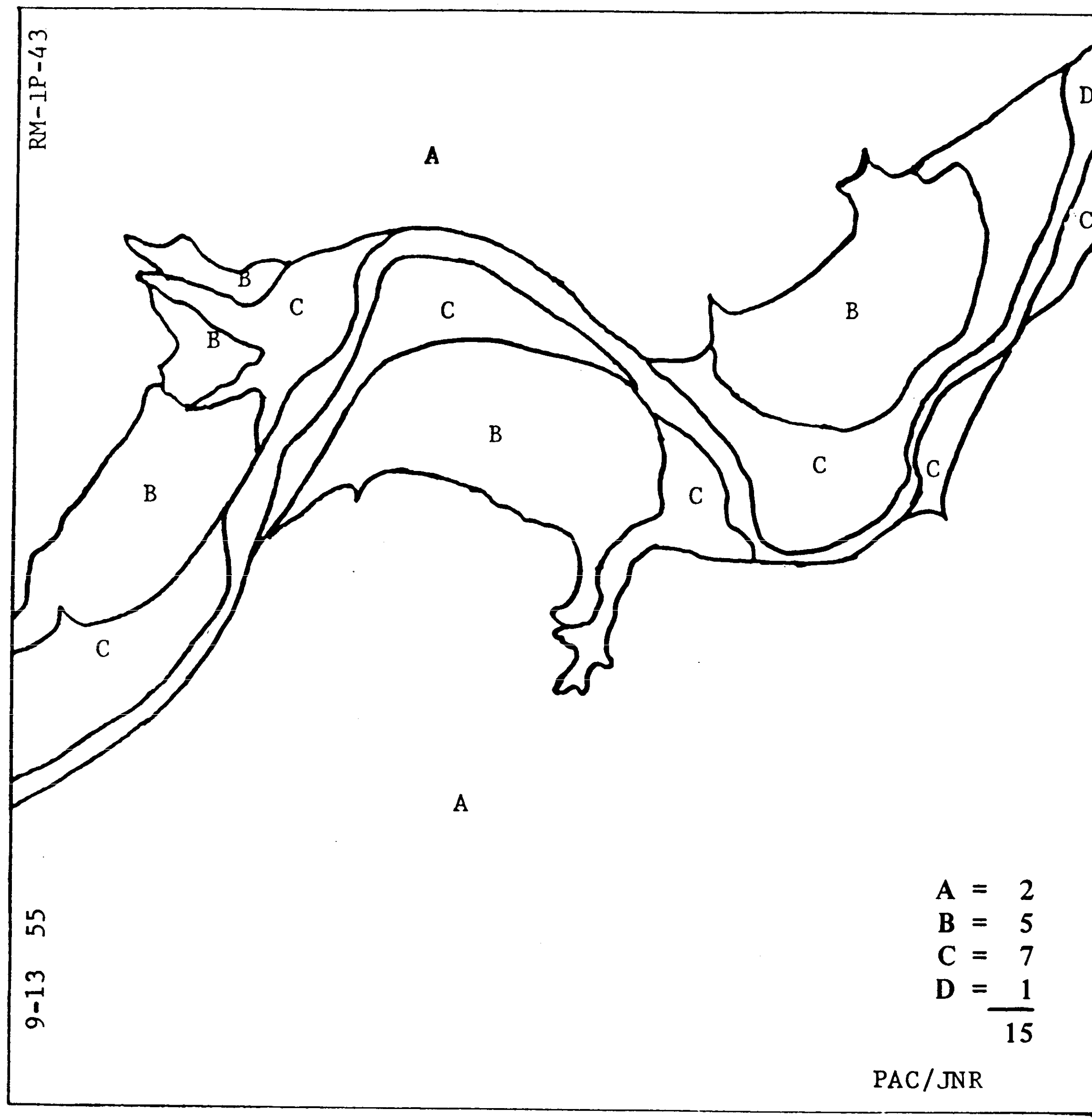


FIGURE I2. Reduced Copy of the Landform Overlay.

TABLE 11. LANDFORM RULES. These rules are taken from material within, or which will be later added to, the Materials Summary Sheets, the Air Photo Patterns Summary Sheets, and the P.I. Logic Sheets. The question/answer sequence provides information that lets the program cite the pertinent rules and thereby come to conclusions.

1. The number of landform types indicates the probable number of different materials or conditions, or combinations of the two.

2. The greater the number of different landform types, the greater the complexity of the area in terms of composition, condition, and structure.

