AD______________

AD 744800

TECHNICAL REPORT

71-53-ES

THAILAND HILL AND MOUNTAIN SLOPE ANALYSIS: DESIGN AND TESTING CONSIDERATIONS

by

JOHN VILETTO, JR.

April 1971

Earth Sciences Laboratory
U.S. ARMY NATICK LABORATORIES
Natick, Massachusetts
01760

Series:
ES-68

IC

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U.S. Army Natick Laboratories Natick, Massachusetts 01760	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Thailand Hill and Mountain Slope Analysis: For Design and Testing Considerations

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

John Viletto, Jr.

6. REPORT DATE April 1971	7a. TOTAL NO. OF PAGES 98	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 71 -53- ES 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ES-68	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Army Natick Laboratories Natick, Massachusetts 01760

13. ABSTRACT

Slope segment gradients and lengths were field-measured in five widely scattered areas of Thailand. In each of these areas the lithology, geologic structure, climate, and vegetation differ considerably. The composite data include 2,798 slope segment lengths and their respective gradients from 157 traverses totaling 49.3 miles.

There are no significant differences in the slope gradient frequency distributions of the five study areas. The composite slope segment gradient distribution is platykurtic from about 5 degrees to almost 30 degrees, and it is positive skewed. The platykurtic part of the curve is + or - 1 percent of the 14.5 percent level of occurrence. The distribution has no suggestion that slope gradients have a tendency to concentrate in several polymodal ranges for soil covered slopes in the large heterogeneous physiographic provinces of Thailand. The occurrence of slope gradients decreases rapidly with increasing gradients above 30 degrees. The percent values for traverse distance by gradient and gradient occurrences are remarkably similar. For example, slopes less than 30 degrees occur 85 percent of the time and they comprise 86 percent of the total traverse distance.

Ia

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Gradients	8					
Length	8					
Data	8					
S lopes	9					
Thailand	9					
Frequency distribution	8					
Military operations	4					

Ih

UNCLASSIFIED
Security Classification

FOREWORD

One of the environmental factors most frequently mentioned as an encumberance to military operations is steep ground slopes. In addition to limiting or even halting cross-country mobility of ground troops and vehicles, they adversely affect effectiveness of firepower, emplacement of weapons, use of specialized equipment, and feasibility of several other military operations.

Little ground-truth (field-measured) slope data for hill and mountain topography has been available to military tactical planners, vehicle and test course designers, or other users.

This study presents ground-truth slope data for hill and mountain areas of Thailand, and investigates frequency distributions of occurrence and percent of total traverse distance by slope gradients.

Mr. Robert S. Fegley and CPT Franklin F. Foit, Jr., both formerly of the U.S. Army Natick Laboratories, assisted in the field and in the initial compilation and coding of field data. CPT Foit, a geologist, also identified the rock samples collected along the traverses.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE

FIGURE

FIGURE

FIGURE

Page

LIST OF TABLES

ABSTRACT

Slope segment gradients and lengths were field-measured in five widely scattered areas of Thailand. In each of these areas the lithology, geologic structure, climate, and vegetation differ considerably. The composite data include 2,798 slope segment lengths and their respective gradients from 157 traverses totaling 49.3 miles.

There are no significant differences in the slope gradient frequency distributions of the five study areas. The composite slope segment gradient distribution is platykurtic from about 5 degrees to almost 30 degrees, and it is positive skewed. The platykurtic part of the curve is plus or minus 1 percent of the 14.5 percent level of occurrence. The composite distribution has no suggestion that slope gradients have a tendency to concentrate in several polymodal ranges for soil-covered slopes in the large heterogeneous physiographic provinces of Thailand. The occurrence of slope gradients decreases rapidly with increasing gradients above 30 degrees. The percent values for traverse distance by gradient and gradient occurrences are remarkably similar. For example, slopes less than 30 degrees occur 85 percent of the time and they comprise 86 percent of the total traverse distance.

INTRODUCTION

Two reports (1959[1] and 1962[2]) on slope gradient frequency have been prepared for the U.S. Army. Both of these, one on Yuma Test Station, Arizona and the other on Fort Knox, Kentucky, used map-measured data. The slope gradient frequency distributions for both of these studies show a systematic quadri-modal frequency distribution. Excluding the present study, the author knows of no army study specifically on slope gradients since the two above mentioned studies.

In the proposed AMC Mobility Research Program[3] of 11 April 1969, the U.S. Army Automotive Command representatives wrote "it is obvious that a vehicle performance model is of little value unless real (underline mine) and representative data are available to serve as an input to the model." In the same report, a call is made for the development of sampling methods such that adequate samples can be obtained with a minimum of effort. The report also states that data are required to define the environmental situations in which vehicles presumably will be used, to provide guidance for the specification of design and performance criteria, and for the specification of engineering test conditions.

---

[1] U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Handbook A Technique for Preparing Desert Terrain Analogs, Technical Report No. 3-506, 1959.

[2] Krenkel, Peter A., Application of Terrain Descriptive Techniques To Fort Knox, Kentucky, Contract No. DA-22-079-eng-300, 30 April 1962, Department of Civil Engineering, Vanderbilt University, Nashville 5, Tenn.

[3] Committee for proposed AMC Mobility Research Program, Proposed AMC Mobility Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., April 1969, p. 1.

Another recent report written in 1968 by the U.S. Army Advanced Materiel Concepts Agency titled, Adverse Effects of Slopes on Military Operations[1] states the following:

> Military Standard 210 on environme tal extremes does not include quantitative information .o assist designers in providing material for military operations in slope conditions of any type. There is no testing guidance for slope situations. Tests are conducted on specific slopes but the relationships of these slopes to natural conditions either in frequency of occurrence or actual occurrence in specific situations is unknown.

The same Ad Hoc report[2] also points out the lack of slope information.

> It was recognized that a major problem exists in the lack of definitive slope information. Quantitati.. slope information is required on a world-wide basis . meet the needs of planners and designers, and means e needed for considering the impact of slopes in system .nalyses.

Bekker (1969)[3] wrote the following about the need of slope data.

> Evaluation of slopes is essential in land locomotion to determine power and fuel requirements and vehicle speed and stability in overturning modes. To accomplish this, surface profiles must be traced and frequency of slope distribution defined.

These examples are but a few of the many official reports, pointing out the need for field-measured slope data.

---

[1]The 2D Ad Hoc Working Group, Adverse Effects of Slope on Military Operations, U.S. Army Advanced Materiel Concepts Agency, Washington, D.C., p. II-15.

[2]Ibid., p. III-1.

[3]Bekker, M.G., Introduction to Terrain Vehicle Systems. The University of Michigan Press, Ann Arbor, Mich., 1969, p. 268.

OBJECTIVES

This study has five objectives:

(1) to provide field-measured slope gradient data for vehicle and test course engineers,

(2) to obtain hill and mountain field-measured slope gradients to complement field-measured lowland slope gradients measured by WES, AFCRL, and PST[1],

(3) to contribute to efforts in the development of sampling, such that adequate samples can be obtained with a minimum effort,

(4) to test a method, including coding of data and format, for quick retrieval of terrain data by computer for specific parameters and geographic areas, and

(5) to contribute ground-truth terrain data applicable for quick computer retrieval.

