COGNITIVE PROCESS IN INTERPRETING THE CONTOUR-LINE PORTRAYAL OF TERRAIN RELIEF

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December 1982

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Terrain relief is portrayed on large-scale topographic maps with contour lines--lines that take any shape necessary to maintain a constant elevation above some datum plane, usually mean sea level. Although military map users must be capable of interpreting all classes of features portrayed on topographic maps, the interpretation of the contour-line portrayal of terrain relief (traditionally referred to as contour interpretation) is clearly the most difficult and most important part of the map-interpretation task.

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The objectives of this research are to (a) gain a more thorough understanding of the fundamental cognitive processes underlying one type of contour-interpretation task, and (b) apply this knowledge in defining improved strategies for teaching this important skill.

The contour-interpretation task investigated--referred to as "position fixing"--required subjects to locate their position on the map after being transported blindfolded to test sites where terrain relief is the only topographic feature available for referencing. A group of six Marine Corps infantrymen, selected because of their acknowledged expertise in map interpretation, exhibited a uniformly high level of skill and a uniform problem-solving strategy. The strategy employed by the experts involved the use of large landforms (macrorelief) to reduce the size of the area-of-uncertainty. Then, small landforms (microrelief) were used to pinpoint on the map their exact location.

A group of six Marine Corps infantrymen with conventional training, but limited experience, performed poorly and employed a problem-solving strategy altogether different from the experts' strategy. The non-experts focused only on microrelief, attempting from the outset to search the large area-of-uncertainty for the map portrayal of small terrain features, such as draws and spurs, that were visible from the test site.

Neither the experts nor the non-experts exhibited a high level of skill in visualizing the contour-line portrayal of visible terrain or, conversely, visualizing the real-world counterpart of a contour-line portrayal. The problem-solving strategy employed by experts indicated that they were aware of this limitation; a recognition of this skill limitation was less apparent in the problem-solving strategy employed by non-experts.

A major conclusion drawn from this research is that training on the cognitive strategy employed by the expert subjects would yield an immediate and substantial increase in the position-fixing skill of military map users who have completed a traditional course of instruction in map interpretation. Moreover, it seems highly probable that both expert and non-expert map users would benefit from training designed to increase their ability to visualize the real-world appearance of a landform portrayed with contour lines and to visualize the contour-line portrayal of a visible landform.

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Finally, Mrs. Nadine McCollim of Anacapa Sciences deserves special thanks for single handedly transcribing the recorded protocols, assisting in the data tabulation, and typing the final report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

INTRODUCTION

THE PROBLEM

Topographic maps have been an essential tool of military forces since the beginning of modern warfare. Despite the ever increasing sophistication of modern weapons systems, success on the battlefield is even more dependent on the soldier's ability to interpret topographic maps than ever before. Current military doctrine has imposed a requirement for a high level of map-interpretation skills on nearly everyone who may be required to take an active part in planning or executing a military operation. However, the skill requirements are particularly great for: pilots of fixed-wing aircraft who must fly low-altitude penetration missions, helicopter pilots who must fly at nap-of-the-earth altitudes, and infantrymen who must plan and execute high-mobility land operations.

The high lethality of modern anti-aircraft weapons has forced both fixed-wing and rotary-wing aircraft to fly low enough to take full advantage of the visual and electronic masking afforded by terrain and vegetation. The requirement to fly at extremely low altitudes has greatly increased the difficulty of both the route selection and the enroute navigation tasks. A high level of skill is required to decode topographic-map symbology with sufficient precision to select the route between an origin and destination that provides maximum masking by terrain and vegetation. A high level of skill is also required to navigate a preselected route and to maintain accurate geographic orientation throughout the mission. Success in enroute navigation requires that the aviator be capable of associating real-world topographic features with the symbolized counterpart on a topographic map. Associating map and real-world features is difficult under the best of circumstances, but it becomes even more demanding when the aircraft is flying at a high rate of speed and at an altitude so low that the aviator may be unable to see topographic features located farther than a few hundred meters from his aircraft's momentary position.

The map-interpretation skill requirements of modern-day infantrymen are no less demanding than those for aviators. Current tactical doctrine stresses that survival of ground forces on the battlefield depends on the capability to plan and execute highly coordinated and highly mobile operations. The requirement for speed and coordination of infantry units has reduced the time available for map study, reconnaissance, and decision-making and, at the same time, has increased the criticality of precise timing and positioning of forces. As a consequence, the infantry-unit leader must be able to interpret topographic-map symbology swiftly and with a high degree of precision in performing a host of planning, navigation, and tactical decision-making tasks.

Aviators and infantrymen must be capable of interpreting all classes of information portrayed on a topographic map, including: terrain relief, hydrography, vegetation, transportation lines, buildings, and a host of other classes of cultural features. The interpretation of terrain relief, however, is clearly the most critical part of the map-interpretation task. Listed below are some of the reasons why this is so.

- Terrain relief provides cover, concealment, a point from which to observe enemy forces, and may constitute an obstacle to movement. As a consequence, a large part of tactical planning and tactical decision-making is based on an analysis of the terrain relief in the area of operations.
- Terrain relief is clearly the most reliable navigational checkpoint feature for both air and ground forces. Terrain relief remains extremely stable over large periods of time. So, unlike other classes of topographic features, terrain relief provides a reliable geographical reference even if the topographic map has not been updated for many years. Moreover, there are many geographical areas in which landforms are more unique in appearance than any other class of feature portrayed on a topographic map.

Despite the obvious importance of terrain relief, few aviators and few infantrymen possess the skills that are necessary to (a) accurately conceptualize the characteristics of landforms from a study of topographic maps, and (b) accurately associate landforms seen in the real world with their symbolized depiction on a topographic map. Both research data and anecdotal evidence are available to support the claim that military users lack the contour-interpretation[1] skills that are necessary to fulfill the performance requirements imposed by current doctrine. For instance, the results of recent research clearly indicate that helicopter pilots--even though seasoned by hundreds of hours of low-altitude flight--quickly become disoriented when they are required to navigate using only terrain-relief information to maintain geographic orientation (Rogers & Cross, 1978).

Although contour interpretation is recognized as an essential skill, the methods presently employed to teach aviators and infantrymen to interpret terrain relief are superficial and clearly ineffective. Classroom instruction on this important topic consists of little more than an explanation of the concept of the contour-line depiction of common types of landforms, such as peaks, saddles, draws, spurs, and so on. Classroom instruction is supplemented by field-training exercises, but field-training exercises are limited in number and scope.

Comments by operational personnel reflect a common belief that contour interpretation is a skill that can be acquired only through many years of experience in the field. However, because most members of any military unit are young, there will never be a time when more than a few of the decision makers in a military unit will have had the number of years experience needed to acquire the requisite level of contour-interpretation skill.

So, the problem is this: contour interpretation is an essential skill that is not being acquired effectively through the training presently received by aviators and infantrymen. An underlying premise of this study is that the failure to develop effective training methods before now stems from the paucity of systematic information about the

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[1]Throughout this report, the abbreviated term "contour interpretation" is used to refer to the composite set of tasks that require the user to decode the contour lines used to depict landforms on topographic maps.

cognitive nature of the contour-interpretation task and the component skills required to accomplish it.

COMMENTS ON THE NATURE OF THE CONTOUR-INTERPRETATION TASK

Description of the Contour-Line Concept

From the earliest times, one of the major cartographic problems has been the representation of three-dimensional terrain relief on a flat map. Various methods have been devised to show the third dimension on maps, but there is universal agreement that the contour-line depiction of terrain relief is the only method that is sufficiently precise for use on the large-scale and medium-scale[2] topographic maps that are used for tactical planning, land navigation, and low-altitude air navigation.

A contour line may be thought of as an imaginary line on the ground that takes any shape necessary to maintain a constant elevation above some datum plane, usually mean sea level. The elevation difference between adjacent contour lines is known as the contour interval. The magnitude of the contour interval is the same throughout a map sheet, but varies from one map sheet to another. The contour interval on different 1:50,000-scale topographic map sheets varies from 10 feet to 100 feet, depending upon the elevation range of landforms portrayed on the map sheet.

There are four different types of contour lines that may be depicted on large-scale maps; they are illustrated in Figure 1 and are discussed below. On most maps, every fifth contour line is drawn with

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[2]The most common large-scale military topographic map is published at a scale of 1:50,000. It is generally recognized that maps with a scale smaller than 1:50,000 are not suitable for tactical planning and navigation by infantry forces, or for NOE navigation by helicopter units. The 1:250,000-scale military topographic map is used for both tactical and strategic planning, and is used for navigation during low-level flight by pilots of high-speed, fixed-wing aircraft. The 1:250,000-scale map is classified as a medium-scale map.

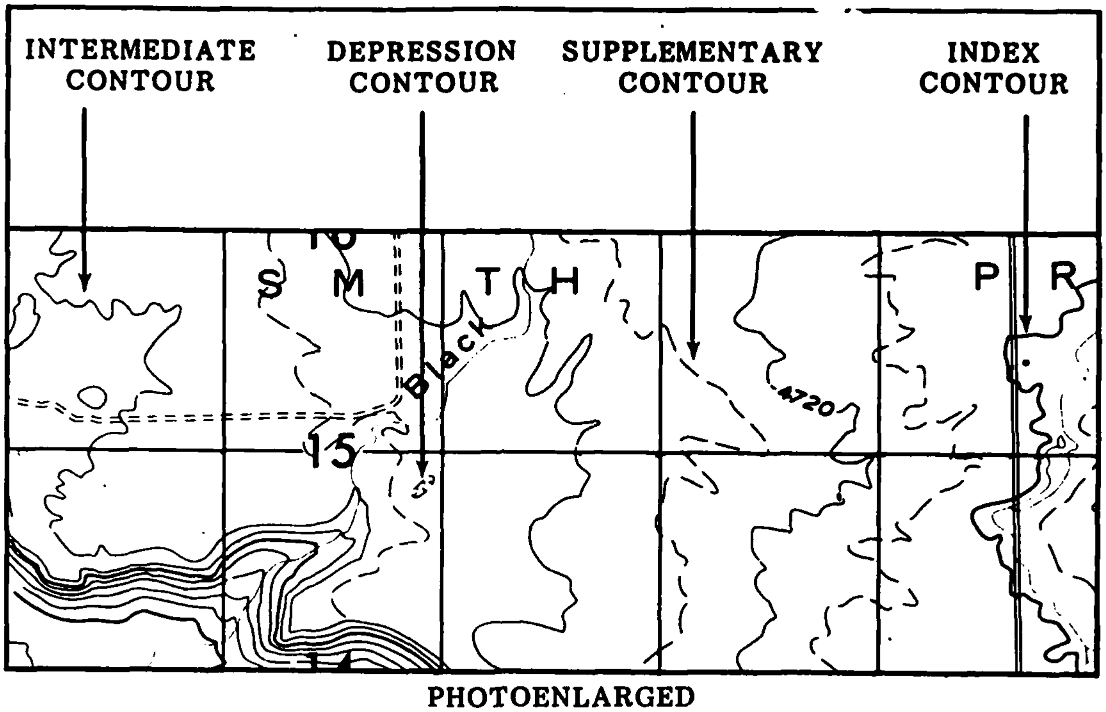

Figure 1. Illustration of four types of contour lines.

a heavier line. These are known as index contours. At some point along each index contour, the line is broken and its elevation is printed in the space. The contour lines falling between index contours are called intermediate contours. They are drawn with a finer line than index contours and usually do not have their elevation given. Both index and intermediate contours are basic contours and have the same significance; index contours are emphasized on the map solely for the purpose of easier reading.

A supplementary contour is a broken line that defines an elevation midway between two basic contours. Cartographers use them, as needed, to portray landforms that cannot be shown adequately by basic contours. A depression contour is distinguished by tic marks along its length and is used to portray depressions or to avoid ambiguity concerning the direction of elevation change. The tic marks always point in the direction of lower terrain.

Contour-line portrayal is planimetrically correct and depicts all the basic parameters of landforms, including: slope, elevation, form, orientation, and size. The precision of the landform depiction varies as a function of the contour interval. When elevation range is large and when slopes are steep, it is necessary to use a large contour interval to avoid excessive coalescing of adjacent contour lines. Contour lines with a large contour interval depict the general shape of large landforms, but do not depict the characteristics of small features on large landforms, such as small draws, shallow saddles, minor spurs, and so on.

Definition of the Contour-Interpretation Task

There are two purposes for defining the contour-interpretation task. One purpose is to define the task in a manner that facilitates an understanding of what it is that operational personnel must do, and why. The second purpose is to define contour interpretation in a manner that helps structure thinking about potential methods for training personnel to perform the task. There appears to be no simple definition that adequately serves both purposes, so the contour-interpretation task is defined in three ways: in terms of task objectives, in terms of the spatial parameters that must be evaluated, and in terms of the general cognitive processes involved.

Definition in Terms of Task Objective

It is accurate to state that contour-interpretation skill can have a profound influence on virtually every phase of a military operation, from tactical planning through the attack of the mission objective. However, little insight about the nature of the contour-interpretation task is conveyed by enumerating the broad operational tasks that may be influenced, such as: formulate Commander's Estimate of the Situation, conduct Tactical Analyses of Terrain, formulate Scheme of Maneuver, Secure Landing Zone, and so on. When defined at this level, the contour-interpretation task is confounded with the map user's ability to interpret other classes of topographic information depicted on the map and his general knowledge of the principles of modern warfare. For this reason, the task objectives must be defined at a lower level of specificity.

At one level of specificity, the objectives of all contour-interpretation tasks can be classified into one of three categories: conceptualizing the lay-of-the-land, correlating specific landforms with their map portrayal, and determining point and area masking. Each of these three are discussed below.

Conceptualize lay-of-land. The conceptualization of the lay-of-the-land in an operational area requires the map user to examine the characteristics of <u>all</u> the topographic features in the area, including: hydrographic features, vegetation, terrain relief, and the full range of cultural features. However, the assessment of terrain relief is clearly the most important and the most difficult part of the overall task, particularly when the assessment must be made off-site with only a topographic map. Conceptualizing the lay-of-the-land usually involves such subtasks as follows:

- Identifying the high ground that provides good observation and fields of fire.
- Identifying the low ground that provides good cover and concealment.
- Identifying slopes steep enough to constitute obstacles to vehicular or foot movement.

Conceptualizing the lay-of-the-land is sometimes difficult or impossible to accomplish without supplementing the map portrayal in some way. As an illustration, first examine the map segment shown in Figure 2 and attempt to conceptualize the high ground, the low ground, and the land areas with very steep slopes. Then examine the map segments in Figure 3, which have been modified to facilitate the conceptualization of the lay-of-the-land. Figure 3a highlights the drainage pattern in the area; Figure 3b facilitates the identification of high ground and low ground; and Figure 3c facilitates the identification of areas with steep slopes. Without map supplements such as these, the burden on the information processing system is probably excessive, although no empirical data are available to support this claim.

Figure 2. Example of an unmodified map segment for use in conceptualizing the lay-of-the-land.

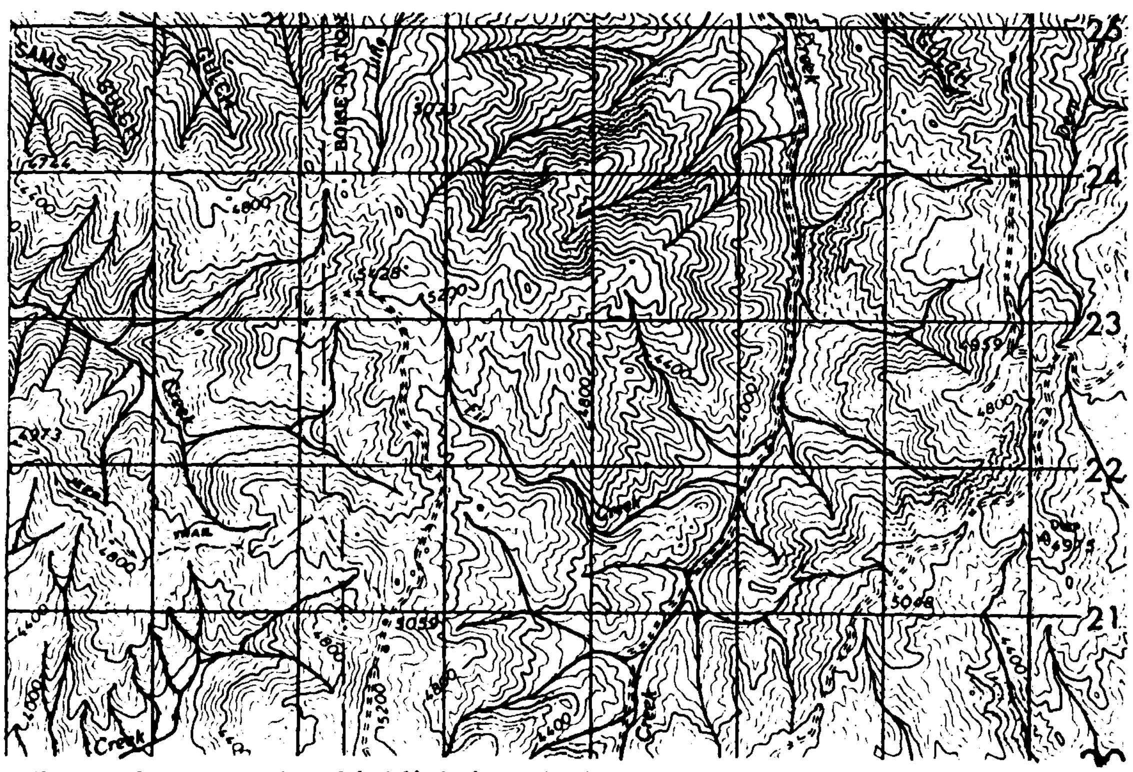

Figure 3a. Overlay highlighting drainage pattern.

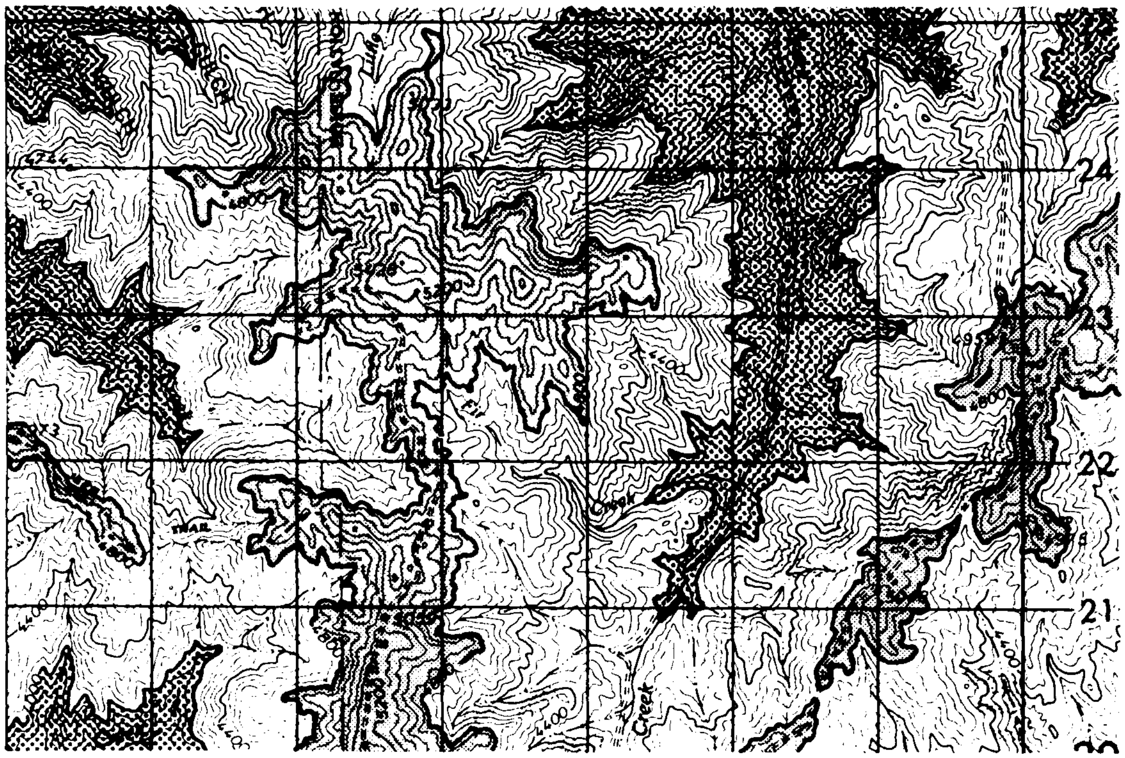

Figure 3b. Overlay identifying high ground (shaded area) and low ground (stippled area).

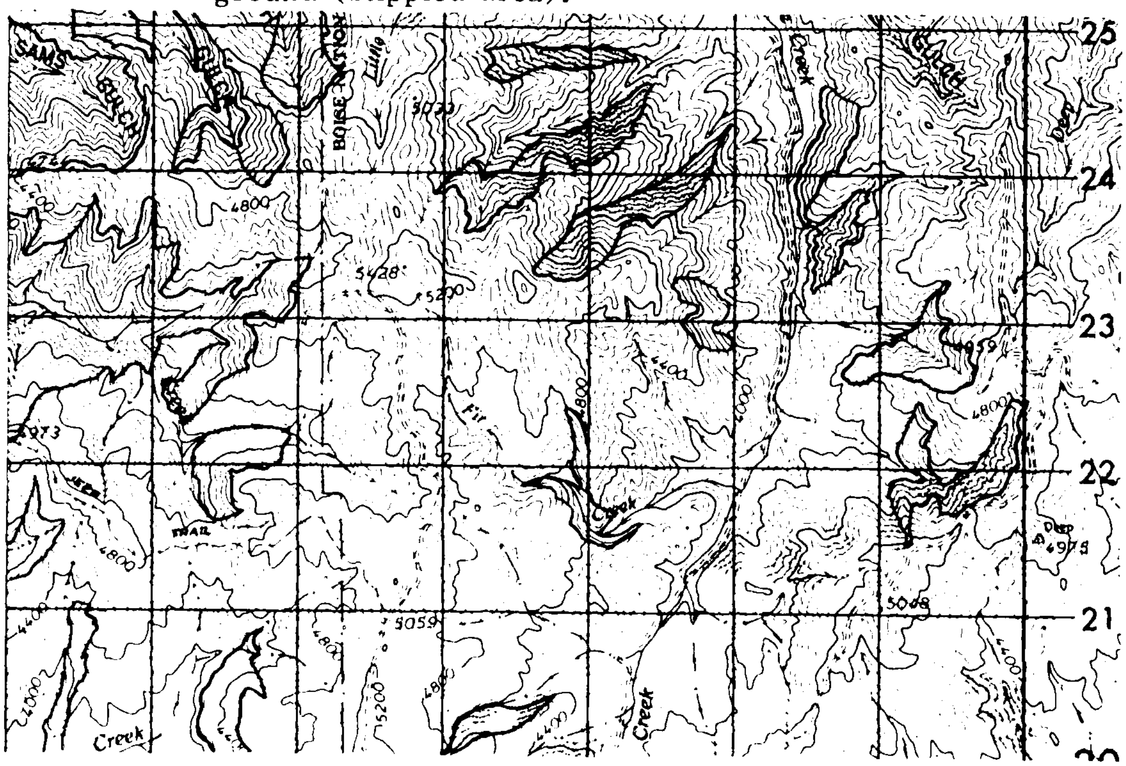

Figure 3c. Overlay identifying areas with steep slopes.

Terrain association.[3] A second objective of the contour-interpretation task is to correlate real-world landforms with their contour-line depiction on the map. Terrain association is a critically important task, and is the one most often cited in existing descriptions of the contour-interpretation task. Terrain association may be a simple matter when the map user is in a high-flying aircraft or standing on a high peak that provides a panoramic view of the area. In such situations, the map user can correlate the presence, shape, orientation, and relative position of numerous landforms that can be seen in their entirety. The task is far more difficult when flying at treetop level, and more difficult still when located on the ground.

When the map user is located at or near ground level, the difficulty of the terrain-association task stems from two related factors. One factor is the limited land area that can be observed. At some locations, map users cannot see beyond a few meters because of the masking by terrain, vegetation, cultural features, or all of these. Generally, the more limited the view, the less likely it is that a landform, or a part of a landform, in view is distinctive enough in its characteristics that it can be associated with the map portrayal.

A second factor that influences the difficulty of the terrain-association task is the point of regard from which landforms are viewed. When at or near ground level, the view of terrain relief is maximally different from the plan-view depiction on the map. As a consequence, terrain association requires the map user to transform (cognitively) the map's plan-view depiction to a horizontal view or, conversely, to transform the horizontal view of the landform to a plan view. Clearly, such transformations constitute an extremely difficult cognitive task at some geographical locations. One of the most difficult situations is one in which a map user is located so close to the base of a ridgeline that

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[3] Hereafter, the task of correlating real-world landforms with their portrayal on the map will be referred to as "terrain association." Although another term may be more descriptive, "terrain association" is already in common usage in existing military publications.

the observed skyline profile is formed by the sides of the ridgeline rather than its crest. Such situations are encountered when a map user is located close to the terminus of a convex slope.

Determine terrain masking. One of the most important contour-interpretation tasks that infantrymen must perform is to determine when the view from one point on the ground to another point is obstructed by intervening terrain. Helicopter pilots are faced with a similar problem when planning and executing nap-of-the-earth[4] flights. In some situations, careful study of the map is sufficient to determine when terrain masking is present. For instance, one can immediately conclude that masking is <u>present</u> when the elevation of at least one point on the intervening terrain is greater than the elevation of both end points. Similarly, one can conclude that masking is <u>absent</u> when the elevation of all intervening terrain is less than the elevation of both end points. The difficulty in assessing terrain masking arises when the elevation of the intervening terrain falls between that of the two end points. When this condition is present, it is necessary to define the sight line between the two end points and to determine if the elevation of the intervening terrain is great enough to intersect the sight line.

Existing training materials teach map users how to construct a terrain profile--an exaggerated side view of the earth's surface along a line between two points. Also, a relatively simple graphic solution to determining masking between two points is possible by using a device called the Defilade Masking Graph (Cross & McGrath, 1976). Both of these methods assume that map users cannot be taught to determine reliably the presence or absence of masking through the unaided examination of the contour-line portrayal of relief. One of the purposes of this study is to determine whether or not this assumption is a valid one.

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[4]Nap-of-the-earth (NOE) flight is flight performed as close to the earth's surface as vegetation, landforms, and man-made objects permit. Airspeed and altitude are varied as influenced by terrain, enemy situation, weather, and ambient light. NOE flight is employed to enhance survivability by degrading the enemy's ability to detect or locate the aircraft.

Definition in Terms of Spatial Parameters Evaluated

Another way of defining the contour-interpretation task is in terms of the spatial parameters that must be judged, measured, and compared when interpreting real-world landforms and landforms portrayed on the map. As was stated earlier, the two-dimensional contour-line portrayal depicts all of the basic spatial parameters of three-dimensional landforms, including: slope, elevation, form, orientation, and size. So, the contour-interpretation task can be defined as the estimation or measurement of these five basic parameters.

It is misleading to assume that most contour-interpretation tasks require the map user to consider all five spatial parameters depicted on a map and to generate a completely veridical visualization of landforms. On the contrary, many contour-interpretation tasks can be accomplished successfully by examining and evaluating two or three of the spatial parameters. This is true even for terrain-association tasks. Therefore, rather than attempting to generate a highly veridical image, the map user may examine only two or three spatial parameters and, thereby, generate an image that is incomplete and highly generalized, but nevertheless adequate for the task.

