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**ACCURACY OF GEOGRAPHIC ORIENTATION
DURING NAP-OF-THE-EARTH FLIGHT
AS A FUNCTION OF
TOPOGRAPHIC MAP CONTOUR-LINE INTERVAL**

Submitted to:

**DEPARTMENT OF THE ARMY
U. S. ARMY RESEARCH INSTITUTE FOR THE
BEHAVIORAL AND SOCIAL SCIENCES
Field Unit (PERI-OA)
Fort Rucker, Alabama**

and

**AVIONICS LABORATORY
U. S. ARMY ELECTRONICS COMMAND
Fort Monmouth, New Jersey**

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 L → experienced pilots participated in the study. *study* The results of the study indicated that the typical Army aviator (although experienced in nap-of-the-earth flight) would not be able to perform navigation at nap-of-the-earth altitudes to the required level of accuracy using a topographic display which portrayed terrain relief and no other topographic features. Performances did not vary in any systematic way with the contour interval of the maps, although contour interval, if tested only with highly skilled participants, would be almost certain to have a marked impact on nap-of-the-earth navigation performance. It is concluded that future topographic displays should include more information than terrain relief alone, and that helicopter pilots expected to perform nap-of-the-earth tactics urgently need additional training in terrain-relief analysis and contour-line interpretation. Data from the simulated in-flight map interpretation task are graphically presented, in Appendix A.

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Steven P. Rogers
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CHAPTER 1

INTRODUCTION

This report describes a study undertaken to explore the relationship between navigation performance and the contour interval of the maps used during nap-of-the-earth (NOE) flight. Because some readers may not be familiar with the special map interpretation and terrain analysis problems encountered in NOE navigation, this introductory chapter provides a discussion of several critical issues: NOE navigation requirements, aids for NOE navigation, encodement of terrain relief by contour lines, and the significance of contour interval and grid-point interval.

NOE NAVIGATION REQUIREMENTS

NOE flight is flight as close to the earth's surface as vegetation and obstacles will permit, varying course, airspeed, and altitude in order to take maximum advantage of the cover and concealment offered by terrain, vegetation, and man-made features. Navigation at altitudes higher than NOE may be conducted by periodically identifying successive checkpoints. In contrast, NOE navigation requires continuous orientation by identifying terrain features along the route and correlating them with features depicted on the map. Even under the best of conditions, navigation at NOE altitudes is a formidable task due to the pilot's limited view of the surrounding terrain. The features that mask the enemy's view of the helicopter also serve to mask the pilot's view of navigational checkpoints. The pilot's view of the surrounding topography may be limited to features within as little as 100 meters from the aircraft. Landforms often cannot be seen in their entirety and the low angle of view adds to the difficulty of ascertaining their contours.

The difficulty of the navigational task is increased greatly when the pilot is unfamiliar with the terrain, when visibility is degraded by darkness or atmospheric conditions, and when adequate maps are unavailable. Despite these adversities, aviators must be able to plan and execute their

missions precisely in both time and space and relate their momentary position to their planned route and to the movements of other friendly ground and air forces. As a *minimum* standard, aviators are expected to navigate to an accuracy of 100 meters at all times (FM 1-1). Aviators must also be able to perform in-flight route selection in response to contingency situations or in the event that precise pre-mission planning is not possible or required.

AIDS FOR NOE NAVIGATION

The military topographic maps currently used for NOE navigation are large enough (22 x 30 inches) to require folding for cockpit use, yet depict an area of only 17 by 20 nautical miles, so that several maps may be needed for some missions. Marking the aircraft's track while holding the map (and sometimes a flashlight) can be awkward, especially when the map must be repositioned, refolded, or exchanged for another map. In addition, the aviator must continually shift his attention away from the map to check cockpit displays (compass, airspeed indicator, and others) and to analyze the visible terrain features without losing his position and orientation on the map.

One approach to simplifying the navigation task is the use of a projected map display. Such displays use film cassettes to store maps, projecting portions of these maps on a small screen. Projected map displays have the advantages of self illumination, area coverage many times larger than paper map sheets, and multiple map scales. The most important advantage of such a display system, however, is that it may be dynamically linked to the aircraft's navigation sensors so that the aircraft's deduced position on the map is continuously updated and displayed. The aviator is thus freed of map handling and cockpit instrument study, and may concentrate on terrain analysis and map interpretation to verify the aircraft's exact position.

Another approach to meeting the tremendous demands of the NOE navigation task is the development of a computer-generated topographic

display. Such a system would store digital topographic data for a large area on a single tape cassette and display portions of this "map" on a CRT screen. The computer-generated system, like the projected map system, would be dynamically linked to the aircraft's navigation sensors.

The single most important advantage of the computer-generated topographic display over paper maps or projected map displays is its promise of truly comprehensive and rapid-response cartographic support. NOE flight requires the use of large-scale maps (1:50,000 or larger). The smaller scale maps (such as 1:250,000 and 1:500,000), which are designed for conventional flight, do not portray sufficient detail for NOE navigation. Only a very small percentage of the earth's surface is currently mapped in large scale and, in the event that a conflict arose in an unmapped area, it could take more than a year to develop conventional topographic maps. Even photo-based maps could require a month or more for preparation. In contrast, the data required to support computer-generated display systems could be obtained for any area of interest in a matter of hours.

A second advantage of the computer-generated topographic display is its potential capability for selective display of the information content and format that is optimal for navigating at NOE altitudes. It is possible to design this system so that operators could be given control over the classes of information that are displayed, and the criteria governing the selection of specific features of a given class to be portrayed, such that the information best meets their momentary needs.

A third advantage of a computer-generated topographic display over conventional map products is its rapid computational capability. Such a display system could easily be programmed to show where the lowest terrain is located, what routes between two or more points would follow the lowest terrain, and what terrain is visible from any given enemy location. Tactical aids of this type would be invaluable both for preflight mission planning and for in-flight decision making.

There appear to be no fundamental technological constraints that would preclude the development and implementation of a computer-generated

topographic display system. The effectiveness of such a system rests largely on an adequate definition of display content and format--what information is needed for mission success and how best to present this information on a CRT display.

THE REQUIREMENT FOR DISPLAY OF TERRAIN RELIEF

Terrain relief--the shape and height of landforms--is clearly the one class of information that *must* be portrayed on any type of topographic map or display. There are several reasons why this is so, including:

- Terrain relief is the only class of topographic features that is nearly always available for use as a geographical reference;
- Terrain relief remains extremely stable over long periods of time, so it can be used as a geographical reference even with outdated topographic source data;
- Landforms tend to be more unique in appearance than any other class of topographic information; and
- Terrain relief has great tactical significance for NOE missions.

There are some areas in the world where the terrain is so uniformly flat that aviators simply cannot navigate by referencing terrain relief alone. Such areas include large swamps, large desert basins, and some large plains areas. However, an examination of topographic maps for the continents of the world will show that areas with uniformly flat terrain are few in number and usually small in size. For the above reasons, terrain-relief information is considered essential, although not always sufficient, for any type of topographic map or display.

TERRAIN-RELIEF ENCODEMENT ON A COMPUTER-GENERATED TOPOGRAPHIC DISPLAY

An acceptable terrain-relief encodement scheme must enable operators to visualize quickly and accurately the real-world counterpart of the landforms that are portrayed on the display. Quantitative criteria for decoding speed and accuracy cannot be defined at this time, but it seems reasonable to establish a requirement for a level of speed and accuracy that is at least equivalent to that obtained from conventional topographic maps. In addition, an acceptable encodement scheme must provide for quick

and accurate decoding over the full range of geographical areas in which NOE missions might be required. There are two parameters affecting the suitability of a terrain-relief encodement scheme: elevation range and precision of terrain feature depiction.

Elevation range is the vertical distance between the lowest and highest landforms portrayed on a map. When the elevation range is small, the encodement scheme must enable the operator to discriminate the landforms that may rise only 40 or 50 feet above the adjacent terrain. When the elevation is great, the encodement scheme must depict landforms that may rise 4,000 feet or more above the surrounding terrain.

In order to evaluate the likely ranges of elevations to be portrayed, an analysis was performed using representative areas in the United States: Colorado, Arizona, Kentucky, and Idaho. Twelve sectional maps were obtained for these areas, and spot elevations were recorded at every second grid line intersection in every vertical grid line. The results of this analysis are shown in Table 1. This table shows the elevation range, in feet, of each of the selected areas and the average of all 12 maps. It is clear from Table 1 that any terrain-encodement scheme must be able to accurately depict landforms of considerable vertical development.

The precision of terrain feature depiction required for NOE navigation is often misunderstood. Though NOE flight may take place in areas of large elevation ranges, the features used for NOE navigation in these areas are often quite small. At conventional flight altitudes, large terrain features can be seen for miles ahead, and their contours are usually unambiguous. But, in NOE flight, the typical look-ahead distance is only 1,000 meters, and the forms of large features are often obscured by smaller, nearer features. Furthermore, the apparent contours of large terrain features are distorted due to the pilot's upward angle of view from his usually very low altitude. Since large terrain features are often obscured, or their appearances distorted during NOE flight, relatively small features often assume great importance as checkpoints. It is not unusual for pilots to navigate by referencing hillocks, saddles, stream

STATE	MAP TITLE	(# DATA POINTS)	RANGE (FEET)
COLORADO	FORT CARSON	(281)	4,280
ARIZONA	FORT HUACHUCA N.E.	(357)	1,850
	FORT HUACHUCA S.E.	(341)	3,200
	FORT HUACHUCA N.W.	(368)	2,400
	FORT HUACHUCA S.W.	(368)	4,800
KENTUCKY	HODGENVILLE	(283)	540
	ELIZABETHTOWN	(294)	420
	VINE GROVE	(294)	480
	ALTON	(294)	480
IDAHO	RATTLESNAKE CREEK	(268)	5,360
	MAYFIELD	(270)	2,000
	DANSKIN PEAK	(270)	3,200
AVERAGE RANGE			2,417

Table 1. Results of an elevation range analysis, showing the elevation range, in feet, of representative geographic areas.

beds, and other terrain features which may have a vertical development of only 50 feet or less, even though mountains may rise hundreds or thousands of feet on either side of the flight path.

In summary, the most severe requirement for a terrain encodement scheme is that it be capable of depicting landforms thousands of feet tall while maintaining sufficient precision to allow pilots to identify the small, unique features useful during NOE flight.

TERRAIN-RELIEF ENCODEMENT BY CONTOUR LINES

Although there are a variety of ways in which terrain relief may be depicted,¹ it is a universal practice to use contour lines on large-scale

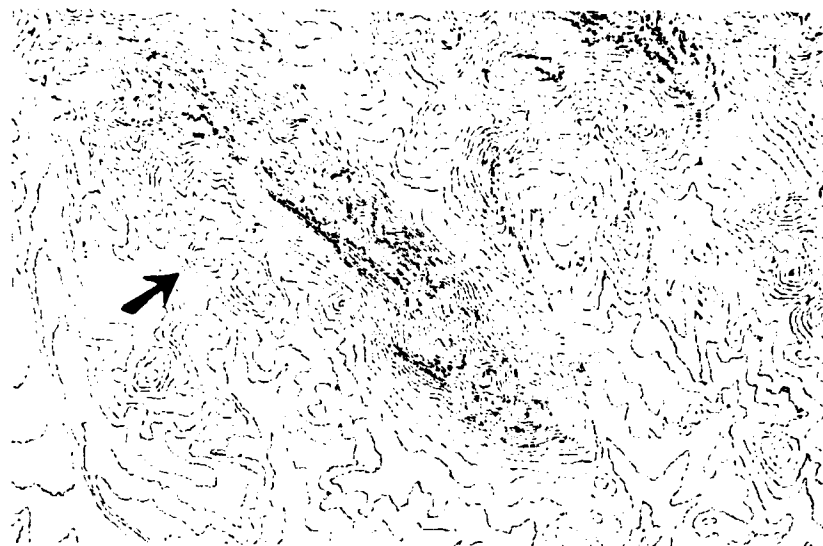
¹For a discussion of the characteristics of various terrain-relief encodement schemes, see Cross, 1977, pp. 26-41.

maps. Contour lines are simply imaginary lines on the ground which take any shape necessary to maintain a constant elevation. All the information necessary for terrain-feature identification--form, orientation, slope gradient, and elevation--is depicted by contour lines. The contour-line technique is the only terrain encodement scheme which meets the severe requirements of NOE navigation: depicting very large elevation ranges while maintaining the precision necessary for referencing small terrain features. There is virtually no limit to the elevation range that may be portrayed by contour lines. The precision of terrain-feature depiction is limited only by the vertical distance between contour lines, known as the *contour interval*.

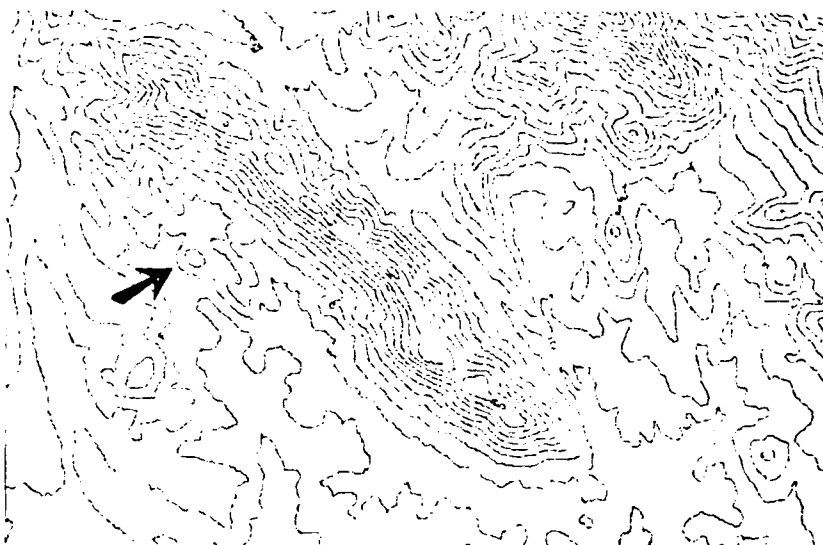
The contour interval varies from map to map, at the discretion of the cartographer. The cartographer bases his selection of contour intervals on map scale and elevation range, generally attempting to make the interval as small as possible without frequent contacts of adjacent contour lines. Contour intervals typically selected for the large-scale maps used for NOE navigation range from 10 to 50 feet, while those used on medium- and small-scale maps range from 50 to 250 feet or more.

Figure 1 shows the portrayal of terrain using three different contour intervals: 40, 80, and 120 feet. This side-by-side comparison clearly shows how the specificity of terrain depiction decreases as the contour interval increases. Hills with well-defined shapes, using the 40-foot contour interval (such as the one indicated by the arrow), become poorly defined at 80 and may disappear entirely at the 120-foot contour interval. Even the large mountain becomes increasingly generalized in shape as contour interval increases.

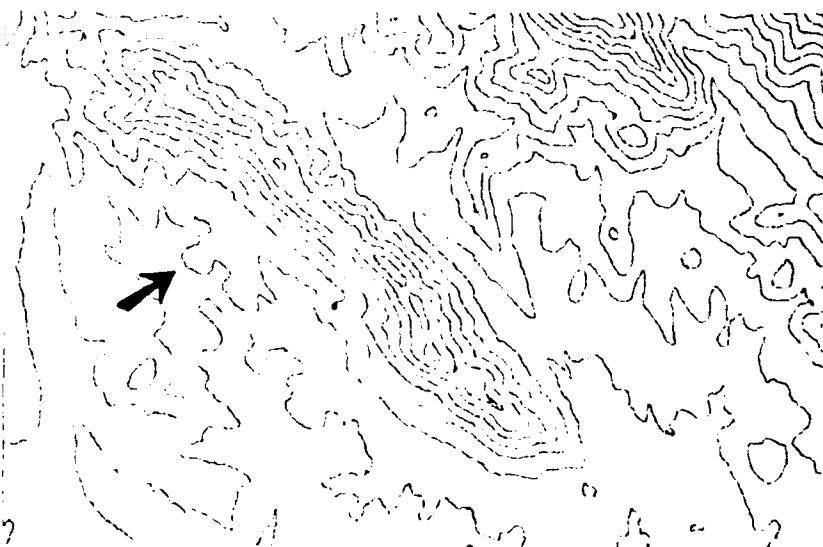
Another way of examining the variation in specificity with changing contour interval is by constructing terrain profiles. A terrain profile is an exaggerated side view of the earth's surface along a line between two points. Profiles are usually constructed by plotting elevation points from a map on graph paper, and connecting the points with a line. It must be remembered, however, that elevations are relatively accurate only at



40-FOOT
CONTOUR
INTERVAL



80-FOOT
CONTOUR
INTERVAL



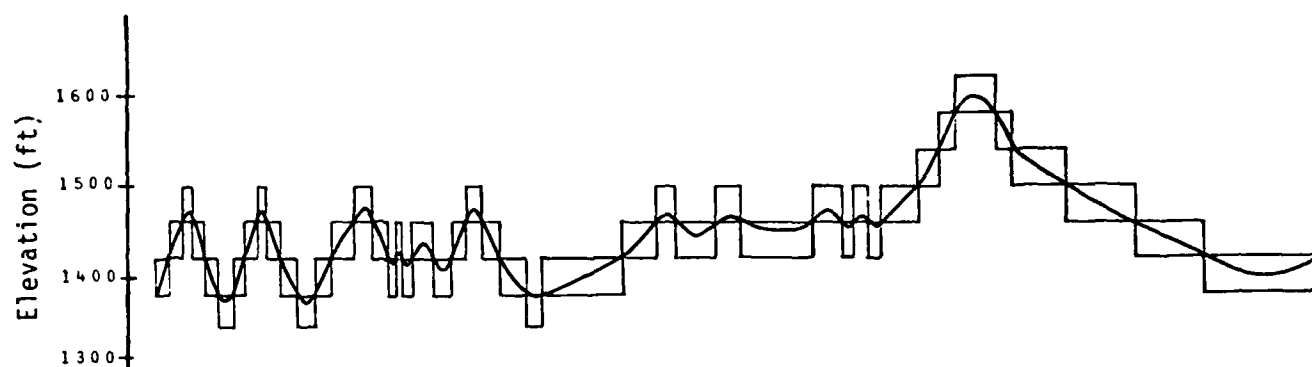
120-FOOT
CONTOUR
INTERVAL

Figure 1. Portrayal of terrain by contour lines using three different contour intervals.