---

[1] Dornbush, Jr., W.K., Mobility Environmental Research Study: A Quantitative Method for Describing Terrain for Ground Mobility, Vol. III, Surface Geometry, Tech. Rpt. No. 3-726, (U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss., Sept. 1967). Regarding the slopes measured, the report, on page 28, states "The vast majority were taken in rice field areas. The remainder were fairly evenly divided among road embankments, termite mounds, borrow pits, sinkholes, and irrigation ditches. In addition, a relatively small number of measurements were taken on almost unique configurations in forested areas and on steep hills and mountain sides."

SELECTION OF STUDY AREAS AND TRAVERSES

The study areas were selected so that there would be topographic, lithologic, structural, climatic, and vegetation differences. The areas also had to be accessible by a ground field vehicle. The available field time and number in the field team had a direct influence on the number of study areas and number of traverses. Approximately one week in the field was allotted per study area for each of the two field periods.

Two field periods, one in 1967 and another in 1969 were used to measure and collect slope gradient data and information in five areas of Thailand (Fig. 1). Data from the 1969 season, a second sample, was needed to determine if the first sample (1967 data) was representative for the area. In 1967, work was done in the following areas: (1) Khorat, (2) Kanchanaburi, (3) Hua Hin, and (4) Ranong. Field work for the 1969 season included the same general areas as for 1967, plus the Chiang Mai area.

General starting points for the traverses were selected the first day in each area while making a reconnaissance of the topography and road conditions. A random selection of traverse starting points and azimuths was not used for several reasons:

(1) The traverse routes were always chosen so that they included hill and/or mountain slopes in contrast to the primarily valley and plains topography selected by WES for their TR No. 3-726 study.[1]

(2) A hill or mountain slope is not always at a reasonable distance at a random point and at a random azimuth from the road or cart trail.

---

[1]Dornbush, Jr. W.K., op. cit. p. 28.

LOCATION OF THAILAND SLOPE GRADIENT STUDY AREAS

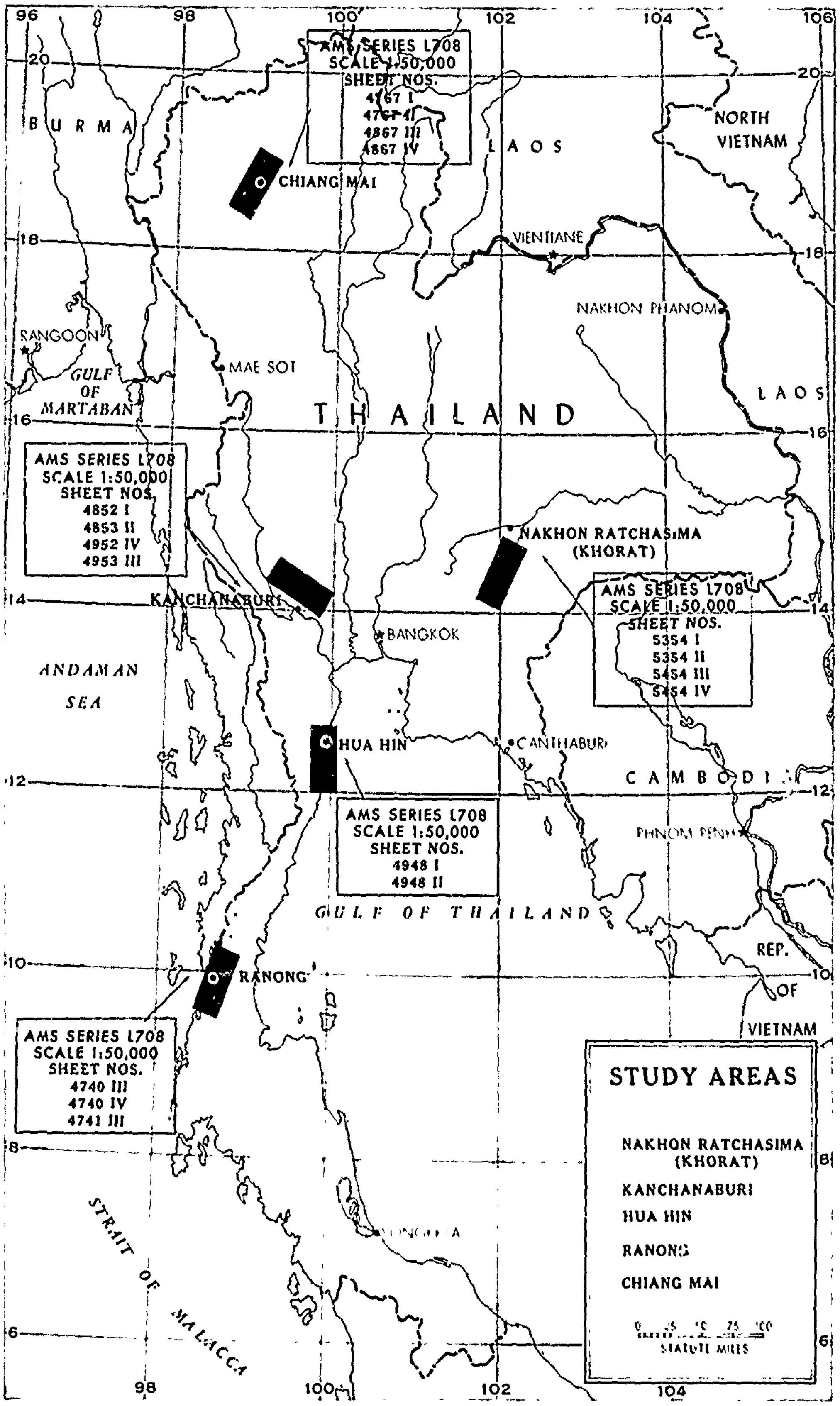


Figure 1

(3) Traverse azimuths must be perpendicular to the contour, rather than at a constant azimuth. This is done in order to measure the maximum gradient at all points along a traverse.

(4) Densely vegetated slopes which restrict range finder measurements to short distances were avoided. Dense vegetation decreases the traverse distance per unit of field time.

(5) Slopes less than about 300 feet in length were generally avoided. Traverse distance per unit time is greater for long traverses than for short traverses.

TABLE I is a tabulation of the number of traverses and total traverse distance for each of the five study areas. The number of traverses in each area varies considerably because of differences in accessibility to hill or mountain slopes, vegetation density, and weather. Traverse locations are indicated on PLATES I through V. Location of traverses are accurate, but for cartographic purposes, traverse lengths are longer than actual traverses.

TABLE I

Number of traverses and total traverse length by study area

Area	1967			1969		
	No. of traverses	Total length feet	Total length miles	No. of traverses	Total length feet	Total length miles
Khorat	12	28,603	5.3	10	15,099	2.9
Kanchanaburi	10	26,852	5.1	20	23,099	4.4
Hua Hin	22	39,988	7.6	28	35,663	6.8
Ranong	20	43,523	8.2	13	12,349	2.3
Chiang Mai				22	35,033	6.6
	64	138,966	26.3	93	121,243	23.0

FIELD METHODS, MEASUREMENTS, AND INFORMATION COLLECTED

Conventional, simple ground field methods were used for measuring and collecting information. Slope gradients were measured with a Brunton compass or an Abney hand level. Slope gradients were measured to the nearest whole degree, and they are correct to within plus or minus 1 degree. Distances were measured by (1) Dietzgen Duo Site Range Height Finder, (2) 100 foot steel tape, and (3) pacing. The majority of the distances were measured with the range finders, which were checked with the 100 foot steel tape at the beginning of each field day.