Considerable insight about the nature of contour-interpretation tasks and how best to train map users to perform them can be gained by defining the set of spatial parameters that are considered by different map users in different topographic contexts.

Definition in Terms of the Requisite Cognitive Processes

Another useful way to define contour-interpretation tasks is in terms of the fundamental cognitive processes that must be employed to accomplish such tasks. There has been no serious attempt to define empirically the types and relative importance of the cognitive processes that underly contour interpretation. However, even a casual study of contour-interpretation tasks is sufficient to enable one to conclude that many of the cognitive processes discussed in the contemporary psychological literature are involved in the interpretation of the contour-line depiction of terrain relief. For instance, the following is a partial list of the cognitive processes that must be brought to bear in the task of orienting oneself geographically through the comparison of real-world landforms with their contour-line depiction on the map:

- Purposeful search
- Pattern recognition
- Information storage and retrieval
- Short-term and long-term memory
- Visualization
- Rotation of a visual image
- Information generalization
- Information synthesis

Defining contour-interpretation tasks in terms of the underlying cognitive processes is of interest from both a practical and a theoretical point of view. An understanding of the underlying cognitive processes almost certainly will lead to insights about more effective training methods and about performance aids that may serve to simplify one or more of the cognitive tasks.

RESEARCH OBJECTIVES

The research on contour interpretation reported by Rogers and Cross (1978) revealed that individuals with similar training varied enormously in the speed and accuracy with which they were able to perform one type of contour-interpretation task--terrain association. It was hypothesized that these differences were largely due to differences in the cognitive strategies and procedures used to perform the contour-interpretation task. The study reported here addresses this hypothesis. Specifically, the study was designed to (a) identify the cognitive strategies and procedures employed by expert map users to accomplish one type of contour-interpretation task, and (b) determine the extent to which cognitive strategy is related to task proficiency. It was reasoned that if beneficial strategies can be identified, teaching the strategies to novice map users almost surely will increase the rate at which they acquire contour-interpretation skill.

METHOD

THE TASK

The type of contour-interpretation task investigated in this study is referred to by operational personnel as "position fixing." This task requires the map user to pinpoint or "fix" his position on the map by associating visible topographic features with their map portrayal. All of the position-fixing tasks were performed at test sites where terrain relief was the only visible topographic feature that would be employed to accomplish the task.

The difficulty of this task is heavily dependent upon the degree of a map user's disorientation. The task becomes impossibly difficult if the map user knows only that his present position is somewhere within a very large area, such as the area covered by a single map sheet--a 22,000 by 28,000 meter area. To ensure a constant and realistic level of task difficulty, a square area 5,000 meters on a side surrounding the test site was outlined on the map. This area is referred to throughout this report as the "area-of-uncertainty." The location of the test site within the area-of-uncertainty varied randomly from one test site to another.

TEST SITES

The four test sites employed in this study were located within the boundaries of Camp Pendleton--a large U. S. Marine Corps reservation located about 50 miles north of San Diego, California. Great care was taken to select test sites where the subjects could accomplish the position-fixing task only by referencing terrain relief. Although a small number of unimproved dirt roads and trails were visible from all test sites, all subjects knew that such roads and trails usually are not selected for portrayal on the map and, therefore, do not constitute a reliable orientation feature. Questioning revealed that none of the subjects had observed any of the test sites prior to the time they participated in the study.

The terrain relief visible from test sites A, B, C, and D is shown in Figures 4, 5, 6, and 7, respectively. The values shows below each photograph indicate the direction the centerline of the camera was aimed when the photograph was taken. As can be seen, the terrain relief in this region is characterized by high, rugged hills that are scored by numerous small draws and occasional wide valleys. The vegetation in this region consists mostly of low-growing scrub brush; trees high enough to mask an observer's view are found only along draws and stream beds.

Pretests showed that there is sufficient terrain relief visible from each test site to enable a skilled map user to accomplish the position-fixing task reasonably quickly and with a high degree of accuracy.

SUBJECTS

Twelve U. S. Marine Corps infantry personnel served as subjects: 10 male commissioned officers, one female commissioned officer, and one male non-commissioned officer. All subjects were on active duty and all were stationed at Camp Pendleton at the time they participated in the study.

One intent of the study is to compare the performance of expert map users with that of novice map users. However, since there was no a priori index of position-fixing skill, it was necessary to select <u>nominal</u> experts and <u>nominal</u> novices and to subsequently classify them as expert or novice based upon their performance on the position-fixing task. The manner in which this was accomplished is described below.

The individuals who participated in the study were drawn from two subject pools. One pool was composed of highly experienced infantrymen who were judged to be expert map users by their peers and supervisors. The second pool was composed of infantrymen who: (a) had successfully completed USMC training in land navigation and map interpretation, (b) had no more than three years post-training experience, and (c) had no non-military training or experience that would contribute to contour-interpretation skill. None of the individuals in this pool were singled out as expert map users by either their peers or supervisors.

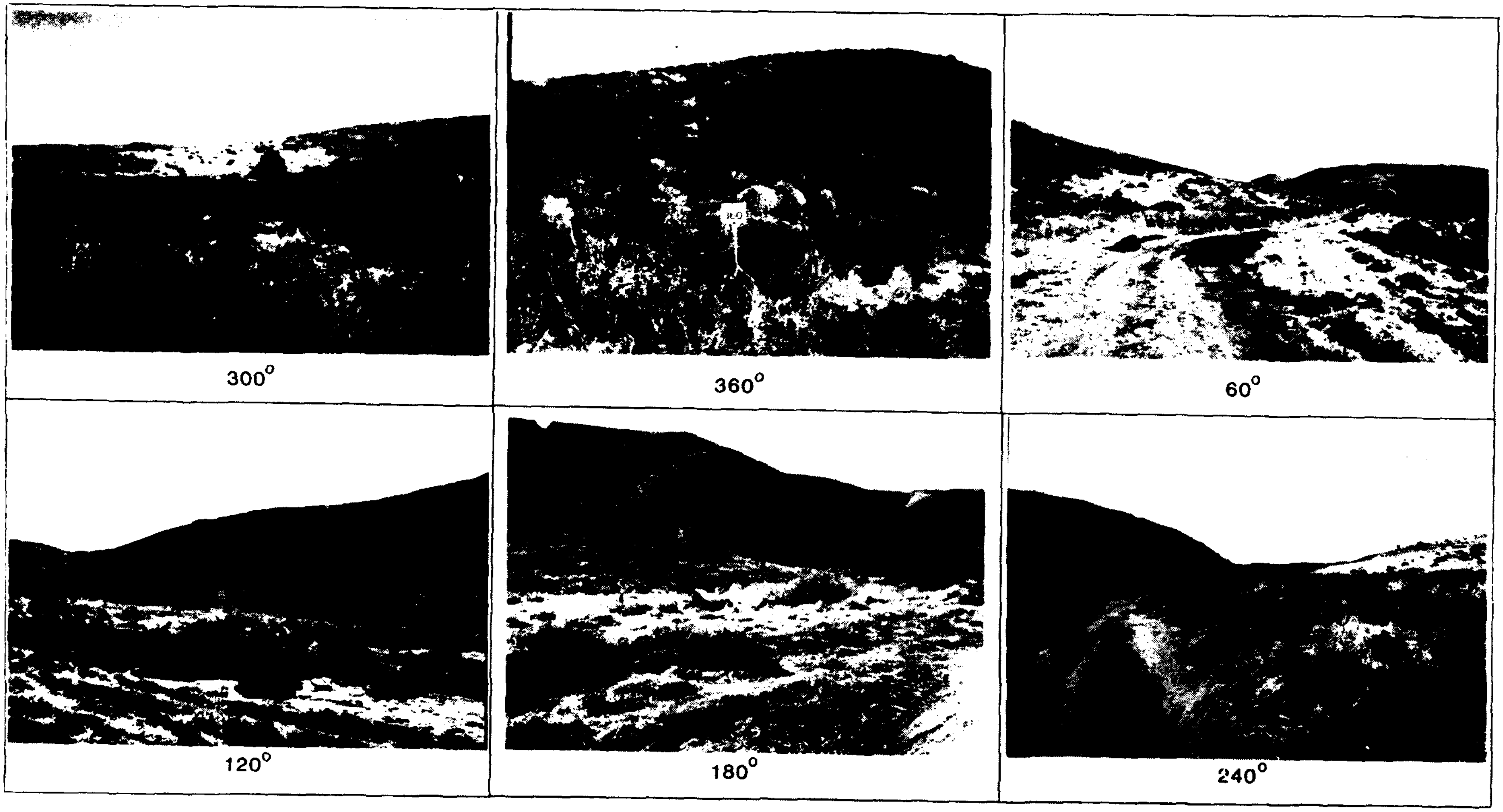

Figure 4. Terrain relief visible from Test Site A.

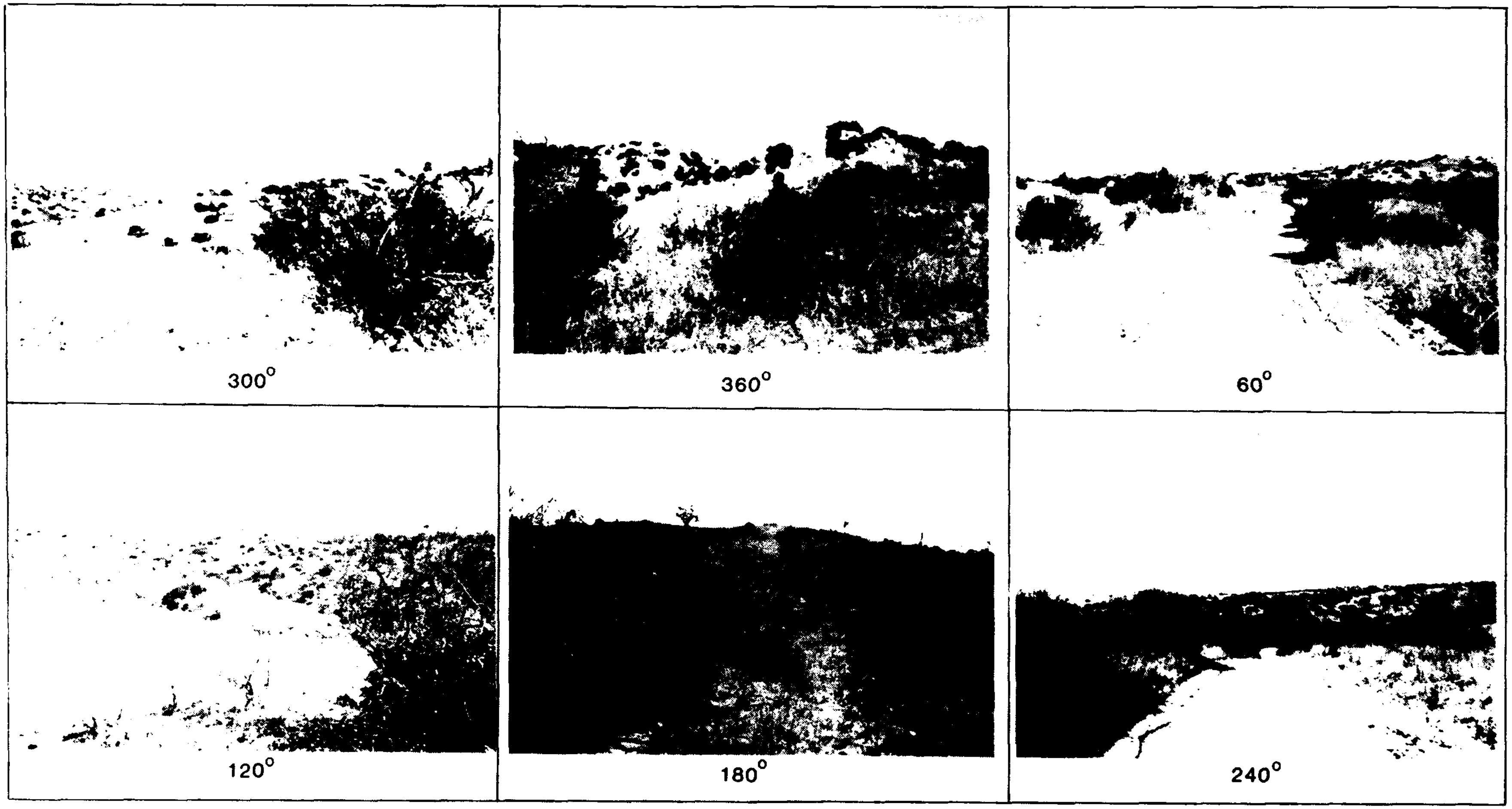

Figure 5. Terrain relief visible from Test Site B.

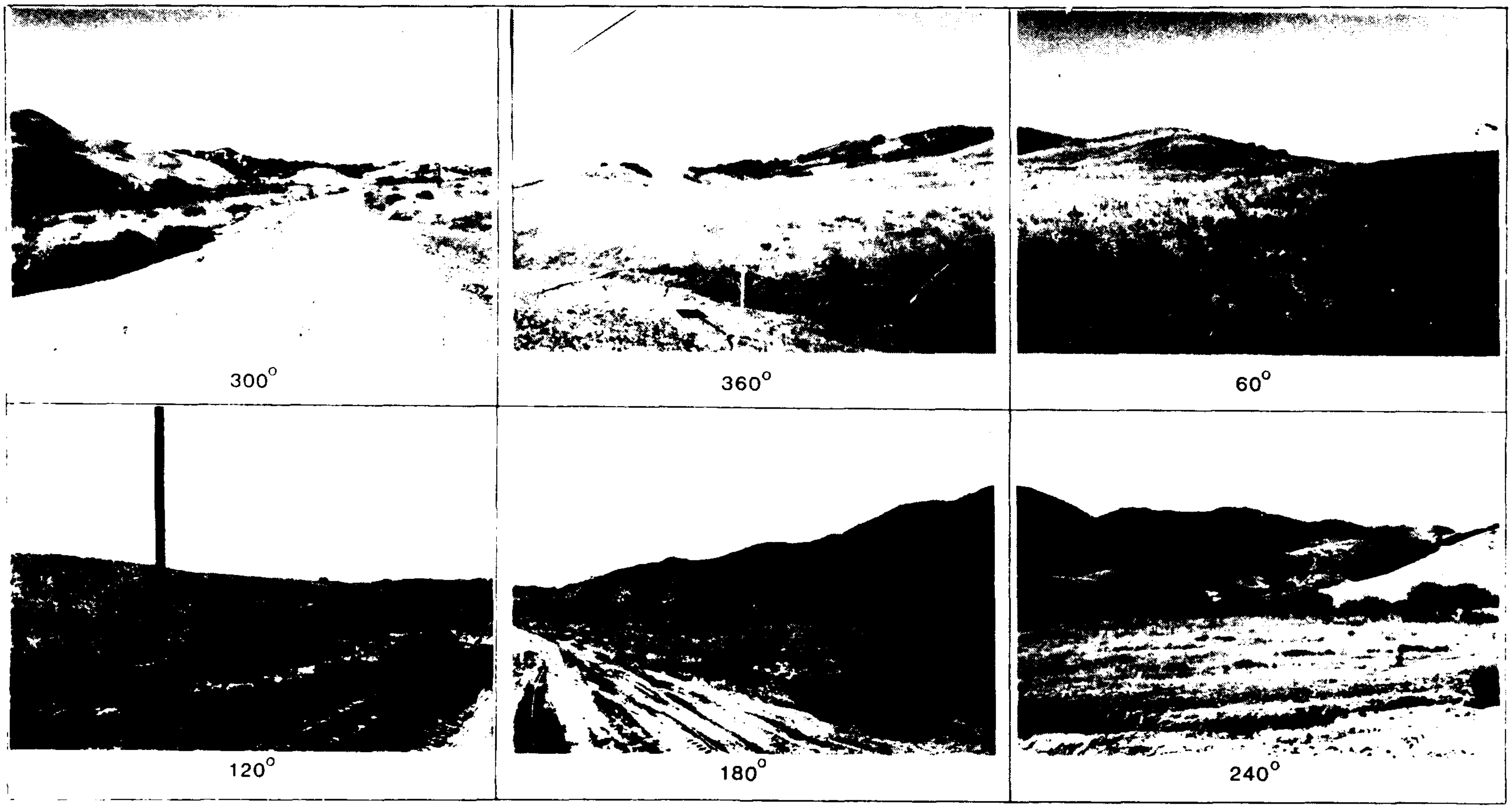

Figure 6. Terrain relief visible from Test Site C.

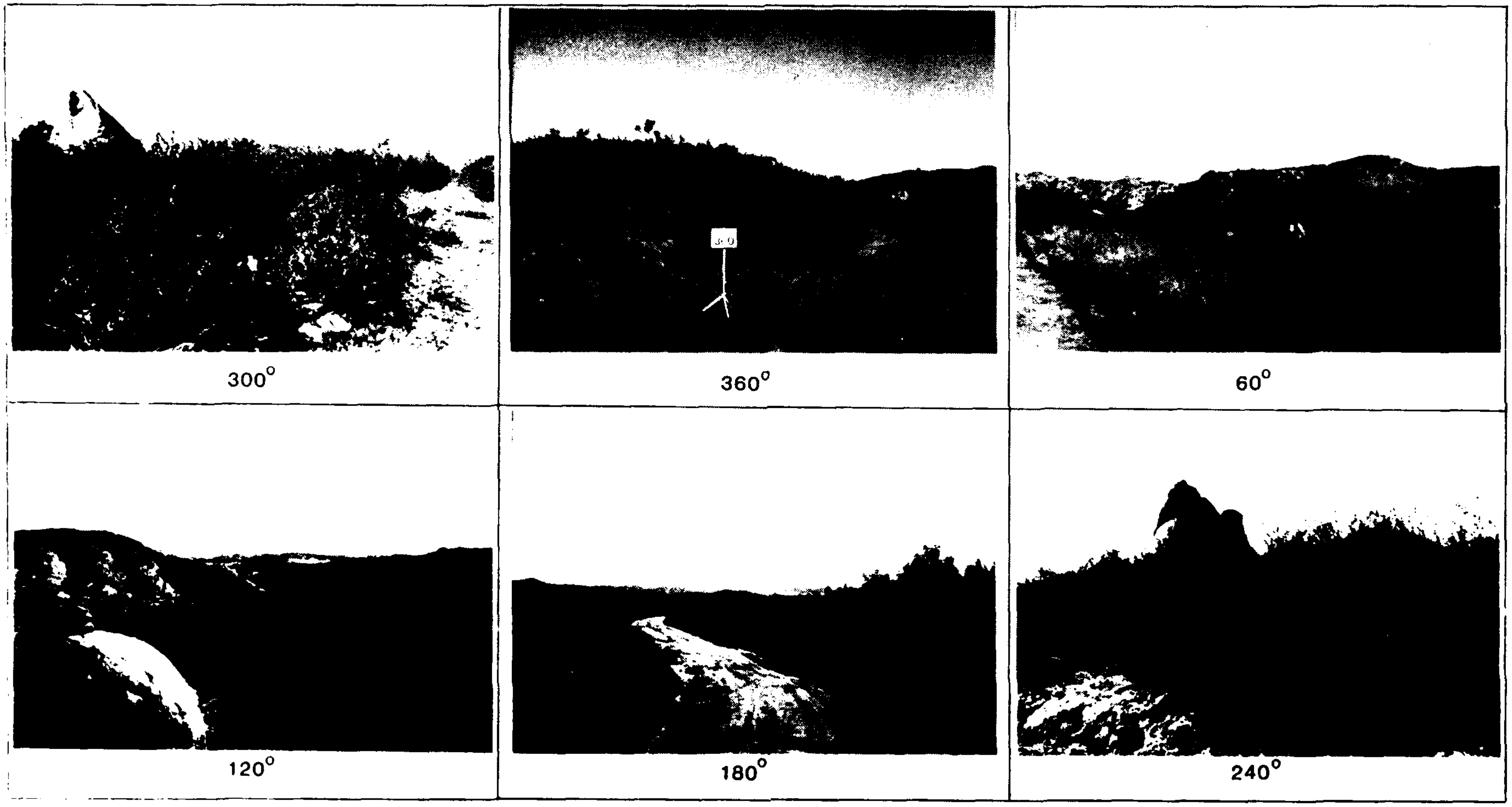

Figure 7. Terrain relief visible from Test Site D.

Individuals drawn from the two subject pools were subsequently classified into two groups based upon the accuracy of their position-fixing performance. Subjects were classified into the expert group only if their position-fixing error at each site never exceeded 300 meters. The remaining subjects were classified into the novice group. Table 1 shows the age, experience, and position-fixing errors of the expert and the novice subjects.

TABLE 1

AGE, EXPERIENCE, AND POSITION-FIXING ERROR FOR "EXPERT" AND "NOVICE" SUBJECTS

				POSITION-FIXING ERROR (IN NUMBERS)			
				TEST SITE			
GROUP	SUBJECT I.D.	AGE	YEARS IN SERVICE	A	B	C	D
EXPERTS	E1*	29	3	0	300	150	0
	E2	33	10	0	0	0	0
	E3	42	20	0	0**	0	0**
	E4	24	2	0	100	100	0
	E5	34	12	0	0	0	250
	E6*	23	2	0	0	300	300**
NOVICES	N1	25	3	100	2600	0	850
	N2*	33	11	1500	500	1250	350
	N3	24	1	1750	2000	0	3750
	N4*	29	5	1000	1500	2700	500
	N5	23	3	300	1100	1100	0**
	N6	25	2	2100	100	600**	650

*Indicates subjects that were reclassified, based on position-fixing performance.

**Data not included in analysis because protocols were lost due to recorder failure.

It was found that nominal expertise was not a reliable predictor of actual expertise at the position-fixing task. The asterisks beside the subject identification codes in Table 1 identify subjects whose nominal expertise did not correspond with their actual expertise. It can be seen that two of the nominal experts performed so poorly that they were classified as novices (N_2 and N_4). Conversely, three of the nominal novices performed so well that they were classified as experts (E_1, E_4, and E_6). This finding belies the opinion of some military personnel that a high level of expertise in map interpretation can be achieved only through many years of experience in the field. More will be said later about the lack of correspondence between nominal and actual expertise.

PROCEDURE

Protocol Recording

A test session commenced with an explanation of the purpose of the research and a description of the task the subject would be required to perform during the test session. After answering the subject's questions about the test procedures, the subject was seated in the transport vehicle and asked to don a pair of wrap-around sunglasses whose lenses had been covered with opaque tape. The glasses prevented subjects from viewing topographic features enroute to the test site that could provide cues about the test site's location.

While enroute to the first test site, a member of the research team described the concept of "thinking-aloud protocols" and explained the need for frequent prompting by the experimenter to ensure a complete record of the subject's thoughts and actions.

Upon arriving at the first test site, the microphone of a portable tape recorder was mounted near the subject's mouth and the recorder was activated. The subject was then given the map, shown the 5,000-meter by 5,000-meter area-of-uncertainty, and instructed to pinpoint the location of the test site on the map with the greatest accuracy possible.

Two techniques were used to ensure that the dialogue could subsequently be related to features in the real world and on the map. First, when the subject referred to a real-world feature in the protocol, the experimenter measured the compass bearing to the feature and verbalized the value of the compass bearing loud enough for it to be recorded on the tape recorder. Second, all map features referred to by the subject were circled and numbered consecutively; this number was used by the subject in all subsequent references to the feature.

Protocol Scoring

The tape-recorded protocols were transcribed, and the typed transcripts were studied by members of the research team. The purpose of the initial, unstructured study of the protocols was to acquire the information needed to develop a framework for systematically scoring the protocols. Figure 8 illustrates the main attributes of the protocol-scoring framework that was developed. The protocol-scoring framework was designed to identify:

- The broad strategy that a subject adopted to solve the position-fixing problem.
- The procedures that a subject employed to perform generic functions dictated by the strategy.
- The low-level operations that a subject employed to complete each procedure.
- The type and location of the map referents[5] and the real-world referents that subjects selected when performing map-terrain matching operations.
- The subject's use of map and compass bearings in performing operations.
- The specific criteria the subject used to accept or reject hypotheses about the location of the map depiction of a visible landform.

The protocol-scoring framework was exhaustive in that it encompassed the strategies, procedures, and operations employed by both the expert subjects and the novice subjects.

The protocols of the 12 subjects were scored, and the resulting data were tabulated and analyzed as necessary to identify the types of strategies, procedures, operations, and referent-selection practices that are associated with both successful and unsuccessful performance of the position-fixing tasks.

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[5] The term "referent" refers to a specific landform or a specific attribute of a landform that a subject chooses to focus on when attempting to associate visible terrain with the map portrayal. A map user may select a "map referent" and search for its real-world counterpart; or, more commonly, the map user selects a "real-world referent" and searches for its map portrayal. In either case, referents are landforms that map users consider unique or distinctive enough to be differentiated from the other landforms in the immediate area.

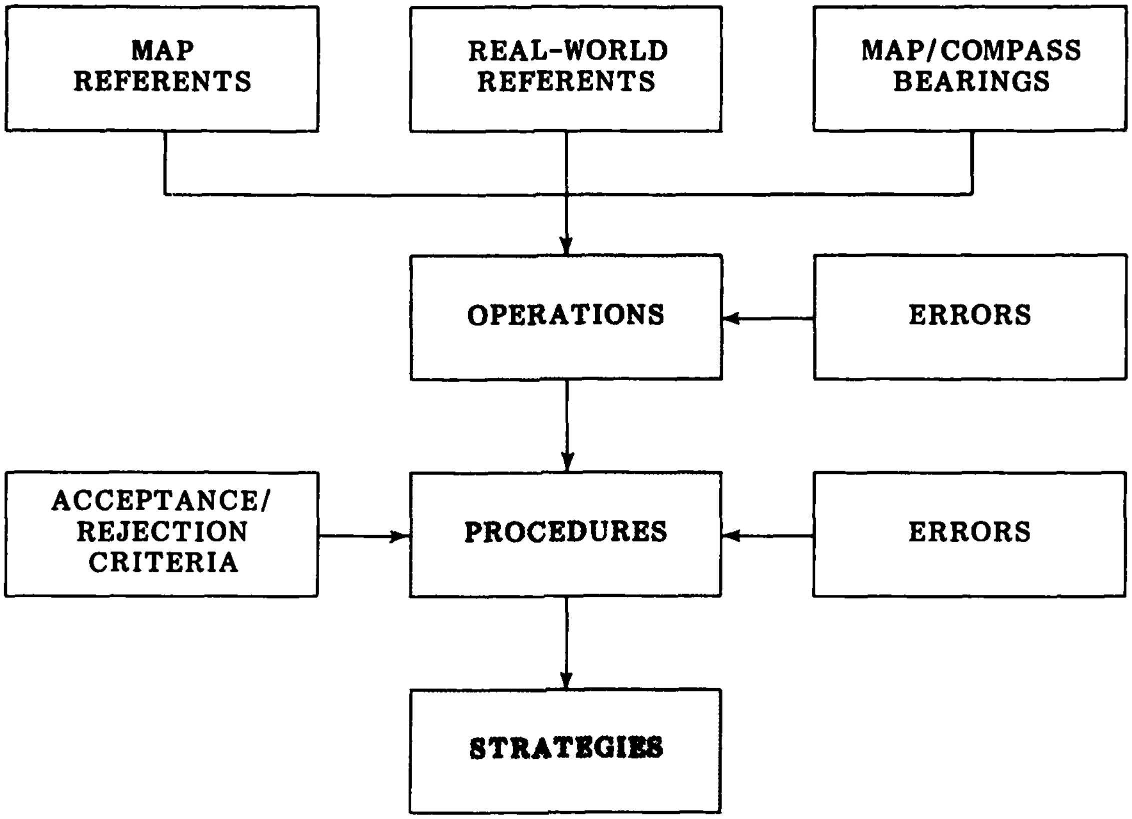


Figure 8. Framework for scoring protocols.