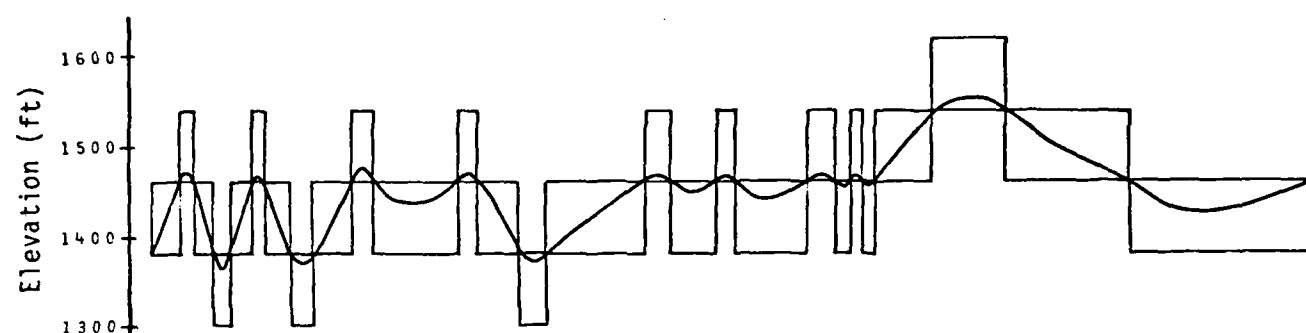
contour lines, and must be inferred between lines. The elevation at a point between two lines may approach the elevation of either line, thus creating "zones of uncertainty," which increase with the contour interval. Three profiles of actual terrain are shown in Figure 2. Each profile is constructed using the same terrain but a different contour interval. The zones of uncertainty for each is also indicated. Two possible profiles have been drawn using the 120-foot contour interval data, neither of which closely resembles the profile constructed from the 40-foot contour interval data.

What is the optimal contour interval for NOE navigation while using a computer-generated topographic display? A CRT display typically lacks the resolution available with hard-copy map products, and places limits on the proximity of the contour lines. Thus, decreasing the contour interval below some level could only be achieved by increasing the scale of the map and, as a direct consequence, reducing the look-ahead distance. In addition, the computer memory requirements and processing time will increase as contour interval decreases. In short, the contour information presented should be sufficient to meet the needs of the flight crew, but not exceed this need. Excess information would be accompanied by excess costs, display clutter, reduced look-ahead distances, and prolonged display update times.

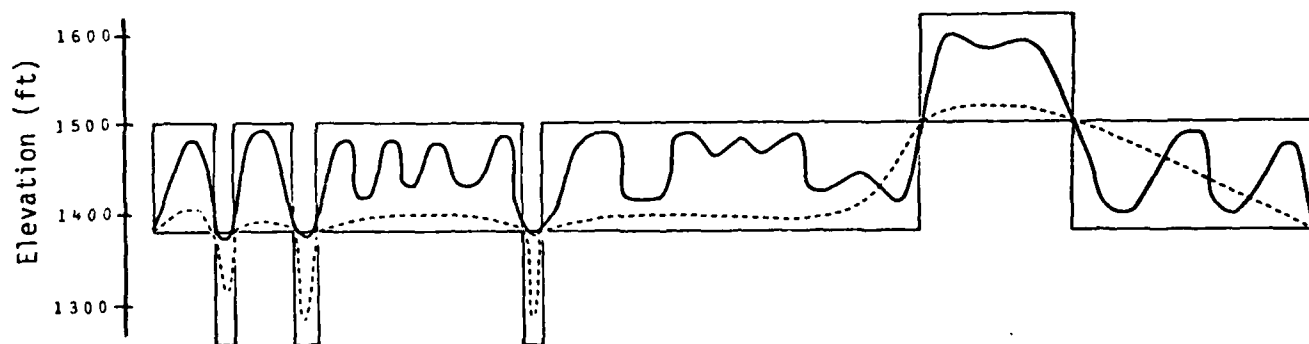
Determining the maximum contour interval acceptable to meet the needs of NOE navigation is not a straightforward analytical task. It is clear from terrain profile analyses and examination of maps that certain types of terrain features are inadequately depicted with increasing contour intervals. Yet the results of such studies are inconclusive with regard to the minimum acceptable contour interval--they show that the information available on a map changes with contour interval but do not reveal how much information the pilot needs. The pilots themselves are not in unanimous agreement on this matter. Informal interviews with pilots revealed that the majority prefer what they are used to--usually 40-foot contour intervals. Others, depending upon their personal techniques for map interpretation, prefer smaller or larger intervals. Some suggested that the interval should depend upon the steepness of slopes in the mapped area.



(a) Terrain profile from a map with a 40-foot contour interval.



(b) Terrain profile from a map with an 80-foot contour interval.



(c) Terrain profile from a map with a 120-foot contour interval.

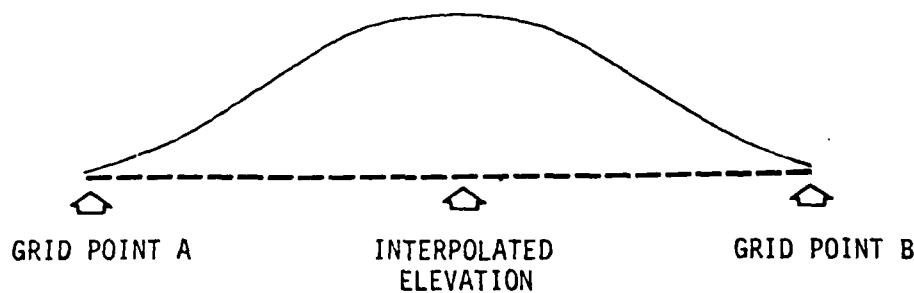
Figure 2. Profiles of one section of terrain constructed from maps with three different contour intervals. The boxes surrounding the profiles show "zones of uncertainty" (see text).

Since neither the analytical evidence nor the pilots' opinions produced an unequivocal answer to the critical question of contour interval, an experimental approach was required. This experiment is described in the following chapter.

THE SIGNIFICANCE OF GRID-POINT INTERVAL

Contour lines, whether drawn conventionally (manually) or by a computer-plotter device, must be derived from elevation data at specific points on the ground. In the case of digital terrain elevation data, elevation information is stored on magnetic tape as a series of x , y , z digital coordinates. The x - y coordinates form a grid across the mapped area, with z being the encoded elevation at each grid point. The elevations at grid points are not necessarily those specific elevations expressed by contour lines. An interpolation process is required to determine where contour lines must fall on the grid--usually between, rather than on, grid points.

There are two outgrowths of the interpolation process which are important in the production of maps. The first is that the farther apart the grid points are placed, the more generalized the contour lines will become. Imagine, for example, that two adjacent grid points were on opposite sides of a hill. The portion of the hill above these two points would not affect the interpolation process, and the hill would "disappear" when the map was plotted, as shown in the sketch below.



It might seem logical to simply eliminate potential problems of this sort by using a data base with very densely packed grid points. The difficulty with this approach lies in the mounting time required for processing the elevation data. Halving the distance between grid points causes their number to increase by a factor of four, because the grid extends in two dimensions. The fewer grid points required for an adequate representation of the terrain, the faster the display system can be updated to reflect the changing position of the aircraft.

The second important outgrowth of the interpolation process is an unusual distortion effect resulting from large grid-point intervals. Digital data is currently available with a grid-point interval of 12.5m--equivalent to 0.25mm on a 1:50,000-scale map. Increasing that grid-point interval to, say, 125m yields 2.5mm between points on the map. Given a steep slope--45°, for example--as many as six (40-foot interval) contour lines may pass between these grid points. Because they are subject to the same interpolation points, contour lines passing within a "box" of four grid points must be parallel. The consequences of these facts are seen as strange geometric quilted effects in maps produced using a large grid-point interval. Such a map is shown in Figure 3. This map was plotted using a 40-foot contour interval and a 125m grid-point interval. Notice that the effects are most pronounced in the steepest terrain.

Figure 4 shows a map plotted of the same terrain using a 40-foot contour interval and 100m grid-point interval. The geometric effect is reduced, but is still unacceptable. Figures 5 and 6 show the same terrain again, employing a 62.5m and 50m grid-point interval, respectively. The geometric effect has almost, but not quite, disappeared in these figures. Examination of Figure 5 and Figure 6 shows that the terrain generalization effects are relatively minor, at least in this type of terrain. Some evidence of "peak-clipping" can be found in less steep areas using a 62.5m grid-point interval, but it is much less severe than that encountered when contour intervals are increased by as little as 20 feet. Use of a 62.5m grid-point interval would reduce the number of data points required to only



Figure 3. A map generated from elevation data using a grid-point interval of 125m.

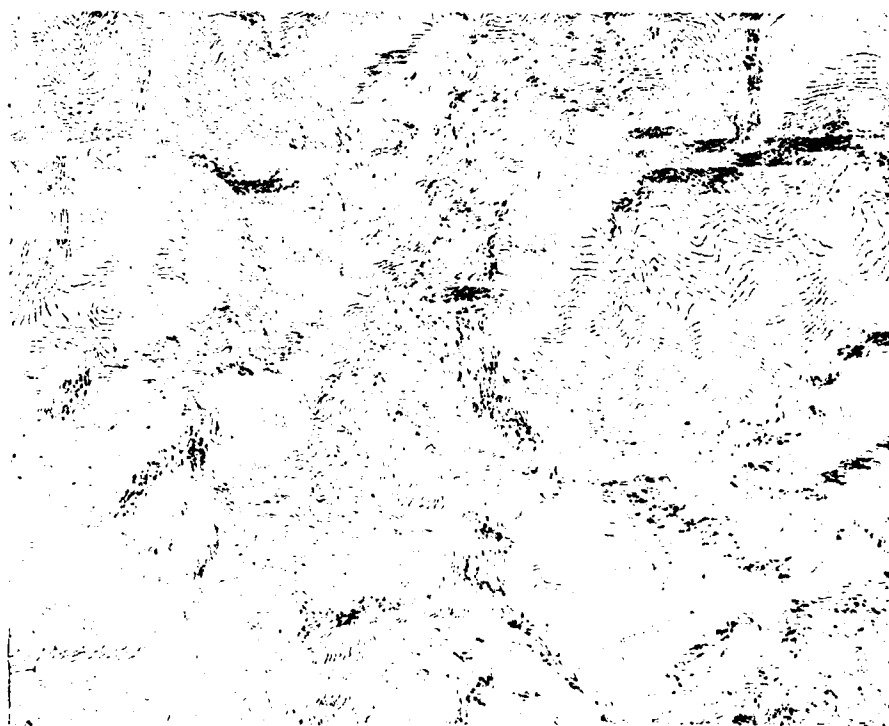


Figure 4. A map generated from elevation data using a grid-point interval of 100m.

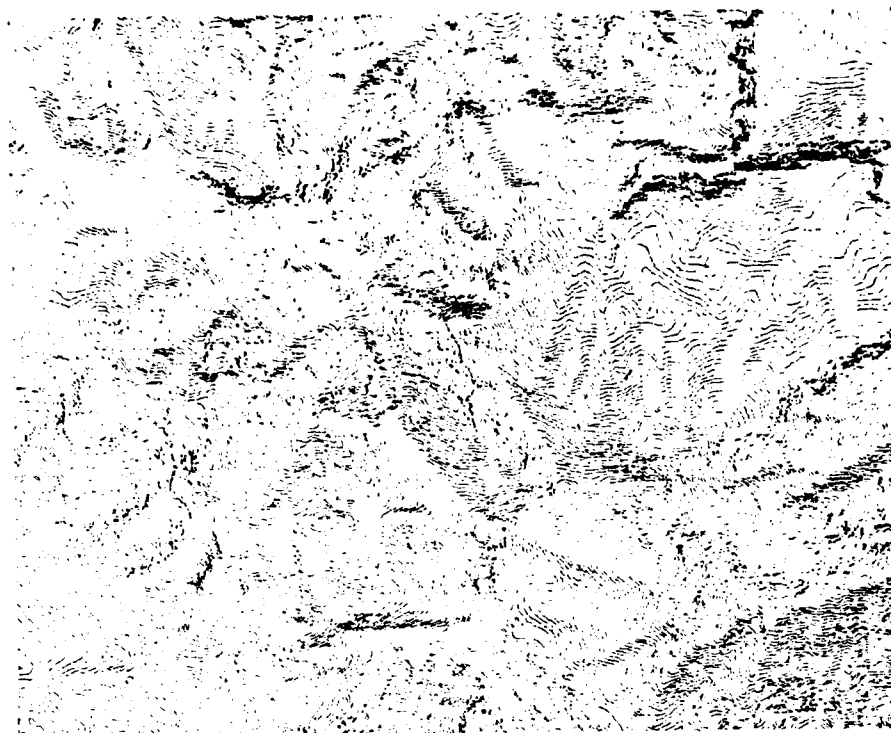


Figure 5. A map generated from elevation data using a grid-point interval of 62.5m.

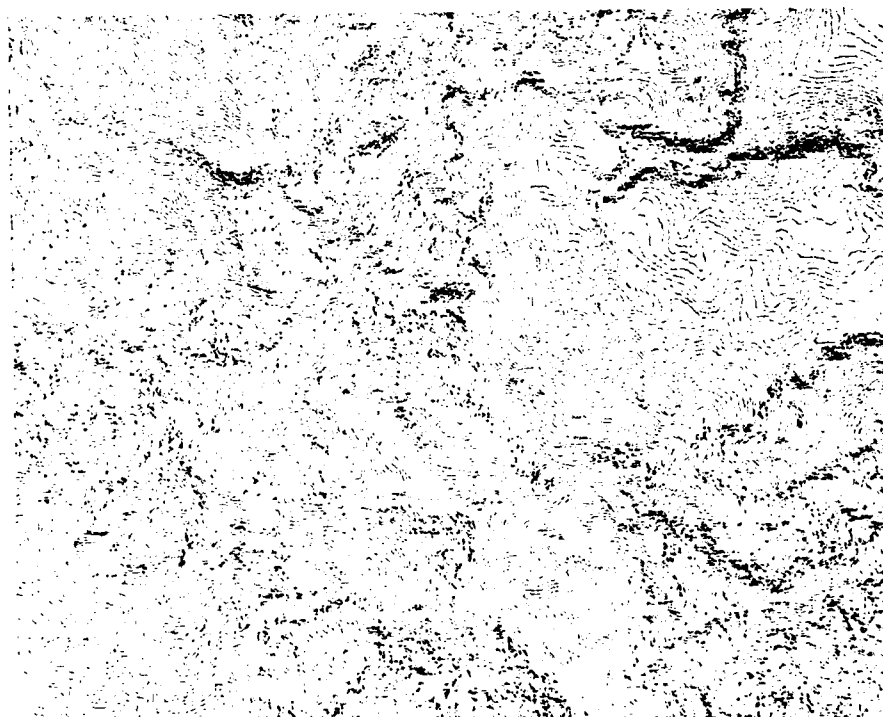


Figure 6. A map generated from elevation data using a grid-point interval of 50m.

four percent of those needed when using a 12.5m interval. Such a reduction is very desirable, providing that the small amount of information lost will not affect the pilot's ability to interpret the map.

As in the case of contour interval, analytical evidence is not sufficient grounds for addressing the critical question of grid-point interval. For this reason, it was decided to include an extended grid-point interval map in the experimental design. This map was produced with a 40-foot contour interval, and a 62.5m grid-point interval. It is hereafter referred to as the "40X" map sheet.

OBJECTIVES OF THE STUDY

The perceptual task of relating the contour lines on a map to the terrain relief on the ground is without doubt the most difficult aspect of map interpretation during NOE flight. Yet, because of the importance of terrain relief, the mastery of this task is expected of all NOE aviators. Because conventional maps used for NOE navigation include additional information (cultural, vegetation, and hydrographic features), it has been difficult to assess aviators' ability to navigate only by relating contour lines to terrain relief. And, since maps of a given area are not available in several contour intervals or grid-point intervals, it has not been possible to directly examine navigation performance as a function of these variables.

The success of a computer-generated topographic display is directly related to the understanding of these relatively unstudied perceptual abilities, as they are employed during NOE navigation. Thus, the objectives of the study were the following:

- To determine the ability of experienced pilots to perform NOE navigation using maps which depict terrain relief and no other topographic information.
- To determine the decrement of NOE navigation performance attributable to increasing the contour interval of terrain relief maps.
- To determine the decrement of NOE navigation performance attributable to increasing the grid-point interval of terrain relief maps.

CHAPTER 2

METHOD

The experiment included two separate tasks. The first task dealt with relating terrain features presented by 35-mm transparencies to their encoded depiction on contour line maps. The second task was concerned with the ability to use these maps in drawing the track of an NOE flight presented by a motion picture. The two tasks are discussed in detail below.