The reliability of the range finders was very good. On all checks the measured distance was never more than plus or minus 2 percent different. Distance measured with the steel tape was to the closest foot. Several distances measured by pacing were checked with the steel tape; these distances checked out at a plus or minus 2 to 4 percent.

Approximate range of rock size and percent of the surface covered by the rocks were noted where they could interfere with movement of men or vehicles. Photographs of traverse slopes, outcrops, large rock blocks, and small rocks were taken to complement the slope gradient data and qualitative material.

LIMITATIONS

This field study, as is true with most field studies, had a number of limiting factors. Large scale (1:24,000) topographic maps or large scale geology maps were not available for Thailand. The best topographic maps of Thailand have a 1:50,000 scale and a 20-meter contour interval. These maps have very limited value for micro surface geomorphology or detailed slope gradient measurements, although they are adequate for location purposes in the field. The best available geology map of Thailand at a 1:2,500,000 scale is very generalized It lacks the detail needed for studies involving micro measurements.

Other limiting factors were dense vegetation, hot and humid weather, and inaccessibility of much of the general study areas to conventional ground vehicles or small four-wheel-drive vehicles. The dense vegetation hindered field work in two ways: (1) limiting visibility which made necessary more distance and gradient measurements over a given distance even though the gradient did not change, and (2) increase traverse time when it was necessary to chop a path through sections of dense vegetation. The hot and humid conditions in conjunction with steep slopes made it necessary to stop frequently for short rests. Because of the sparse and poor roads and cart trails, many traverse sites were walked to from the roads or cart trails which were not negotiable by the field vehicle.

All the above limitations posed problems but not the most limiting one. They did, however, all contribute to the one major overall limitation which was available time for field measurements. Available field time was about six weeks for each of the two field periods. The field team consisted of only two persons; this presented the greatest limitation. Nevertheless, a large number of slope gradient and slope segment length measurements were obtained. The field methods used are acceptable and the best possible considering the environment, a field crew of only two, and the limited field time.

PHYSIOGRAPHY

In this section a brief physiographic description is included for Thailand as a whole. This section is followed by brief sections on each of the five study areas. Each of these five sections also includes a subsection titled "Selected Militarily Significant Features." The features included in these subsections are only a very small number of the militarily significant features in the area. The few features or conditions discussed are those that presented some problem for the field team while walking the traverses or concern some special feature or condition.

Thailand - General

Thailand can be divided into three major structural provinces: (1) Khorat Plateau[1], (2) Chao Phraya Depression, and (3) Northern and Western Folded Mountain Ranges. These folded mountains extend southward into the Malay Peninsula.

[1]Khorat is also referred to as Nakhon Ratchasima on some official maps and reports, but in this report Khorat is used.

In spite of the relatively small size of Thailand with only three major structural provinces, the country has great diversity of topography, landforms, and rock types. Much of the country has had several periods of orogeny which were responsible for faulting, folding, mountain building, regional uplift or downwarp, intrusions, and metamorphism. This complex geologic history is responsible for the great variety of topography in Thailand.

PLATE VI shows a major part of the "1950 Reconnaissance Geologic Map of Thailand." This map is very general, but unfortunately, it is the best available. A summary of the stratigraphy shows the large number of rock types found in Thailand (APPENDIX I). The rock types for specific areas are much more complicated than one realizes from the geology map (PLATE VI). The Khorat area is a good example. On the geology map, the area is indicated as Khorat series, and the complexities are evident when checked in APPENDIX I. Several members of this series have been metamorphosed to varying degrees in many locations. For example, sandstones and shales have been altered respectively to quartzite and slate.

In some cases the altered rocks are more resistant to weathering and erosion than the unaltered rocks. The resulting differences in rock hardness and the several processes of weathering and agents of erosion are responsible for the great diversity of landforms, relief, gradients, and surface conditions in Thailand.

Khorat Study Area

This study area is part of the scarp slope of the Khorat Plateau where the sedimentary strata dip approximately 7 degrees to the northeast (Figs. 2 and 3). The Plateau, a dip slope, topography is flat to undulating with very little relief or dissection (Fig. 3). In contrast, the scarp slope is highly dissected and local relief ranges from about 200 to 1,200 feet. The northern of two scarp slopes associated with the Khorat Plateau is very conspicuous (Fig. 2). Several of the Khorat study area traverses were made on this northernmost scarp slope (PLATE I).

Sandstones, conglomerates, and marly concretionary limestone locally metamorphosed to quartzite, phyllite, and slate are truncated by the scarp slope of the Khorat Plateau. A massive sandstone formation caps this series of rocks, and it is exposed along much of the top edge of the escarpment (Fig. 4).

Selected Militarily Significant Features

The cap-rock zone is the most difficult part of the escarpment to negotiate. Men on foot can negotiate, with some difficulty, any section of the cap-rock zone, but for ground vehicles, the author believes the cap-rock zone would present a "no go" situation.

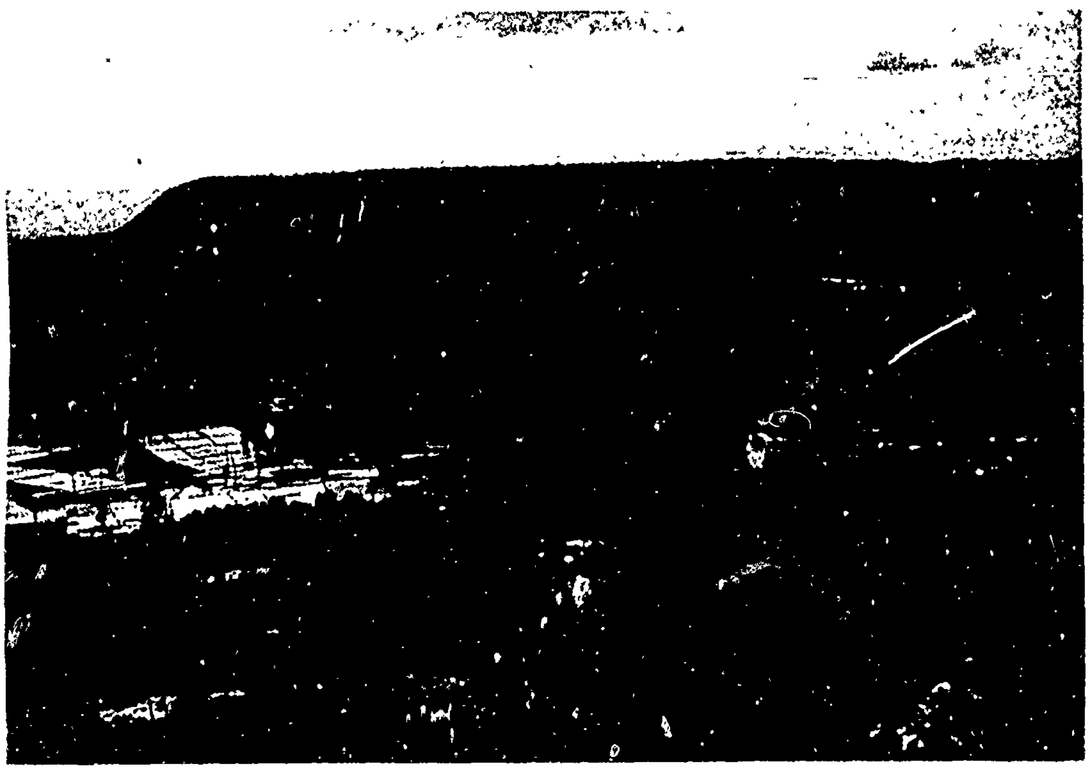


Figure 2. Khorat study area: Escarpment of sedimentary strata dipping gently (7 degrees) to the northeast. Escarpment on the west side of Friendship Highway viewed from the top of the escarpment on the east side of the highway. Note the commanding view of the highway.