RESULTS

The results of the protocol scoring revealed no strategy or procedure that was always associated with successful performance of the position-fixing task. Similarly, there was no strategy or procedure that was used exclusively by either the expert or the novice subjects. It was found, however, that some strategies and procedures are used far more often by experts than novices, and are far more often associated with successful than unsuccessful performance. Because of the nature of the findings, it is necessary to define the full complement of strategies and procedures revealed by the protocol analysis and to describe the relative frequency with which the strategies and procedures were used by members of the two groups of subjects.

The presentation of findings begins with a description of the strategies that were employed. The strategies are defined in terms of the sets of procedures adopted by the subjects in their attempt to accomplish the position-fixing task. The description of strategies is followed by a description of each procedure employed by the subjects and a description of the operations required to perform each procedure. The results of various tabulations and analyses are presented to support conclusions drawn about the nature and utility of the various strategies and procedures employed by the subjects.

DESCRIPTION OF STRATEGIES EMPLOYED

The position-fixing activities of the most successful subjects can be divided into two distinct phases. The objective of the first phase is to reduce the size of the area-of-uncertainty from the 5,000 meter square area outlined on the map to a smaller size area. The objective of the second phase is to pinpoint the exact location of the test site within the newly defined area-of-uncertainty. Figures 9 and 11 identify the procedures and illustrate the interrelationship among the procedures used in the first and second phases, respectively.

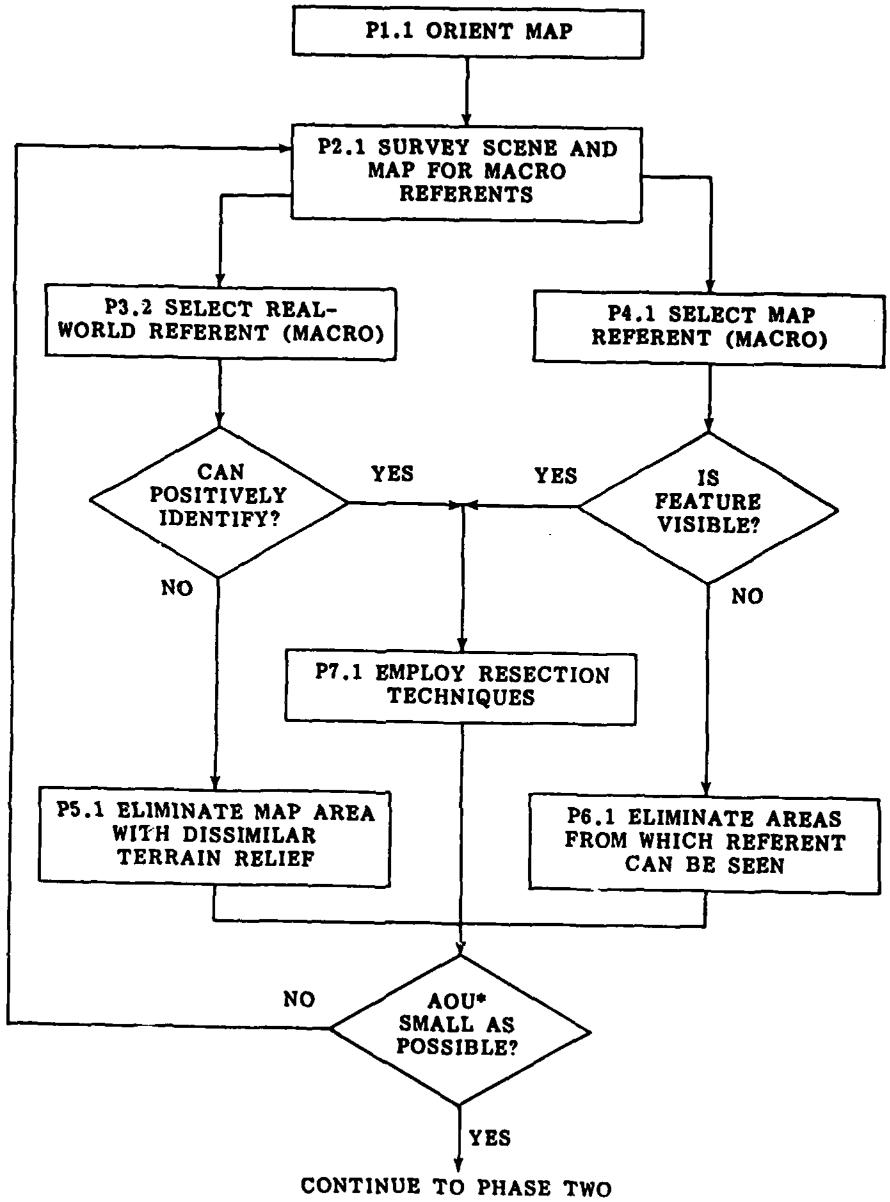
Uncertainty Reduction Strategies

There is no question that successful performance of the position-fixing task is heavily dependent upon the subject's inclination and ability to reduce the size of the area-of-uncertainty before attempting to pinpoint the exact location of the test site on the map. The reason is clear. Even the most capable subjects are unable to search for and identify, in a large area-of-uncertainty, the map portrayal of the relatively small relief features that are visible from the test site.

Uncertainty reduction was attempted by expert subjects on every test trial except one. Uncertainty reduction was attempted far less often by the novice subjects. Only one novice subject attempted uncertainty reduction at all four test sites; one novice failed to attempt uncertainty reduction at any of the four test sites. As a group, novice subjects attempted uncertainty reduction on 64% of the test trials vs. 95% of the test trials for expert subjects.

The four paths through the task-flow diagram in Figure 9 represent four possible strategies for reducing the size of the area-of-uncertainty. Table 2 lists the set of procedures that define each strategy and shows for expert and novice subjects the percent of test trials in which the corresponding strategy was used at least once. The first percentage value in each column is based upon the total number of test trials (21 test trials for experts and 22 test trials for novices). The percentage value in parentheses is based upon only the number of test trials in which an uncertainty reduction strategy was used (20 for experts and 14 for novices).

For purposes of illustration, examine the first set of percentage values in the column entitled "NOVICE." The first percentage value--45%--indicates that Strategy UR-1 was used at least once in 45% of all test trials (N=22) for which protocols were recorded. The percentage value in parentheses--71%--indicates that Strategy UR-1 was used in 71% of the trials on which some form of uncertainty reduction was attempted (N = 14).



*AOU = Area-of-uncertainty on map.

Figure 9. Procedures used to reduce the size of the area-of-uncertainty on the map.

TABLE 2

FREQUENCY OF USE OF UNCERTAINTY REDUCTION STRATEGIES

STRATEGY	PROCEDURES	PERCENT TEST SITES EXPERT N[1] = 21 (20)	PERCENT TEST SITES NOVICE N = 22 (14)
UR-1[3]	P1.1, P2.1, P3.1, P5.1	76%[2] (80%)	45% (71%)
UR-2	P1.1, P2.1, P3.1, P7.1	33% (35%)	18% (29%)
UR-3	P1.1, P2.1, P4.1, P6.1	14% (15%)	5% (7%)
UR-4	P1.1, P2.1, P4.1, P7.1	--	--

[1]The first N indicates the total numbers of test trials; the N in parentheses indicates the number of test trials in which some form of uncertainty reduction was attempted.

[2]The first percentage value is based upon the total number of test trials. The second percentage value, in parentheses, is based upon only the number of test trials in which an uncertainty reduction strategy was used.

[3]UR = Uncertainty reduction (strategy).

Subjects who attempted some form of uncertainty reduction often iterated through the procedures in Figure 9 more than once. That is, after iterating through the procedures once, the subjects decided that the area-of-uncertainty was still not small enough, so iterated through the procedures again. Some subjects iterated through the procedures as many as four times. The expert subjects who attempted uncertainty reduction iterated through the procedures an average of 1.9 times; the novice subjects who attempted uncertainty reduction averaged 1.6 iterations.

All four strategies include Procedure 1.1 (Orient Map) and Procedure 2.1 (Survey Scene and Map for Macro Referents). The strategies differ in the type referent that is selected (real-world vs. map) and the manner in which the referent is used.

Strategy UR-1. Both the expert and the novice subjects adopted Strategy UR-1 far more frequently than any other uncertainty reduction strategy. It can be seen in Table 2 that Strategy UR-1 was used at least once by experts on 76% of the test trials and used at least once by novices on 45% of the test trials. An illustration of the use of Strategy UR-1 is presented below.

Figure 10 shows the location of Test Site A (marked by "X") and the 5,000 meter area-of-uncertainty that was outlined on each subject's map. Upon surveying the terrain relief visible from Test Site A, all subjects observed that the site was located in a large canyon that ran northeast and southwest from the test site. The more skillful subjects selected the canyon as a real-world macro referent (P3.1) and proceeded to reduce the size of the area-of-uncertainty by eliminating areas on the map with dissimilar relief (P5.1). By noting the presence and orientation of the canyons on the map, the skillful subjects were able to reduce the area-of-uncertainty to the canyons labeled A, B, C, D, E, and F in Figure 10. Many subjects then noted other visible characteristics of the canyon, such as the sharp northward bend in the canyon about 400 meters west of the test site, and correctly reduced the area-of-uncertainty to either Canyon A or D.

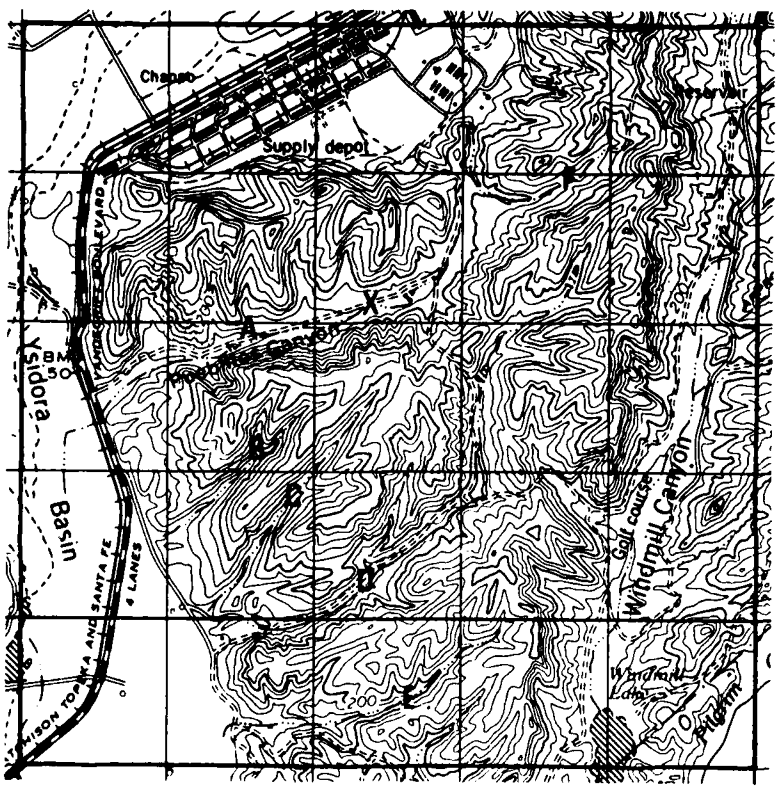


Figure 10. Area-of-uncertainty at Test Site A.

A relatively small amount of contour-interpretation skill is required to employ Strategy UR-1 at Test Site A. A map user needs only the ability to recognize the generic contour-line portrayal of a canyon and the ability to measure the width and orientation of a canyon. It seems certain that all the subjects who participated in this study had sufficient contour-interpretation skill to use Strategy UR-1 at Test Site A.

It is important to note that Strategy UR-1 is the only one of the four uncertainty reduction strategies that does not require the map user to positively associate a map feature with its real-world counterpart. The implications of this observation will become more clear as the other strategies are discussed.

Strategy UR-2. The second most frequently used strategy--Strategy UR-2--is used far less frequently than Strategy UR-1. Table 2 shows that Strategy UR-2 was used by experts in only one-third of the test trials and by novices in only 18% of the test trials. Strategy UR-1 and Strategy UR-2 differ only in the last procedure of the set. In Strategy UR-2, the map user identifies a real-world macro referent (P3.1), is able to positively identify the map portrayal of the macro referent, and uses a compass to perform a one-point resection on the feature. Briefly, a one-point resection is performed by (a) measuring the azimuth (α) and estimating the distance (D) to a real-world feature, (b) computing the back azimuth (measured azimuth α minus 180 degrees), and (c) locating the point on the map that is the appropriate bearing ($\alpha - 180°$) and distance (D) from the map portrayal of the referent.

The size of the area-of-uncertainty after the execution of a one-point resection (P7.1) depends upon the accuracy of both the azimuth measurement and the distance estimate. The accuracy of the azimuth measurement and the distance estimate, in turn, are dependent upon the size of the referent and its distance from the test site. At some locations, Strategy UR-2 enables a map user to reduce the size of the area-of-uncertainty to an area no larger than one- or two-hundred meters across. However, in selecting test sites for this study, care was taken to avoid sites from which easily identifiable macro features were visible. This fact, in part, accounts for the relative infrequency with which Strategy UR-2 was employed in this study.

Strategy UR-3. The third most frequently used strategy--Strategy UR-3--was used by experts in only 14% of the test trials and by novices in only five percent of the test trials. In Strategy UR-3, the map user selects a macro referent on the map (P4.1), is able to confidently conclude that the macro referent cannot be seen from the test site, and eliminates from further consideration all the areas on the map from which the macro referent could be seen (P6.1).

The infrequency with which Strategy UR-3 was used is a result of the difficulty and the relative inefficiency of this strategy. To illustrate, suppose a map user observes what appears to be a prominent and uniquely shaped hill portrayed on the map and selects that hill as a map referent (P4.1). In order to employ Strategy UR-3, the subject must correctly conclude that the hill selected as a map referent is not visible from the test site. In order to determine whether or not the hill is visible, the map user must be capable of accurately visualizing the real-world counterpart of the map referent. Such visualization is a task that requires a level of contour-interpretation skill that even expert subjects may not possess. Without question, Strategy UR-3 requires considerably more contour-interpretation skill than either Strategy UR-1 or Strategy UR-2.

Assuming that the map user correctly concludes that the hill is not visible from the test site, he must then define the areas on the map from which the map referent can be seen (P6.1). (Judging whether one point on the map is visible from another point on the map is referred to as judging "intervisibility.") This task also requires a high level of contour-interpretation skill. It requires that the map user be capable of identifying all the points on the map from which the hill would not be masked from view by intervening terrain relief.

Even if the map user performs P6.1 with considerable skill, he will be unable to reduce the size of the area-of-uncertainty by a significant amount unless the hill selected as a map referent is very high and the surrounding terrain is very flat.

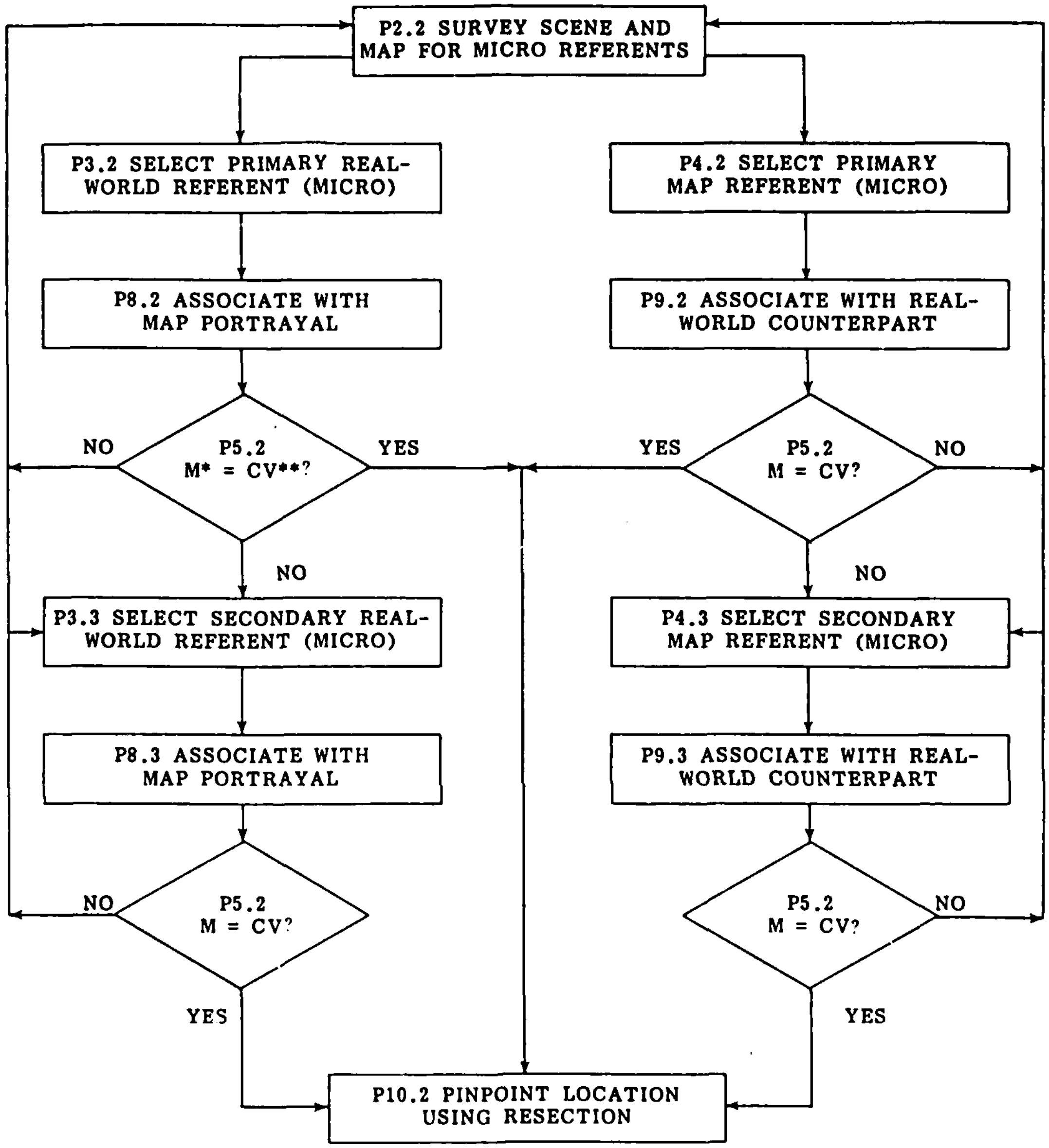
In short, Strategy UR-3 requires more skill in visualizing the real-world appearance of the contour-line portrayal of a landform and requires more skill in judging intervisibility than either Strategy UR-1 or UR-2 except in the rare situation in which a prominent feature is visible from a great distance.

Strategy UR-4. Although Strategy UR-4 is a feasible strategy, it was never used by either expert or novice subjects. Strategy UR-4 is highly similar in method and difficulty to Strategy UR-2. The strategies differ only in whether a map referent or a real-world referent is selected. Strategy UR-4 requires the map user to positively identify the real-world counterpart of a feature on the map selected as a map referent. This task is extremely difficult when the initial area-of-uncertainty is as large as that used in this study. To employ Strategy UR-4, the map user must be highly proficient at visualizing the real-world counterpart of a feature portrayed on the map. Even if the map user is capable of such visualization, scores of map referents could be chosen and analyzed before one is selected that is visible from the test site. Thus, Strategy UR-4 would be a practical uncertainty reduction strategy only when the initial area-of-uncertainty is very small.

Position Location Strategies

Once subjects had reduced the size of the area-of-uncertainty to the greatest extent possible (Phase One), they adopted strategies aimed at pinpointing the exact location of the test site within the area-of-uncertainty (Phase Two). The sets of procedures that subjects employed to accomplish this part of the position-fixing task are referred to as position location (PL) strategies.

Figure 11 shows the composite set of procedures employed by subjects in their attempt to pinpoint the exact location of the test site



* M = Number of correct matches.
**CV = Subjects' internal criterion value.

Figure 11. Procedure used to pinpoint test site.

on the map. The definition of an optimal or preferred PL strategy is complicated by the fact that subjects can and did iterate through certain procedures several times before arriving at a decision about the exact location of the test site. It was found that (a) no procedure was uniformly used or uniformly avoided by either group of subjects, (b) every subject employed numerous procedures on each test trial, and (c) most subjects used a given procedure repeatedly during a given test trial. As a consequence, effective PL strategies can be defined only in terms of the type of procedures used and the frequency with which each procedure was used.

The procedures in Figure 11 can be grouped into four procedure sets based upon the type of referent that is selected. Each procedure set, in turn, can be divided into either three or four subsets, depending upon the procedure the subject selects after completing the corresponding procedure set. The procedure sets and subsets are defined in Table 3. The column entitled "PROCEDURE CODES" identifies the specific procedures that comprise each procedure set and subset; the procedure codes refer to the procedures named in Figure 11. Note that each row contains either three or four codes to the left of the arrow and one code to the right of the arrow. The three codes to the left of the arrow define the procedures that comprise the procedure set; the code to the right of the arrow defines the first procedure selected after the corresponding procedure has been completed and, thus, defines the procedure subset. The last four columns of Table 3 show the average number of times per test site each procedure set and subset was used by experts and novices.

Before discussing each procedure set and subset in detail, the general strategy employed by the subjects will be described and several important terms will be defined.

General Strategy

Figure 11 shows that Phase Two activities always commence with a survey of the scene and map for micro referents (P2.2) and always ends with the use of resection techniques to pinpoint the location of the test site on the map (P10.2). All the procedures between the common initial and final procedures are of three general types. First, a subject must select a referent--either a map referent or a real-world referent.

TABLE 3

FREQUENCY OF USE FOR PROCEDURE SETS/SUBSETS USED TO PINPOINT LOCATION OF TEST SITE

TYPE REFERENT	DESIGNATION		PROCEDURE CODES	AVERAGE FREQUENCY OF USE PER TEST TRIAL			
				EXPERTS		NOVICES	
	SET	SUBSET		SET	SUBSET	SET	SUBSET
PRIMARY REAL-WORLD	1	a	P2.2, P3.2, P8.2, P5.2 → P2.2	6.4	4.1	6.5	5.2
		b	P2.2, P3.2, P8.2, P5.2 → P3.3		1.3		.5
		c	P2.2, P3.2, P8.2, P5.2 → P4.3		.6		.4
		d	P2.2, P3.2, P8.2, P5.2 → P10.2		.4		.4
PRIMARY MAP	2	a	P2.2, P4.2, P9.2, P5.2 → P2.2	2.6	2.2	5.8	4.7
		b	P2.2, P4.2, P9.2, P5.2 → P3.3		.1		.3
		c	P2.2, P4.2, P9.2, P5.2 → P4.3		.2		.4
		d	P2.2, P4.2, P9.2, P5.2 → P10.2		.1		.4
SECONDARY REAL-WORLD	3	a	P3.3, P8.3, P5.2 → P2.2	2.9	1.1	1.0	.6
		b	P3.3, P8.3, P5.2 → P3.3		1.0		.1
		c	P3.3, P8.3, P5.2 → P4.3		.4		.2
		d	P3.3, P8.3, P5.2 → P10.2		.4		.1
SECONDARY MAP	4	a	P4.3, P9.3, P5.2 → P2.2	1.4	.6	1.0	.7
		b	P4.3, P9.3, P5.2 → P4.3		.3		.1
		c	P4.3, P9.3, P5.2 → P3.3		.4		.1
		d	P4.3, P9.3, P5.2 → P10.2		.1		.1
				13.3		14.3	

Second, the subject must attempt to associate the referent with its real-world or map counterpart. Finally, the subject must make a decision about whether he has been successful in his attempt to associate the referent with its real-world or map counterpart.

It is important to note that the subject does not necessarily terminate his activities when he assumes that he has correctly matched a real-world feature with its map portrayal. Rather, when a correct match is assumed, the subject (a) increases the value of an "internal counter" by one and (b) compares the counter value with his personal criterion for the number of features he must correctly match before he is willing to conclude that he can successfully pinpoint the location of the test site on the map.

The diamond-shaped blocks in Figure 11 represent the decision-making procedure (P5.2) described above. The "M" in these blocks refers to "matches" of a terrain and map feature; the adjacent "CV," an abbreviation for criterion value, refers to the number of correct matches a subject requires before he is willing to terminate Phase Two activities. The data analyses revealed that, on the average, experts required 6.9 matches and novices required 3.8 matches per site before they were willing to commit themselves in pinpointing the exact location of the test site. This finding is clear evidence that even expert map users lack confidence in their ability to positively associate any given map feature with its real-world counterpart; in fact, the results indicate that experts are even more aware of this limitation in their ability than novices. It seems reasonable to conclude that recognizing this skill limitation is an important facet of expertise.

Types of Referents

Among the most important insights gained from studying the subjects' protocols is the finding that subjects select and use altogether different types of referents for different purposes. In order to discuss meaningfully the subjects' referent-selection behavior, referents have been classified and named as follows:

- map referent versus real-world referent,
- macro referent versus micro referent, and
- primary referent versus secondary referent.

The terms "map referent" and "real-world referent" were defined earlier (see footnote 5). Briefly, a map referent is defined as any landform or part of a landform portrayed on the map that a map user chooses to focus on when attempting to associate visible terrain with the map portrayal. A real-world referent is defined as any visible landform or part of a landform the map user chooses to focus on when attempting to associate visible terrain with the map portrayal.

A macro referent is a large landform that a map user focuses on when attempting to reduce the size of the area-of-uncertainty. By definition, macro referents are used only during Phase One of the position-fixing task. Hill masses, ridgelines, and valleys are examples of macro referents that are commonly used. A micro referent is a small landform or, more commonly, a small part of a landform. Small draws, small saddles, and small spurs are examples of micro referents. By definition, micro referents are used only during Phase Two of the position-fixing task.

The difference between primary and secondary referents stems from the reasons for which they are selected. A primary referent (real-world or map) is selected because of its relatively unique, easily identifiable physical characteristics. That is, a map user selects a terrain feature as a primary referent only if he considers it unique enough in its physical characteristics to enable him to associate it with its map or real-world counterpart. Secondary referents are selected because of their proximity to a primary referent rather than because of the uniqueness of their physical characteristics.

To illustrate the difference between a primary and a secondary referent, suppose a map user selects as a primary real-world referent a prominent saddle in a ridgeline. Once the map user has located what he believes to be the map portrayal of the saddle, he attempts to confirm the association by noting smaller, less distinctive relief features in close proximity to the saddle. For instance, the map user may note a small spur forming on the ridgeline about 300 meters to the left of the saddle. The map user reasons that if he has correctly identified the map portrayal of the saddle, he should see the portrayal of a small spur about 300 meters to the left of the portrayed saddle. The main point to be made is this. The map user would never have selected the small spur as a primary referent because he realizes that it is unlikely he could differentiate the map portrayal of the small spur from the portrayal of numerous other small spurs in the vicinity. Even so, confirmatory information can be obtained by simply noting that a small spur is portrayed on the map at the correct direction and distance from the primary referent. In short, the map user merely notes the presence or absence of a secondary referent in a prescribed location rather than attempting to determine whether its size and shape corresponds with its map or real-world counterpart.

Discussion of Common Procedure Sets/Subsets

The four procedure sets and their respective subsets are discussed below. The reader should keep in mind that all four procedure sets involve:

- selection of a referent,
- association of a referent with its map/real-world counterpart, and
- comparison of the counter value "M" with a personal criterion value "CV" for the number of correct matches required before terminating Phase Two activities and making a final decision about the test site's location.