3. If the number of landform units is greater than the number of landform types, then one, some, or all of the types can occur more than once in the area, i.e. there is a repetition of type.

4. The more the landform types are repeated, vertically and horizontally, the greater the likelihood of an orderly structure, e.g. bedding and layering.

5. Relatively flat surfaces are considered as plains.

6. Plains are most frequently formed by sedimentation and deposition.

7. Smooth and uniformly flat level surfaces. These are most frequently associated with granular materials originally deposited in a basin or trough.
   NOTE: Rules must also be stated about plains that are not uniformly flat, i.e. the surfaces are rolling, pitted, or otherwise irregular.

8. Vertical or near-vertical faces. Associated with truncated, or dissected, granular deposits.
   NOTE: This characteristic is also associated with undercutting of aeolian silt deposits, erosion in fluvial silt deposits, ground water sapping of granular soils, exposed faces of sandstone and limestone beds, some basalt flows, road cuts in loess, etc., and such must be taken into consideration when constructing the general set of rules and questions.

9. Smooth, uniformly flat and level surfaces adjacent to and along a riverbed. Indicative of terraces and terrace remnants, i.e. granular deposits.

10. Different terrace levels within the river valley. Indicative of separate stages of downcutting by the river.

TABLE 11. Continued

11. Concordancy (i.e. all at same level) of tops of separated landform units. Indicative of relatively flat-lying sedimentary units.

12. Ridgeline patterns with relatively long linear or curvilinear segments. Indicative of relatively flat-lying sedimentary formations.

13. Ridgeline patterns with near-parallel ridge, finger-like branching, and spur development. Indicative of relatively flat-lying sedimentary formations.

14. Stairstepped slopes. Indicative of sedimentary deposits, with beds sufficiently thick to interrupt the slope at the photo scale being used.
    NOTE: Basalt flows can also show a stairstep development.

15. Smooth slopes in sedimentary rocks. No indication of stairstep development. Suggestive of thinly bedded sedimentary units.

16. Contour-like banding of photo tones or vegetation units. Indicative of sedimentary units of different composition.

17. Compound gradient on hill slopes of thinly bedded sedimentary rocks with upper portion steeper than the lower portion. Suggestive of interbedded limestones and shales and a colluvial mantle over the lower part.
    NOTE: This also indicates a potential problem for engineering construction, i.e. unstable slopes, or slopes that can become unstable if the toe is cut, or if there is excess rain, etc.

The following presents a type of question sequence that could be used as part of a knowledge-base interactive analysis system. For the most part, these questions are derived from information contained in, or which will be added to, the P.I. Logic Sheets. Specific questions, i.e. questions about a specific pattern type, come from the dominant and supportive pattern indicator columns. Wherever possible, questions will refer to Air Photo Indicator Sheets that can serve as examples of the pattern element being questioned. These questions were tested on the full size air photos of the stereotriplet shown in figure 1. Within the question sequence, the numbered items represent computer presentation. Under some of these questions, notes have been added as explanatory information. These notes are not part of the program. Items in parentheses on the right hand side represent the analyst's response, Y indicating yes, N indicating no. Bracketed entries indicate those items that the computer could provide if requested.

1. How many separate areas of landform are present? (15)

2. How many landform types are present? (4)

   NOTE 1: This pattern grouping was given four types, i.e. A, B, C, and D. One could also come up with three groups by considering units B and C to be the same type, which is probably what an experienced analyst would do.

   NOTE 2: Ratio of the answers to questions 1 and 2 is repetition factor. The higher that number, the more probable it is that the area has an ordered structure. Repetition factor = 3.75.

3. Are any of these units water bodies? (Y)

   [If no, go to question No. 6]

   NOTE 1: For the most part, identifying and discussing water bodies is done under the drainage factor. Usually water areas of any extent are labeled during the landform analysis so that all of the area is accounted for.

   NOTE 2: Ignore small water bodies, such as farm ponds, isolated small ponds, quarries, etc. These can be discussed under the drainage factor.

4. Is there but one water body? (Y)

   NOTE: If no, then continue questions to establish the number, arrangement, and pattern. This sets the basis for eliminating items from the landform sequence and for designating questions about the water bodies, which would be handled under drainage.

5. Are the boundaries of the water body sharp and well defined? (Y)

NOTE: If no, then must proceed with questions that would probably lead to swamps, wetlands, etc. Must be demined why they are not well defined.

For the present, remove this unit from the landform list.

6. For the designated landform groups, which statement is most descriptive? (5)

(1) Each is a different landform, i.e. each is of a different shape.