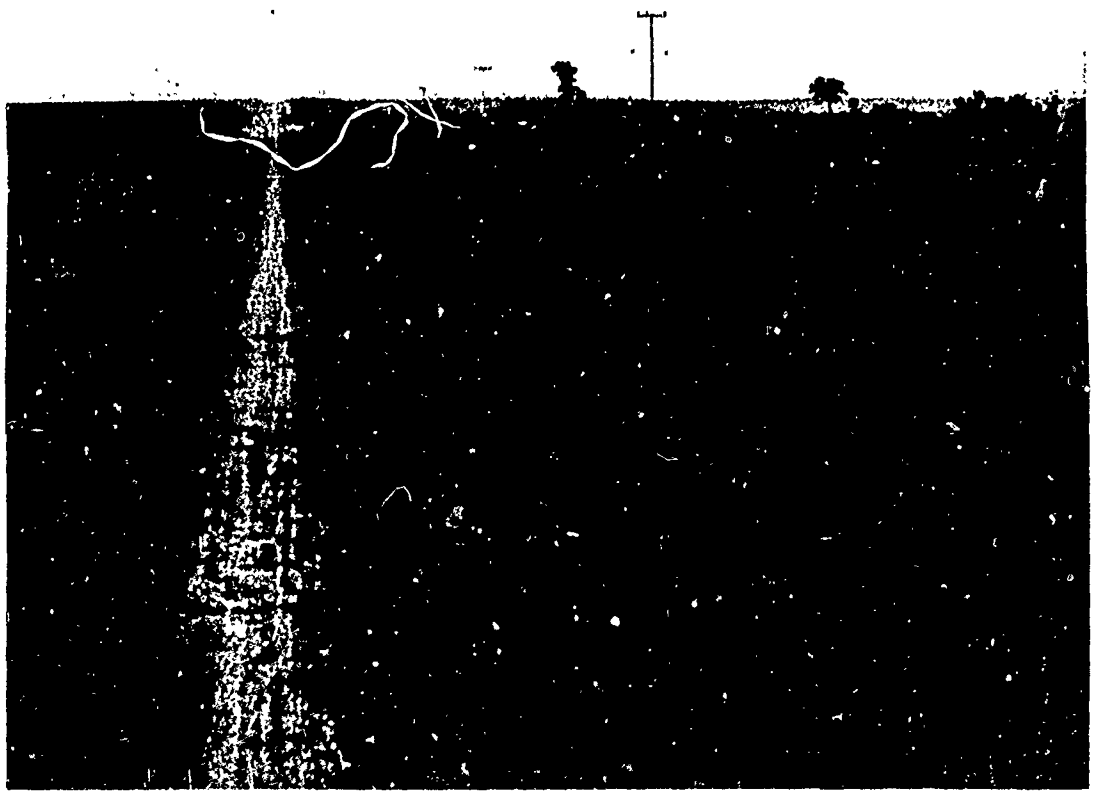


Figure 3. Flat to undulating surface of the Khorat Plateau. Flat to undulating topography of the Khorat Plateau eight miles north of the escarpment edge of Figure 2.

The cap-rock zone of the escarpment has three forms:

(1) A cap rock overhanging from a few feet to as much as 15 feet.

(2) A nearly vertical cliff, 10 to 15 feet high with large rock blocks at the base of the cliff ranging in size from a large suit case to a large American automobile (Figs. 4, 5, and 6).

(3) A continuous cover of the above mentioned rock blocks.

Figure 4. Khorat study area: Cap rock of the Khorat escarpment. Picture taken from site #2 of traverse #58.

For guerilla-type forces these overhanging cap-rock sections are excellent for shelter, storage, observation, and gun sites. From these sites a small force of men with little equipment could control the movement of troops, supplies, and vehicles over the main highway (No. 23, the Friendship Highway) through the escarpment area. The cave-like overhanging cap-rock site shown in Figure 5 has a commanding view (Fig. 2) of a long stretch of the Friendship Highway between Khorat and its Friendship Airfield and Bangkok.

Figure 5. Khorat study area: Militarily significant cave-like cap-rock site. Cap rock is 15 to 20 feet thick at this point. The slope gradient below the base of the cap rock is 40 degrees. Picture shows site #24 of traverse #53.

Figure 6. Khorat study area: Base of Khorat escarpment cap rock with large rock blocks on the 30 degree slope segment. Picture shows site #6 of the traverse #54.

Below the cap-rock zone, ease of off-road movement by men and vehicles increases with distance downslope from the cap-rock zone. Figures 7, 8 and 9 are a series of photographs that show slope gradients and surface conditions at three, higher to lower elevations, sites (17, 7 and 5 along traverse #51. Traverse #51 is located a few miles east of the Friendship Highway (PLATE I). Slope gradients for the three sites (17, 7 and 5) are respectively 38, 6 and 11 degrees.

Figure 7. Khorat study area: Escarpment cap rock and slope below the cap rock. Vertical face of cap rock and 38 degree slope below the cap rock at site #17 of traverse #51.

There are marked differences in rock size and percentage of the surface covered by rocks on the slope below the cap-rock zone. On each of the three photographs (Figs. 7, 8 and 9), it is obvious that the frequency and size of rocks are obstacles to the mobility of men and vehicles. In Figures 8 and 9 the approximate percentage of the surface covered by rocks is 60 to 80 percent. The rocks in Figure 8 range in size from a suit case to a little larger than a standard government desk. The rocks in Figure 9 range in size from a typewriter to a large footlocker.

Figure 8. Khorat study area: Sandstone rocks on slope below the cap rock. The majority of the rocks range in size from a large suit case to a little larger than a standard size government office desk. The rocks cover 60 to 80 percent of the 6 degree slope near site #7 of traverse #51.

Figure 9. Khorat study area: Sandstone rocks on slope below the cap rock. The majority of the rocks range in size from a typewriter to a footlocker. The rocks cover 60 to 80 percent of the 11 degree slope segment near site #5 of traverse #51.

A second series of photographs (Figs. 10, 11, 12 and 13) are traverse sites only 4 miles west of the above mentioned series (Figs. 7, 8 and 9) which are on the east side of the highway. The same formation caps the escarpment on both the east and west sides of the highway. Rock coverage on the study slopes west of the highway (Figs. 10, 11, 12 and 13) ranges from about 10 to around 40 percent. For traverses (Figs. 7, 8 and 9), on the east side of the highway, the rock cover is about 30 percent for a minimum and about 80 percent for a maximum.