It is important to note that the procedure sets differ in the type of referent that is selected while the subsets of a given procedure set differ only in the first procedure performed after completing the procedure set.

Procedure Set 1. Procedure Set 1 consists of the four procedures listed below:

- survey scene for micro referents (P2.2),
- select primary real-world referent (P3.2),
- associate real-world referent with map portrayal (P8.2), and
- adjust counter value and compare with criterion (P5.2).

Table 3 shows that Procedure Set 1 was used far more frequently than any other procedure set and that it is used with about equal frequency by experts and novices. At each test site, Procedure Set 1 was used an average of 6.4 times by experts and 6.5 times by novices. This means that the average subject selected and attempted to associate more than six different primary real-world referents per test site. Novices iterated back through Procedure Set 1 (Subset 1a) slightly more often than experts--5.2 versus 4.1 iterations per test site. Conversely, experts more often used Subset 1b, which is to select a secondary real-world referent (P3.3) after completing an iteration of Procedure Set 1. Experts and novices used Subset 1c and Subset 1d with about equal frequency.

The repeated iterations through Procedure Set 1 is clear evidence of the subjects' lack of confidence in their ability to positively associate a real-world referent with its counterpart on the map. This lack of confidence is well founded. Even the expert subjects were in error in nearly 18% of the instances in which they judged that they had located the map portrayal of a real-world referent; novice subjects were in error in over 64% of the instances in which they concluded that they had correctly matched a real-world referent with its map portrayal.[6]

Procedure Set 2. In Procedure Set 2, the subject selects a primary map referent (P4.2) and attempts to associate it with its real-world counterpart (P9.2). Otherwise, Procedure Set 2 is the same as Procedure Set 1. It can be seen in Table 3 that novices used Procedure Set 2 more than twice as often as experts (5.8 versus 2.6 iterations per test site). Experts' disinclination to use Procedure Set 2 is clearly the most significant difference in the position-fixing strategies employed by the two groups of subjects. Locating the real-world counterpart of a map referent tends to be difficult and time consuming--mainly because a map user can never be certain that the real-world counterpart of a map referent is visible and identifiable from the map user's point of regard. Even in a relatively small area-of-uncertainty, it is possible to select scores of map referents before one is selected that is, in fact, visible from a given point on the ground. These findings strongly suggest that the use of Procedure Set 2 is not a justifiable strategy unless the map user has a very accurate notion of his position on the map.

Although experts infrequently elected to use Procedure Set 2, they can use it effectively when they choose to do so. The experts' error rate in associating map referents with their real-world counterpart is 12%--versus an error rate of 18% when associating a real-world referent with its counterpart on the map. In contrast, when novices attempt to associate a map referent with its real-world counterpart, the error rate is about 83%--versus an error rate of 64% when novices attempt to associate a real-world referent with its map counterpart. The differences in the experts' and novices' error rate in executing Procedure Set 2 is partly the result of the experts' disinclination to select a map referent until they had a reasonably accurate notion of the test site's location.

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[6]Caution must be exercised in interpreting the error rate of novices because, by definition, novices in this study are individuals who were unsuccessful in their attempts to perform the position-fixing task.

Procedure Subset 2a is used far more frequently than any of the other three subsets. This means that, once Procedure Set 2 has been selected, it is highly likely that the map user will iterate back through Procedure Set 2 one or more times before adopting a different procedure. Table 3 shows that, on the average, Subset 2a is used by experts 2.2 times per test site and by novices 4.7 times per test site.

Procedure Set 3. The objective of Procedure Set 3 is to select a secondary real-world referent (P3.3) and to associate it with its counterpart on the map (P8.3). It will be recalled that a secondary referent is a feature selected as a referent because of its proximity to a primary referent, rather than because of the uniqueness of its physical characteristics. Table 3 shows that experts used Procedure Set 3 nearly three times as often as novices (2.9 versus 1.0 iterations per test site). When Procedure Set 3 is used, the subjects often iterate back through Procedure Set 3 (Subset 3b) or search the map and the visual scene for another primary referent (Subset 3a). The other two subsets, Subset 3c and Subset 3d, are used infrequently by both experts and novices.

The use of Procedure Set 3 was assumed only when it was perfectly clear from the protocol that the subject had selected a secondary referent. It is certain that subjects sometimes employed Procedure Set 3 without verbalizing their actions. As a consequence, the data on the relative frequency with which Procedure Set 3 is used is almost certain to be highly conservative.

The use of Procedure Set 3 represents a second major difference in the position-fixing strategies employed by expert and novice subjects.

Procedure Set 4. In Procedure Set 4, subjects select a secondary map referent and attempt to associate it with its real-world counterpart. It can be seen in Table 3 that experts use Procedure Set 4 an average of 1.4 times per test site and that novices use Procedure Set 4 an average of only once per test site. In the typical case, a subject uses Procedure Set 4 once and then searches the scene for another primary referent (Subset 4a). Only rarely do subjects iterate back through Procedure Set 4 (Subset 4b).

There is no obvious reason why Procedure Set 4 is not used as often as Procedure Set 3. In fact, it would seem logical to alternate between Procedure Set 3 and Procedure Set 4 until all the secondary referents in the proximity of a primary referent have been exhausted. It is possible that this finding is an artifact of the protocol analysis technique. That is, it is possible that subjects sometimes were using both Procedure Set 3 and Procedure Set 4 without verbalizing that fact.

Characteristics of an Effective PL Strategy

Defining a single, optimal PL strategy is not possible because successful performance of the task is not associated with any one set of procedures. Nevertheless, the results presented above make it possible to describe several characteristics that are essential for an effective PL strategy. These characteristics are described below.

At the outset of the problem-solving task, the map user should concentrate on surveying the scene for primary real-world referents that can easily be associated with their map portrayal. The map user should not select primary map referents until he is reasonably confident that he knows his position on the map within a few hundred meters. Even then, there is no evidence that the selection of primary map referents is a more effective strategy than the selection of another primary real-world referent.

Once the map user believes he has associated a primary real-world referent with its map portrayal, he should search for secondary referents in close proximity to the primary referent. Either real-world or map features may be selected as secondary referents, so long as (a) the feature's general shape is identifiable, and (b) an accurate estimate can be made of the secondary referent's bearing and distance from the primary referent.

The map user with reasonable skill should continue to select referents and attempt to associate them with their map or real-world counterpart until he believes that he has correctly matched at least seven features. It seems reasonable to assume that an even greater number of matches should be sought if the map user is inexperienced or otherwise lacks skill in the terrain-association task. However, this study provides no data to support the assumption that a lack of skill can be offset by requiring a greater number of assumed matches.

Finally, the map user should use resection procedures to pinpoint his exact location on the map. The map user should perform a two- or three-point resection using the smallest and closest features that can be confidently associated with their map portrayal.

DESCRIPTION OF PROCEDURES/OPERATIONS EMPLOYED

The purpose of the previous section was to define strategies by specifying the set of procedures that must be performed to implement the strategy. The purpose of this section is to define procedures by specifying the set of operations that must be performed to implement the procedure. All of the procedures of interest were introduced in the previous section. They include:

Phase One Procedures

- orient map using compass (P1.1),
- survey scene and map for macro referents (P2.1),
- select real-world macro referent (P3.1),
- select macro map referent (P4.1),
- eliminate map areas with dissimilar terrain relief (P5.1),
- eliminate areas on map from which map referent can be seen (P6.1),
- employ resection techniques in reducing the size of the area-of-uncertainty (P7.1),

Phase Two Procedures

- search scene and map for primary micro referents (P2.2),
- select primary real-world micro referent (P3.2),
- associate primary real-world micro referent with map portrayal (P8.2),
- select primary micro referent on map (P4.2),
- associate primary map referent (micro) with real-world counterpart (P9.2),

- select secondary real-world micro referent (P3.3),
- associate secondary real-world micro referent with map portrayal (P8.3),
- select secondary micro referent on map (P4.3),
- associate secondary map referent (micro) with real-world counterpart (P9.3),
- compare number of matches "M" with criterion value "CV" (P5.2), and
- pinpoint location using resection technique (P10.2).

There is a great deal of commonality among the procedures listed above. First, there are some types of operations that are common to many different procedures. For instance, the operation "visualize real-world appearance of map portrayal" or the operation "visualize the contour-line portrayal of a visible landform" is an essential part of nearly every procedure. Also, there are some procedures that require essentially the same set of operations--the procedures differ only in the type of referent that is selected. Because of these commonalities, a detailed discussion of each of the 18 procedures listed above would be highly repetitious. To avoid unnecessary repetition, a decision was made to discuss in detail a set of eight procedures that, together, encompass all of the important operations revealed by this research. The procedures discussed in detail include: Procedure 2.1, Procedure 3.1, Procedure 5.1, Procedure 3.2, Procedure 4.2, Procedure 8.2, Procedure 3.3, and Procedure 8.3.

A detailed task-flow diagram has been prepared for each of the procedures listed above except Procedure 5.2. Procedure 5.2 does not require multiple operations to complete, so a task-flow diagram is unnecessary. Each task-flow diagram identifies the operations that must be completed, including the key decisions that must be made, and shows the interrelationship among the operations. A full set of the task-flow diagrams are presented in Appendix A (Figures A-1 through A-17). The discussion presented in this section should provide the reader with sufficient information to interpret the task-flow diagrams for the procedures not discussed in detail.

Three of the procedures listed above--Procedure 1.1, Procedure 7.1, and Procedure 10.2--are accomplished by employing routine operations that are discussed in every basic text on map and compass use. These procedures and operations have little relevance for this research, so they have not been discussed in detail. Interested but uninitiated readers will have to refer to a different source for descriptions of the methods used to perform the following operations:

- determine angle of declination (printed on map margin),
- use compass to determine magnetic north,
- compute grid north by adding/subtracting G-M angle,
- align compass with north-south grid line,
- align grid lines on map with grid north on compass,
- measure magnetic azimuth to landforms,
- convert azimuth to grid-back-azimuth,
- plot on map grid-back-azimuth line from landform,
- estimate range to landform,
- estimate probable error associated with azimuth measurement, and
- estimate probable error associate with range estimation.

The field observations and the subsequent protocol analyses provided insufficient information to make an objective assessment of how frequently the various operations were performed, how well they were performed, and the extent to which the success of the position-fixing task was influenced by each operation. Even so, the composite knowledge gained during the course of this research left the experimenters with many strong impressions that are considered worthy of note. As a consequence, the following section is sprinkled liberally with impressions and descriptions of the observations that led to these impressions. Needless to say, these impressions must be considered speculative until supported by data from additional research.

Comments on Visualization

To accomplish the position-fixing task, the map user must successfully locate the map portrayal of real-world referents or, conversely, must locate the real-world counterpart of map referents. Since a visible landform and its map portrayal are encoded differently, the map user must translate the two into a common encoding format before it is possible to compare them. In principle, three types of translations are possible:

- the map user can mentally translate the visible landforms into a contour-line encodement,
- the map user can mentally translate the contour-line pattern into a three-dimensional form, or
- the map user can translate both the visible landform and the contour-line pattern into one or a set of descriptive terms, such as "draw," "large draw," "large steep-sided draw."

A similar type of translation is required to select an effective referent. An effective real-world referent is one whose map portrayal is distinctive and, conversely, an effective map referent is one whose real-world image is distinctive. Hence, regardless of the type of referent selected, translation to a different encoding format must be accomplished in order to judge the feature's distinctiveness.

Throughout the remainder of this report, the types of translations described above are referred to as "visualizations." The results of this study leave no doubt that some form of visualization is taking place even in the instances in which the translation is mediated by descriptive terms. However, the methods used in this study are not of the type needed to determine the type and specificity of the images that are formed, held in memory, and compared. Nor do such methods provide specific information about the role of verbal mediation in these processes. Although opinions and impressions concerning the nature of the visualization process are presented here, additional research is needed to resolve uncertainties about the nature of the visualization process.

Procedure 2.1: Survey Scene and Map for Macro Referents

There are no landforms that serve as useful macro referents in all topographic contexts. To be useful, a macro referent must be distinctive. Specifically, the landform must have a recognizable map portrayal, it must have a distinguishable real-world appearance, and its form must be unique enough so that it is not easily confused with other landforms in the vicinity. The purpose of Procedure 2.1 is to gather the information about the local terrain relief that is needed to judge whether or not a specific landform is distinctive enough to serve as a useful macro referent. The operations required to accomplish Procedure 2.1 are shown in Figure 12.

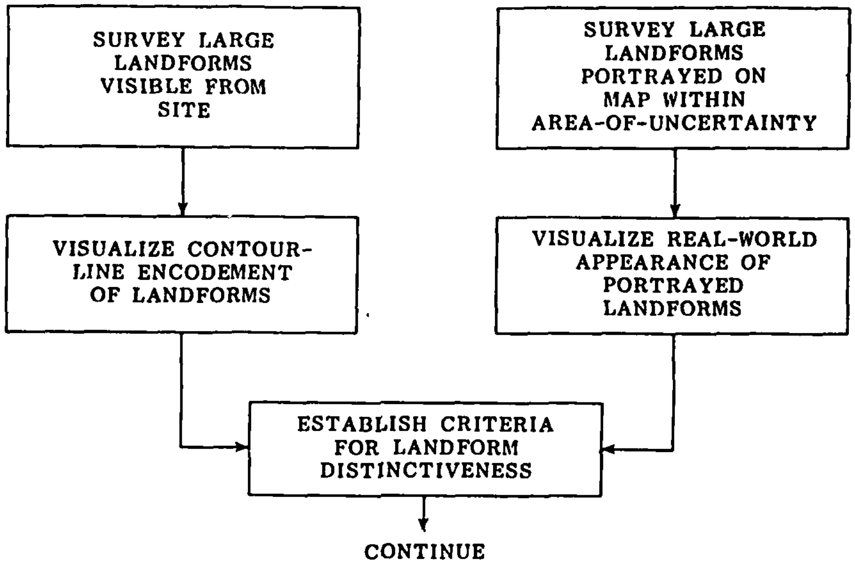


Figure 12. Operations required to survey scene and map for macro referents (P2.1).

First, both the visible scene and the area-of-uncertainty on the map must be systematically surveyed with the intent of gaining a notion of the characteristics of the large landforms present in the area, particularly the ones visible from the test site. Some of the subjects in this study referred to these operations as "getting a feel for the lay-of-the-land." Secondly, it is necessary to visualize the contour-line encodement of landforms observed in the real-world and to visualize the real-world appearance of landforms portrayed on the map. Finally, the composite information gained from searching the scene and map must be synthesized and used to establish criteria for landform distinctiveness in that topographic context.

Several observations led to the impression that few subjects performed Procedure 2.1 effectively and with a conscious awareness of this procedure's exact purpose. Although data on the subjects' initial search behavior were not recorded, the researchers recall only a few subjects--all experts--who performed a thorough 360-degree search of the visual scene and who performed a detailed study of the entire area-of-uncertainty on the map before selecting their first referent. This impression is supported by the fact that there were numerous instances in which subjects selected landforms as macro referents that were not sufficiently distinctive to serve as effective referents. Also relevant is the fact that the protocols contain few statements indicating that subjects were consciously attempting to establish criteria for judging the distinctiveness of large landforms.

Procedure 3.1: Select a Real-World Macro Referent

The objective of Procedure 3.1 is to select a large landform visible from the test site that will serve as an effective referent in reducing the size of the area-of-uncertainty. Figure 13 shows the operations that must be performed to complete Procedure 3.1 and shows the sequence in which they must be performed. The operations shown in Figure 13 assume that a set of criteria for landform distinctiveness has been established as a result of completing Procedure 2.1.

At the outset, the map user searches the scene until he observes a landform that is considered a potentially useful macro referent. A landform can serve as a useful referent only if its map portrayal is distinctive--recognizable and relatively unique. In order to judge the probable distinctiveness of the landform's map portrayal, the map user must visualize the contour-line encodement of the landform. Once this translation has been accomplished, the map user must judge the distinctiveness of the landform by evaluating the resulting "image" of the contour-line portrayal in terms of the criteria for distinctiveness defined in Procedure 2.1.

If the candidate landform is judged to be sufficiently distinctive, the map user evaluates the landform's uncertainty reduction potential. That is, the map user asks himself: "Can I use this landform as a

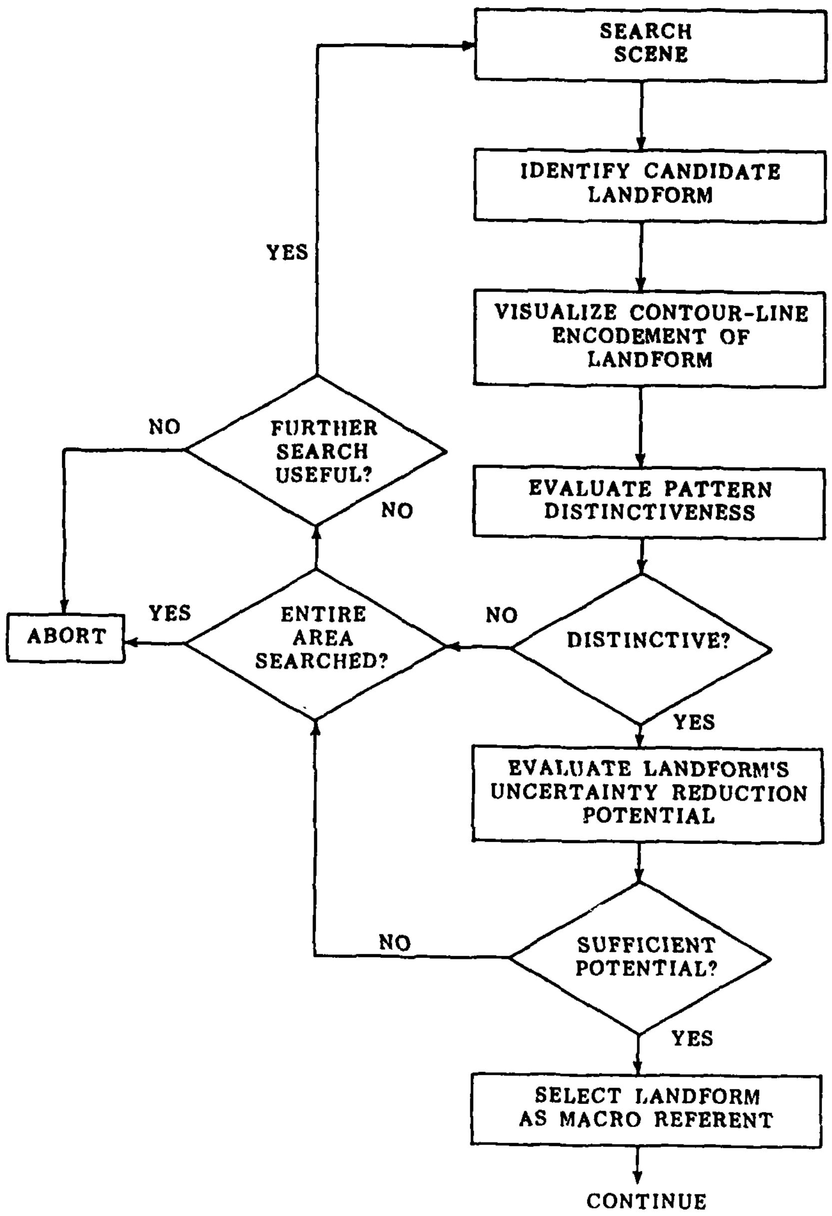


Figure 13. Procedure for selecting a real-world macro referent (P3.1).

referent to reduce the size of the area-of-uncertainty?" If the answer is affirmative, the landform is selected as a real-world macro referent and the map user proceeds to either Procedure 5.1 or Procedure 7.1. If the landform is judged insufficiently distinctive or if it is judged to lack sufficient uncertainty reduction potential, the map user either aborts the procedure or iterates through it again, depending upon whether the entire scene has been searched and whether further search is considered warranted.

When the protocols were recorded, great care was taken to identify and record on the map the features the subjects selected as real-world macro referents. The 52 features that expert subjects selected as macro referents were classified by type, and the relative frequency of each feature type was tabulated. The types of features selected and the relative frequency with which each type was selected are as follows:

- orientation of canyon or large draw (34.6%),
- ridgeline or large spur (19.2%),
- large hill or prominent peak (13.5%),
- orientation of stream bed (9.6%),
- orientation of road (9.6%),
- area with abundance of steep/shallow slopes (5.8%),
- high ground (3.8%),
- road/creek junction (1.9%), and
- buildings (1.9%).

It can be seen that a majority of the landforms selected as real-world macro referents are large, easily recognizable landforms whose directional orientation can be measured or estimated. Examples include canyons, large draws, ridgelines, and large spurs. Linear features such as streambeds and roads can prove extremely valuable in reducing the size of the area-of-uncertainty. More subjects undoubtedly would have chosen roads as macro referents if this study had been conducted in an area where roads provide reliable information. Some landforms that could have served as valuable real-world macro referents were seldom chosen. Valuable but infrequently selected landforms include high ground, low ground, and areas with an abundance of steep/shallow slopes. There were many instances in which the area-of-uncertainty could have been reduced by at least one-half if such landforms had been selected as macro referents.

The type of referents that serve as useful real-world macro referents will vary from one topographic context to another, so the types of features identified should be considered representative for only the type topography in which this study was conducted.

Procedure 5.1: Eliminate Map Areas with Dissimilar Terrain

The operations required to accomplish Procedure 5.1 are shown in Figure 14. Prior to initiating the first operation in Procedure 5.1, the map user must have selected a visible landform as a macro referent (Procedure 3.1). The objective of Procedure 5.1 is to use the real-world macro referent to reduce the size of the area-of-uncertainty on the map.

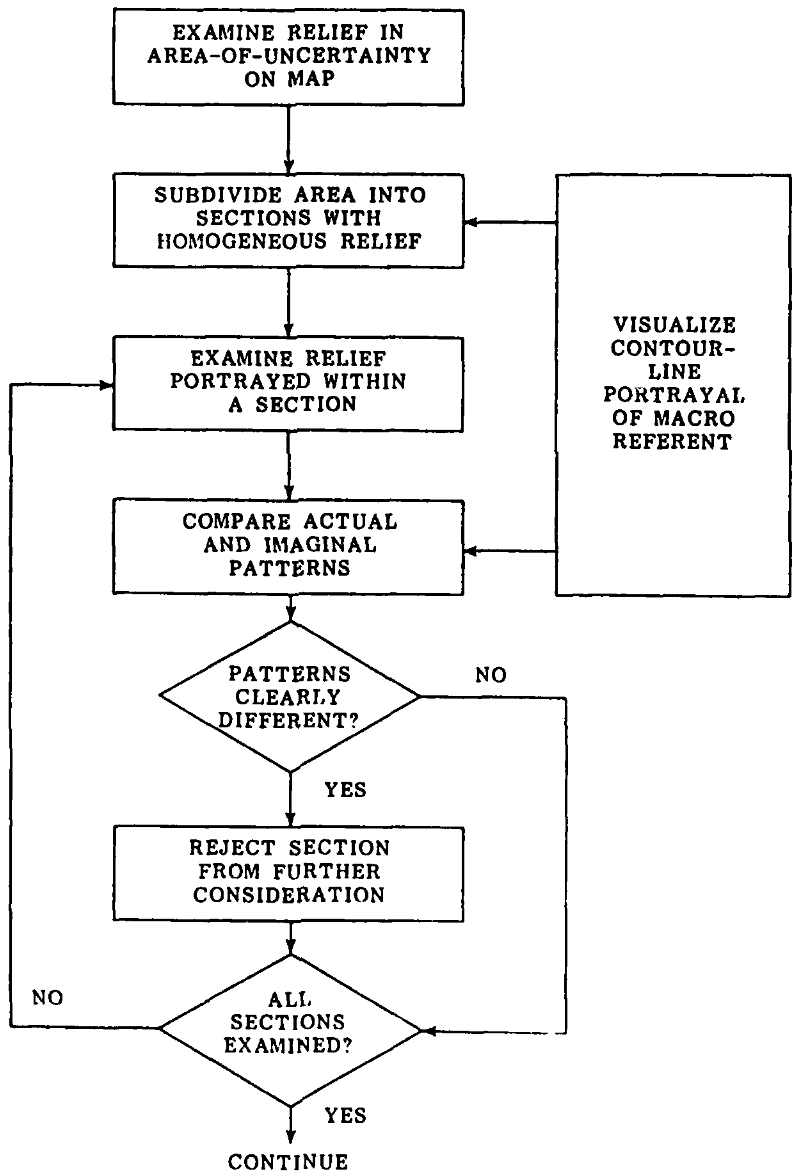


Figure 14. Procedure for eliminating map areas with dissimilar terrain relief (P5.1).

Map users commence this procedure by examining the terrain relief portrayed in the area-of-uncertainty on the map and by subdividing the area into sections within which the terrain is homogeneous with respect to criteria dictated by the macro referent. If the macro referent is a large canyon with a northeast-southwest orientation, homogeneous terrain would consist of (a) all canyons with appropriate size and orientation, and (b) all other areas. If the referent is "high ground," homogeneous terrain would consist of (a) all areas that have terrain with an elevation great enough to be considered "high ground," and (b) all other areas. As is shown in Figure 14, the map user must visualize the contour-line portrayal of the real-world referent in order to define the criteria to be used in subdividing the initial area-of-uncertainty into sections with homogeneous terrain.

Once the area-of-uncertainty has been subdivided into sections, the map user must visualize the contour-line portrayal of the macro referent, examine the terrain relief portrayed within a given section, and compare the imaginal contour-line portrayal with the contour-line pattern portrayed on the map. If the patterns are judged to be clearly different, the section is rejected from further consideration; otherwise, it is judged to be an area in which the test site may be located. This procedure is continued until all sections within the original area-of-uncertainty have been evaluated. When the first iteration of Procedure 5.1 has been completed, the map user may select another real-world macro referent and iterate through 5.1 again or may iterate through another uncertainty reduction procedure.

The operation "Compare Actual and Imaginal Patterns" typically was performed in a very conservative manner. That is, the subjects tended to reject a section on the map only if there were very great differences between the actual and the imaginal contour-line patterns. There were many instances in which even the expert subjects failed to reject areas with terrain relief that was highly dissimilar from the feature selected as a macro referent. The most reasonable explanation of this conservativism is that even the most skilled subjects lacked confidence in their ability to visualize the contour-line encodement of a large landform and to compare the resulting image with the contour-line portrayal on the map.

Procedure 3.2: Select Primary Real-World Micro Referent

The objective of Procedure 3.2 is to select a relatively small landform as a primary referent. Procedure 3.2 is a Phase Two procedure, so it is not employed until the map user has reduced the size of the area-of-uncertainty to the greatest extent possible. The operations required to accomplish Procedure 3.2 are identified in Figure 15 and are discussed below.