TERRAIN FEATURE IDENTIFICATION

I. Task

Pilots viewed 35-mm transparencies of terrain features at Fort Huachuca, Arizona. The photographs were obtained from a helicopter at positions known to the experimenters. The pilots were requested to study each transparency and select the site on their map from which the photograph was taken. Four possible sites (labeled A, B, C, and D) were identified on the map by means of an overlay. There was a separate transparency and overlay for each of eight trials.

II. Apparatus

The transparencies were presented to the observers via a Kodak Carousel Projector and a screen of such size and located at such distance to present an image of approximately 20° of visual arc. The angle of view of the terrain was 64° .

The maps distributed to the pilots were printed from originals developed by Anacapa Sciences using the facilities of the Computer Center at the University of California at Santa Barbara, and digital data from the Defense Mapping Agency. These maps consisted only of contour lines--no hydrographic, vegetation, or cultural features were depicted. Maps were plotted in three different contour intervals: 40, 80, and 120 feet, and were based on a 12.5m grid-point interval. In addition, one map (40X)

was plotted using a 40-foot contour interval and an extended (62.5m) grid-point interval. All of the maps portrayed the same area at the same scale: 1:50,000.

Map overlays were used to indicate the four possible sites to the pilots. A sample map with overlay markings is shown in Figure 7. The point of each "V" represents the location from which the transparency might have been taken and the arms of the "V" show the angle of view.

III. Procedure

The pilots who participated in the experiment were seated in dimly lit classrooms, or other suitable spaces, facing the projection screen. The four different types of map sheets were distributed in order of pilot appearance, along with pens, penlights, and packets of overlay sheets. The instructions were read and the first transparency was presented. After a two-minute interval, the screen was darkened and pilots recorded their site selection and positioned the subsequent overlay. This procedure continued until all eight transparencies had been presented.

IV. Participants

The participants were all experienced pilots. Preliminary testing was done with the aid of 18 pilots from A Company, 7th Aviation Battalion, Fort Ord, California. Subsequent testing was performed with 54 pilots from Lowe Field and Hanchey Field at Fort Rucker, Alabama, and with 18 pilots from G Troop, 1st Cav. of Fort Knox, Kentucky, during their participation in a training exercise at Fort Irwin, California. The hours and areas of NOE experience of each pilot were recorded. None of the pilots had flown in the Fort Huachuca area. The average amount of NOE experience was over 220 hours.

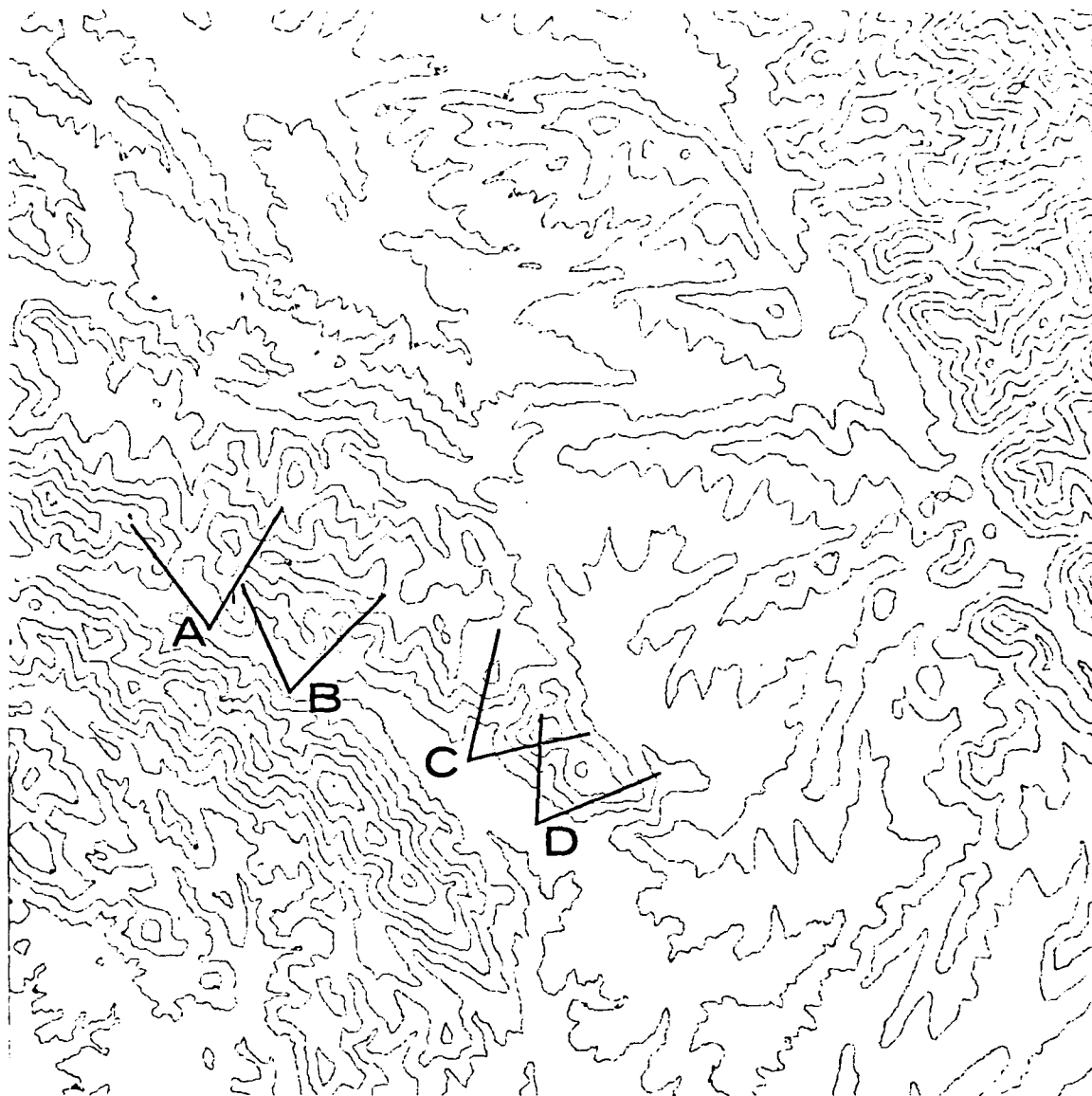


Figure 7. A sample of a map sheet with overlay markings used in the terrain-feature identification task.

IN-FLIGHT MAP INTERPRETATION

I. Task

The pilots viewed a 16-mm motion picture of an NOE flight path at Fort Huachuca, Arizona. The exact flight path was known to the experimenters. The film consisted of two portions, one of very mountainous terrain and one of a region of low hills. The mountainous portion was 12 minutes in length and the hilly portion was 9.5 minutes in length. The pilots were requested to draw the aircraft's track on the contour map and, at six stop points in each portion of the film, to mark the aircraft's exact location with an "X." The correct flight paths and stop points are shown in Figure 8 and Figure 9 (using a 120-foot contour interval map).

II. Apparatus

The film was presented to the pilots via a Visual Instrumentation Corporation Selecta-Frame Model 16N-2 Projector with a 25-mm lens. The projected image area covered approximately 20° of visual arc. The angle of view of the terrain was 84°.

The maps were the same ones used by the pilots in the previous part of the experiment--each pilot used the *same* map, and was thus exposed to only one of the three contour intervals during the entire experimental session. Measurement aids were distributed to simplify finding starting point coordinates.

III. Procedure

The pilots remained in their seats after the conclusion of the terrain-feature identification task. The measurement aids were distributed and the instructions read for the in-flight map interpretation task. The pilots used the measurement aid to locate the starting point of the flight (corresponding to six-digit grid coordinates read by the experimenter). The film commenced and stopped at predesignated frames. The last frame of each flight segment was maintained on the screen for 10 seconds and then the projector was turned off. The pilots attempted to determine the point

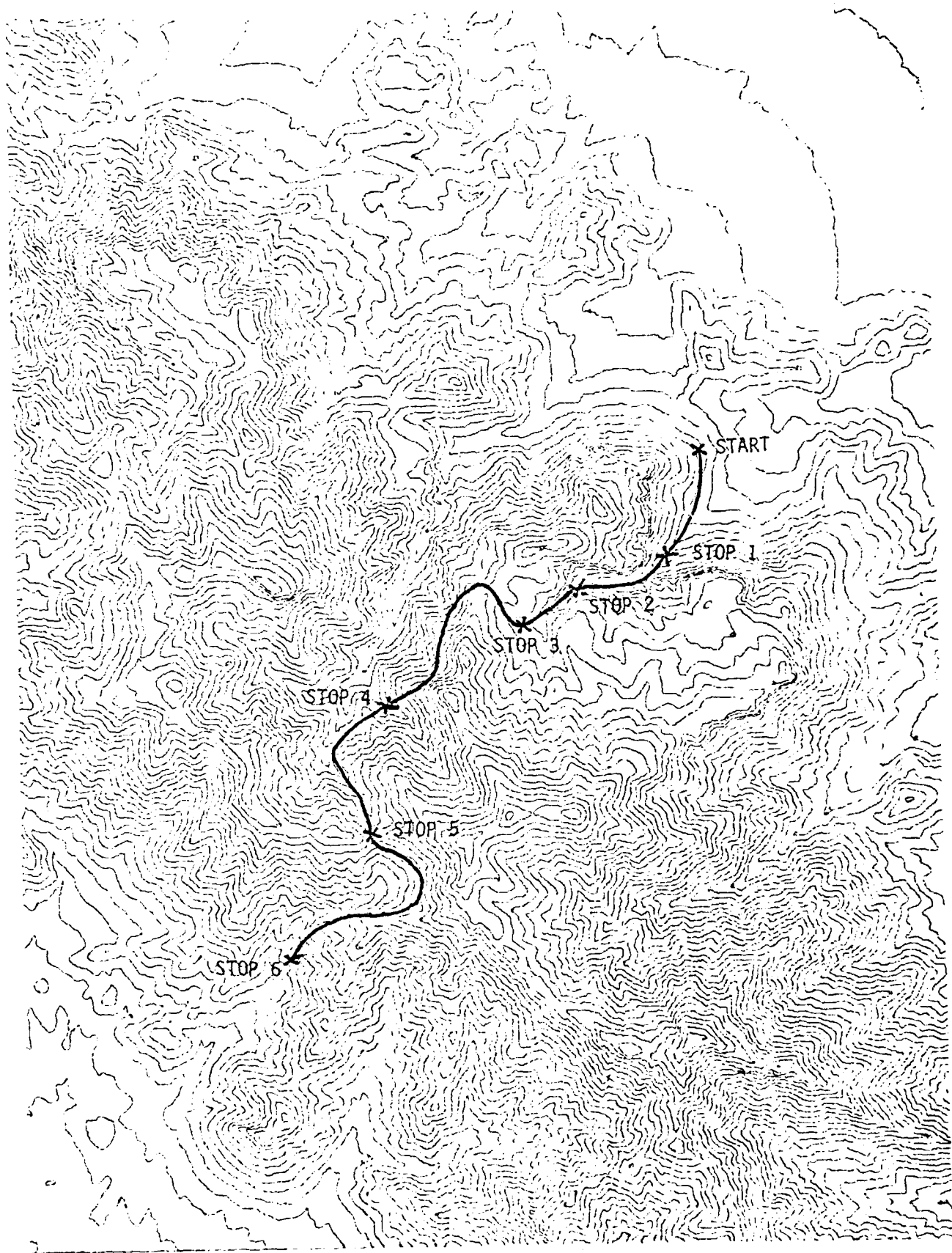


Figure 8. The flight path and stop points in the mountainous terrain portion of the in-flight map interpretation task.

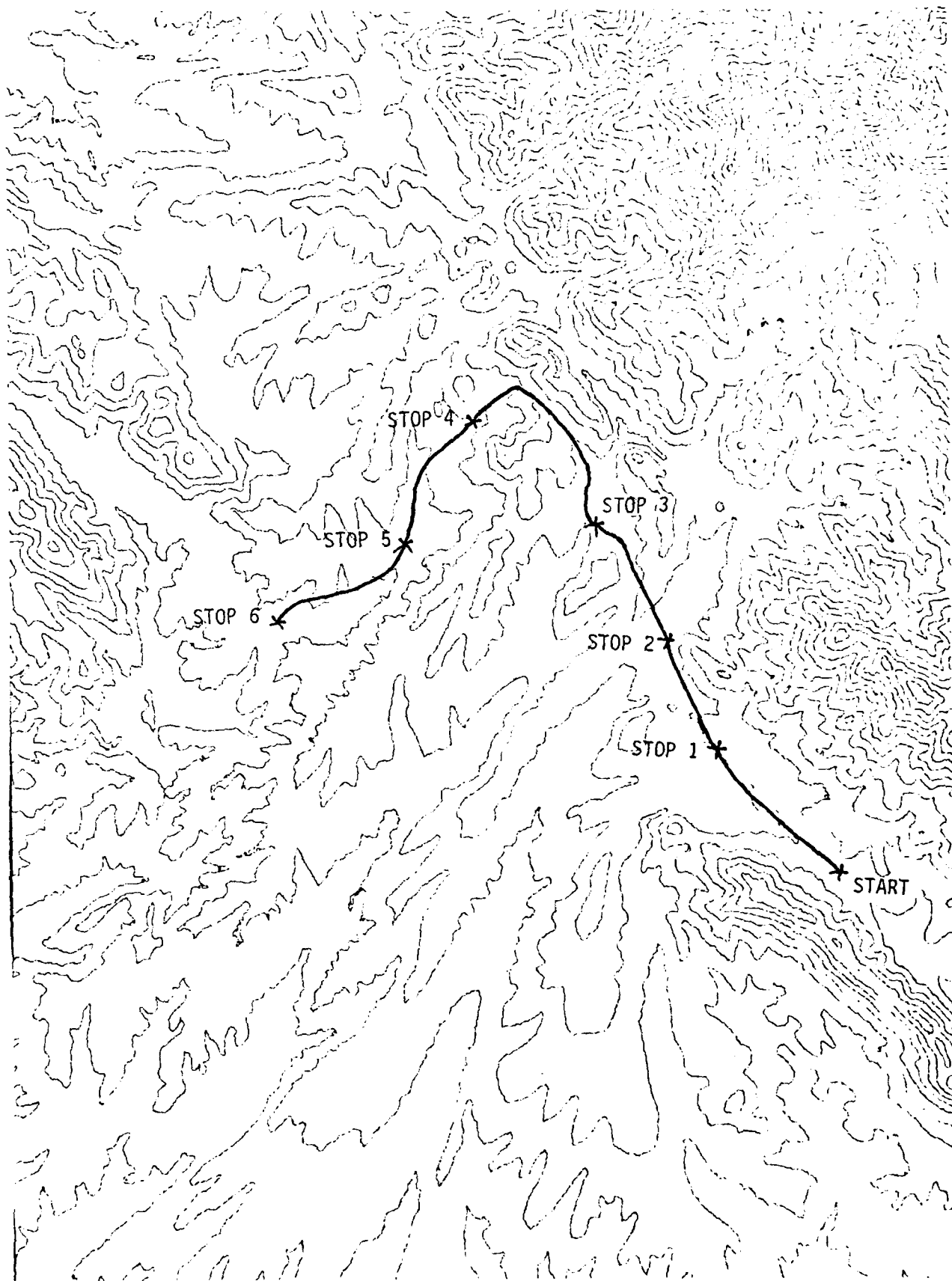


Figure 9. The flight path and stop points in the hilly terrain portion of the in-flight map interpretation task.

on the map corresponding to the ground position from which the last frame was recorded, and mark it with an "X." The experimenter then read the grid coordinates for the actual location of the frame and the pilots marked this point on their maps with an "O." This procedure assured that all pilots were reoriented for the beginning of every flight segment. The initial headings of each flight segment were provided to the pilots, but no further heading information was given during the segment, even when obvious course changes occurred. Flight segment durations and airspeeds were varied in order to deter dead-reckoning solutions. Flight durations varied between one and three minutes. Airspeeds varied between 16 and 39 knots (at a constant film rate of six frames per second). Inter-trial intervals were variable, lasting until each pilot had located the starting point for the upcoming flight segment.

CHAPTER 3

RESULTS

Scoring of the terrain-feature identification task was straightforward; multiple-choice selections were either correct or erroneous. Scoring of the in-flight map interpretation task was achieved by measuring the distance (in millimeters) between the correct map location of each stop and the map location indicated by the pilot's mark. The findings of primary interest, those bearing on the relationship between navigation performance and contour interval and between navigation performance and grid-point interval, are presented first. These findings are followed by other results which are useful in interpreting the overall patterns of performance.

TERRAIN FEATURE IDENTIFICATION

The average number of correct answers (out of eight possible) on the terrain-feature identification task and the standard deviation for each type of map sheet is shown in Table 2.

	CONTOUR INTERVAL			
	40	40X	80	120
MEAN NUMBER CORRECT	3.44	2.89	2.47	3.12
STANDARD DEVIATION	0.92	1.02	1.33	1.45

Table 2. Mean number correct on the terrain-feature identification task as a function of contour interval and grid-point interval.

It is very surprising that performance with a 40-foot contour interval was not, on the average, obviously superior to that using a 120-foot contour interval, yet inspection of the data showed that the best and worst scores were about equally distributed across the four map-sheet categories.

These data were submitted to a one-way analysis of variance which revealed no statistically significant differences between the mean performances using the four different types of map sheets.

It seemed possible that extreme simplicity or difficulty of some of the eight test items might have obscured the expected performance differences. Examination of the data showed some of the eight trials to be, in fact, considerably more difficult than others, as shown in Table 3. Nevertheless, examinations of only the most or least difficult trials, or only those of medium difficulty did not reveal any consistent trends in map-sheet superiority.

	TRIAL NUMBER							
	1	2	3	4	5	6	7	8
PERCENT CORRECT ANSWERS	9.2	68.4	18.4	31.6	56.6	38.6	38.6	15.8

Table 3. The percentage of correct answers obtained on each of the terrain-feature identification trials.