Figure 10. Khorat study area: Firing range at base of tree-covered Khorat escarpment. Close-up of escarpment end shown in Figure 2.

Figure 11. Khorat study area: Rocks on escarpment slope above f'~ing range. Slope in the foreground below trees is 18 degrees; in the tree zone, it is 27 to 30 degrees. Picture shows part of slope for traverse #58.

Figure 12. Khorat study area: Rocks on escarpment slope above firing range. Slope in the foreground is 23 degrees; in the tree zone, it is 27 to 38 degrees. Picture shows part of traverse #60, above site #12.

Figure 13. Khorat study area: Cap rock block zone above firing range. Cap rock and large rock blocks at site #2 of traverse #60 and the 37 degree slope below the cap rock.

Kanchanaburi Study Area

This area is part of the eastern margin of the western folded mountains that extend south into the Malay Peninsula. This area is mostly flat land between the scattered, linear hills and mountains of the main complex to the west along the Thailand-Burma border. Local relief of these hills and mountains ranges between 50 and 1,000 feet.

These hills and mountains rise abruptly from the relatively flat surface underlain by alluvium and colluvium (Figs. 14, 15 and 16). There is a distinct break-in-slope where the colluvium abuts the base of the slope. The break-in-slope is from around 4 to 6 degrees up to about 12 to 15 degrees.

Figure 14. Kanchanaburi study area: Sharp break-in-slope at base of Khao Uai. Picture shows broad view of Khao Uai, the hill on which traverse #1 was made.

Figure 15. Kanchanaburi study area: Sharp break-in-slope at base of Khao Tong. Picture shows broad view of Khao Tong which is the mountain for traverse #5. Slope in foreground is 1 degree.

Figure 16. Kanchanaburi study area: Thick deposit of alluvial and colluvial material transformed into laterite at the base of Khao Tong.

The most common bedrocks are limestone, shale, sandstone, and sandy shale. Some of these rocks have been metamorphosed to varying degrees at different places to marble, phyllites, argillites, quartzites, and slates.

Selected Militarily Significant Features

The Khao Uai slopes on which traverses #1 through #4 were conducted would present problems to both men and vehicles, but for different reasons. These slopes have a hard soil surface over large sections of the hills. Some of the sections are 100 percent covered with small subangular quartzitic pebbles ranging in size from about 1/4 to 4 inches square (Fig. 17). The combination of the hard surface

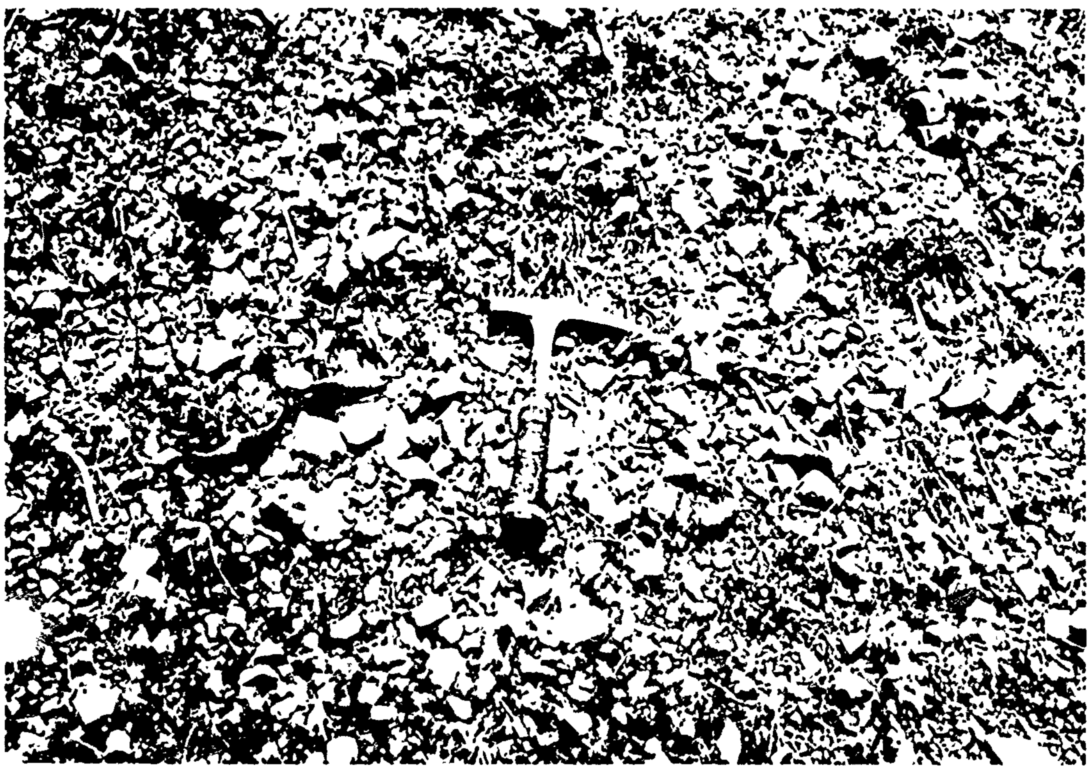


Figure 17. Kanchanaburi Study area: Pebble-covered hard soil of Khao Uai slope. Picture shows pebble-covered 19 degree slope at site #10 of traverse #1.

and subangular pebbles makes footing treacherous. Traversing many segments of these slopes is like walking on a ramp scattered with marbles. Members of the field crew lost their footing and fell several times in spite of wearing the Tropical Combat Boot with the treaded sole and heel.

The second condition or feature not conducive to ground vehicle mobility across these slopes are zones of small irregular terracettes. They are step-like features that vary in size and spacing. Length is from 2 to 3 feet to about 20 feet; tread is about 1 to 3 feet; and the rise from about 6 inches to around 3 feet (Fig. 18). Terracettes are common on slopes ranging between 15 to 25 degrees.

Figure 18. Kanchanaburi study area: Quartzitic pebble-covered terracettes on Khao Uai. Pebble-covered terracettes on slopes of 19 to 28 degrees between sites #10 to #13 of traverse #1.

These terracettes would cause problems for vehicles and their occupants. Some vehicles would get hung-up attempting to traverse these features. The vehicles that did not get hung-up might be damaged by the bouncing effect. Moreover, the bouncing effect would make it difficult, if not impossible, for the driver to maintain control unless the vehicle speed is very slow.

The percent of the surface covered by rocks varies considerably on the Kanchanaburi hillsides as it does in the Khorat Study Area. Kanchanaburi traverse #9 is a good example of the frequency of rocks being markedly different on two contiguous slope segments (Figs. 19 and 20). The segment between sites 42 and 43 is contiguous and immediately downslope from the segment between sites 41 and 42. Figure 19 shows large limestone outcrops and rocks between sites 42 and 43. Figure 20 shows a surface almost free of outcrops and rocks between sites 41 and 42.