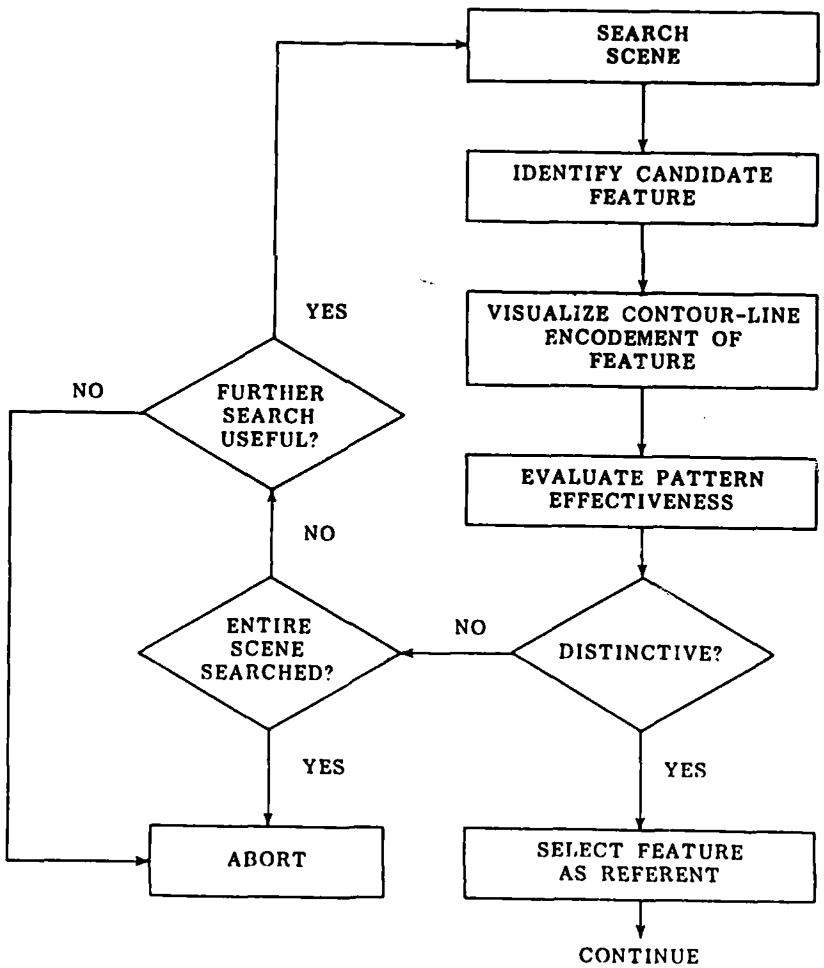
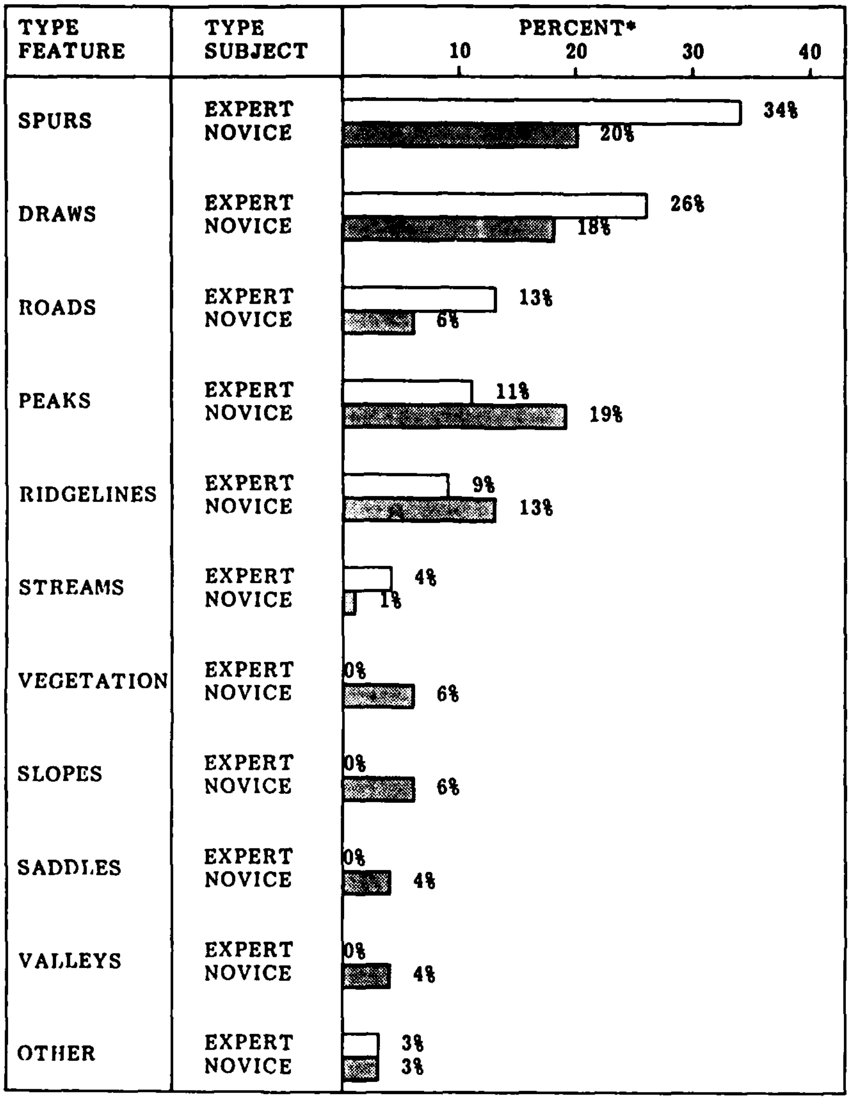


Figure 15. Procedure for selecting a primary real-world micro referent (P3.2).

The map user commences Procedure 3.2 with a visual search of the terrain relief in close proximity to the test site. (The proximity of real-world micro referents to the test site is discussed in more detail later.) When a candidate feature has been identified, the contour-line encodement of the feature must be visualized and the distinctiveness of the contour-line pattern must be evaluated. If the pattern is judged to be distinctive, the map user adopts the feature as a referent and attempts to associate it with its map portrayal (Procedure 8.2). If the pattern is judged to be non-sufficiently distinctive, the map user rejects the feature and continues to search for another candidate feature until the entire terrain has been searched, or further search is judged to be fruitless.

Much of the difference between experts and novices can be traced to differences in the type of features they select as real-world referents and differences in the proximity of the features to the test site. Figure 16 shows the types of features that were selected as real-world micro referents (primary) and shows the relative frequency with which each type of feature was selected by expert subjects and novice subjects. When interpreting Figure 16, it should be kept in mind that the type and distribution of features selected as referents are heavily dependent upon the topographic context. The type and distribution of features selected in a different topographic context almost surely would differ from those shown in Figure 16.

The test sites used in this study were deliberately located in areas so remote that there were no man-made features present that serve as reliable referents. All subjects were instructed that most of the roads (all unimproved roads) visible from the test site are seldom selected for portrayal on the map and, therefore, do not constitute reliable referents. Even so, it can be seen that roads accounted for 13% of the referents selected by experts and six percent of the referents selected by novices. The attempt to use unimproved roads as referents in this area, or any other area, is clearly counterproductive and represents a lack of proper instruction in map interpretation. The



*Experts N = 208; Novices N = 160

Figure 16. Type and relative frequency of real-world micro referents (primary) selected by expert subjects and novice subjects.

erroneous selection of unimproved roads as referents undoubtedly would have been far more frequent if subjects had not been given explicit instructions not to do so.

Since the position-fixing task was accomplished with great precision by the expert subjects, their referent-selection practices can be used as a standard against which to compare the referent-selection practices of the less successful novices. It can be seen in Figure 16 that (a) novices select spurs and draws less often than experts, and (b) novices select peaks and ridgelines more often than experts. Taken together, however, these four referents account for 80% of the real-world micro referents selected by experts and 70% of the referents selected by novices. What appears to be more important is the fact that novices selected some features as referents that were never selected by experts. Vegetation, slopes, saddles, and valleys were never selected as real-world micro referents by experts; yet, 20% of the referents selected by novices were one of these four types of features.

The selection of vegetation as a real-world micro referent is clearly counterproductive. Vegetation is seldom portrayed on the map with sufficient precision to enable a map user to associate its map portrayal with its real-world appearance. Clearings in forested areas and isolated copses occasionally can be associated with their map portrayal, but the type of scrub brush present in the vicinity of the test sites is never a reliable checkpoint feature. Apparently, all of the experts and most of the novices are aware of this fact.

In principle, the steepness of slopes can serve as a reliable referent. In practice, all of the expert subjects and most of the novice subjects lack confidence in their ability to estimate the slope of a visible landform, to estimate the slope of a landform portrayed on the map, or both. Even the few novices who selected slopes as a referent failed to quantify the magnitude of a slope more specifically than merely classifying it as "a steep slope" or "a shallow slope."

In some areas, saddles serve as useful referents. In this area, however, the saddles tended to be too large and located too far away to serve as useful micro referents. The same comment applies to valleys. That is, the valleys in the vicinity of the test sites are so large that they have no value as micro referents even though they are of great value as referents in procedures aimed at reducing the size of the area-of-uncertainty.

Figure 17 shows the cumulative distribution of distances from the test site to the various landforms that were selected as real-world micro referents by expert subjects (solid line) and novice subjects (dashed line). It can be seen that experts tend to select as referents landforms that are located in closer proximity to the test site than the landforms that novices select. The median distance to these referents is about 450 meters for experts and 565 meters for novices; the 75th centile distance is about 730 meters for experts and 1000 meters for novices. Some novices selected features as real-world micro referents that are located more than 3000 meters from the test site. Judging from these findings, an important part of skill in the position-fixing task is the knowledge that landforms located in close proximity to the test site can

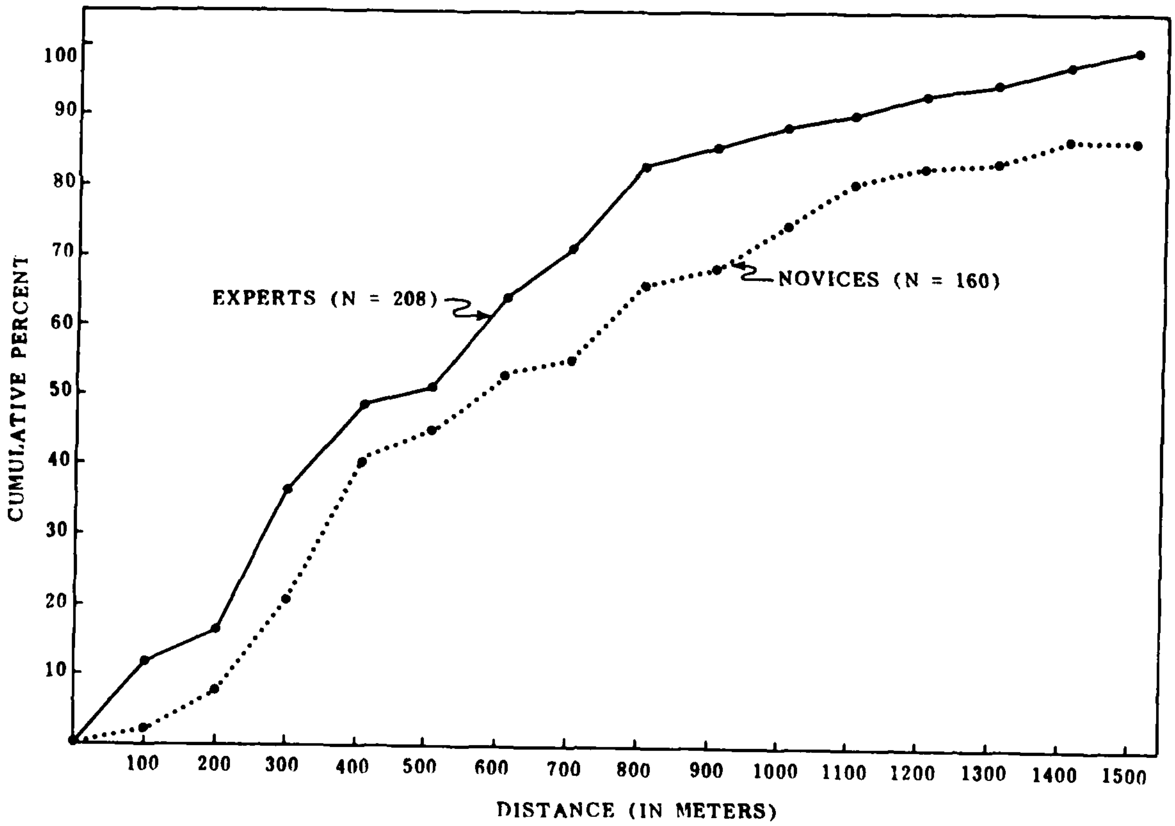


Figure 17. Cumulative distribution of the distance between the test site and landform selected on real-world micro referents (primary).

be more easily associated with their map portrayal, and that the accuracy of resection techniques is inversely related to the distance to the features used as referents.

Procedure 8.2: Associate Primary Real-World Micro Referent with Map Portrayal

Having selected a visible landform as a micro referent, a map user must accomplish the operations shown in Figure 18 in order to associate that feature with its map portrayal. The map user commences Procedure 8.2 by searching the area-of-uncertainty on the map for a contour-line pattern that matches the map user's conceptualization of the contour-line depiction of the visible referent. When a candidate pattern is identified, the actual pattern on the map must be compared with the map user's image of the contour-line depiction of the visible feature that has been adopted as a referent. If the map user concludes that the patterns match, the map user's internal "counter" (the counter that keeps track of the number of correct matches) is increased by a value of one and the map user continues to another procedure. If the map user is confident that the patterns do not match, he continues to search the map for candidate patterns or, if the entire area-of-uncertainty has been searched, aborts the procedure.

There were many instances in which the subjects were uncertain about whether the actual pattern matched the imaginal pattern. In the face of such uncertainty, many subjects simply aborted Procedure 8.2 and searched for another referent. However, there were a few subjects who dealt with uncertainty by becoming more analytical; they attempted to estimate or measure one or more parameters of the landform and to compare not only the generic shape of the actual and imaginal pattern but the value of specific parameters of the landform as well.

This important point can best be illustrated with an example. Suppose a map user has selected a "small draw" as a real-world micro referent. The map user must visualize the contour-line portrayal of the small draw and then must search the area-of-uncertainty on the map for

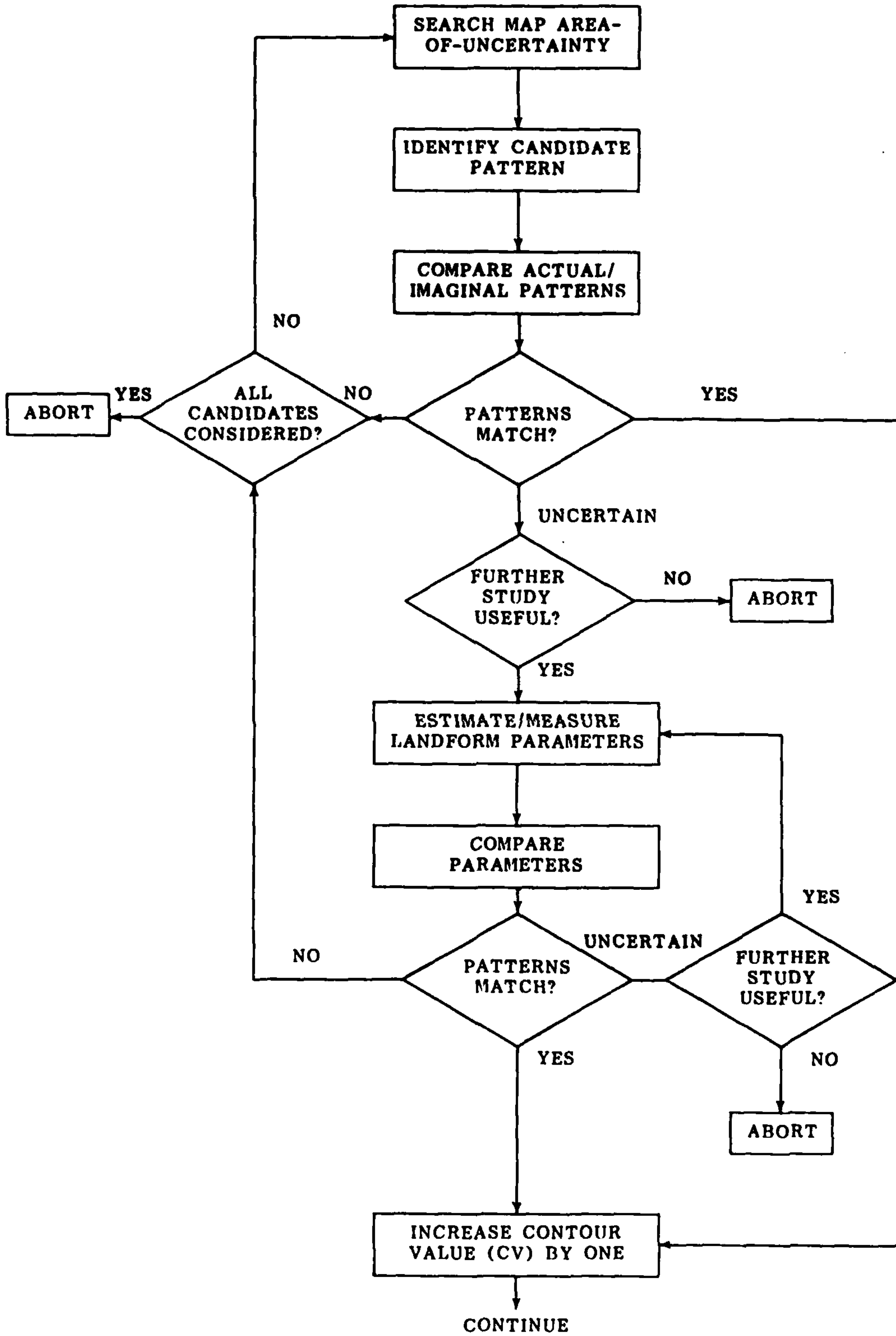


Figure 18. Procedure for associating primary real-world micro referents with map portrayal (P8.2).

a contour-line pattern similar to the one being held in his memory. It is highly probable that the map user will find, within the area-of-uncertainty on the map, many contour-line depictions that can be classified as small draws. When faced with this situation, many subjects concluded that the small draw was not a useful referent and proceeded to look for a better referent. A few subjects examined the real-world draw more closely and attempted to estimate one or more of its specific dimensions, such as: the distance between the mouth and the head of the draw, the absolute steepness of its sides, the relative steepness of its sides, and the changes in elevation between the head and the mouth of the draw. Armed with these parameters, the map user reexamines map depictions of the small draws and evaluates them in terms of the parameters of interest. For instance, if the map user estimated that the head of the real-world draw is 300 meters from its mouth, he would measure this parameter on the map and make a decision about whether the difference between the estimated and measured value is small enough to be accounted for by errors of estimate/ measurement.

Table 4 shows the number and the outcome[7] of attempts by subjects to associate a referent with its real-world or map counterpart. It can be seen in Table 4 that (a) experts made significantly more correct matches and significantly fewer erroneous matches than novices, and (b) expert and novice subjects do not differ significantly in the relative percent of recognized mismatches and uncertain matches.

These findings leave no doubt that experts are more proficient than novices at associating a real-world referent with its map portrayal. However, even the expert subjects cannot be considered highly

[7] There were some instances in which subjects selected and then rejected a referent without verbalizing their thoughts clearly. In such cases, there was insufficient information on the transcript of the protocol to determine the outcome of an attempt to associate a referent with its real-world or map counterpart. These cases were not included when tabulating the data shown in Table 4. For this reason, the number of referents selected is slightly higher than the number of associations attempted.

TABLE 4

NUMBER AND OUTCOME OF ATTEMPTS TO ASSOCIATE A REAL-WORLD REFERENT WITH ITS COUNTERPART ON THE MAP

SUBJECT SAMPLE	ASSOCIATIONS ATTEMPTED	CORRECT MATCHES	RECOGNIZED MISMATCHES	UNCERTAIN MATCHES	ERRONEOUS MATCHES
NOVICE	159	19%	23%	24%	34%
EXPERT	181	46%*	17%	27%	10%*

*Indicates percentage values differ at the .05 level of significance.

proficient at this procedure. In 10% of the attempted associations, the experts erroneously assumed they had located the map portrayal of the real-world referent. In another 27% of the cases, the expert subjects were unable to decide whether or not a particular feature portrayed on the map matched the real-world referent. This same trend is apparent throughout this study. That is, regardless of the type of referent that is selected, experts make more correct and fewer erroneous matches than novices, and experts were frequently unable to determine whether they had located the map or real-world counterpart of the referent.

Procedure 4.2: Select Primary Micro Referent on Map

The objective of Procedure 4.2 is to select a feature portrayed on the map for use as a primary micro referent. Figure 19 shows the operations that must be performed to accomplish Procedure 4.2 successfully. Initially, the map user must:

- search the area-of-uncertainty on the map,
- identify a candidate feature,
- visualize the real-world appearance of the contour-line portrayal of the candidate feature, and
- evaluate the probable distinctiveness of the feature.

If the map user judges the feature to be not sufficiently distinctive (recognizable and relatively unique), he rejects the feature as a referent and searches the area-of-uncertainty on the map for a better primary micro referent. Conversely, if the map user concludes that the feature is sufficiently distinctive, he must then evaluate the probable visibility of the feature. The feature is selected as a referent only if

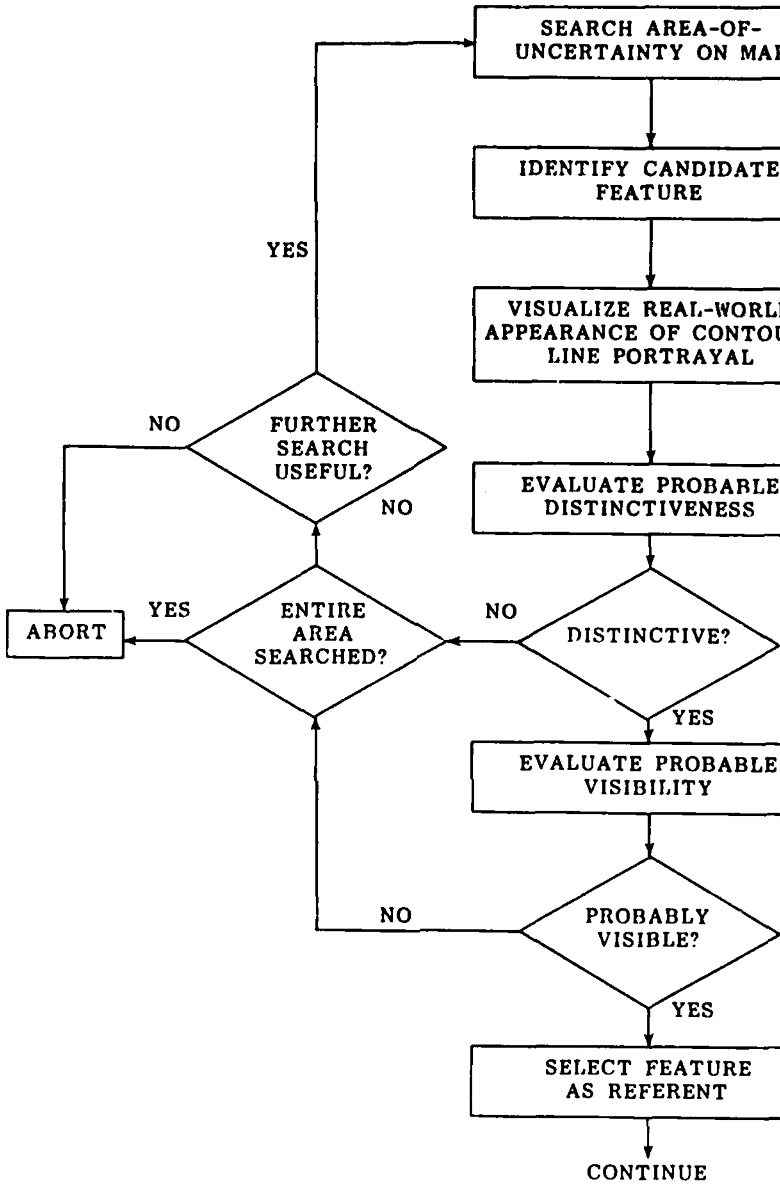


Figure 19. Procedure for selecting a primary micro referent on map (P4.2).

it is judged visible; otherwise, the map user rejects the feature and searches the area-of-uncertainty on the map for another candidate feature.

In the earlier discussion of strategies, it was stated that strategies that require the selection of a map referent are not effective if used before the map user has a reasonably accurate notion of his location on the map. There are at least three reasons that such strategies tend to be ineffective. The first and most important reason is that an enormous amount of time can be spent selecting and attempting to associate map referents whose real-world counterpart is not visible from the map user's location. Even if the area-of-uncertainty is relatively small, there may be hundreds of features portrayed on the map within the area-of-uncertainty that cannot be seen from the map user's location. A substantial amount of time can be spent in determining that a map feature is not visible; and even when a map user correctly determines that a feature is not visible, he usually has little more information about his location than when he started.

A second reason why the use of map referents (micro) tends to be ineffective is that it is often extremely difficult and time consuming to determine, from map study alone, whether or not a feature portrayed at one point on the map is visible from another point. For instance, examine Figure 20 and attempt to determine whether the peaks indicated by the arrows are visible from the point marked with an "X." It takes a substantial amount of skill to determine from map study alone that only peak "D" can be seen from the point marked "X." The slope along the north side of Pueblitos Canyon is so concave that the sloping terrain completely masks peaks "A," "B," and "C" from view.

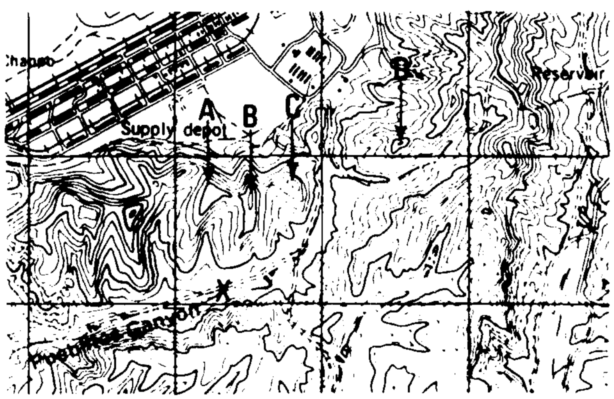


Figure 20. Illustration of the difficulty of judging the visibility of features portrayed on the map.

A third reason for the ineffectiveness of strategies utilizing map referents stems from the fact that there is a generally low correlation between the visual prominence of features portrayed on the map and the visual prominence of their real-world counterpart. Even expert map users tend to select map referents because of the visual prominence of the map portrayal rather than the visual prominence of the real-world counterpart of the feature. For example, the blue circle depicting a small pond is among the most visually prominent features portrayed on the map. Yet, because of the lack of vertical development, small ponds in the real world often cannot be seen from a distance greater than 100 meters. The same can be said for numerous natural and man-made features that lack vertical development.

Figure 21 shows the types of features selected as map micro referents (primary) and shows the relative frequency with which each type of feature was selected by expert subjects and novice subjects. The tendency to select map referents because of the visual prominence of the map portrayal is evident for both experts and novices, but the tendency is much stronger for novices. Spurs, draws, ridgelines, peaks, and saddles are all reasonably good choices of map referents in the type of topography in which the test sites were located. The other features selected--roads, lakes, streams, vegetation, slopes, valleys, and buildings--represent poor choices of map referents, but all are features whose map portrayal is visually prominent. The portrayal of roads and lakes is particularly compelling. Together, roads and lakes accounted for 28% of the map micro referents selected by the expert subjects, despite the fact that (a) all subjects were told that most roads in the vicinity of the test sites are not portrayed on the map, and (b) even a cursory examination of the topography surrounding the test sites is sufficient to inform the subjects that no large lakes such as the ones selected as map referents are visible from the test sites.