IN-FLIGHT MAP INTERPRETATION

The mean error distance, per stop, on the in-flight map interpretation task and the standard deviation for each type of map sheet is shown in Table 4. The average errors are shown as map distances, in millimeters, but it is useful to recall that each millimeter on the map is the scale equivalent to 50 meters on the ground.

	CONTOUR INTERVAL			
	40	40X	80	120
MEAN ERROR DISTANCE (mm)	9.48	9.48	8.76	9.94
STANDARD DEVIATION	10.35	8.77	8.86	9.70

Table 4. Mean error distance (per stop) on the in-flight map interpretation task as a function of contour interval and grid-point interval.

It is evident that the performances did not differ markedly as a function of contour interval. These data were submitted to a two-way, repeated measures analysis of variance using an unweighted means solution for unequal group size (Winer, 1971). This analysis showed no statistically significant differences between the performances on the four types of map sheets. As in the terrain-feature identification task, the obvious differences between the information presented on the various map sheets did not lead to any consistent differences in the pilots' performances.

Figures 10 and 11 show the dispersion of stop positions indicated by pilots using all four types of map sheets. It is apparent from examination of these figures that there was a very large range of skill exhibited by the sample population of pilots. In fact, the lowest average error by a pilot was 3.2mm whereas the highest was 22.7mm (both were using a 40-foot contour-interval map). It seemed possible that a number of extremely poor performances might be masking the differences between maps of differing contour intervals. For this reason, the analysis of variance was repeated using only the most skillful half of the pilots in each contour-interval group. Again, there were no statistically significant differences between performances on the four types of map sheets.

Finally, on the premise that differences might be more in evidence in hilly terrain or mountainous terrain alone, separate analyses of variance were performed on the data from the first and last six stops, including only the most skillful half of the pilots in each map-sheet group. These analyses, too, failed to show any significant differences between performances using the four types of map sheets, regardless of the type of terrain.

ADDITIONAL FINDINGS--TERRAIN-FEATURE IDENTIFICATION

It is interesting to consider how well the pilots might have done on the terrain-feature identification task by chance; that is, by pure guessing. This can be done by computing the binomial distribution for a one-in-four chance repeated eight times. The likelihood of certain numbers of correct answers is shown in Table 5.

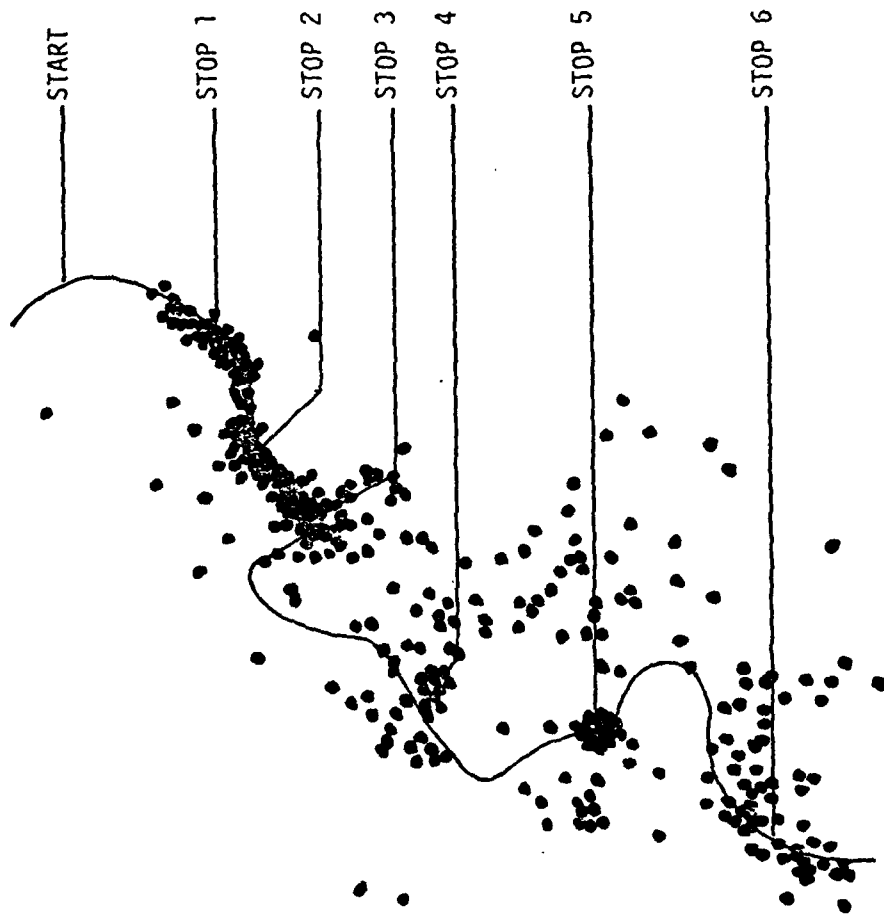


Figure 10. The actual flight path and stop points in the mountainous terrain, and the stop points as marked by the pilots.

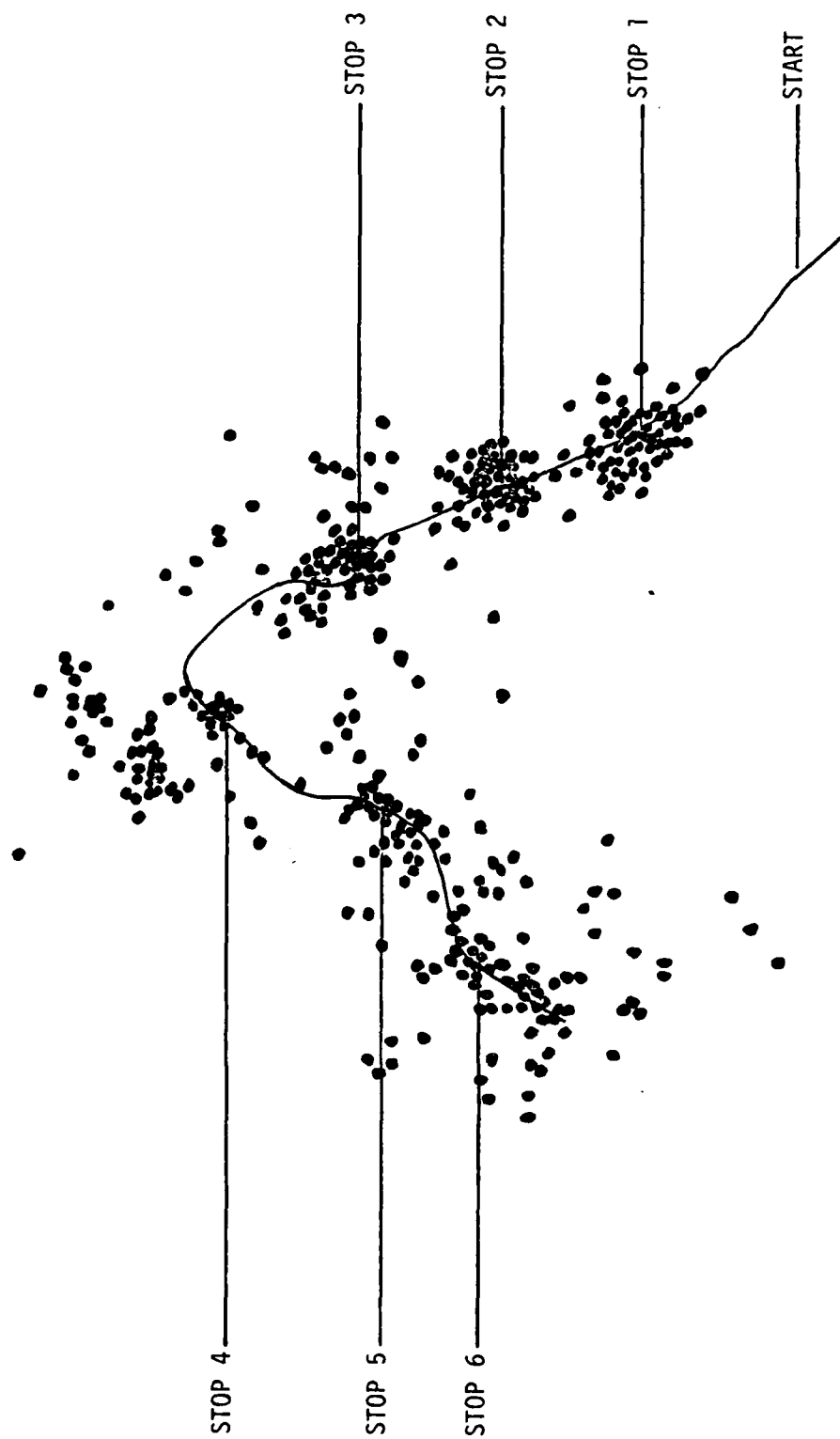


Figure 11. The actual flight path and stop points in the hilly terrain, and the stop points as marked by the pilots.

	NUMBER CORRECT								
	0	1	2	3	4	5	6	7	8
PROBABILITY	.100	.267	.312	.208	.086	.023	.004	.0004	.00002

Table 5. The probability of obtaining zero to eight correct answers by chance, given eight trials with one chance in four of a correct answer on each trial.

Multiplying these probabilities by 72 participants, the expected number of correct responses may be compared with the actual number achieved by the pilots, as shown in Table 6.

	NUMBER CORRECT						
	0	1	2	3	4	5	6
EXPECTED BY CHANCE	7.2	19.2	22.5	15.0	6.2	1.7	0.3
ACHIEVED BY PILOTS	3	7	15	21	21	4	1

Table 6. The numbers of individuals obtaining zero to six correct answers on the terrain-feature identification task, as expected by chance and as achieved by pilots in the experiment.

Performing a Pearson χ^2 test on this table² reveals the pilots' performance to clearly differ from chance ($\chi^2_{(4)} = 53.54$, $p < .001$). However, if one correct response is subtracted from each pilot's score, the distribution of correct responses would no longer significantly differ from a chance distribution. In short, the pilots, on the average, got only one more trial correct than they would have gotten by simply guessing at the correct responses.

Correlation coefficients were computed to evaluate the relationship between performances on the terrain-feature identification task and the number of hours of NOE flight experience accumulated by each pilot. The correlation coefficients are presented in Table 7.

²The expected and achieved values for six correct answers were excluded from the χ^2 test because they were too small to meet its statistical assumptions.

	CONTOUR INTERVAL			
	40	40X	80	120
r	.29	-.07	.22	.05

Table 7. Pearson product-moment correlation coefficients (r) expressing the relationship between NOE flight experience and performance on the terrain-feature identification task for each map sheet.

These correlations are quite low, indicating little relationship between hours of NOE flight experience and ability to select the correct answers in the terrain-feature identification task, regardless of the map sheet used.

ADDITIONAL FINDINGS--IN-FLIGHT MAP INTERPRETATION

The four analyses of variance performed with data from the in-flight map interpretation task did not reveal significant differences in performance attributable to contour interval or grid-point interval. There were, not surprisingly, strongly significant differences between performances at the various stops, as was shown by each of the four analyses of variance. The average error ranged from 4.6mm on the least difficult stop to 16.7mm on the most difficult stop. It is evident from Figures 10 and 11 that the pilots' marks are much more tightly clustered around some stops than others. A detailed examination of performances at each stop is included as Appendix A. In general, it may be said that differences in performance at the various stops are attributable to the presence or absence of very obvious terrain features and the opportunities available for use of dead-reckoning information.

It is important to note, however, that in the four analyses of variance, the two-way interaction (contour interval and stop) was never near statistical significance. In other words, the lack of a relationship between performance on this task and the map sheet used, held true regardless of the difficulty of the stop. Just as real differences were not masked by the erratic performances of the less-skilled half of the pilots, neither were they masked by various levels of difficulty at the 12 stops.

Correlation coefficients were computed to examine the relationship between performances on the in-flight map interpretation task and the

number of hours of NOE flight experience accumulated by each pilot. The correlation coefficients are presented in Table 8.

		CONTOUR INTERVAL			
		40	40X	80	120
r	AREA				
	MOUNTAINOUS	-.10	.67	-.31	-.01
	LOW HILLS	.27	.15	-.35	-.13

Table 8. Pearson product-moment correlation coefficients (r) expressing the relationship between NOE flight experience and performance on the in-flight map interpretation task for each map sheet.

If NOE experience had been strongly related to the ability to perform this task, these coefficients would have been large, and negative (indicating less error with greater experience). Instead, only five were negative, and these were small. It appears that skill in in-flight map interpretation (as measured by this test) was not consistently related to NOE flight experience.

SUMMARY OF RESULTS

Neither the terrain-feature identification task nor the in-flight map interpretation task produced results linking performance level with variation in contour interval or grid-point interval. Performances ranged widely in accuracy and, on the average, were less than excellent. Performance levels were not predictable from the pilots' hours of NOE experience.

CHAPTER 4

DISCUSSION

The failure to identify any significant differences among performances attributable to the different contour and grid-point intervals is startling. The sample of pilots was large, two different types of tasks were employed, two different types of terrain were studied, and visible differences among the four map sheets were abundantly in evidence. How can it be that no significant differences emerge? The answer is clearly *not* that contour interval and grid-point interval are unimportant to NOE navigation. Such a conclusion would only be logical if performances were extremely good regardless of the map sheet used. Instead, the performances were mostly quite poor with all map sheets.

There are two reasons why no differences were shown among performances on the different map sheets: variation in skill level among pilots, and generally poor overall performance. These two factors effectively precluded the expected differences among groups.

Consider, for a moment, an analogous experiment testing the differences among race cars. Random passers-by near the track are invited to drive a lap in one of several cars, attempting to complete the lap in the minimum possible time. Since the range of driving skill would vary a great deal in such an experiment, the final lap times would tell much more about the drivers' skills than about the quality of the cars. And, since the racing skills would be relatively low, few drivers would be able to take full advantage of special transmissions, suspensions, and so forth, so these differences among cars would not be reflected in the lap times.

This analogy is quite direct. The helicopter pilots did vary greatly in skill level, and the average skill level was too low to enable most of the pilots tested to make full use of the wealth of information available in the maps. As a result, the important differences among map sheets were not reflected in the error data.

The poor performances were quite unexpected--the pilots were experienced, and most had been selected as instructors. On the other hand, the maps in this experiment are different from any others the pilots had used, in that only terrain relief information was provided. No cultural, hydrographic, or vegetation features were depicted; nothing but contour lines was printed on the map sheets. Certainly navigation is simplified when pilots can reference roads, streams, tree lines, and other such information on the ground with symbols on the map.

Furthermore, the in-flight map interpretation task was designed to deter "dead-reckoning"--the estimation of current position from course, speed, and time since the last positively identified checkpoint--to induce the pilots to rely on map interpretation and terrain analysis. Reduction of dead-reckoning information (by withholding airspeed and heading information) might well be expected to have a negative impact on navigation performance.

Unfortunately, it was not possible to completely eliminate all potential cues for dead-reckoning. Pilots could estimate airspeed and heading changes from the motion pictures, and could estimate or actually measure elapsed time. Awareness of the opportunities for intermittent use of dead-reckoning is critical in understanding the results of the in-flight map interpretation task. A complete review and analysis of performances at each of the 12 stop points, using each of the four map sheets, is provided in Appendix A. This review and analysis indicated that performances were best when flight segments ended at extremely obvious terrain features and when dead-reckoning solutions were applicable. When neither of these conditions were met, performances suffered greatly.

Some of the pilots, concerned by their own poor performances, commented that the experimental tasks were not fair, realistic tests of their navigational abilities. The comments usually fell in one of three categories: (a) the fields of view were too restricted--180° or even 360° would have to be used to represent actual flight conditions; (b) pilots don't fly without instruments--airspeed and heading information are always

available to aid navigation; and (c) roads, streams, and other such features are always shown on maps.

It is true that a pilot has more than a 64° or 84° field of view from his aircraft. The terrain visible within these fields, however, was rich with contour information. Adding a greater field of view would primarily have provided more opportunities for the pilots to locate an extremely obvious terrain feature so that map interpretation and terrain analysis would have been greatly simplified or unnecessary.

It is also true that airspeed and heading information is available in the aircraft. However, tactical missions often require many changes of course and speed so that dead-reckoning becomes nearly impossible. Furthermore, once disoriented, heading and speed information is of little help in reorientation.

Finally, it is true that most maps have cultural, hydrographic, and vegetation symbols to aid navigation. But, in combat conditions, there may be few of these features present, and their use as course checkpoints may be tactically inadvisable. Only terrain relief is nearly always available for use as a geographical reference.

The fact that NOE experience was not correlated with ability to perform the experimental tasks seems to indicate that pilots are not practicing terrain relief analysis and map contour-line interpretation, but are depending upon cultural, hydrographic, and vegetation features (as well as area familiarity) during their NOE flights.

Overall, if the experimental tasks were unrealistic, they may have been easier than those required during an actual NOE mission. The pilots had no concerns with any tasks except navigation and the visible terrain contained a great deal of information. The airspeeds were not particularly fast during the in-flight task, and the pilot received exact coordinates, specifying his position every one to three minutes. In addition, the two different experimental tasks were employed so that the pilots would have, in one case, the advantage of long periods of time for correlating terrain features and their representations on the map and, in the other case, the

advantage of knowledge of the flight path history. Finally, evidence that the tasks were not unreasonably difficult is provided by the several pilots who performed them with very little error.

CONCLUSIONS

The objectives of this experimental study were to determine the ability of experienced NOE pilots to perform NOE navigation using maps which depict only terrain relief, and to determine the performance decrements attributable to increasing the contour interval and grid-point interval of these maps. The conclusions of the study follow.