Surface conditions of different slopes underlain with the same rock type also varies considerably. Figures 19 and 21 show two slopes underlain with limestone. Figure 19 shows many outcrops, some with 6 to 8 foot vertical sides; there is very little loose rock on this 34 degree slope. Figure 21 shows few outcrops, but the 30 degree slope is about 75 percent covered with rocks ranging in size from about 4 inches square to about 1 by 1 by 2 feet.

In addition to steep slope gradients, outcrops, and surface rocks, intermittent stream channels are obstacles to off-road movement of men and vehicles. These intermittent stream channels are cut into the deep colluvial material between some of the hills; especially the hills that are continually being cut over for charcoal material and bamboo cane. Figures 22 and 23 show the size and configuration of two intermittent stream channels. Near their headward end, these channels range in size from about 6 to 10 feet across the bottom and 3 to 8 feet deep. Their banks are nearly vertical to vertical along most of their lengths. Some distance from the originating slope, the channels regress by decreasing in depth and width until they have merged with the surface and no longer exist.

Some parts of the carbonate hill and mountain complex across the river from Kanchanaburi look like the pepino hills of Puerto Rico (Fig. 24). Thick carbonate formations are potential areas for caves. No time was available for mapping caves, but two of them were entered to get an idea of their size.

Figure 19. Kanchanaburi study area: Limestone outcrops and rocks on slopes of Khao Noen Prang. Six to eight feet vertical limestone outcrops on 34 degree slope between sites #42 and #43 of traverse #9.

Figure 20. Kanchanaburi study area: Relatively rock-free slope on Khao Noen Prang. Relatively rock-free 28 degree slope between sites #41 and #42 of traverse #9.

Figure 21. Kanchanaburi study area: Limestone rock-covered slope on Khao Phu Lan. Thirty degree slope about 75 percent covered with limestone rocks ranging in size from about 4 inches square to about 1 by 1 by 2 feet near site #16 of traverse #55.

The smaller of the two caves entered is in Khao Phy Lan. Traverse #56 passes a short distance from one of its entrances. This cave is entered through a hole about 3 feet in diameter. The passageway drops on a gradient of at least 45 degrees. The passageway increases in size and decreases in gradient for about 50 yards. At this point, it opens into a large cavern with about 20 by 30 feet of floor space and with a height of around 30 to 40 feet at the center. At the top and to one side of the cavern there are small openings to the surface where enought light enters so that one can read or write during the daytime. Local youngsters were playing nearby and pointed the cave out to the field crew.

Figure 22. Kanchanaburi study area: Intermittent stream channel cut into colluvial material between closely spaced hills. Channel is a short distance from base of hill for traverse #7.

A second cave was visited in the eastern end of a rugged mountain complex. This complex is west of the Mae Nam Khwae Noi and about 2 miles upstream from its confluence with the Mae Nam Khwae Yai. The karstic nature of this rugged hill and mountain complex is evident by the many large closed contour depressions (PLATE II). These large solution basins are especially noticeable in the mountain section to the west of the Mai Nam Khwae Noi.

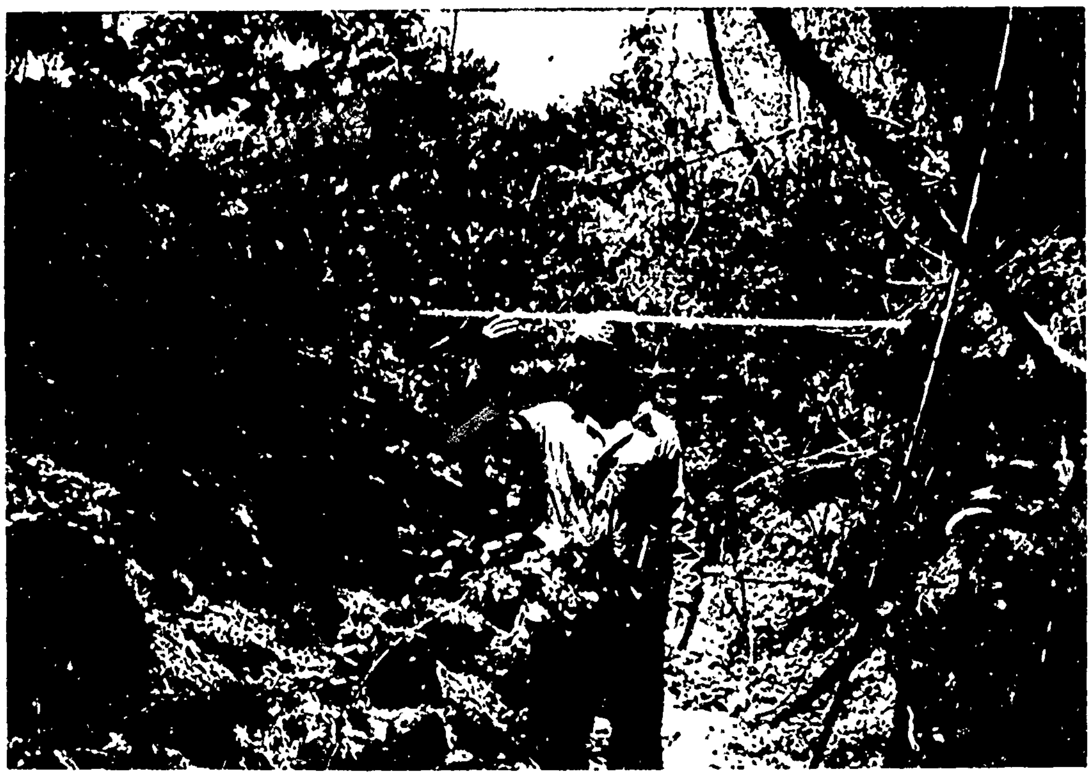


Figure 23. Kanchanaburi study area: Intermittent stream channel cut into colluvial material between closely spaced hills. Channel is a short distance from lower end of traverse #8.