It seems reasonable to assume that the distribution of real-world micro referents selected by expert subjects represents a near-optimal selection of referents for the type topography in which the test sites

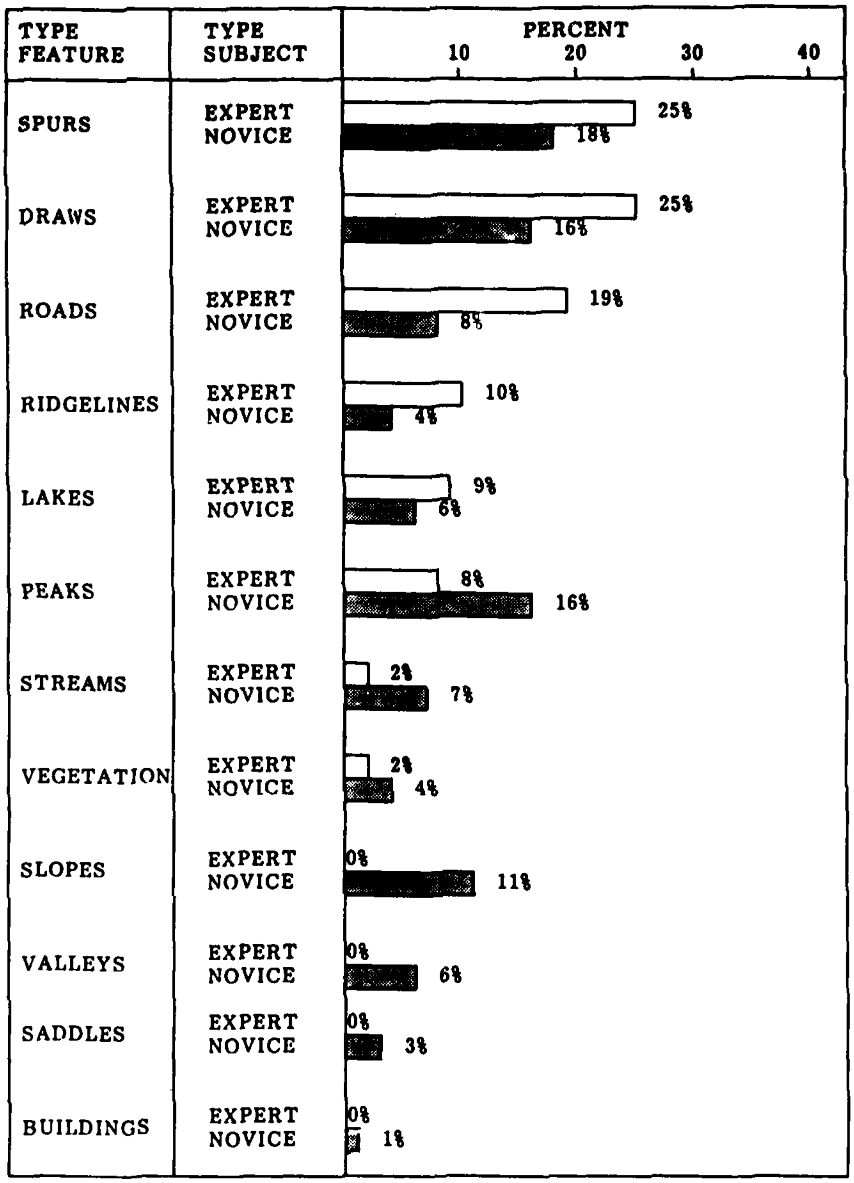


Figure 21. Type and relative frequency of map micro referents (primary) selected by expert and novice subjects.

were located. The difference in distribution of map referents and real-world referents (see Figure 16) is probably the result of map users' tendency to select features because of the visual prominence of the map portrayal.

The curves in Figure 22 show the cumulative distribution of the distance between the test site and the features selected as map micro referents (primary). It can be seen that the map referents selected by the novice subjects are, on the average, considerably farther from the test site than the map referents selected by the expert subjects. For instance, it can be seen that the median distance for expert subjects (about 800 meters) is only slightly over one-half as great as the median distance for novice subjects (about 1500 meters).

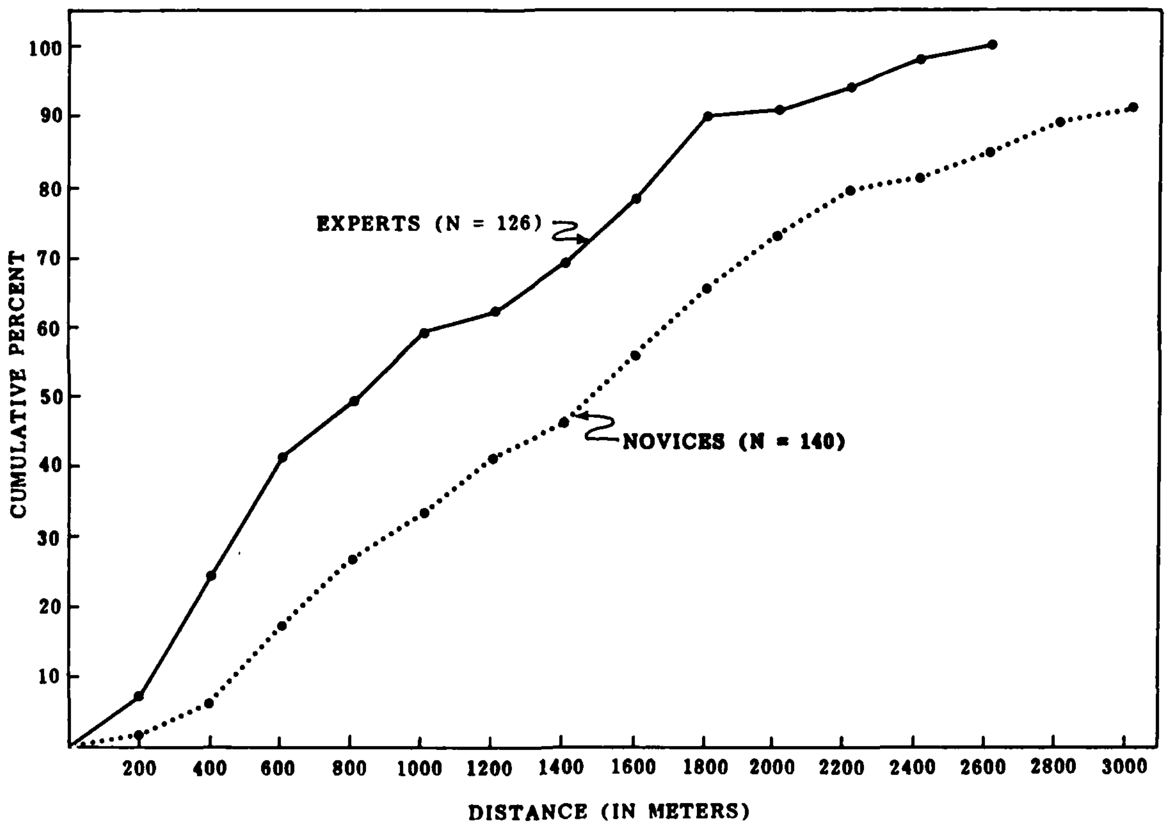


Figure 22. Cumulative distribution of the distance between the test site and landform selected as map micro referents (primary).

This difference between experts and novices is due mainly to a tendency by experts to avoid using map referents until they have a reasonably accurate notion of the location of the test site. However, both expert and novice subjects select map referents that are much farther from the test site than the features they select as real-world referents. An examination of Figure 17 will show that the median distance from the test site to real-world micro referents is about 450 meters for experts and about 565 meters for novices. So, considering the experts and novices together, the median distance to map referents is more than twice as great as the median distance to real-world referents.

Only about 10% of the real-world referents selected by experts are located more than 1000 meters from the test site, and yet 42% of the map referents selected by experts and 67% of the map referents selected by novices are located farther than 1000 meters from the test site. So, for the most part, the time spent attending to map features located farther than about 1000 meters from the test site is wasted. This is further evidence that strategies involving the selection of map referents are not nearly as effective as strategies that involve the selection of a real-world referent.

Procedure 9.2: Associate Primary Map Referent (Micro) with Real-World Counterpart

Figure 23 shows the operations required to associate a primary map referent (micro) with its real-world counterpart. After having selected a map feature as a primary referent, the map user performs essentially the same set of operations that are required to associate a primary real-world referent with its map portrayal (see Figure 18 and the discussion of Procedure 8.2 in the text). Since these operations were described in detail earlier, there is no need to describe them here. However, it is important to report that, as was true for Procedure 8.2, subjects dealt almost exclusively with generic patterns in their attempts to match a map feature with a real-world feature. That is, when faced with uncertainty about whether the generic patterns match, few subjects attempted to resolve this uncertainty by attempting to estimate or measure the value of specific parameters of the landforms and to use this quantitative information in judging whether the patterns match.

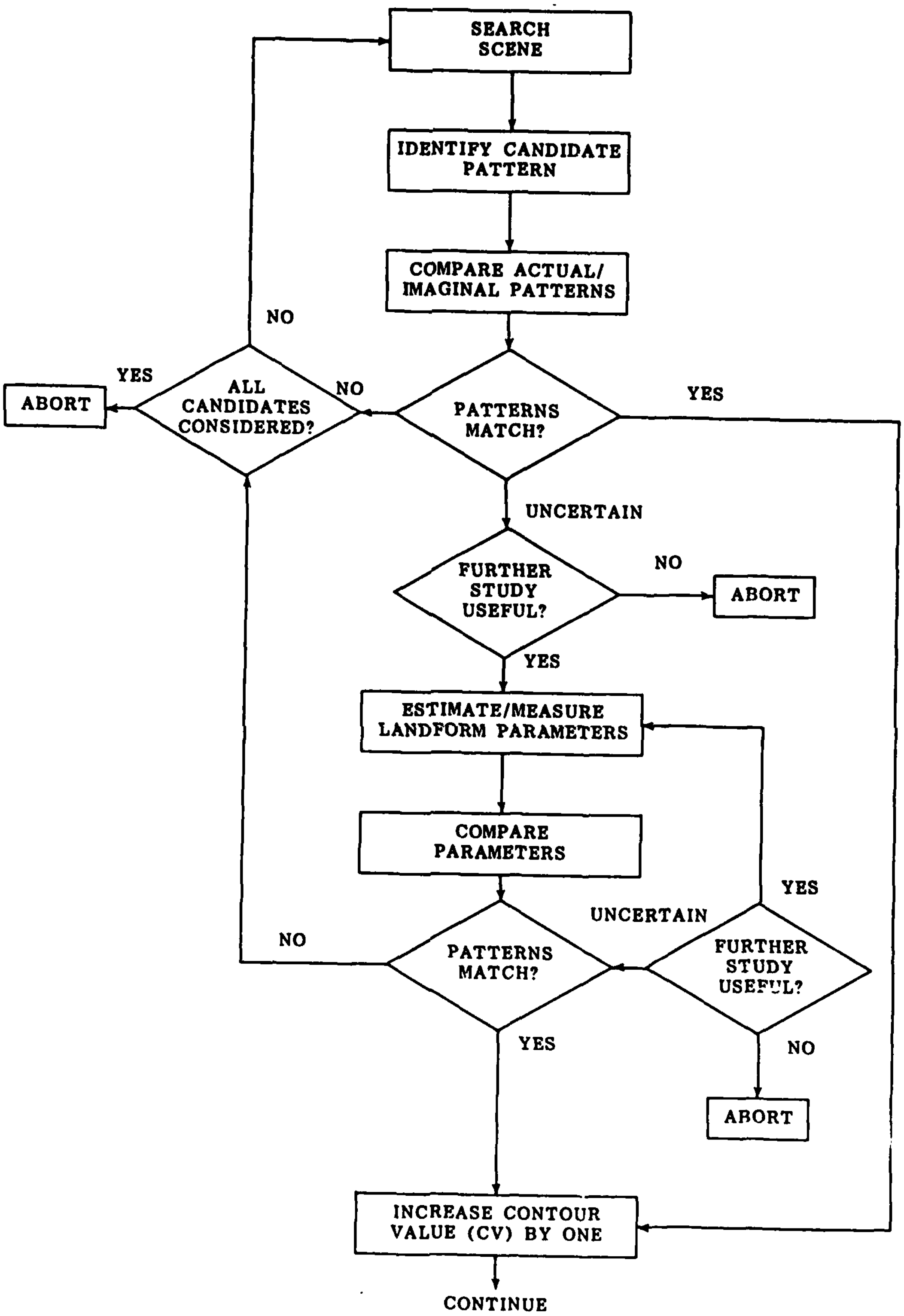


Figure 23. Procedure for associating primary map referent (micro) with real-world feature (P9.2). (This procedure assumes that the map referent is visible from operator's point of regard.)

Table 5 shows the outcome of attempts to associate a map referent with its real-world counterpart. It can be seen in Table 5 that a map referent was selected and an association was attempted about twice as often by novices than by experts. This finding substantiates an earlier observation that experts are more aware than novices of the inherent inefficiency of strategies that are based upon the use of map referents. Experts and novices are similar in the frequency with which they correctly recognize a mismatch (about one-third of the cases) and the frequency with which they discard a referent because they cannot resolve their uncertainty about whether or not the map referent matches a particular real-world feature (slightly less than one-quarter of the cases).

TABLE 5

NUMBER AND OUTCOMES OF ATTEMPTS TO ASSOCIATE A MAP REFERENT WITH ITS REAL-WORLD COUNTERPART

SUBJECT SAMPLE	ASSOCIATIONS ATTEMPTED	CORRECT MATCHES	RECOGNIZED MISMATCHES	UNCERTAIN MATCHES	ERRONEOUS MATCHES
NOVICE	103	8%	30%	25%	37%
EXPERT	53	41%*	32%	21%	6%*

*Indicates that percentage values differ at the .01 level of significance.

However, experts and novices differ greatly in the relative number of correct matches and erroneous matches. Table 5 shows that only eight percent of the associations attempted by novices resulted in a correct match. In contrast, 41% of the associations attempted by experts resulted in a correct match. The difference between experts and novices is even greater if one considers only the cases in which the subjects assumed that they had correctly matched a map referent to a real-world feature. Of the cases in which novices concluded a correct match, the conclusion was a correct one only 17% of the time. In contrast, experts were correct in 88% of the cases in which they concluded they had correctly matched a map referent with its real-world counterpart.

Procedure 3.3: Select Secondary Real-World Referent

The operations required to select a secondary real-world referent (Procedure 3.3) are shown in Figure 24 and are discussed below. Before proceeding, however, the distinguishing characteristics of secondary referents, described in detail in an earlier section of this report, should be reviewed. They are:

- A secondary referent can be selected only after the map user has selected a primary referent and believes that he has correctly associated it with its counterpart in the real-world or on the map.
- A secondary referent is selected because of its proximity to a primary referent, rather than because of the uniqueness of its physical characteristics.
- The distance and bearing from a primary referent are the main factors that map users consider in attempting to associate a secondary referent with its counterpart in the real-world or on the map.

The map user begins Procedure 3.3 by searching the scene in close proximity to a primary real-world referent that the map user believes he has successfully associated with its counterpart on the map. Once a candidate feature has been selected, the map user must (a) visualize the contour-line encodement of the feature, and (b) judge whether the pattern is sufficiently distinctive. The criteria used in judging the distinctiveness of a feature being considered for use as a secondary referent are much more lax than the criteria used to judge the distinctiveness of a feature being considered for use as a primary referent. A feature being considered as a primary referent is considered distinctive only if the map user judges that its size and shape are sufficiently unique to enable him to distinguish the feature from other similar features present in the area-of-uncertainty. The feature being considered for use as a secondary referent is considered sufficiently distinctive if the map user judges that he can merely identify its generic shape and can judge its bearing and distance from the feature selected as a primary referent. If the pattern is judged distinctive enough, the feature is selected as a secondary referent. If not, the map user continues to search the scene for a suitable referent until the

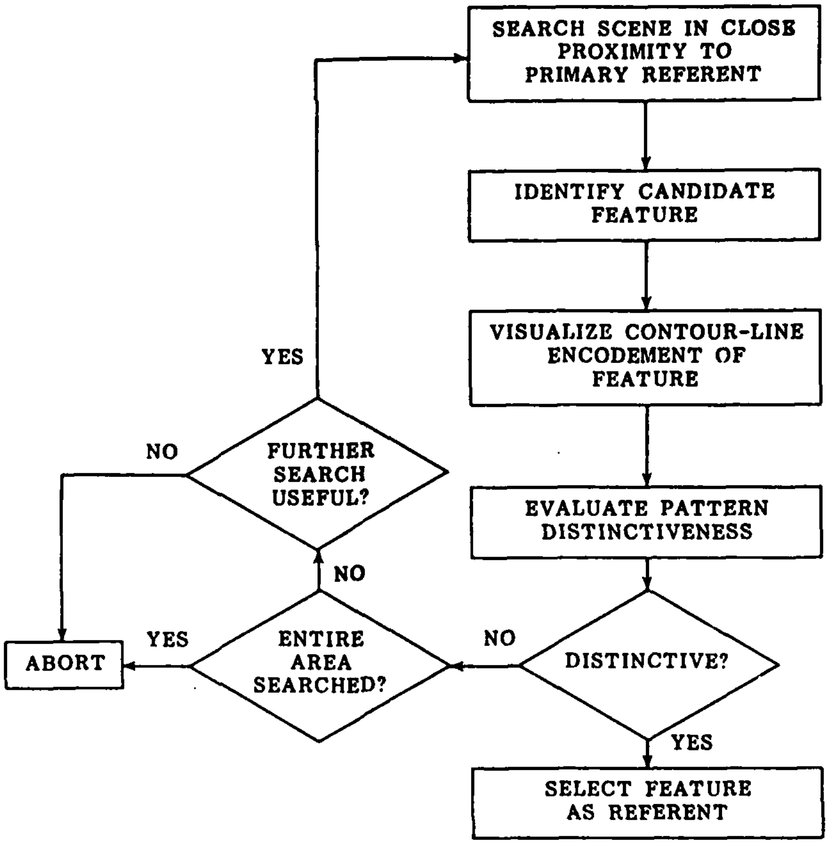


Figure 24. Procedure for selecting secondary real-world referent (P3.3).

entire scene has been searched or until further search is considered fruitless.

Strategies that involve the selection of a secondary real-world referent were used far more frequently by experts than by novices. Each expert subject selected an average of 3.2 secondary real-world referents per test site; novice subjects, by contrast, selected an average of only one secondary real-world referent per site. Every one of the expert subjects employed strategies that require the selection of secondary real-world referents, and each expert subject selected secondary real-world referents with about equal frequency. Two of the novice subjects selected no secondary real-world referents whatsoever; the remaining novice subjects selected secondary real-world referents with about equal frequency.

Procedure 4.3--Select Secondary Map Referent--has not been selected for detailed discussion because the operations required to perform Procedure 4.3 are so similar to those described above. (The operations required to perform Procedure 4.3 are identified in Appendix A, Figure A15.) However, it is worth noting that secondary map referents were selected less frequently than secondary real-world referents by both novice and expert subjects. Expert subjects selected an average of 1.5 secondary map referents per test site; novice subjects selected an average of .9 secondary map referents per test site.

Procedure 8.3: Associate Secondary Real-World Referent with Map Portrayal

The operations employed to associate a secondary real-world referent to its map portrayal are shown in Figure 25. It can be seen that the first operation performed after selecting a secondary real-world referent is to estimate the bearing and range of the secondary referent (real-world) to the primary referent (real-world). Then, the map user must:

- identify the point on the map that is located at a corresponding bearing and range from the primary referent,
- examine the contour-line portrayal at that point on the map and visualize the real-world appearance of that portrayal, and
- compare the actual form of the secondary referent with the imaginal form created by visualizing the actual appearance of the landform depicted with the contour lines.

If the map user judges that the patterns match, he increases the value of his internal counter by one and continues to another procedure. If the map user is uncertain about the match, he aborts Procedure 8.3 and adopts another procedure. Finally, if the map user is confident that the patterns do not match, he rejects the conclusion made earlier that he has, in fact, identified the map portrayal of the primary real-world referent that formed the basis for selecting the secondary referent.

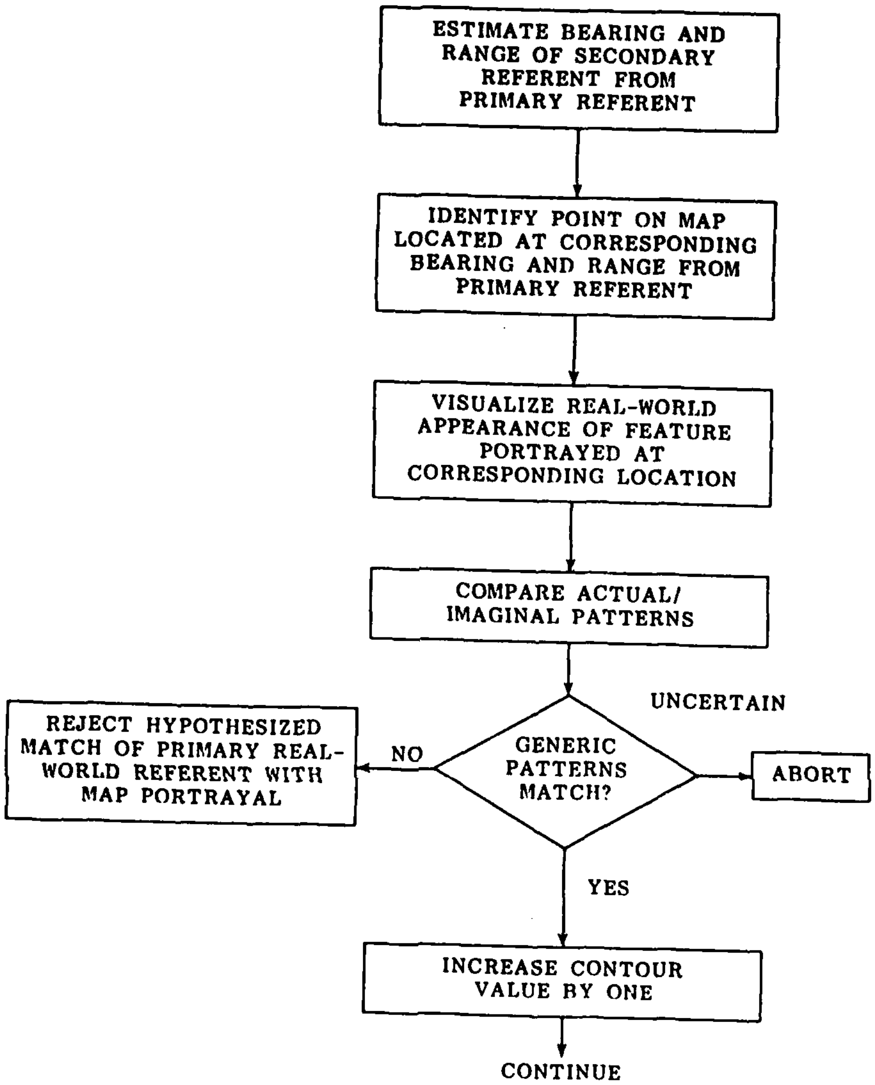


Figure 25. Procedure for associating secondary real-world referent with map portrayal (P8.3).

Examination of the types of errors made in attempting to associate a secondary real-world referent with its map portrayal indicate that subjects place far more weight on the bearing and range from the primary referent than on the precise size and shape of the secondary referent. For example, there were numerous instances in which subjects erroneously associated a secondary real-world referent with a feature that had the correct generic shape but a dramatically different size. For instance, subjects often erroneously associated a real-world draw with the map portrayal of a draw that was much larger or much smaller than the actual draw selected as a secondary referent. These types of errors probably reflect subjects' inattention to detail more than their inability to observe the differences between the real-world landform and a contour-line portrayal. However, no definitive data are available to support this claim.

Table 6 shows the number and outcomes of attempts to (a) associate secondary real-world referents with their counterpart on the map, and (b) associate secondary map referents with their real-world counterpart. Considering secondary real-world referents first, it can be seen that experts attempted nearly three times as many associations as novices (67 vs. 23) and that experts' association attempts are far more often successful than novices' attempts. The right-hand column in Table 6 shows that 52% of novices' association attempts and seven percent of experts' association attempts resulted in an erroneous match. If recognized mismatches and uncertain matches are eliminated from consideration, it can be shown that novices were in error in 75% of the cases in which they concluded they had located the map portrayal of a secondary real-world referent; the corresponding value for experts is only eight percent.

TABLE 6

NUMBER AND OUTCOMES OF ATTEMPTS TO ASSOCIATE SECONDARY REFERENTS WITH THEIR COUNTERPART ON THE MAP OR IN THE REAL WORLD

TYPE REFERENT	SUBJECT SAMPLE	ASSOCIATIONS ATTEMPTED	CORRECT MATCHES	RECOGNIZED MISMATCHES	UNCERTAIN MATCHES	ERRONEOUS MATCHES
SECONDARY REAL WORLD	NOVICE	23	17%	22%	9%	52%
SECONDARY MAP	EXPERT	67	87%*	3%	3%	7%*

The data on subjects' attempts to associate a secondary map referent with its real-world counterpart shows two important trends. First, expert subjects and, to a lesser extent, novice subjects selected fewer secondary map referents than secondary real-world referents. Expert subjects selected less than one-half as many secondary map referents as secondary real-world referents. Second, attempts to associate a secondary map referent with its real-world counterpart was accomplished successfully less often than attempts to associate a secondary real-world referent with its map portrayal. This trend is more prevalent for expert than for novice subjects. Although novices made slightly fewer errors in secondary map associations than secondary real-world associations, a much larger percentage of novices' secondary map-association attempts resulted in an uncertain match (32% vs. 9%).

DISCUSSION

The results of this research provide strong support for the supposition that cognitive strategy is an important element of position-fixing skill. The results also provide a substantial amount of information about the types of procedures and operations that map users must be capable of performing in order to implement the two-phase strategy that consistently was found to lead to successful performance of the position-fixing task. It seems certain that the research results provide sufficient information to develop a training program that would yield an immediate and substantial increase in the position-fixing skill of military map users who have completed a traditional course of instruction in map interpretation. Such a training program should focus on three broad objectives.

First, the trainee should be provided instruction on the fundamental concepts underlying the two-phase, problem-solving approach to accomplishing the position-fixing task. Specifically, the instruction should ensure that the trainee understands the concept of uncertainty reduction and understands the reasons why he must strive to reduce the size of the area-of-uncertainty to the greatest extent possible before any attempt is made to pinpoint his location. The trainee also must be taught the concepts underlying the selection and use of the various types of referents (map/real-world, micro/macro, and primary/secondary).

The second broad objective is to teach the trainee how to search for and select referents for use during both the uncertainty reduction phase and the position-location phase of the task. The trainee must be taught the inherent advantages of selecting real-world referents and must be taught how to search for and identify real-world referents that are the most distinctive ones available. Special emphasis should be placed on instruction aimed at teaching the trainees to make maximal use of secondary referents during the position-location phase of the task.

The third broad objective is to provide training that will enhance the trainee's ability to associate a referent with its real-world counterpart or its map portrayal. An important part of this training is teaching trainees to recognize their individual capabilities and limitations in performing this difficult procedure. Given the limited ability to associate real-world and map features that was exhibited by the expert subjects who participated in this study, the least risky training approach would teach trainees to deal with the generic shapes of landforms and to offset the obviously high error potential of matching generic shapes by iterating through the matching procedure numerous times--each time with a different microrelief referent.

Although the information from the present research is considered adequate for developing a training program that would enhance the skill of novice map users, it is believed that further research on selected topics would yield information that would make possible the development of a training program that would enhance the skills of even highly experienced map users. This claim stems from the observation of numerous instances in which even the most successful of the expert subjects performed certain operations in a far from optimal fashion. The following paragraphs describe what are considered to be the most important skill deficiencies of the expert subjects and describes in a very general way the type of research that must be conducted in order to identify the type of training that would be needed to eliminate these skill deficiencies and to assess the value of such training.