1. *The typical NOE pilot would not be able to perform NOE navigation to the required level of accuracy using a topographic display which portrayed terrain relief and no other topographic features.* The minimum standard expected for navigational accuracy is 100 meters. The average error at measured points in this experiment was about 500 meters, and ranged up to about 5,000 meters.

2. *Contour interval and grid-point interval, over the ranges studied, and the terrain and pilots sampled, exert no measurable influence on NOE navigation performance.* Because the pilots' terrain-relief analyses and contour-line interpretation skills varied greatly and were generally inadequate, the differences in information provided by different contour intervals and grid-point intervals were not sufficient to produce corresponding differences in the NOE navigation performances.

3. *Contour interval and grid-point interval, if tested only with highly skilled participants, would be almost certain to have a marked impact on NOE navigation performance.* There were vast differences between pilots in terrain-relief analysis and contour-line interpretation skills. Some were quite proficient in maintaining orientation by relating landforms on the ground to those depicted on their maps. If a group of such proficient pilots were to be established by intensive training to an asymptotic level of performance and additional experiments conducted, it is extremely likely that the contour interval and grid-point interval of maps would be

shown to influence NOE navigation performance. The magnitude of these performance differences, however, cannot be predicted on the basis of the knowledge now in hand.

4. *If a computer-generated topographic display is to be acceptable and useful to the average pilot today, it must include more information than terrain relief alone.* Some combination of cultural, hydrographic, and vegetation features will be needed to supplement contour data on displays used for NOE navigation. It was anticipated that such information would be necessary in exceedingly flat areas, but it is now clear that it is needed even when terrain contour is more pronounced. The features to be depicted, the criteria governing their selection in various circumstances, and the methods for their encodement, are all subjects requiring additional research.

5. *Helicopter pilots expected to perform NOE tactics urgently need additional training in terrain-relief analysis and contour-line interpretation, regardless of their previous NOE flight experience.* The levels of these skills are generally inadequate in groups of pilots averaging over 200 hours of NOE flight, and are apparently unrelated to the specific number of hours of NOE experience a pilot has accumulated. It is recommended that additional training be undertaken employing map sheets such as those used in this experiment, i.e., with contour lines only, so that pilots will have no other option than to scrutinize the relief information on the map and relate it to landforms on the ground.

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APPENDIX A

REVIEW AND ANALYSIS OF PERFORMANCES ON THE IN-FLIGHT MAP INTERPRETATION TASK

Statistical analyses of absolute error levels cannot fully convey the nature of the difficulties experienced by the pilots in attempting to perform the in-flight map interpretation task. In order to provide more specific quantitative and qualitative information to the reader, this appendix provides a review and analysis of task conditions and performances at each of the 12 stop points, using each of the four map sheets.

Figures 8 and 9 in Chapter 2 show the entire flight path and all stop points in the mountainous and hilly portions of the task. The 12 figures presented in this appendix each present a limited part of the flight path, superimposed on sections of the four different map sheets. The correct locations of the stop points are identified by straight lines intersecting the flight paths. The stop points, as identified by the pilots, are depicted by dots on the map sheet section corresponding to the contour interval and grid-point interval used by each pilot. The following narrative describes conditions and performances illustrated by the 12 figures.

The first segment of the filmed flight began in mountainous terrain on the side of a steep slope with the aircraft heading due south. The flight path curved around to the southwest, extending for a total distance of 1,200 meters. The average aircraft speed was 39 knots. The flight was directly into the mouth of Carr Canyon, with steep walls rising hundreds of feet on either side. It is not surprising, then, that the pilots showed relatively little lateral error in estimating the aircraft position. On the other hand, their fore-aft error was extensive, often ranging out to 1,000 meters ahead of their actual location. It is noteworthy that the majority of the errors were ahead rather than behind the correct location. When the pilots were advised of the coordinates of their actual location, many evidenced surprise and remarked that they were not used to flying so slowly. These errors, and the accompanying remarks, were the first

evidence that many of the pilots were attempting a dead-reckoning solution to the navigation task rather than one of terrain analysis and map interpretation.

The flight between the first and second stops was relatively short and slow--950 meters at 19 knots. The course continued to the southwest still tightly bounded by the steep canyon walls. Again, the pilot errors were primarily in the fore and aft axes of the flight path.

From Stop 2, the flight path continued in a southwesterly direction at an average speed of 17 knots, and for a distance of 600 meters. At this point in the flight, the narrow canyon began to open up into a broad area of considerably less steep slopes. With the canyon walls no longer bounding the flight path, the lateral errors increased markedly. The fore-aft errors were still strongly in evidence.

From Stop 3 to Stop 4, the navigation task became more difficult for three reasons: longer flight duration, more heading changes, and less obvious terrain features. The average aircraft speed was 26 knots over a distance of 2,250 meters, including three significant heading changes. The course first turned right to a northwesterly heading, then dropped over a ridge and turned to a southwesterly heading. It then continued over a series of ridges and draws, bending to the right once more before arriving at Stop 4. The turns and duration of this particular segment of the flight made a dead-reckoning approach to navigation difficult and the pilots' performance was exceedingly poor. The errors in locating aircraft position ranged out to 5,000 meters (not shown in the figures). Errors exceeding 2,000 meters were not uncommon.

From Stop 4 to Stop 5, the course progressed to the southwest taking a turn toward the southeast, at an average speed of 16 knots. The length of the segment was 1,550 meters. This is an interesting flight segment because the dead-reckoning approach was somewhat frustrated by the turn in the course (a number of pilots selected the wrong canyon). On the other hand, the segment ended at a pronounced and easily recognizable terrain feature--a saddle. As a result, the fore and aft errors were nearly

eliminated. Most of the errors were those of pilots who selected the wrong canyon and simply marked the most likely appearing saddle when they saw the situation of Stop 5. Saddles up to 3,500 meters away from the correct location were selected in some instances.

The flight from Stop 5 to Stop 6 was 2,400 meters in length and was flown at an average speed of 32 knots. The segment began on a southerly heading, then bent sharply to the left and began a long semi-circular turn to a westerly heading, then continued on a long curving turn to a southerly heading. Like Stop 4, this flight segment foiled a dead-reckoning approach by its turns, and failed to end at an extremely obvious terrain feature. As a result, the errors were quite large, often extending to beyond 3,000 meters from the correct checkpoint location.

In the second portion of the task, in hilly terrain, the distance between the start of the course and Stop 1 was 1,650 meters, flown at an average speed of 33 knots. The course began on a northwesterly heading and made several very subtle turns, stopping in a broad flat area. The errors at this point were small and seemed to be evenly dispersed around the correct checkpoint.

The route from Stop 1 to Stop 2 continued on a northwesterly heading with almost no heading changes. The length of this segment was 1,150 meters and it was flown at an average speed of 31 knots. Since it continued at the same speed and heading as the last segment, this segment was an ideal one for dead-reckoning. Thus, it is not surprising to see a very tight pattern of checkpoint marks, with relatively little error. It is noteworthy that this stop offers very little in the way of terrain features to help achieve such accuracy.

From Stop 2 to Stop 3, the course continued on a northwesterly heading for a distance of 1,350 meters, flown at an average speed of 33 knots. Before the end of this segment, the aircraft made a shallow left turn. The terrain features were somewhat more easily identifiable at Stop 3 than Stop 2, so the error pattern should have been smaller if navigation had been based on map interpretation, or larger if navigation had

been based on dead-reckoning and was disrupted by the turn. It is evident that the error pattern at Stop 3 was larger than that of Stop 2.

Stop 4 in the hilly terrain was somewhat similar to Stop 4 in the mountainous terrain, in that the flight segment preceding this stop was a relatively long one (2,150 meters), there were three significant turns, and the terrain features present were not extremely obvious ones. Thus, it is not surprising to find that the error pattern around the correct checkpoint location was extremely large. Errors of 2,000 meters or more were quite common. It again seems likely that this level of performance was due to the failure to properly interpret the map, and to rely instead on a dead-reckoning solution which was rendered inaccurate by changes to unknown headings. Average airspeed for this portion of the flight was 31 knots.

From Stop 4 to Stop 5, the course progressed in a southwesterly direction for a distance of 1,450 meters, at an average speed of 31 knots. The course bent slowly to the left and then somewhat back to the right. Since the course followed an obvious stream bed (the lowest portion of the terrain), the lateral errors were less extensive than the fore-aft errors, except in the case of the 120-foot contour interval map sheet, in which it is difficult to determine the lowest terrain.

From Stop 5 to Stop 6, the course began on a southwesterly heading, left the stream bed, bent to the right and then back to the left over a distance of 1,500 meters, at an average airspeed of 30 knots. The terrain in this area was relatively difficult to analyze due to its low slope gradients, and a dead-reckoning approach was difficult because of the turns. It is not surprising, then, to see a very large error pattern emerging at Stop 6. The errors fan out in all directions from the actual checkpoint, although they are predominantly ahead of the true location.

In summary, these data show that performances were best when navigating near extremely obvious terrain features, or when dead-reckoning solutions were applicable. When terrain in the surrounding area was not unmistakable, or when the course curved and the flight continued for two minutes or more, disorientation was likely to occur. Had the pilots been less dependent on

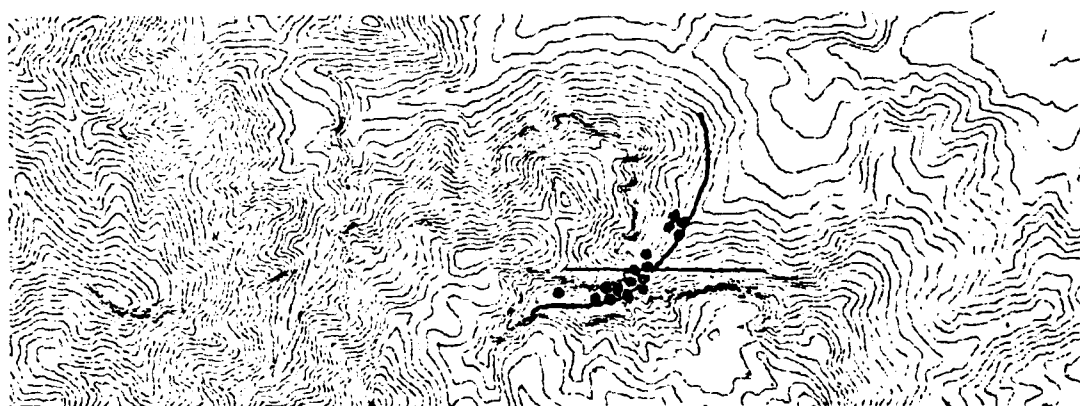
obvious terrain features and dead-reckoning, and more skilled in terrain-relief analysis and map contour-line interpretation, the number and magnitude of errors could have been sharply reduced, as was shown by the few pilots who performed consistently well.



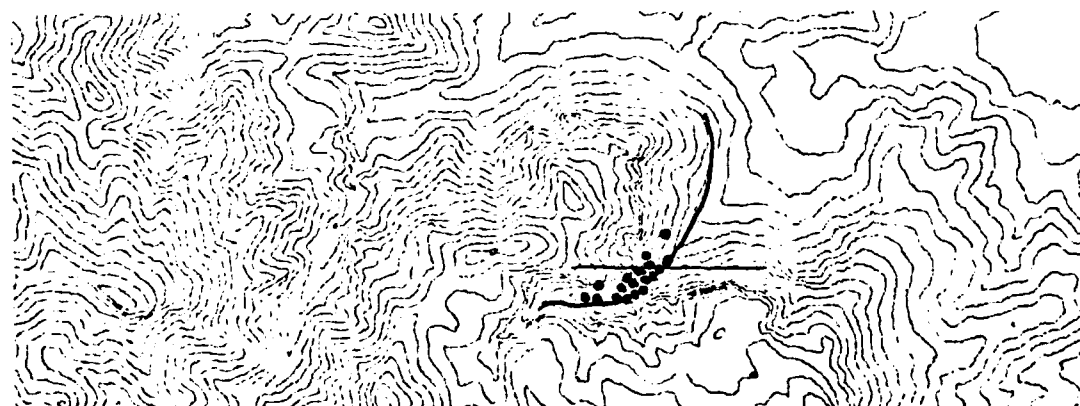
40



40X



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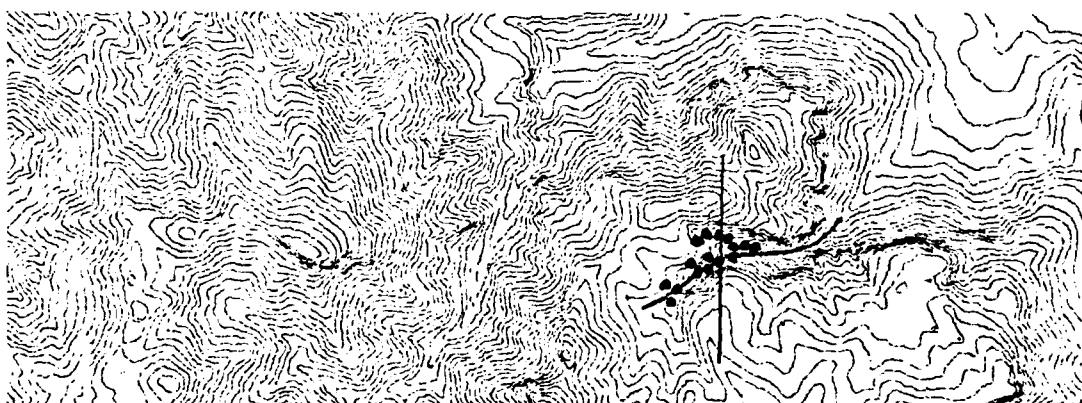
Figure 12. Mountainous terrain--Stop 1.



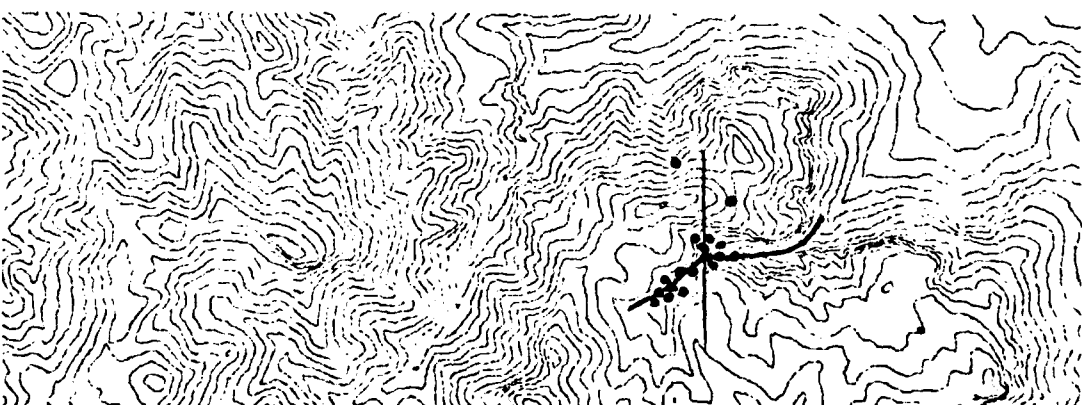
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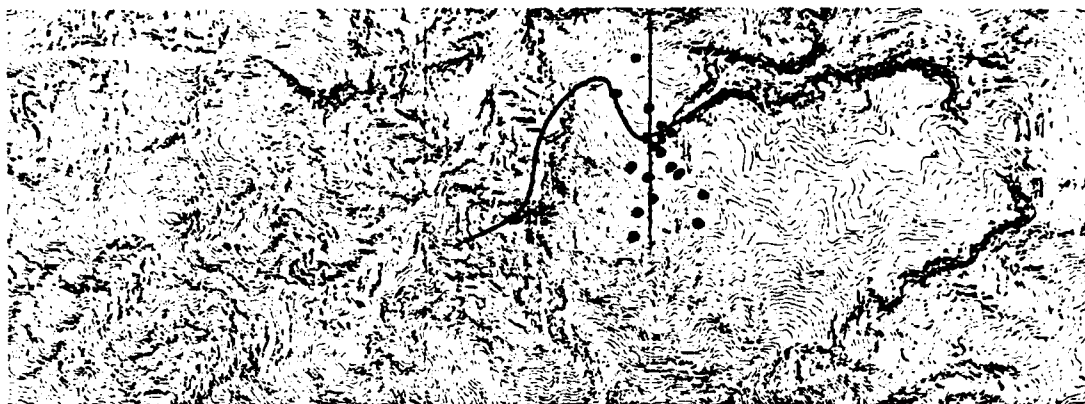


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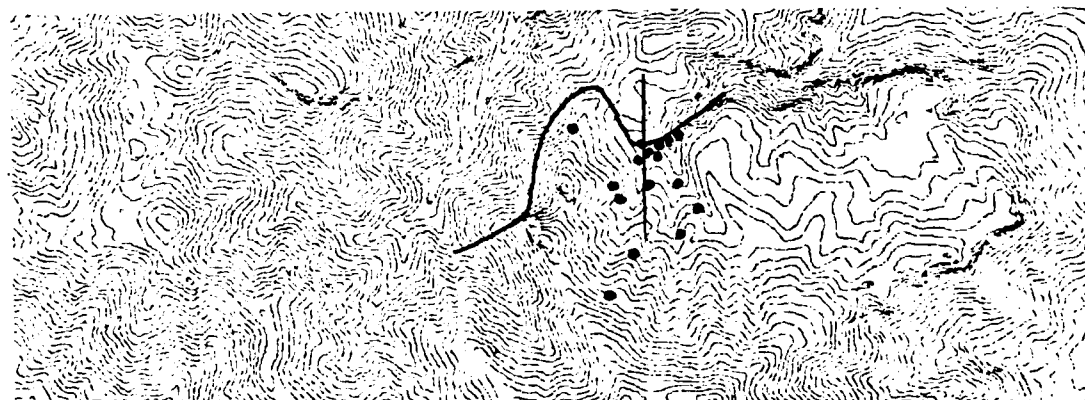
Figure 13. Mountainous terrain--Stop 2.