(2) All are the same in shape, but differ in horizontal location.

(3) All are the same in shape, but differ in both horizontal and vertical location.

(4) Some are the same in shape, but differ in horizontal location.

(5) Some are the same in shape, but differ in both horizontal and vertical location.

7. Group all landform units that have the same shape, but differ only in location (horizontal and horizontal/vertical) into one type. How many landforms are there? (2)

NOTE: In most cases landforms of the same type and at the same elevation, or which are an obvious but interrupted continuation, are put into the same class. Landform units can be of a type but put in different classes because of elevation differences, e.g. a series of mesas, buttes, terraces, etc. All of these are some form of plain, which could be classified into different types on the basis of elevation. An experienced analyst would have made this grouping initially.

LF units = 14
LF types = 2
Ratio = 7.0
LF Rule 1. Conclude that the area is composed of at least two different materials and/or conditions.
LF Rule 3. Conclude that all landform units are repeated.
LF Rule 4. Conclude that area has an ordered structure.

Select landform subroutine for discussion.

Designate by number.

1. hills and mountains
2. plains (i.e. flat surfaces)
3. basins and valleys
4. uncertain (2)

NOTE: Each group needs a question sequence to allow for classification within the group.

1. Is the surface smoothly and uniformly flat? [See Indicator 0068] (Y)
   NOTE: If no, must then proceed through questions and rules associated with other types of plains, e.g. rolling, pitted, etc.

2. Are these landform units in the upper third of the elevation range? (N)

3. Are these landform units in the middle third of the elevation range? (N)

4. Are these landform units in the lower third of the elevation range? (Y)

5. Are these landform units the lowest elevations in the image? (Y)
   NOTE: The river as a unit was removed from discussion (refer to question 5); therefore, these are the lowest units.

6. Are these landform units associated with a river? (Y)

7. Are these landform units adjacent to the riverbed? (Y)

8. Are these landform units distributed along the riverbed? (Y)

9. Are they on both sides of the riverbed? (Y)
   NOTE: Yes answers to questions 6 through 9 force certain conclusions about shape of the landform unit and adjacent topography. The units are smoothly flat, and because they are adjacent to the river, the river edge of the plain must drop off toward the river and further questions are not needed to establish this fact. There must, however, be a set of questions that can be used as a subroutine for any landform in order to establish its topographic relations to the adjacent

terrain. Questions 10 and 11 represent such a subroutine.

10. Are the boundaries of these landform units well defined? (Y)

11. Are the boundaries defined primarily by topographic changes? (Y)
NOTE: Can have boundaries that are a result of tone changes or combinations of tone changes and slight topographic changes.

12. With reference to going up or going down, are the topographic changes the same around the perimeter of these landform units? (N)
NOTE 1: If same, must then determine if landform goes up, which would be indicative of basins, calderas, solution valleys, collapse features, etc., or down, which would be indicative of mesas, buttes, terraces, benches, etc.

NOTE 2: Because of the no answer to question 12, some of the land adjacent to the units must go up and some must go down. One could insert a question confirming this (to serve as a flag). A no answer to this is in contradiction to the previous reasoning and the program would automatically stop at this point and request the analyst to go back over these same questions. In case of subtle relief changes, this type of flagging might be advisable.

13. Are the areas on the river sides of these landform units lower in elevation? (Y)

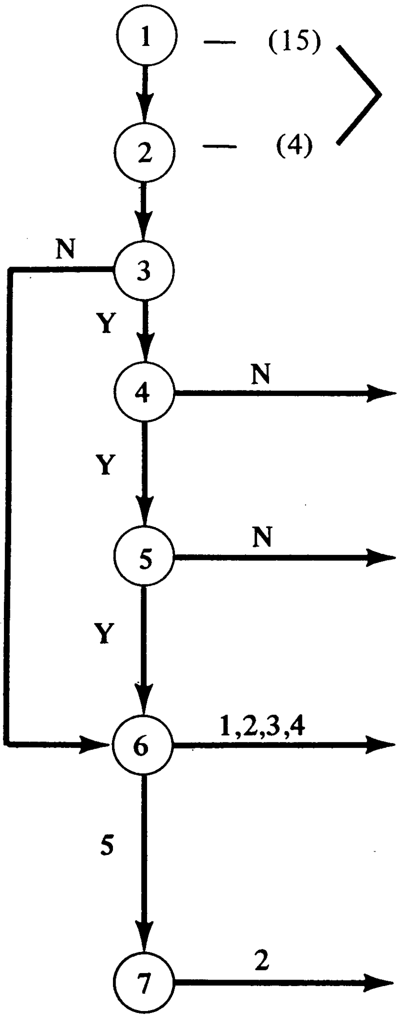
14. Are the slopes between the landform unit surface and surface of the lower area vertical, or nearly so? [See Indicator 0053.] (Y)

Landform Rules 6, 7, 8, 9, and 10. Conclusions for landform unit designated as B, which is a set composed of two subsets:

Landform units are granular terraces formed by the deposition of sands and gravels.