The successful implementation of the position-location phase (Phase Two) of the position-fixing strategy is heavily dependent upon the selection of referents that are truly distinctive. Yet, numerous instances were observed in which expert subjects surveyed the scene and map in a haphazard manner and selected landforms as referents that clearly were not the most distinctive ones available. This was particularly true for map referents; even expert subjects often selected features whose map portrayal is distinctive but whose real-world appearance is among the least distinctive features available. This finding suggests a need for research that would (a) identify the optimum methods for surveying the visual scene and the map, and (b) reveal optimal methods for identifying the most distinctive landforms present. Since the criteria for distinctiveness is certain to vary from one geographical area to another, the research must investigate landform distinctiveness in the full range of topography in which map users may be required to operate.

None of the expert subjects exhibited a high degree of proficiency in judging whether or not a particular contour-line pattern is, in fact, the map portrayal of a visible landform. Novices' proficiency at this task, of course, was far less than that of the experts. Although experts did not make an exorbitant number of errors in matching real-world features with their map portrayal (about 10% errors), in nearly one-third of their attempts they were unable to decide whether or not the contour-line pattern was the portrayal of the real-world feature in question. A study of the erroneous matches and uncertain matches that resulted from experts' attempts to associate a map feature and a real-world feature suggests that the operation referred to heretofore as "visualization" is the weak link in the association procedures (Procedure 8.2, Procedure 9.2, Procedure 8.3, and Procedure 9.3). Apparently, a great deal of information is lost when map users attempt either to translate a visible landform into a contour-line format or to translate a contour-line portrayal into a three-dimensional form.

A study of the manner in which the association procedures were performed suggests that what is stored in most subjects' memory is a generic form, without specific dimension or other detail. Apparently, this image is similar to the mental image one has of a generic house--an image that may have no specific size or color and that may lack other specific detail, such as number and location of windows and doors. Such generic images are adequate for performing many cognitive tasks, but a more specific image almost surely would be more suitable for use in performing the association procedures.

Additional research is needed to determine whether map users can be trained to generate more veridical images of landforms and, if so, to determine the impact of such training on map users' ability to perform a variety of map-interpretation tasks, including the position-fixing task. There is a need to investigate the benefits of at least two types of training. Both types of training would be designed to teach map users to (a) generate a more veridical image of the real-world appearance of a landform portrayed with contour lines, and (b) generate a more veridical image of the appearance of the contour-line portrayal of a visible landform. One type of training would be designed to teach map users to generate veridical images without the benefit of any type of aid other than the map. The second type of training would be designed to teach map users to generate more veridical images through the use of aids for measuring (or more accurately estimating) parameters of both visible landforms and the map portrayal of landforms. The training must teach users to assess all parameters of landforms--slope magnitude, elevation, length/width, range, and directional orientation. A number of potentially useful aids are now available and, undoubtedly, other aids could easily be developed.

One of the most interesting findings of this research is that subjects selected as referents an extremely limited set of simple landforms. The entire set includes spurs, ridgelines, draws, valleys, peaks, hills, and saddles. (Some subjects used different terms to refer to these basic landforms, such as "finger" rather than "spur" and "hollow" rather than "draw.") The protocols revealed no instance in which a subject selected as a referent a more complex landform pattern, such as the pattern formed by a set of parallel spurs and draws or the pattern formed by a set of bifurcating draws. The failure to use complex patterns as referents is surprising in light of the fact that a complex pattern is certain to be much more unique in appearance than any one of the elements from which it is formed.

It is possible that this finding is merely an artifact stemming from the methods used in this study. Military instructional programs on map interpretation teach military personnel only a limited lexicon for describing landforms. A reasonably comprehensive review of existing training material indicates that the lexicon taught in military programs is precisely the same as the set of landforms named above. It is therefore possible that subjects selected more complex landforms as referents but simply did not have the vocabulary to describe the forms they were using. What appears to be a more plausible explanation is that the limited lexicon for landforms had a major influence on the subjects' perception of landforms. That is, when the subjects viewed the surrounding terrain relief, they perceived as unitary objects only the small, simple landforms whose names they had been taught. If the latter explanation is valid, it seems probable that great gains in map-interpretation skill could be achieved by developing a more extensive lexicon for landforms and teaching subjects to perceive and use as referents more complex landform shapes.

SUMMARY

Terrain relief is portrayed on large-scale topographic maps with contour lines--lines that take any shape necessary to maintain a constant elevation above some datum plane, usually mean sea level. Although military map users must be capable of interpreting all classes of features portrayed on topographic maps, the interpretation of the contour-line portrayal of terrain relief (traditionally referred to as contour interpretation) is clearly the most difficult and most important part of the map interpretation task. The objectives of this research are to (a) gain a more thorough understanding of the fundamental cognitive processes underlying one type of contour-interpretation task, and (b) apply this knowledge in defining improved strategies for teaching this important skill.

The contour-interpretation task investigated--referred to as "position fixing"--required subjects to locate their position on the map after being transported blindfolded to test sites where terrain relief is the only topographic feature available for referencing. A group of six Marine Corps infantrymen, selected because of their acknowledged expertise in map interpretation, exhibited a uniformly high level of skill and a uniform problem-solving strategy. The strategy employed by the experts involved the use of large landforms (macrorelief) to reduce the size of the area-of-uncertainty. Then, small landforms (microrelief) were used to pinpoint on the map their exact location.

A group of six Marine Corps infantrymen with conventional training, but limited experience, performed poorly and employed a problem-solving strategy altogether different from the experts' strategy. The non-experts focused only on microrelief, attempting from the outset to search the large area-of-uncertainty for the map portrayal of small terrain features, such as draws and spurs, that were visible from the test site.

Neither the experts nor the non-experts exhibited a high level of skill in visualizing the contour-line portrayal of visible terrain or, conversely, visualizing the real-world counterpart of a contour-line

portrayal. The problem-solving strategy employed by experts indicated that they were aware of this limitation; a recognition of this skill limitation was less apparent in the problem-solving strategy employed by non-experts.

A major conclusion drawn from this research is that training on the cognitive strategy employed by the expert subjects would yield an immediate and substantial increase in the position-fixing skill of military map users who have completed a traditional course of instruction in map interpretation. Moreover, it seems highly probable that both expert and non-expert map users would benefit from training designed to increase their ability to visualize the real-world appearance of a landform portrayed with contour lines and to visualize the contour-line portrayal of a visible landform.

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APPENDIX A

TASK-FLOW DIAGRAMS FOR PROCEDURES

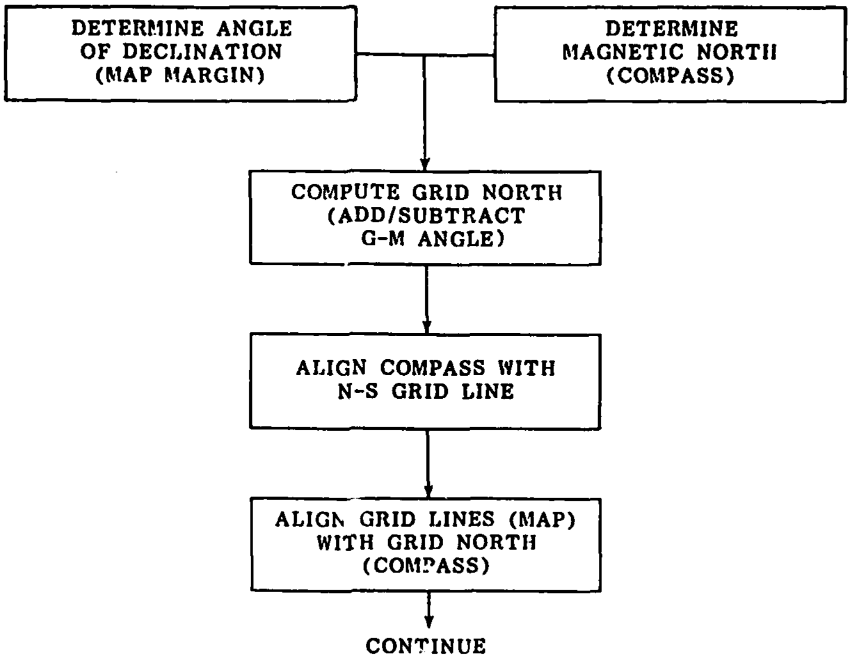

Figure A1. Procedure for orienting map using compass (P1.1)

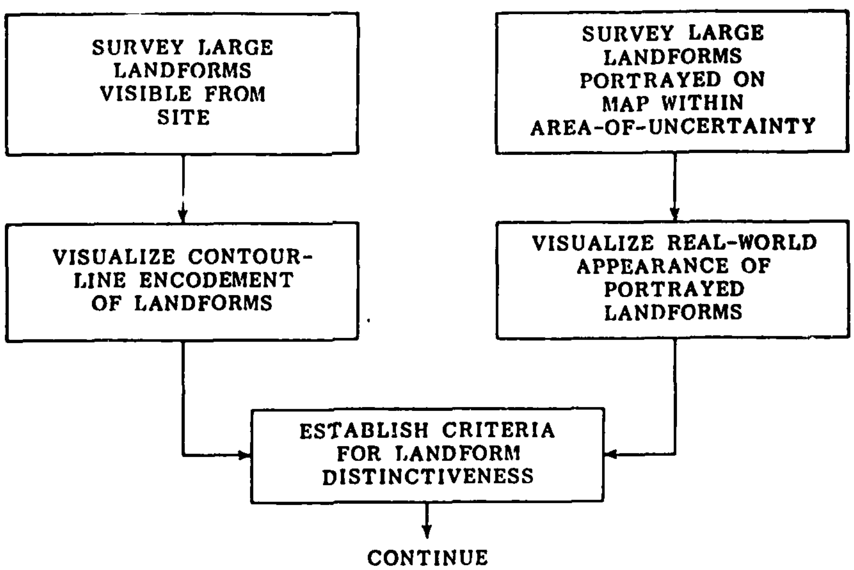

Figure A2. Operations required to survey scene and map for macro referents (P2.1).

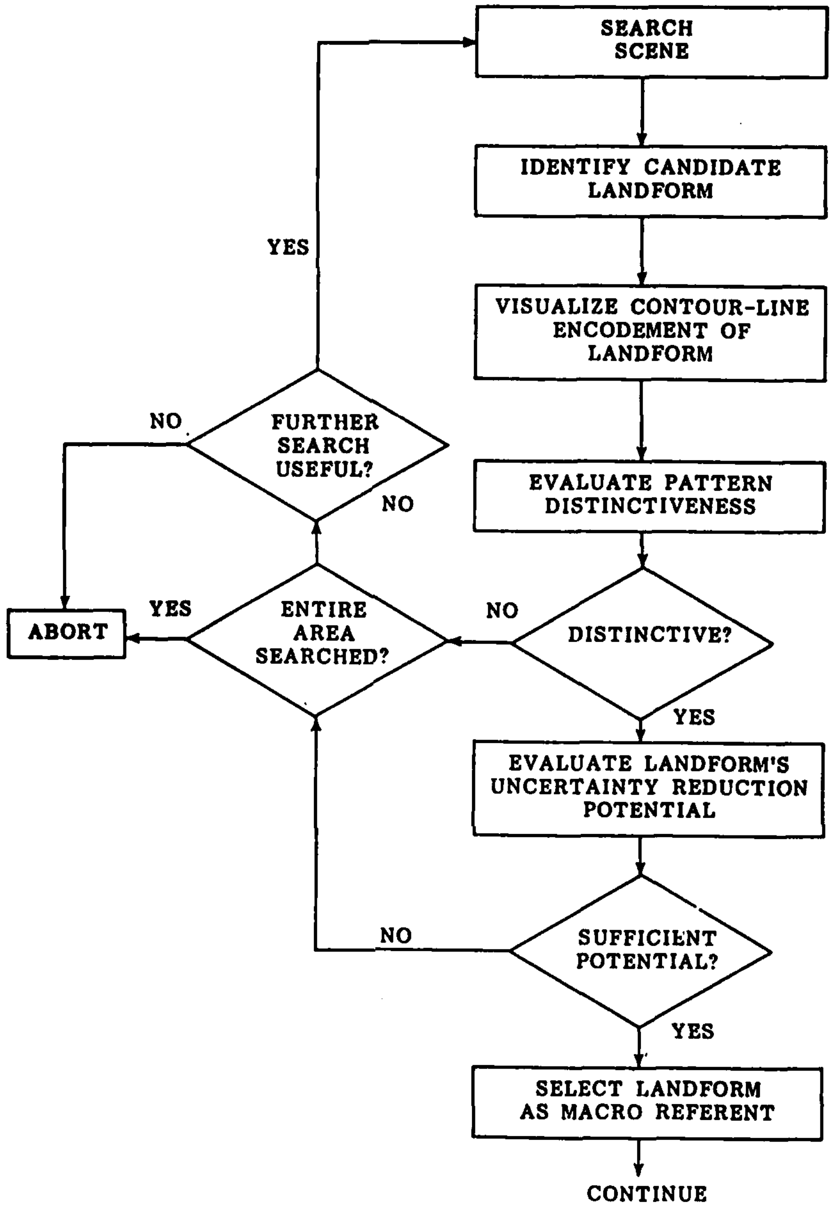

Figure A3. Procedure for selecting a real-world macro referent (P3.1).

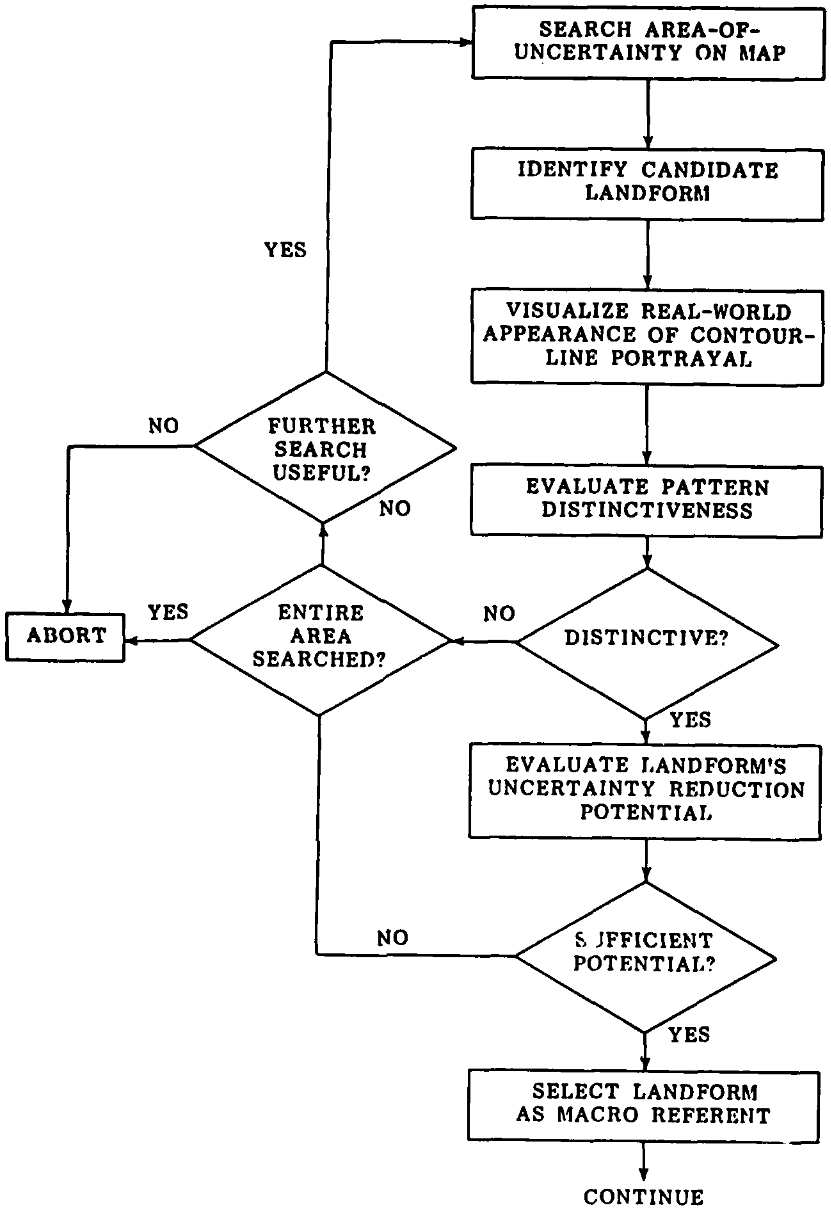

Figure A4. Procedure for selecting macro referent on map (P4.1).

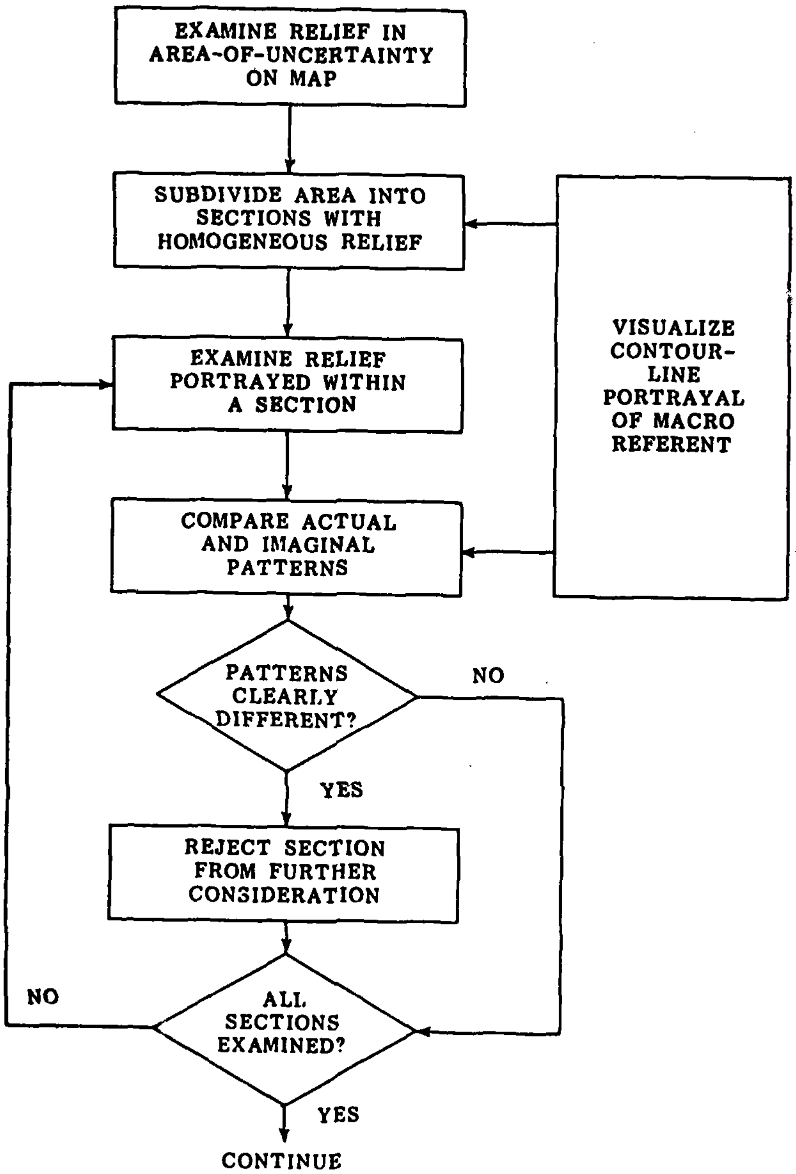

Figure A5. Procedure for eliminating map areas with dissimilar terrain relief (P5.1).

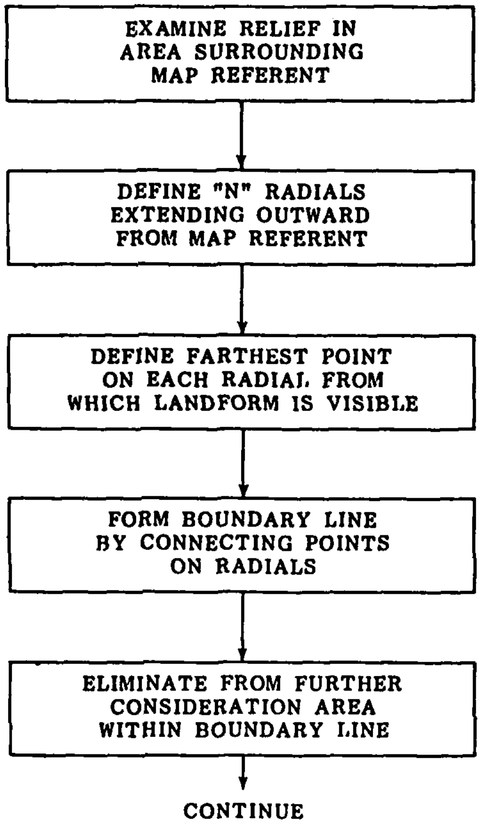

Figure A6. Procedure for eliminating areas from which referent can be seen (P6.1).

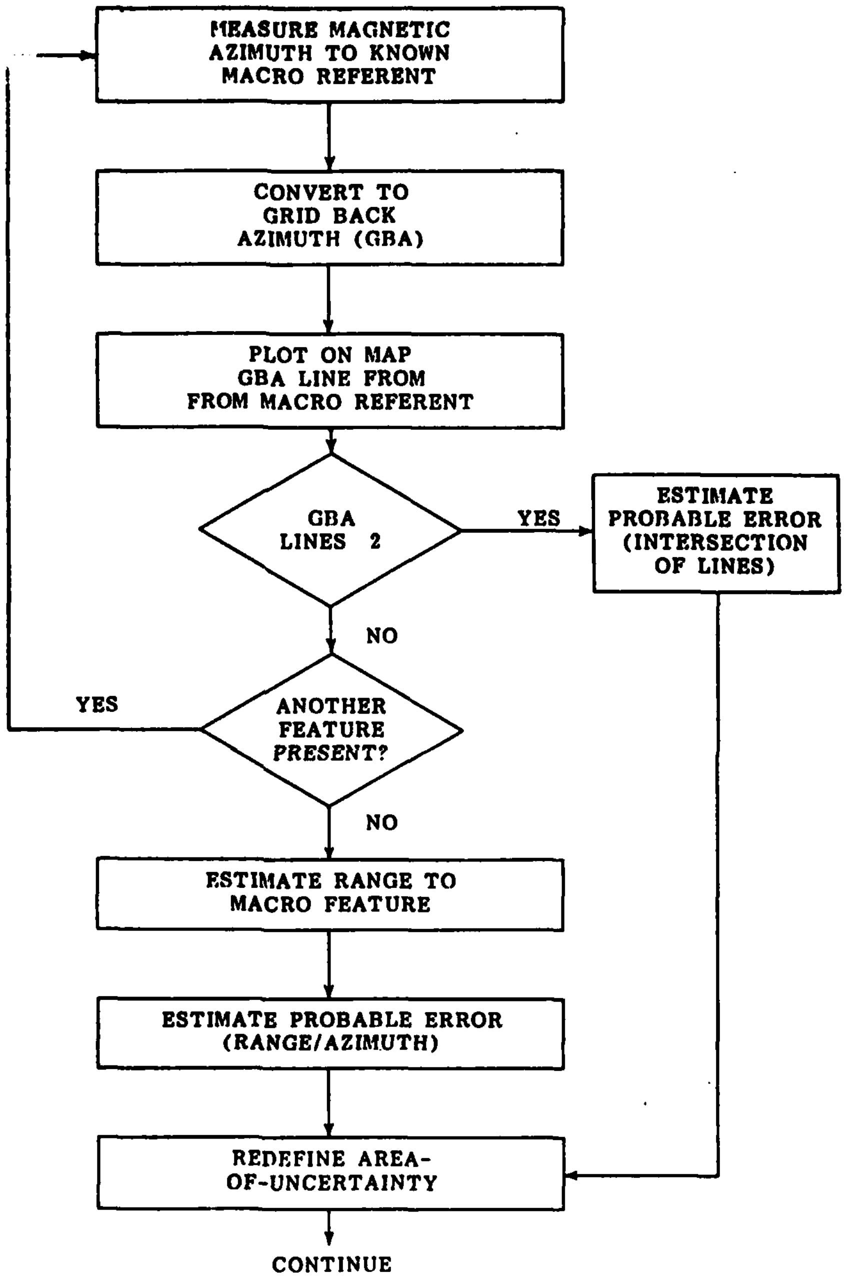

Figure A7. Procedure for reducing area-of-uncertainty using resection technique (P7.1).

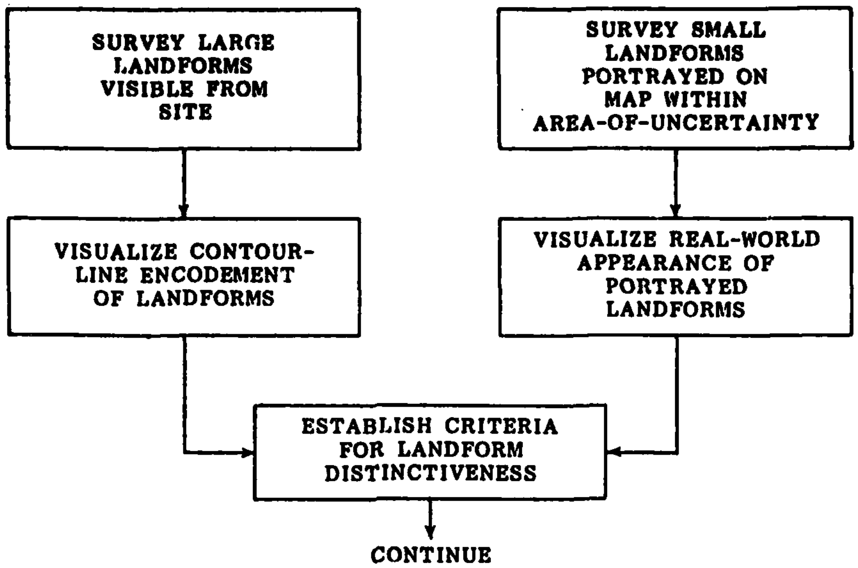

Figure A8. Procedure for searching scene and map for primary micro referents (P2.2).

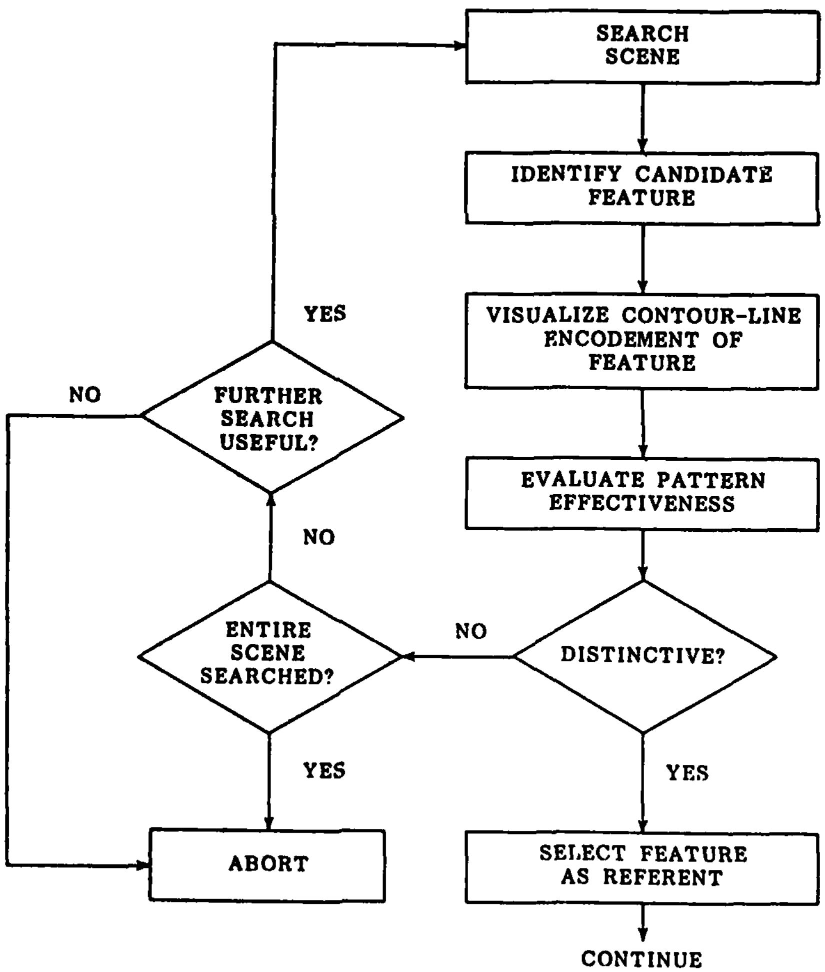

Figure A9. Procedure for selecting a primary real-world micro referent (P3.2).