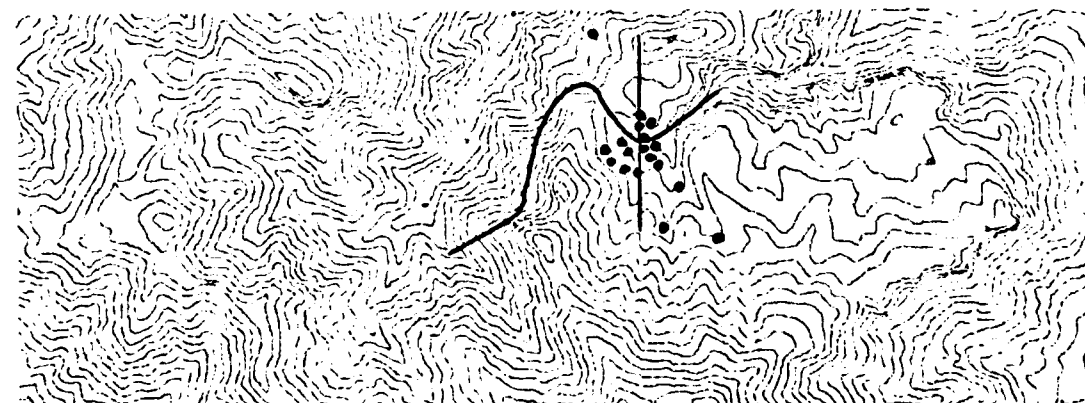
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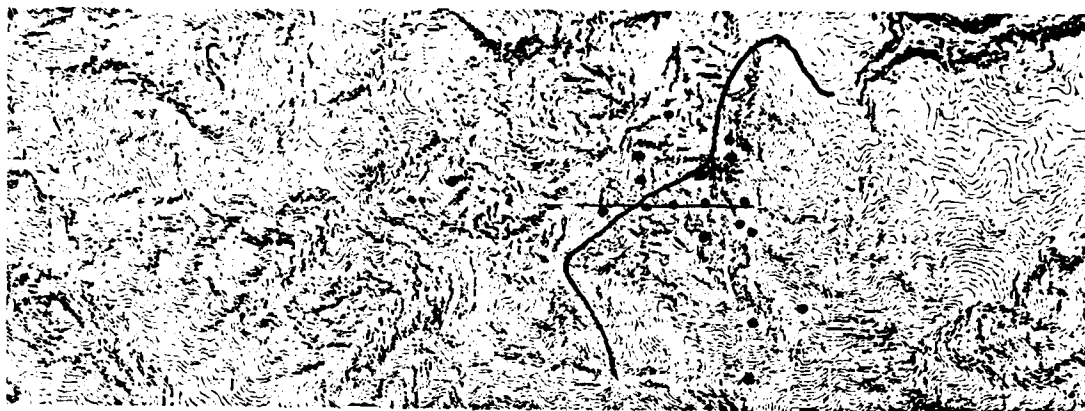


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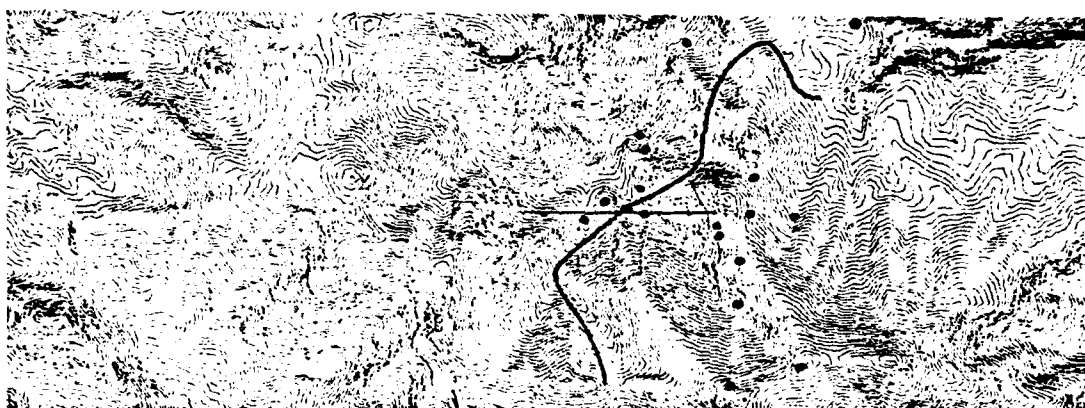


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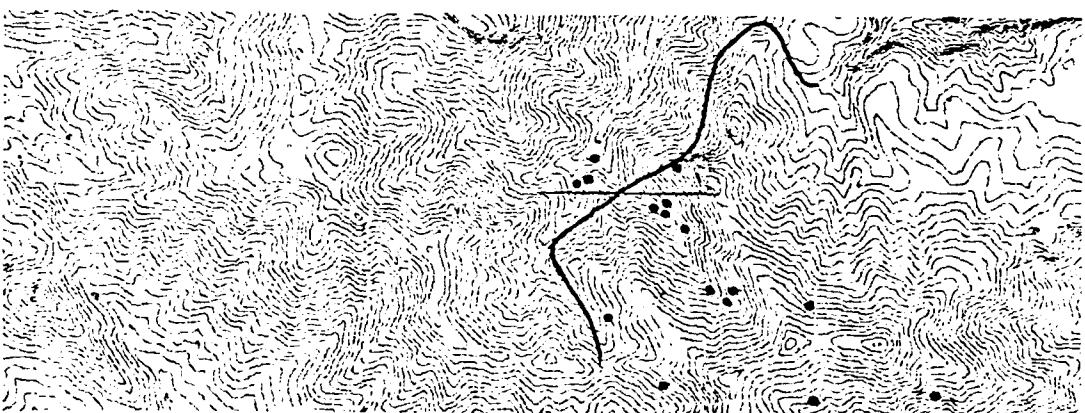
Figure 14. Mountainous terrain--Stop 3.



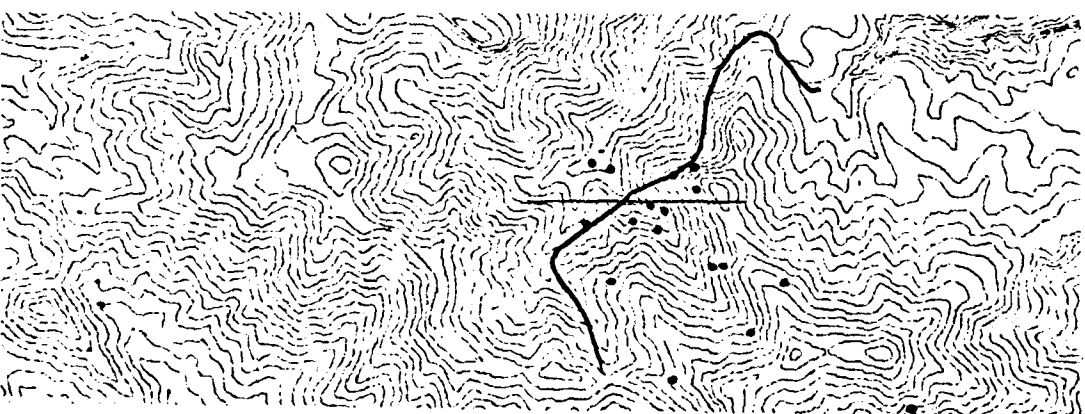
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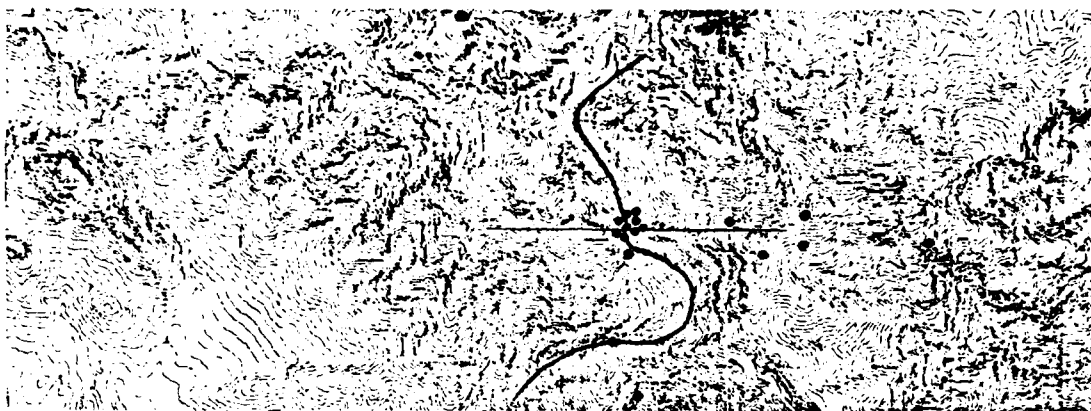


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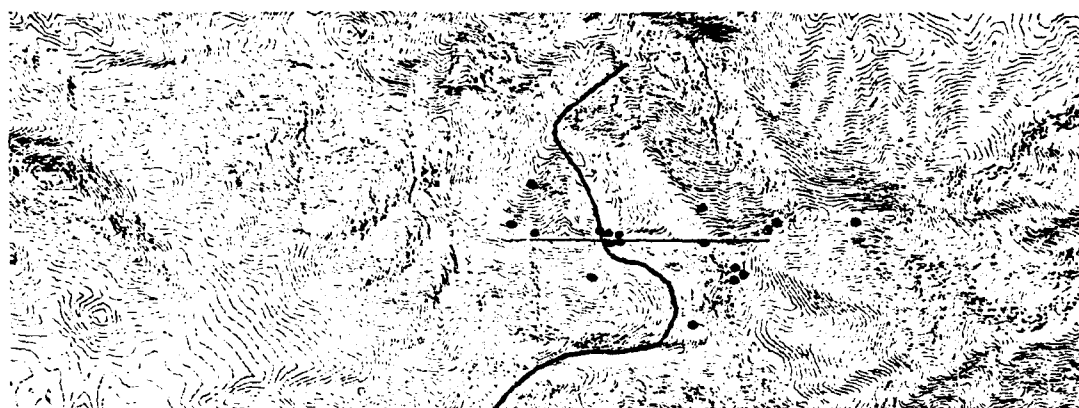


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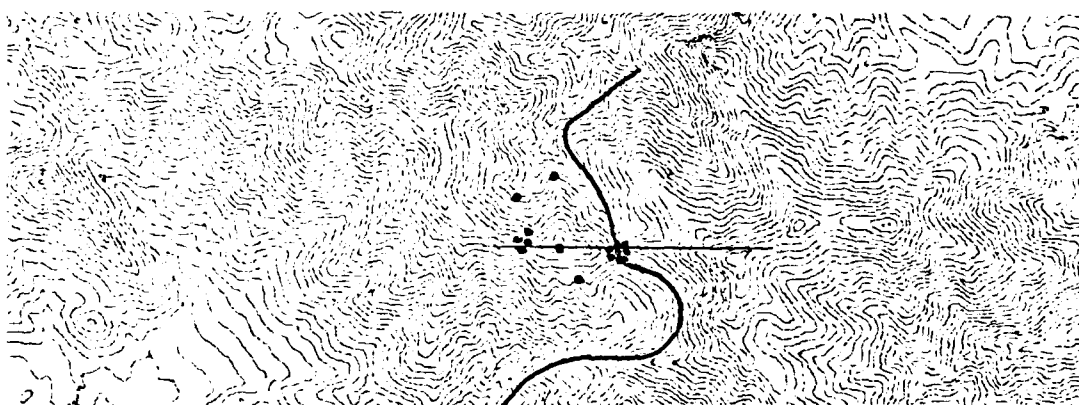
Figure 15. Mountainous terrain--Stop 4.



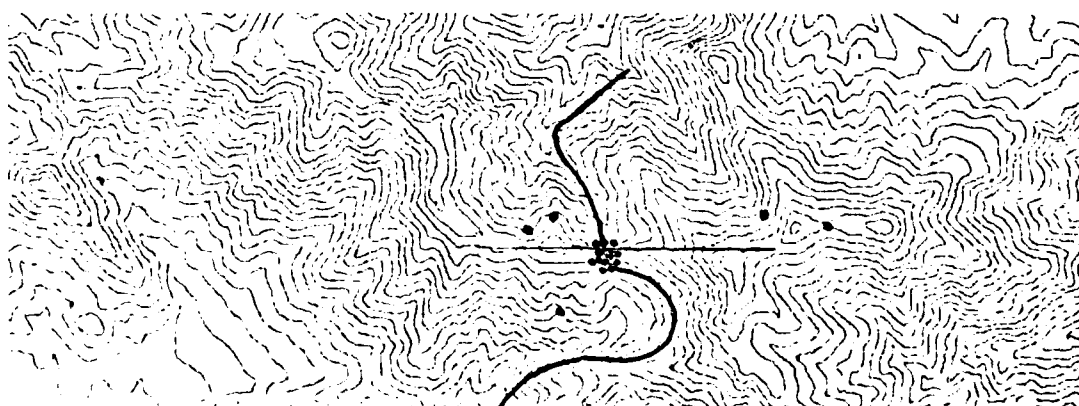
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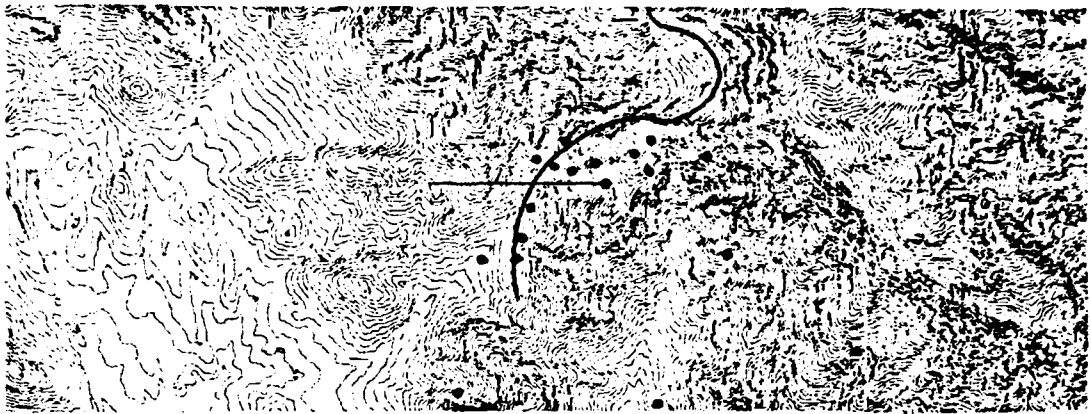


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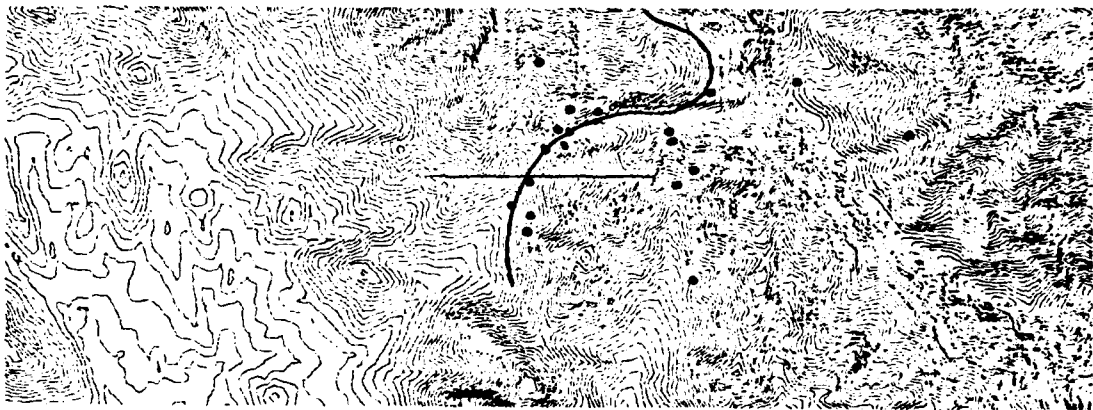


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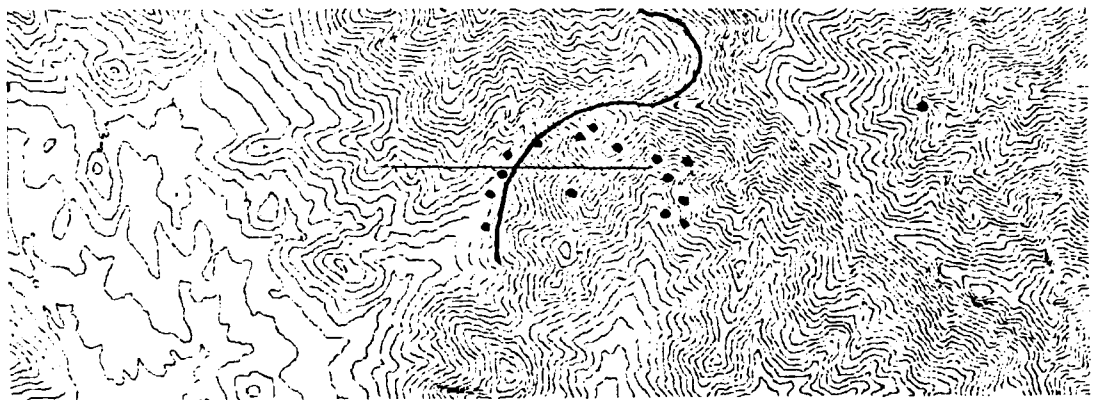
Figure 16. Mountainous terrain--Stop 5.