Different stages of river downcutting dissected this deposit, leaving the terrace remnants at different elevations.

INTRODUCTORY LANDFORM ROUTINE



$\frac{15}{4} = 3.75$ repetition factor

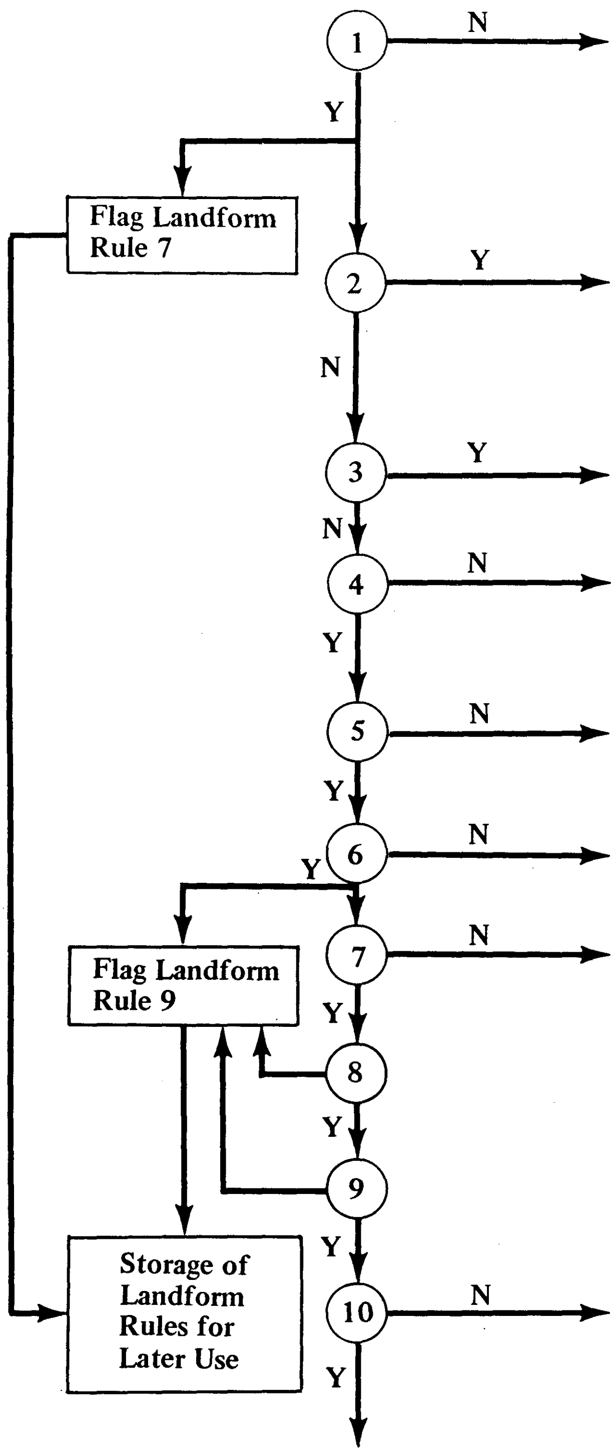
Question sets to establish pattern and arrangement of the water bodies, e.g. are there a few large bodies?; are there any small bodies?; are individual shapes symmetrical?; are individual shapes irregular?; are they arranged in a pattern?; etc. These questions direct attention towards elliptical bay areas, sequences of glacial lakes, permafrost, etc.

Question sets that lead to consideration of swamps, wetlands, thermokarst, sedimentation, etc.

Question set needed for each of the four possibilities.

Conclude LFU = 14, LFT = 2
REPETITION FACTOR = 7.0
↓
FLAG: LF Rules 1, 3, and 4
↓
GO TO SUBROUTINE

LANDFORM SUBROUTINE NO. 2 – PLAINS (i.e., flat surface)



Questions to define other types of plains. Is the surface generally flat with scattered irregularities? If yes, then are the irregularities depressions or elevations? Is the surface rolling? Is the surface undulating? etc.