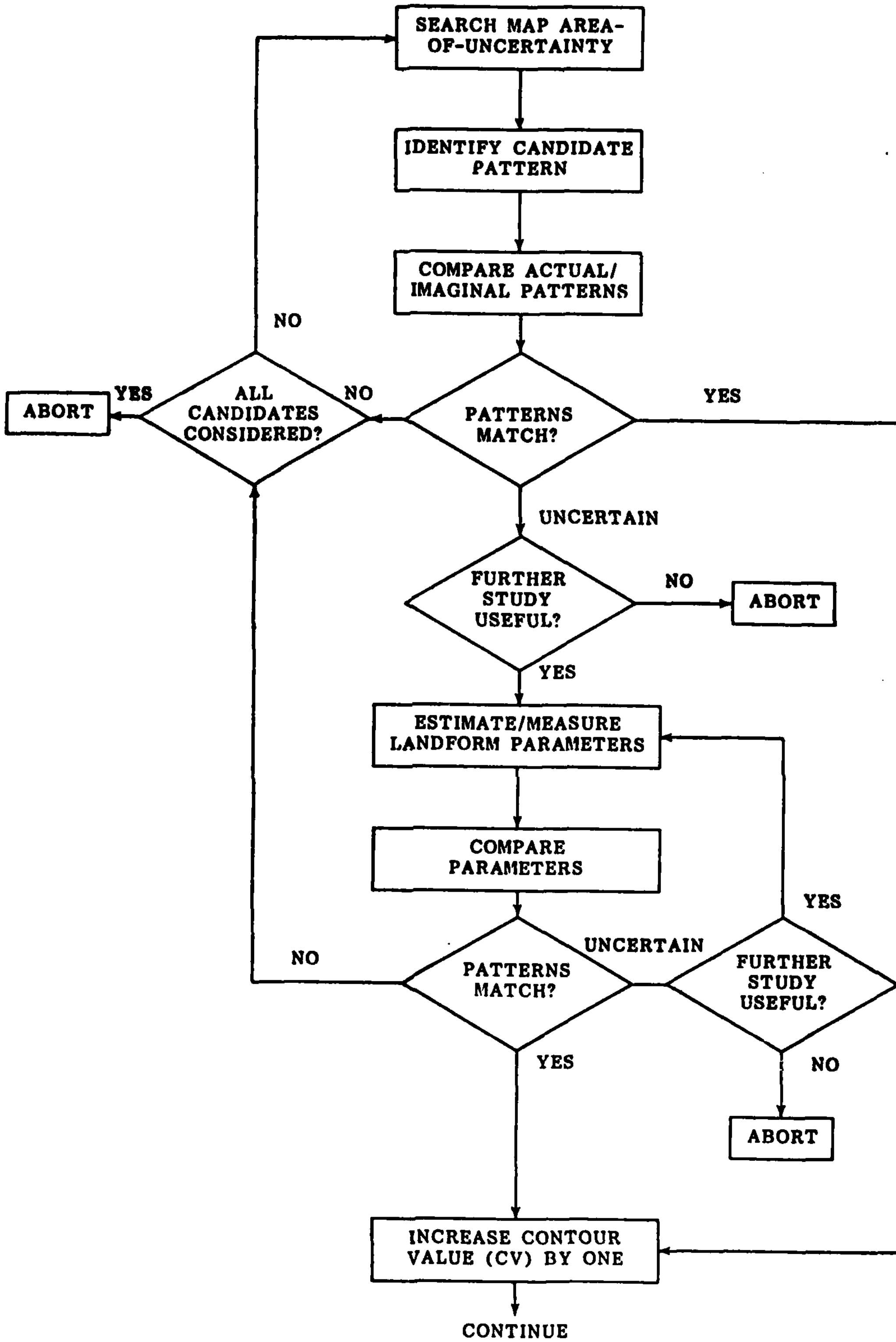

Figure A10. Procedure for associating primary real-world micro referents with map portrayal (P8.2).

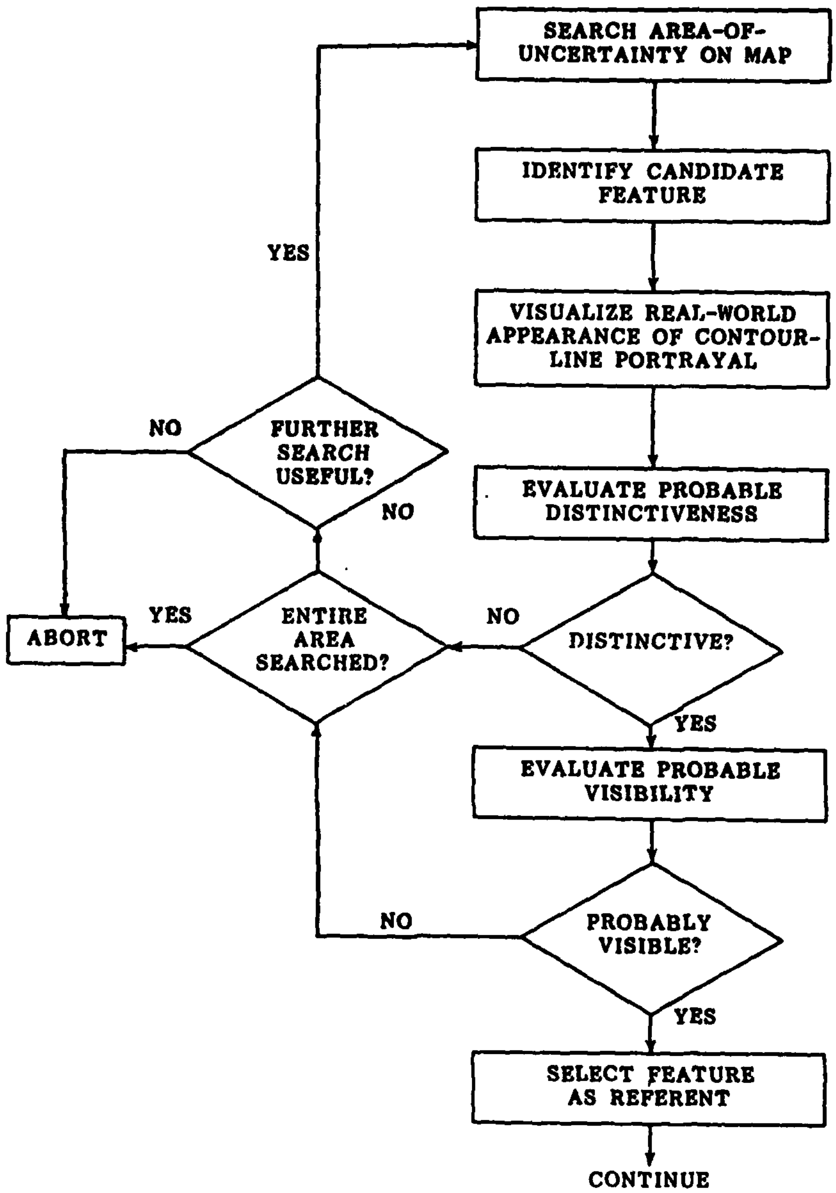

Figure A11. Procedure for selecting a primary micro referent on map (P4.2).

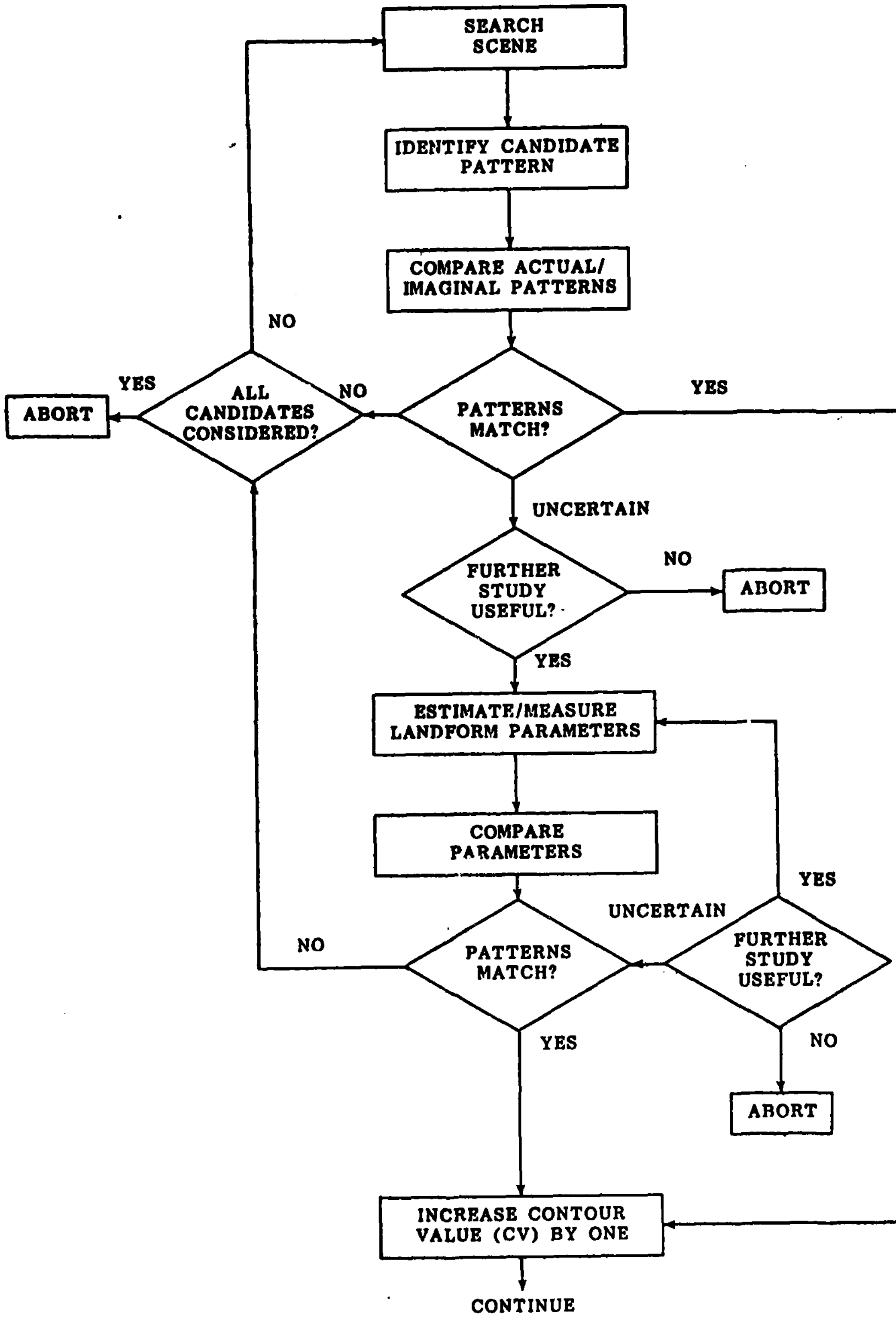

Figure A12. Procedure for associating primary map referent (micro) with real-world feature (P9.2). (This procedure assumes that the map referent is visible from operator's point of regard.)

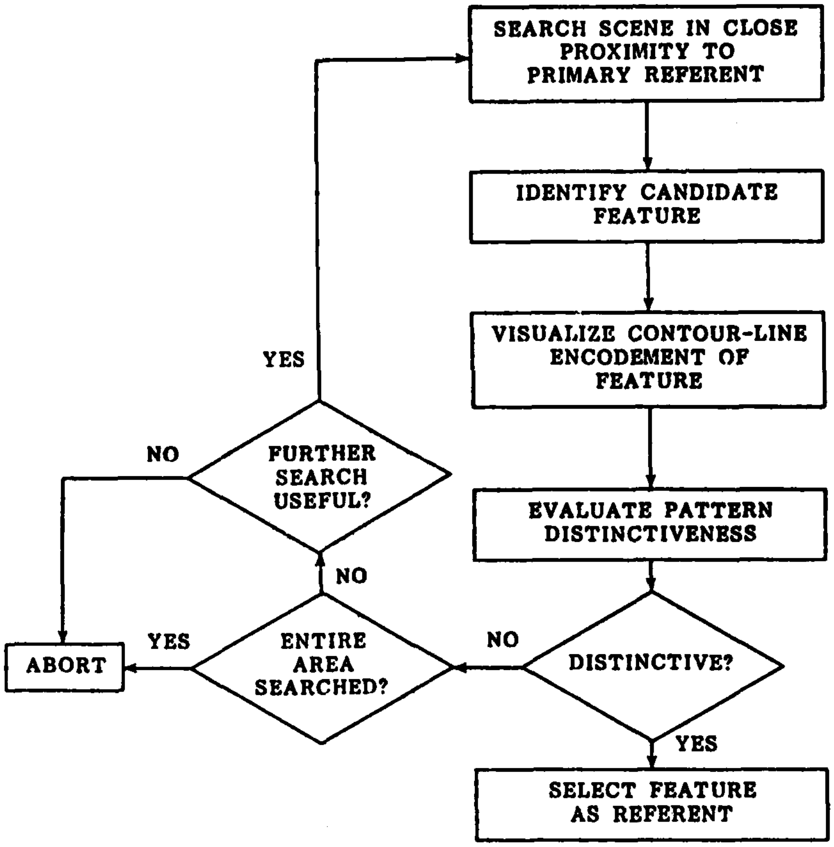

Figure A13. Procedure for selecting secondary real-world referent (P3.3).

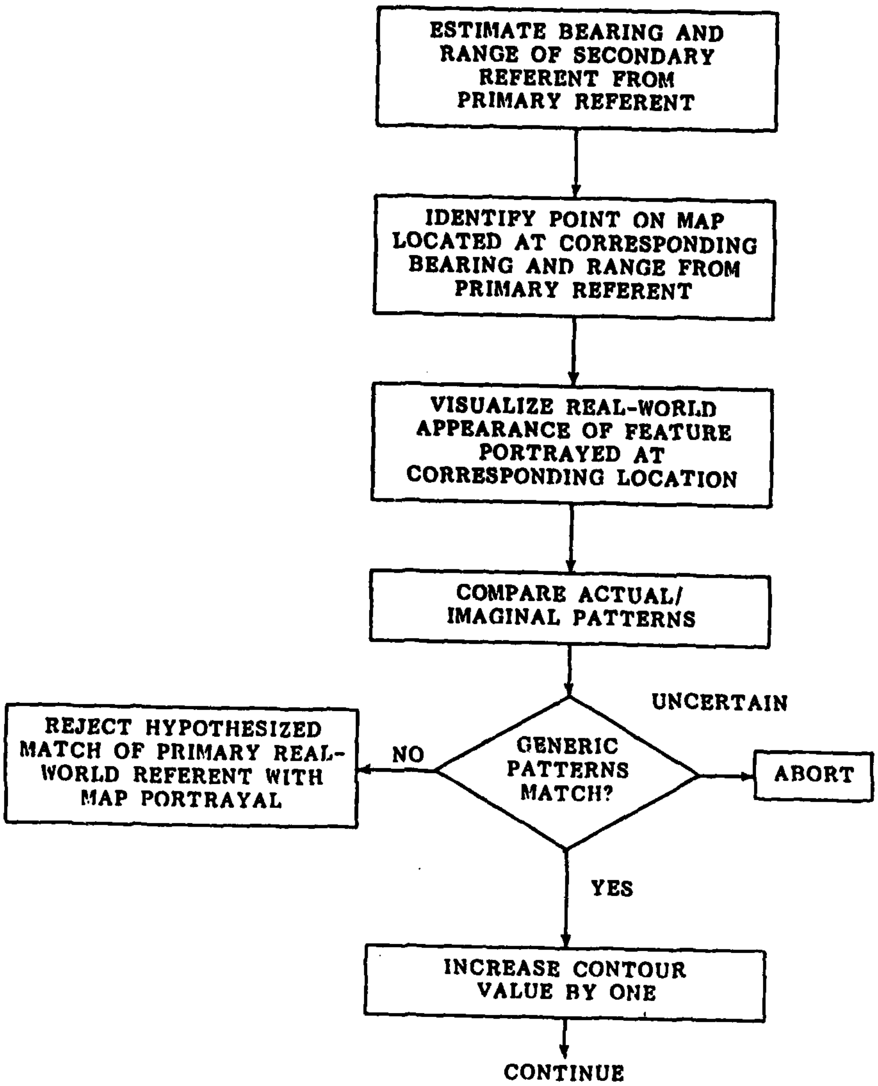

Figure A14. Procedure for associating secondary real-world referent with map portrayal (P8.3).

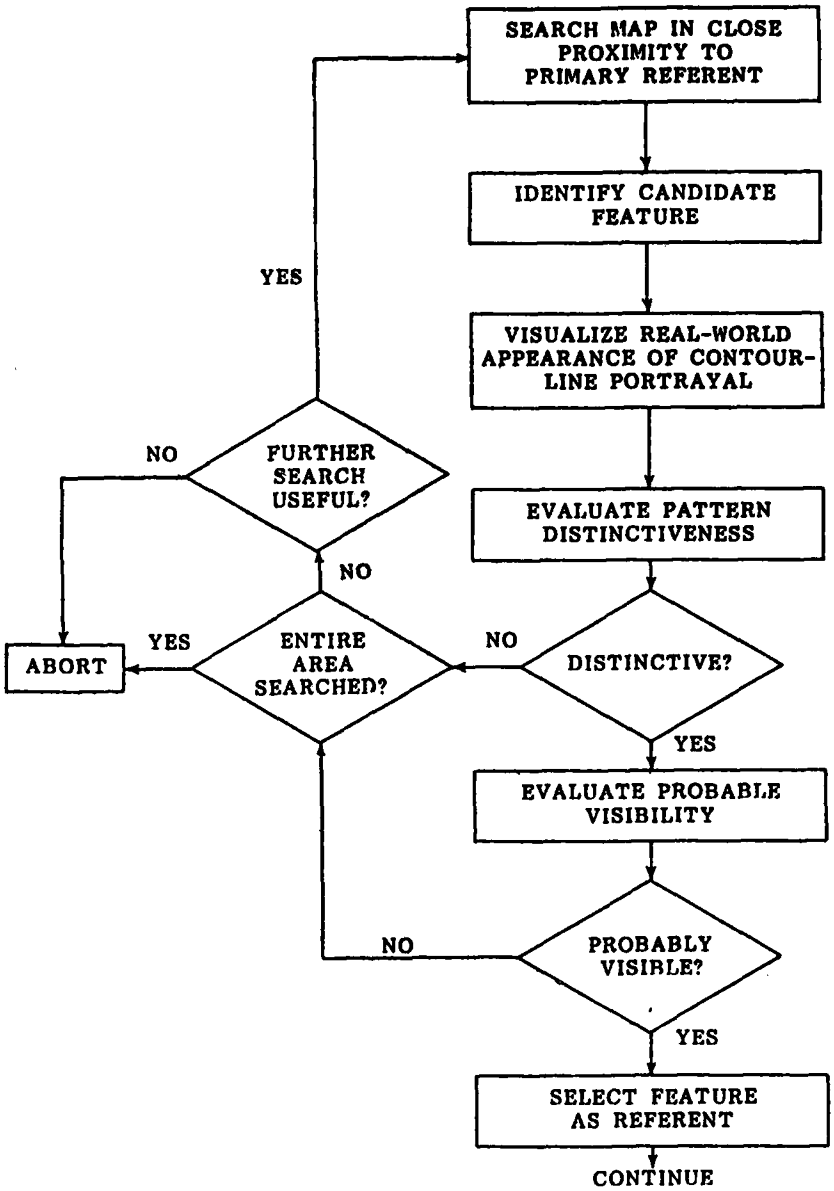

Figure A15. Procedure for selecting a secondary map referent (P4.3).

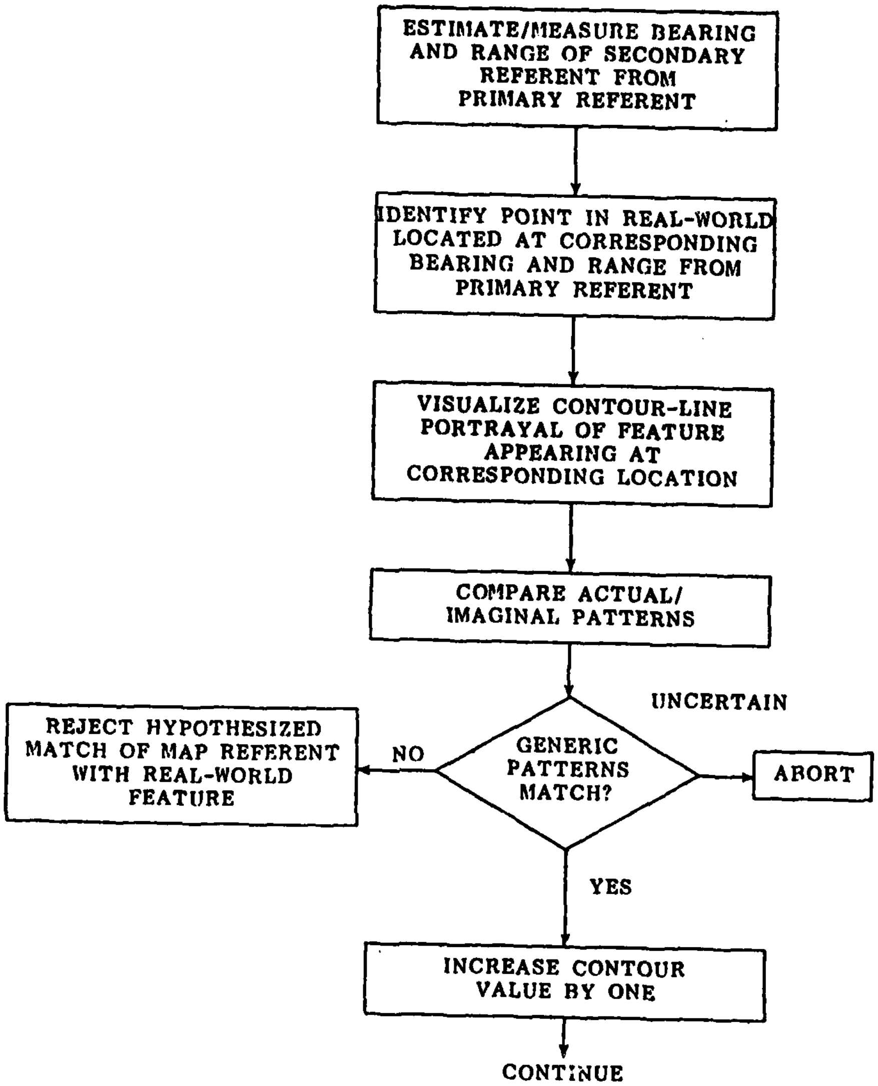

Figure A16. Procedure for associating secondary map referent with real-world counterpart (P9.3).

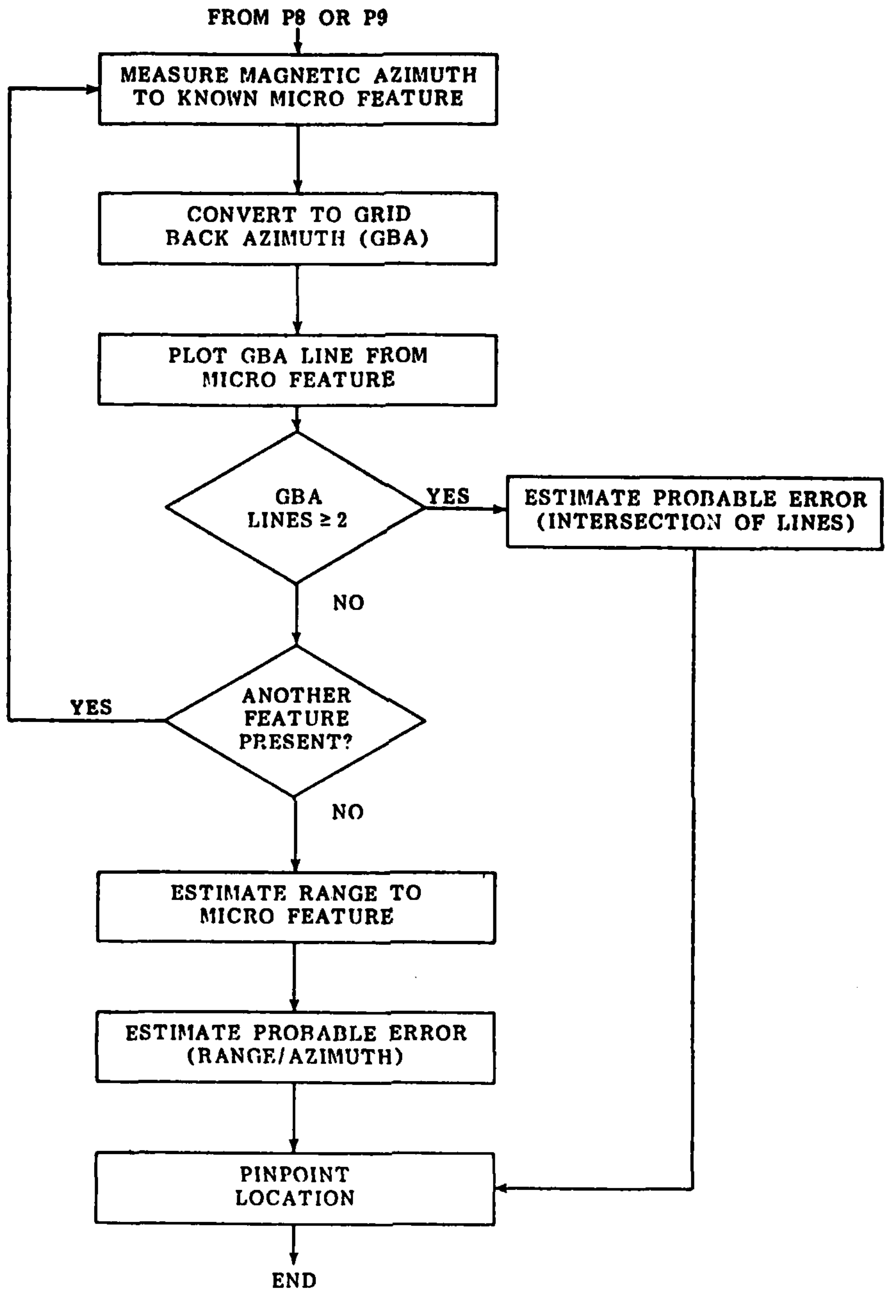

Figure A17. Procedure for using resection technique to pinpoint location (P10.2).