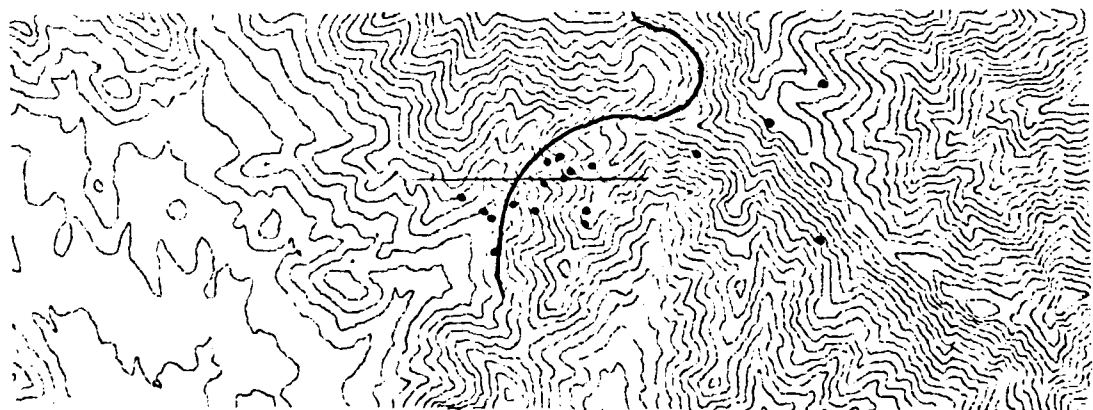
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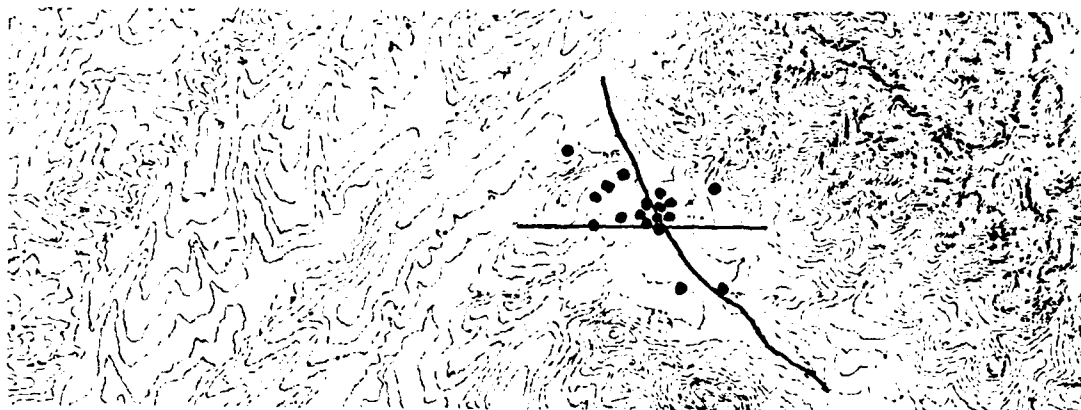


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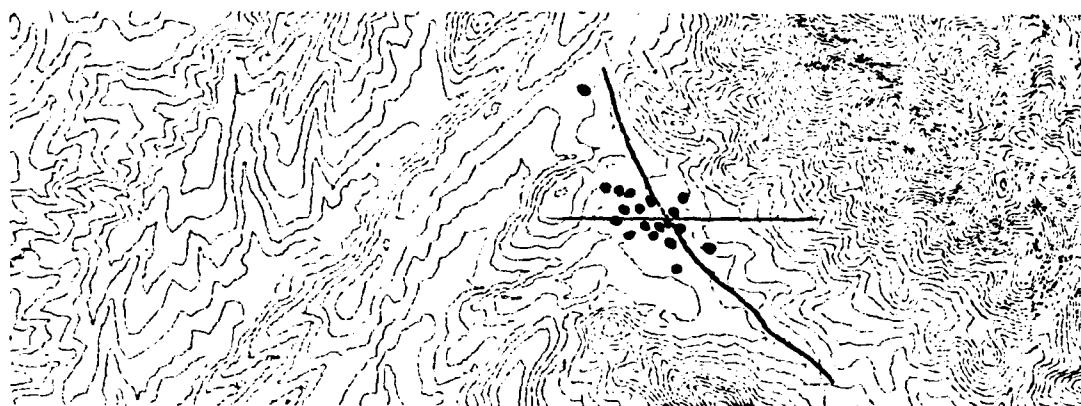


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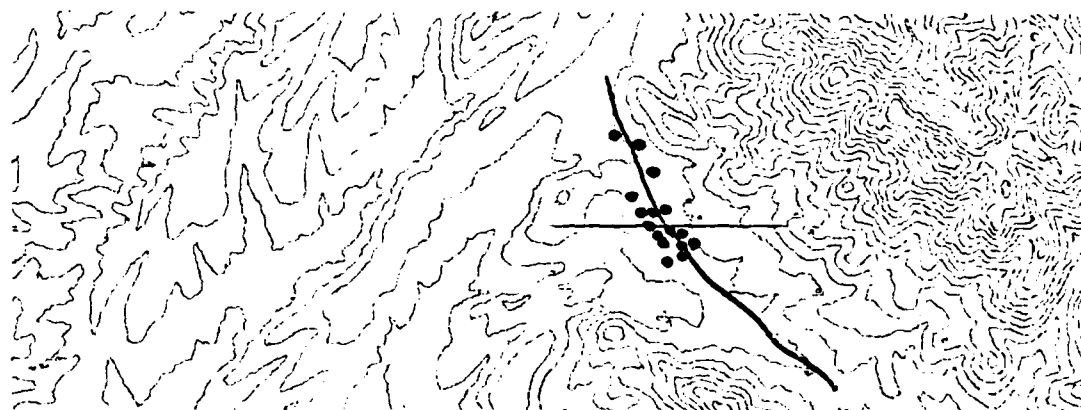
Figure 17. Mountainous terrain--Stop 6.



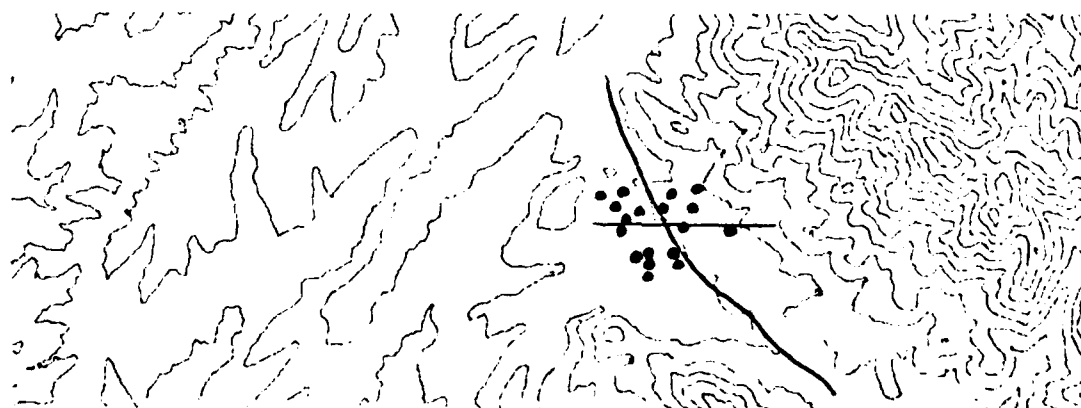
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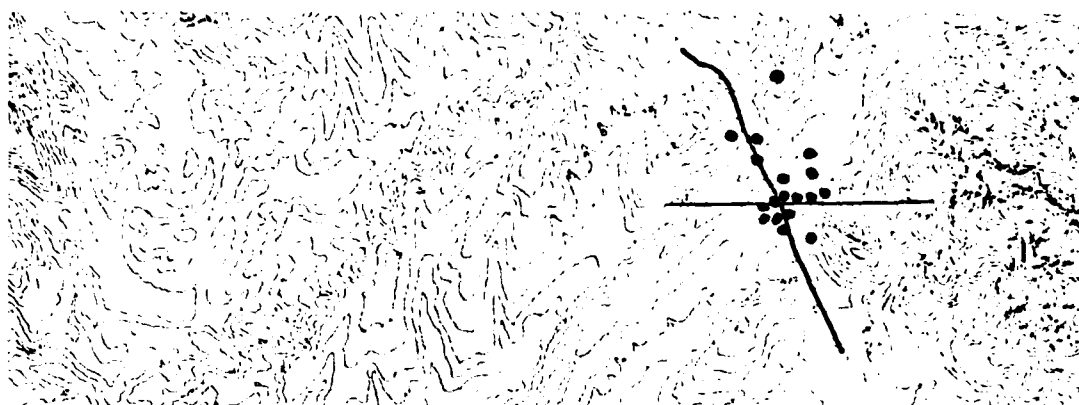


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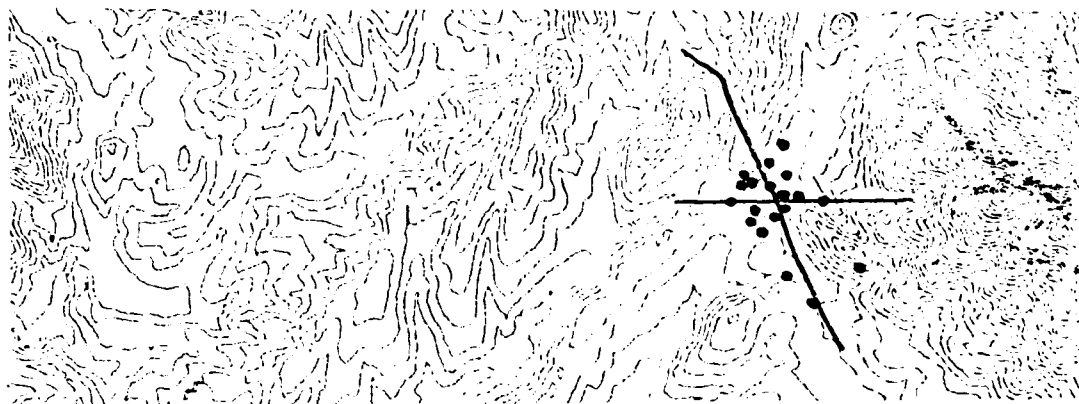


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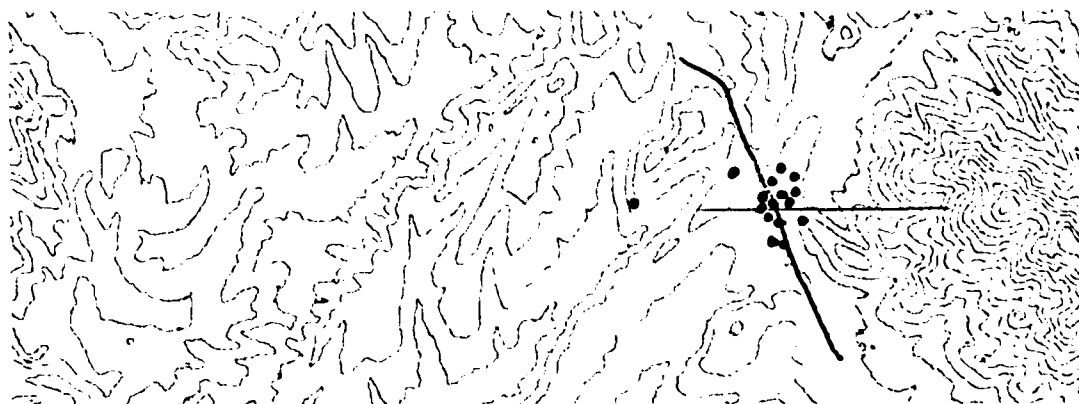
Figure 18. Hilly terrain--Stop 1.



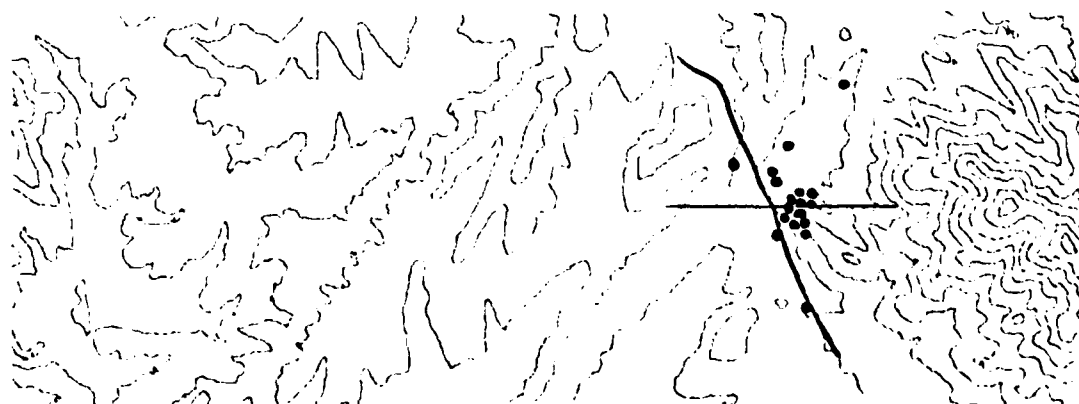
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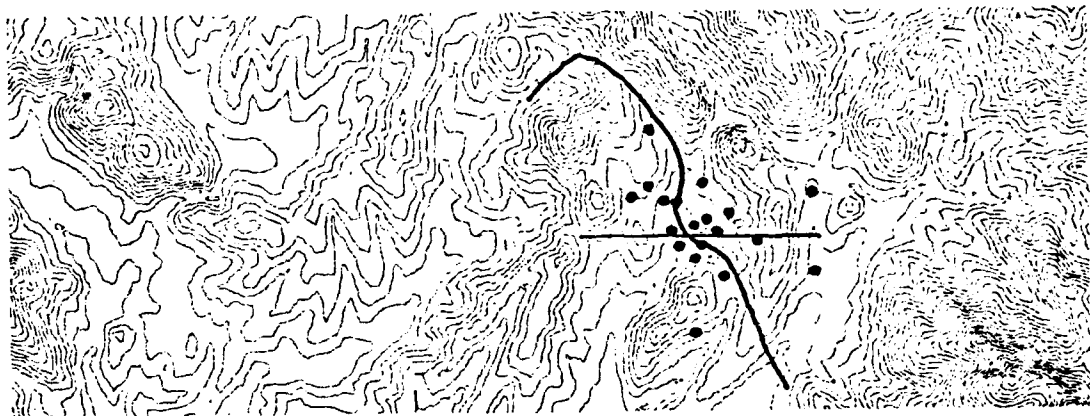


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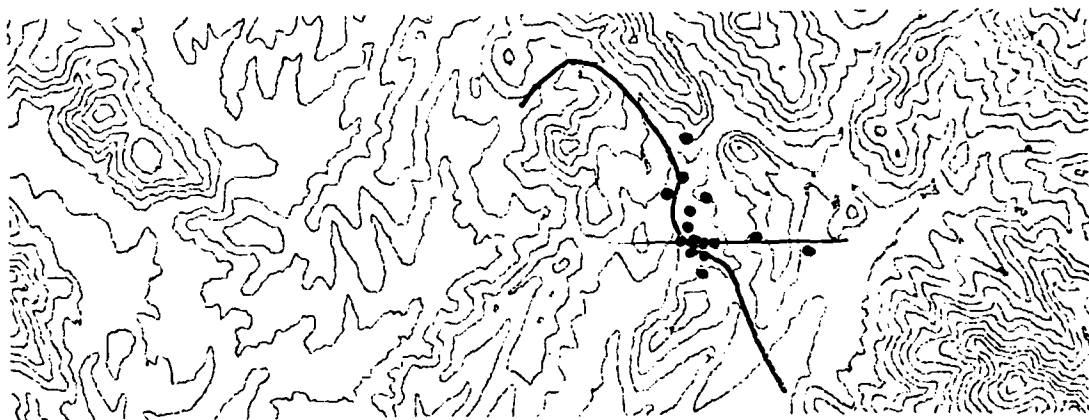
Figure 19. Hilly terrain--Stop 2.