Are these landform units the highest elevation? If yes, then develop question sets to establish surface and edge characteristics. These are directed towards mesas, buttes, etc.

Questions to establish surface and edge characteristics directed towards benches, terraces, and steps formed by exposed beds.

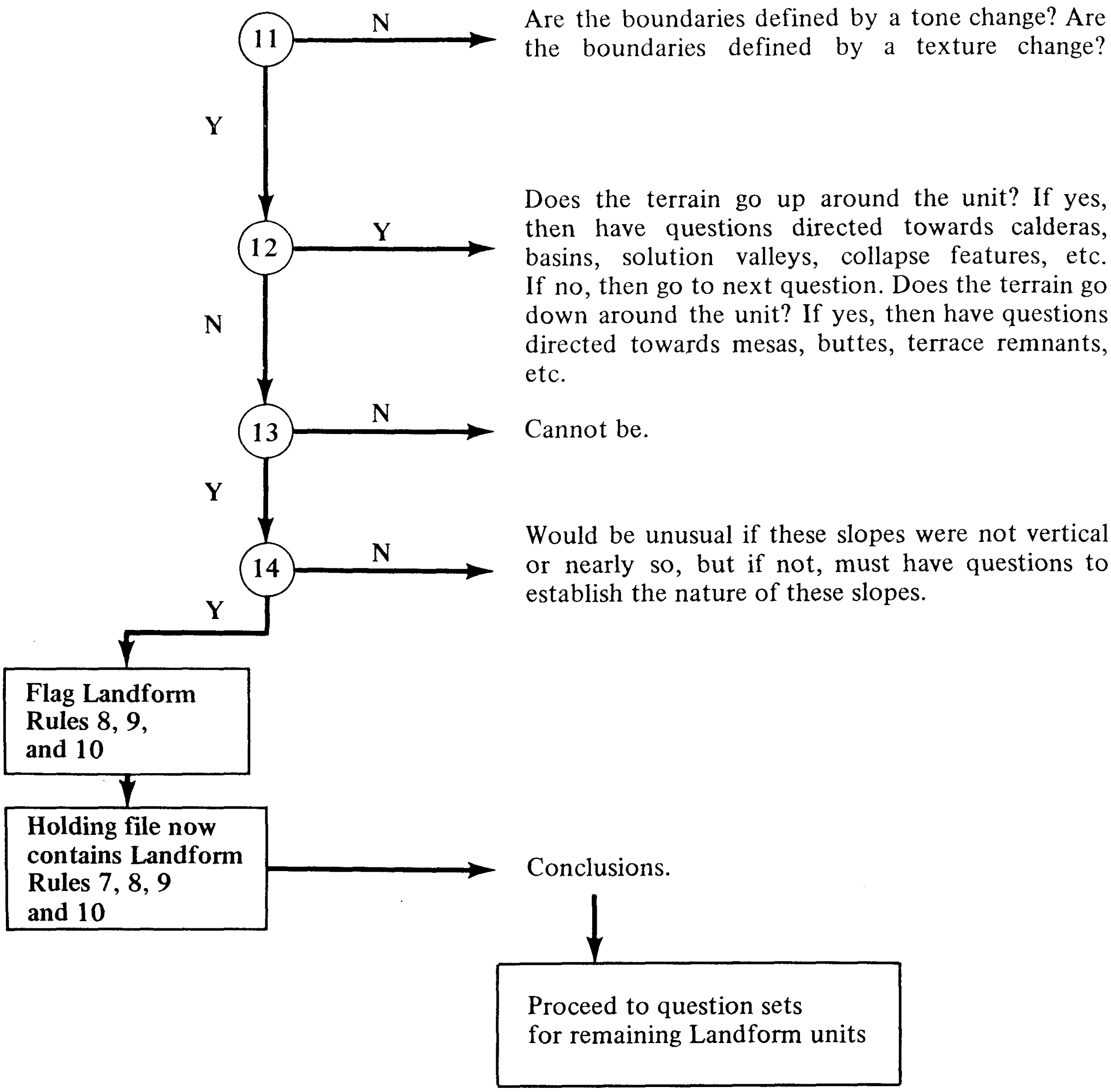
Cannot be.

Questions to establish surface and edge characteristics directed towards benches, terraces, or steps of exposed bedding surfaces.

Cannot be.

Cannot be.

Questions to establish nature of the boundary. The boundary can be obscured by vegetation, or caused by a subtle change in relief or tone/texture, or both.



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