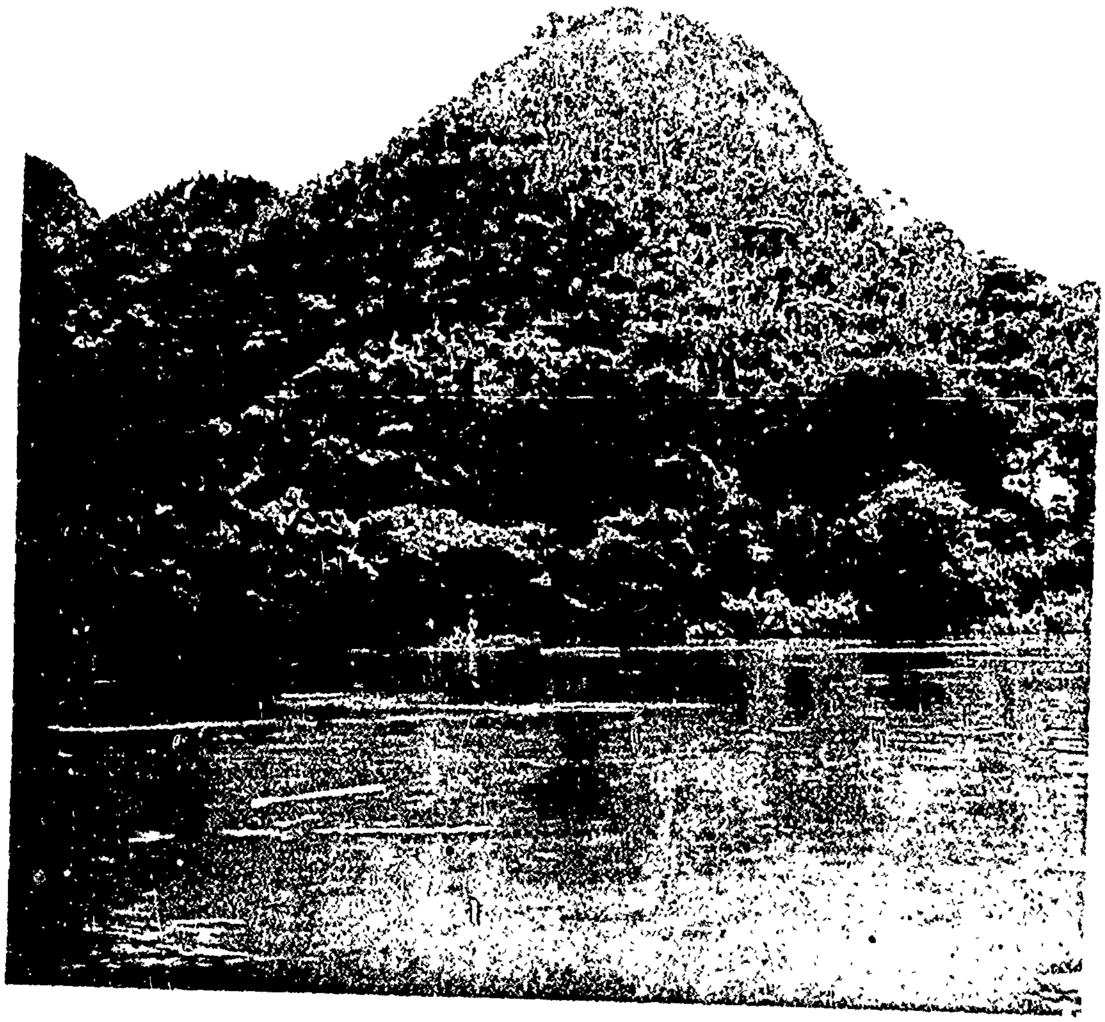


Figure 24. Kanchanaburi study area: Pepino type limestone hills. Gradients on these slopes exceed 25 degrees and frequently short segments of 30 to 50 degrees are encountered.

The second cave entered is larger than the first and the passageway is considerably less steep. The passageway is at least 6 feet high throughout most of its length, and in many places it is 10 to 15 feet wide. This cave also has a large cavern. This cavern has about 25 by 35 feet of floor space, and it is around 25 feet high. A sitting Buddha, at least 8 feet high, occupies a small section of the cavern (Fig. 25). A small gasoline generator near the upper entrance generates electricity for the cave and its passageway.

These two caves, as are the cave-like sites along the top edge of the Khorat Plateau scarp slopes, are militarily significant. Neither of the two caves entered has a commanding view like the Khorat escarpment cave-like sites. There could, however, be some caves that have a commanding view of the rivers, railroad and main highway of the Kanchanaburi area.

Figure 25. Kanchanaburi study area: Carbonate cavern with a large sitting Buddha. Cavern has roughly 25 by 35 feet of floor space and is about 25 feet high at the center.

The capacity of the caves for guerilla-type forces is considerably greater than the cave-like sites in the Khorat escarpment area. For example, the two caves described could accommodate between 50 to 75 indigenous men with all their food and equipment needs for several months.

Finding the caves in the carbonate areas is much more difficult than finding the cave-like sites. Most of the Khorat escarpment cave-like sites could probably be spotted by observers in a slow helicopter flying low along the scarp side of the escarpment. On the other hand, relatively few caves in the carbonate formations can be spotted from slow, low flying helicopters. Until the state-of-the-art of cave detection by air-borne systems is developed, the caves must be found by ground troops and trained dogs systematically scouring all the potential cave areas.

Hua Hin Study Area

This coastal plain has a discontinuous linear complex of metamorphic hills and mountains trending north-northwest to south-southeast (PLATE III). All the Hua Hin traverses except Nos. 13, 14 and 15 were walked on this discontinuous linear complex of metamorphic hills and mountains. Foothills and mountains of the sedimentary Kanchanaburi series begin 2 to 3 miles to the west of the linear complex of hills and mountains. Traverses 13, 14 and 15 are about 8 miles inland from the coast on a foothill of the eastern margin of the Kanchanaburi series which underlies the eastern two-thirds of the peninsula in this region.

The Hua Hin study area topography is predominantly flat coastal plain with a small percentage, no more than 10 percent of relatively low hills and mountains. Local relief on both the linear complex of hills and mountains and the foothills of the Kanchanaburi series ranges from about 100 to 1,200 feet. At least half of the hills and mountains rise abruptly with a marked break-in-slope (Figs. 26 and 27). These breaks-in-slope are like those in the Kanchanaburi study area. The gradients are about 4 to 7 degrees on the colluvium and about 12 to 15 degrees just above the colluvium.

The most commonly encountered outcrops in the linear complex hills and mountains were gneisses, schists, quartzites, marble, and granite. Many sedimentary rock types make up the Kanchanaburi series, but only one rock type, a sandstone, was seen along traverses 13, 14 and 15. These are the only Hua Hin traverses over Kanchanaburi series slopes.

Figure 26. Hua Hin study area: Sharp break-in-slope at base of hill.

Selected Militarily Significant Features

Ground-truth reveals many reasons why men and ground vehicles would have considerable difficulty, or at least be slowed down while negotiating these slopes. The major obstacles for men and vehicles are high frequency of large rocks, nearly vertical to vertical outcrops, and small rocks covering sections of some slopes (Figs. 28, 29, 30, 31, 32 and 33). Each of these figures show conditions on different traverses. On many segments of several traverses, the large rocks and outcrops cover 30 to 70 percent of the surface on slopes ranging from

Figure 27. Hua Hin study area: Sharp break-in-slope at base of hill.