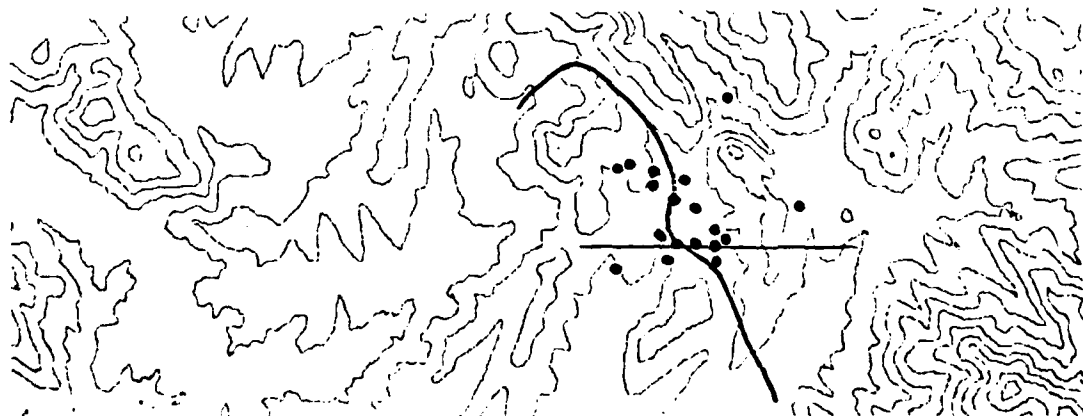
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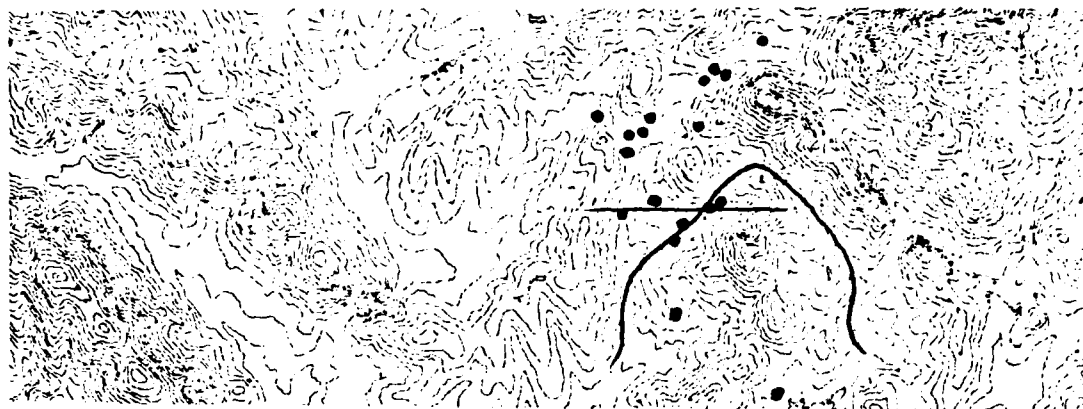


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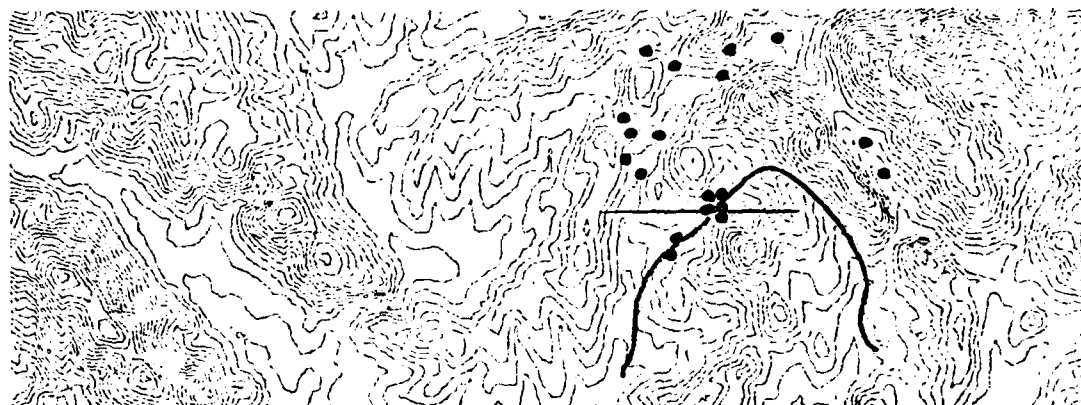


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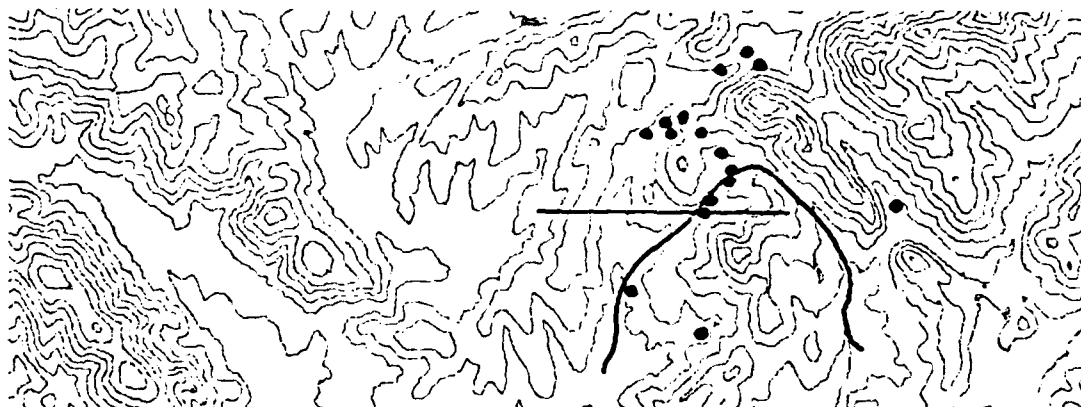
Figure 20. Hilly terrain--Stop 3.



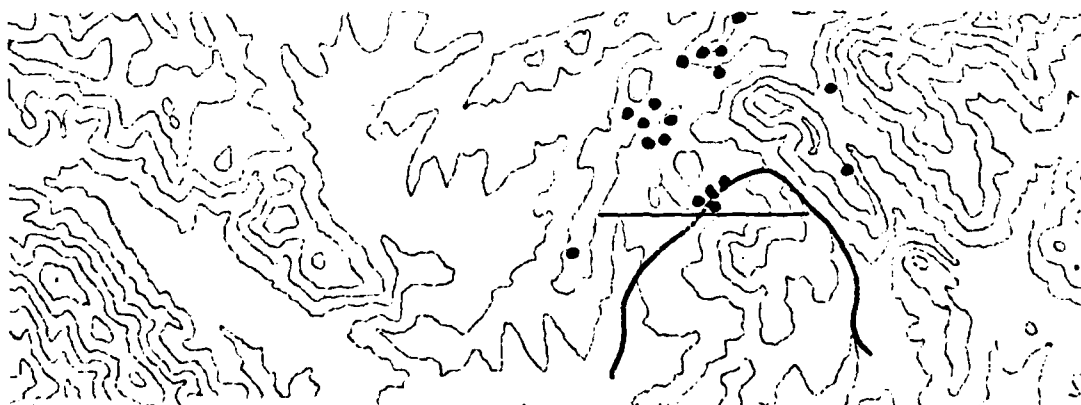
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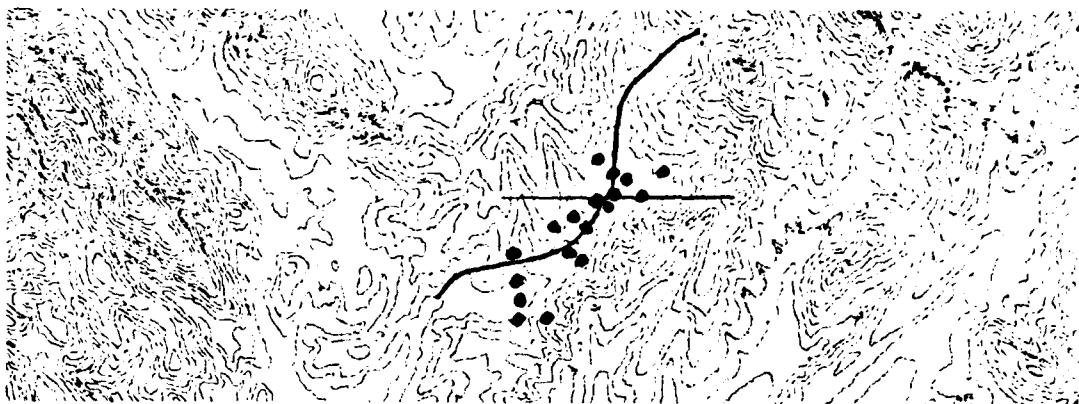


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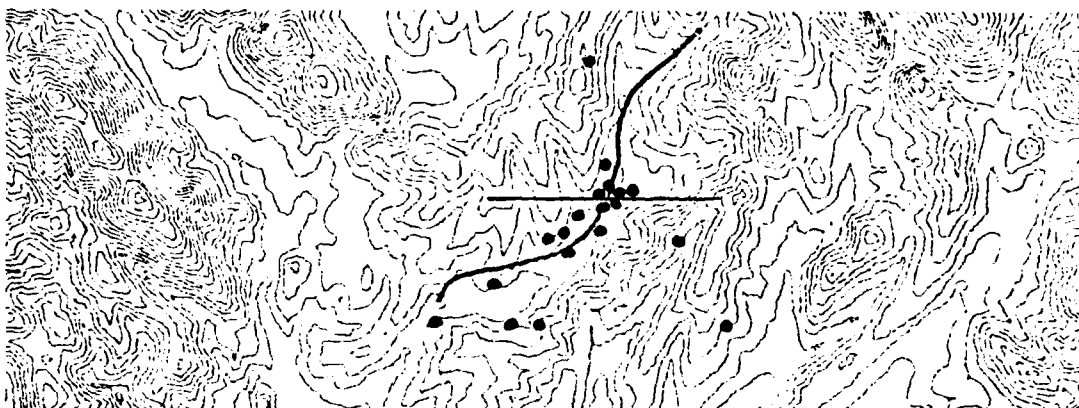


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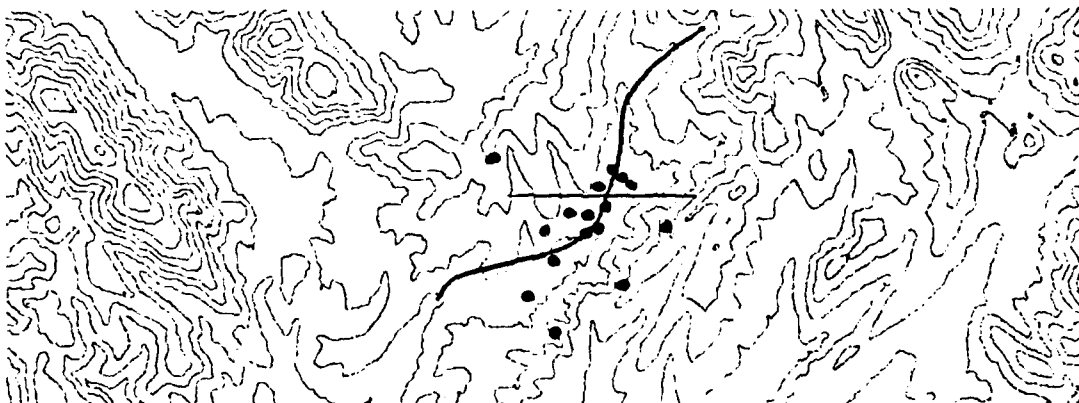
Figure 21. Hilly terrain--Stop 4.



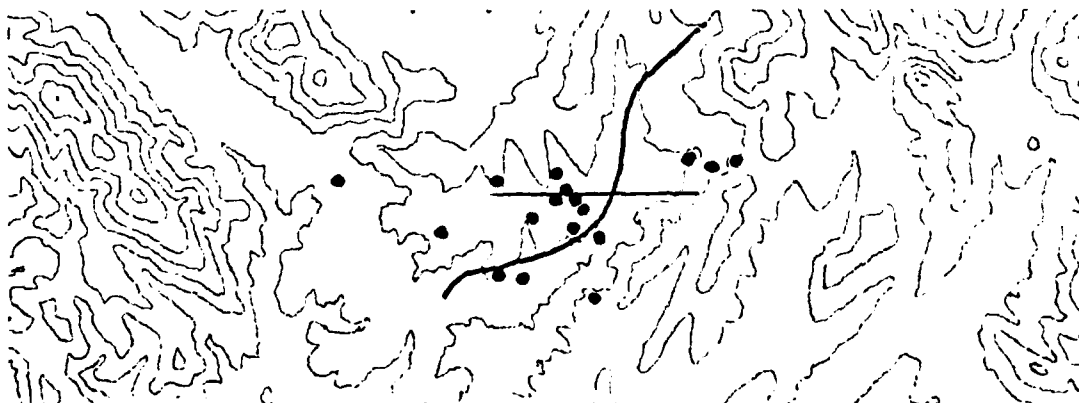
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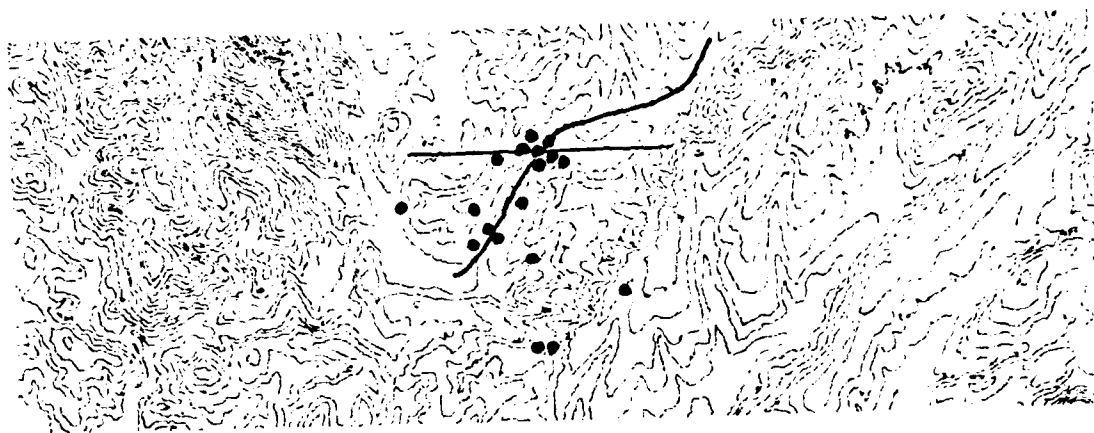


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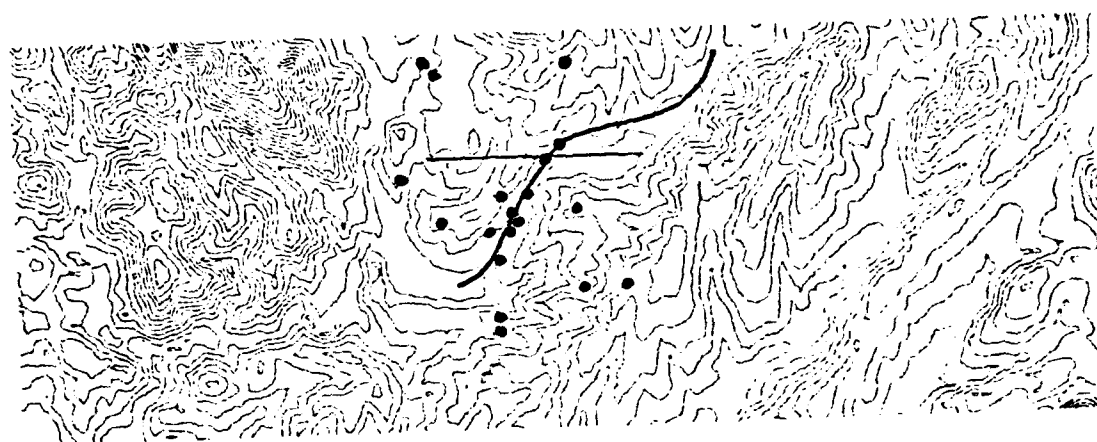


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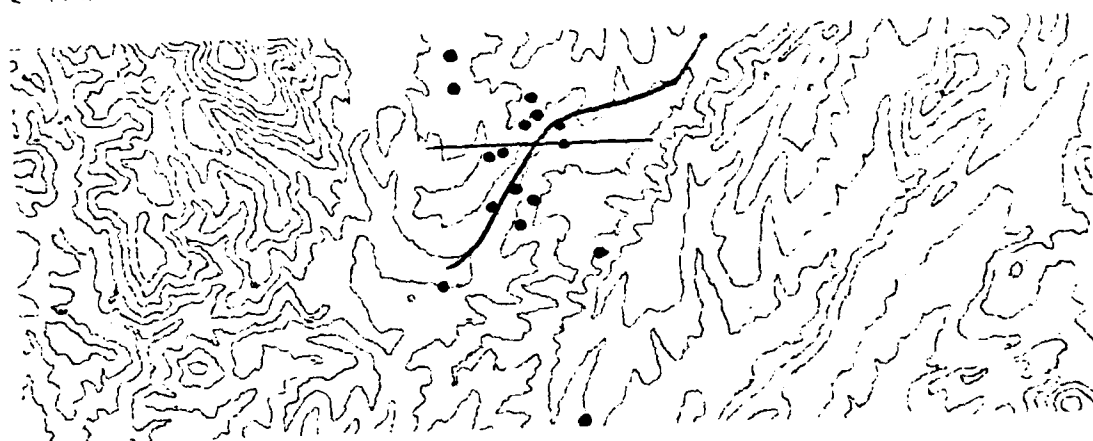
Figure 22. Hilly terrain--Stop 5.



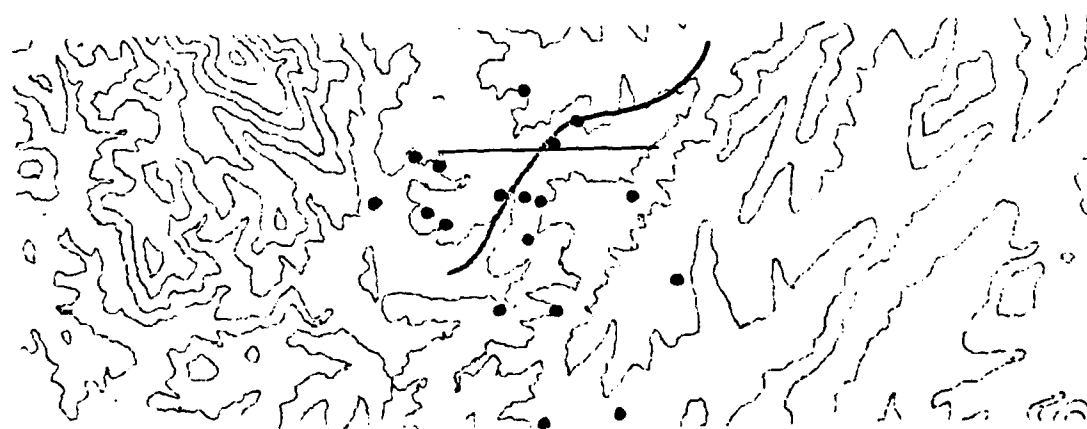
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Figure 23. Hilly terrain--Stop 6.