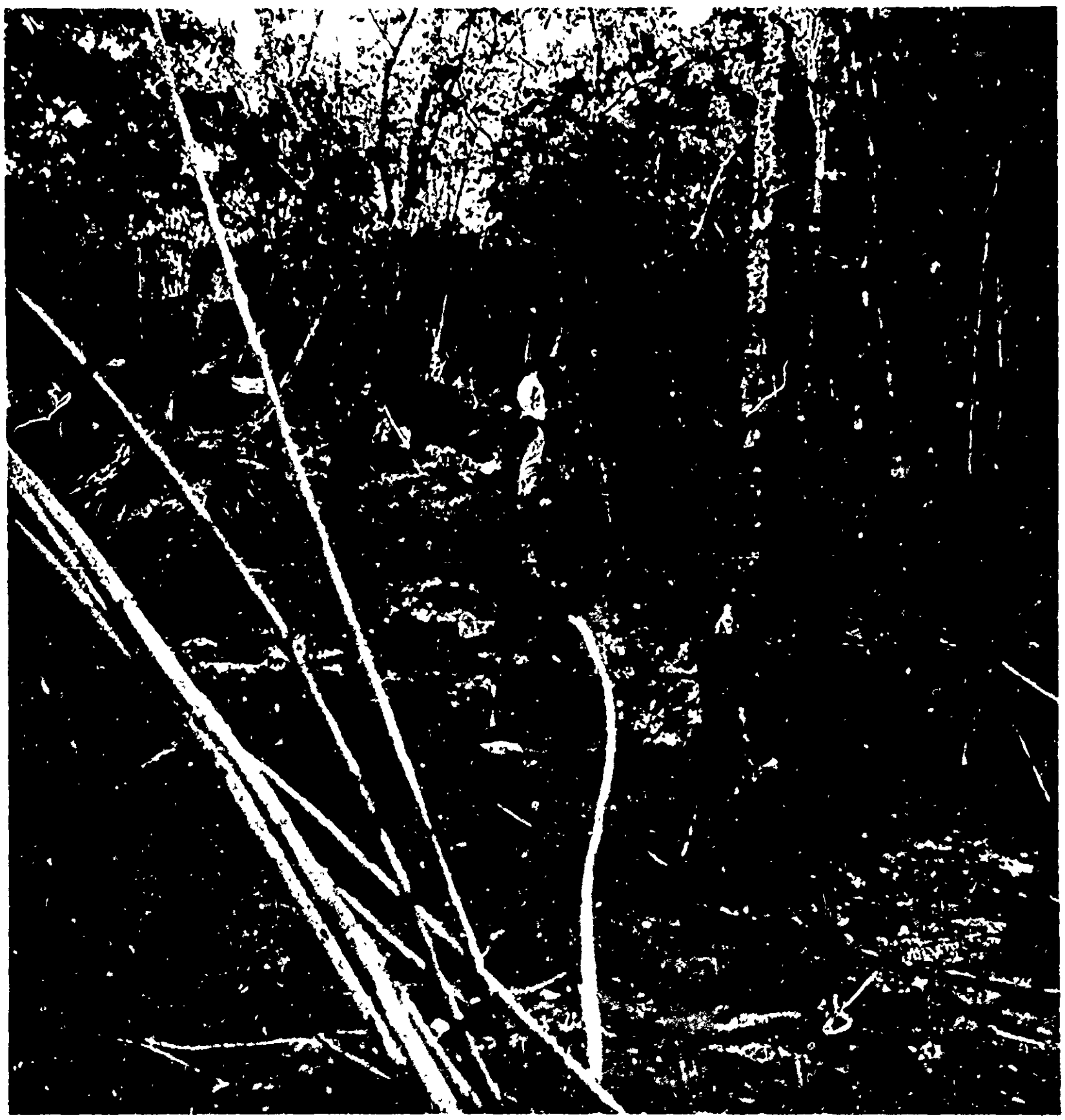


Figure 28. Hua Hin study area: Large rocks and outcrops near bottom of hill for traverse #51. The majority of the rocks range in size from a typewriter to a standard size government office desk. The slope is 18 degrees near site #5 of traverse #51.

Figure 29. Hua Hin study area: Large rocks and outcrops at crest of hill. Rocks and outcrops at crest of hill on which traverse #54 was made.

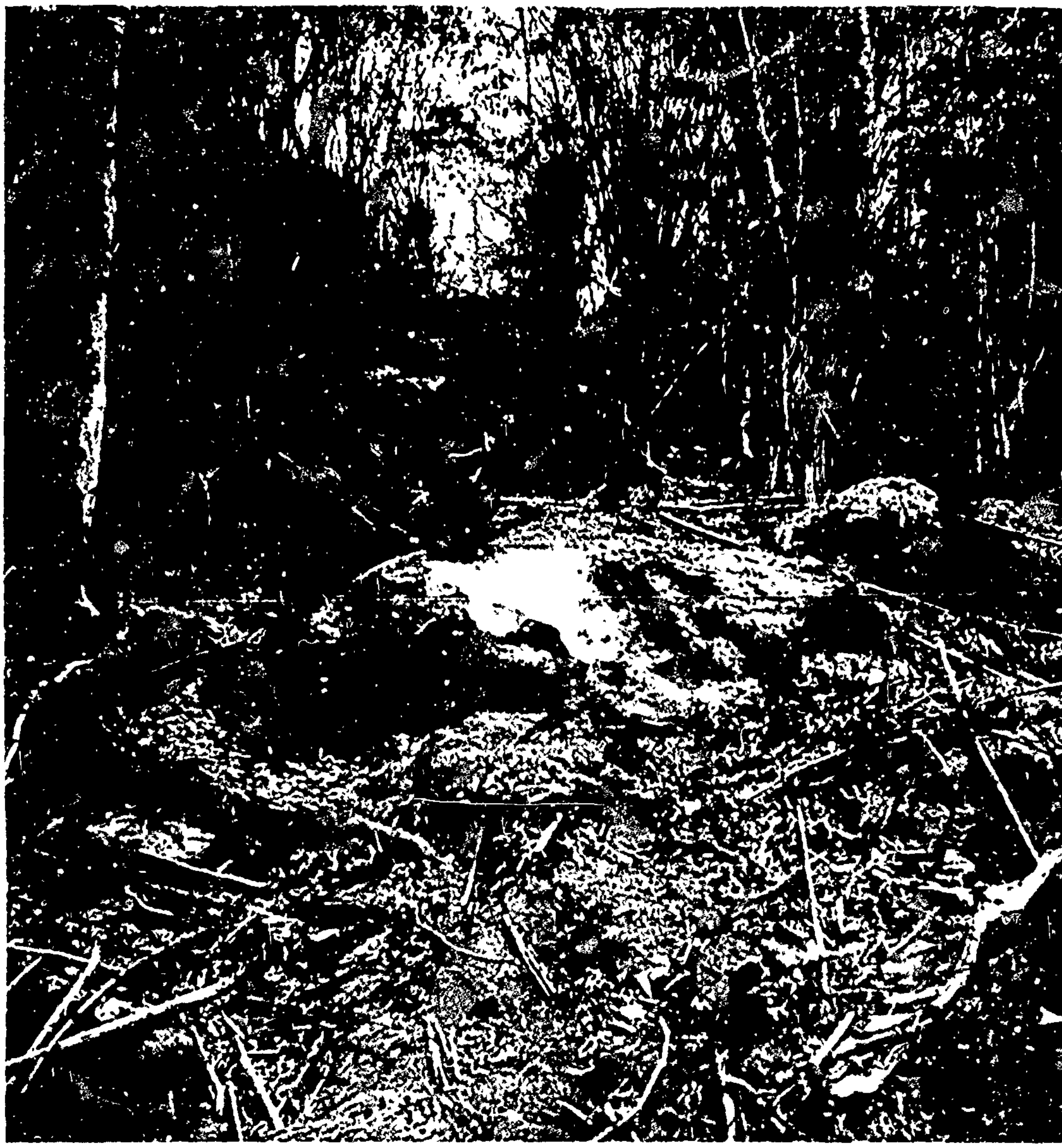


Figure 30. Hua Hin study area: Large rocks and outcrops near top of hill. Large rocks and outcrops cover about 75 to 90 percent of the surface near the upper limit of traverse #59.

Figure 31. Hua Hin study area: Large rocks and outcrops on 10 degree slope segment. Large rocks and outcrops on 10 degree slope segment at site #15 of traverse #72.

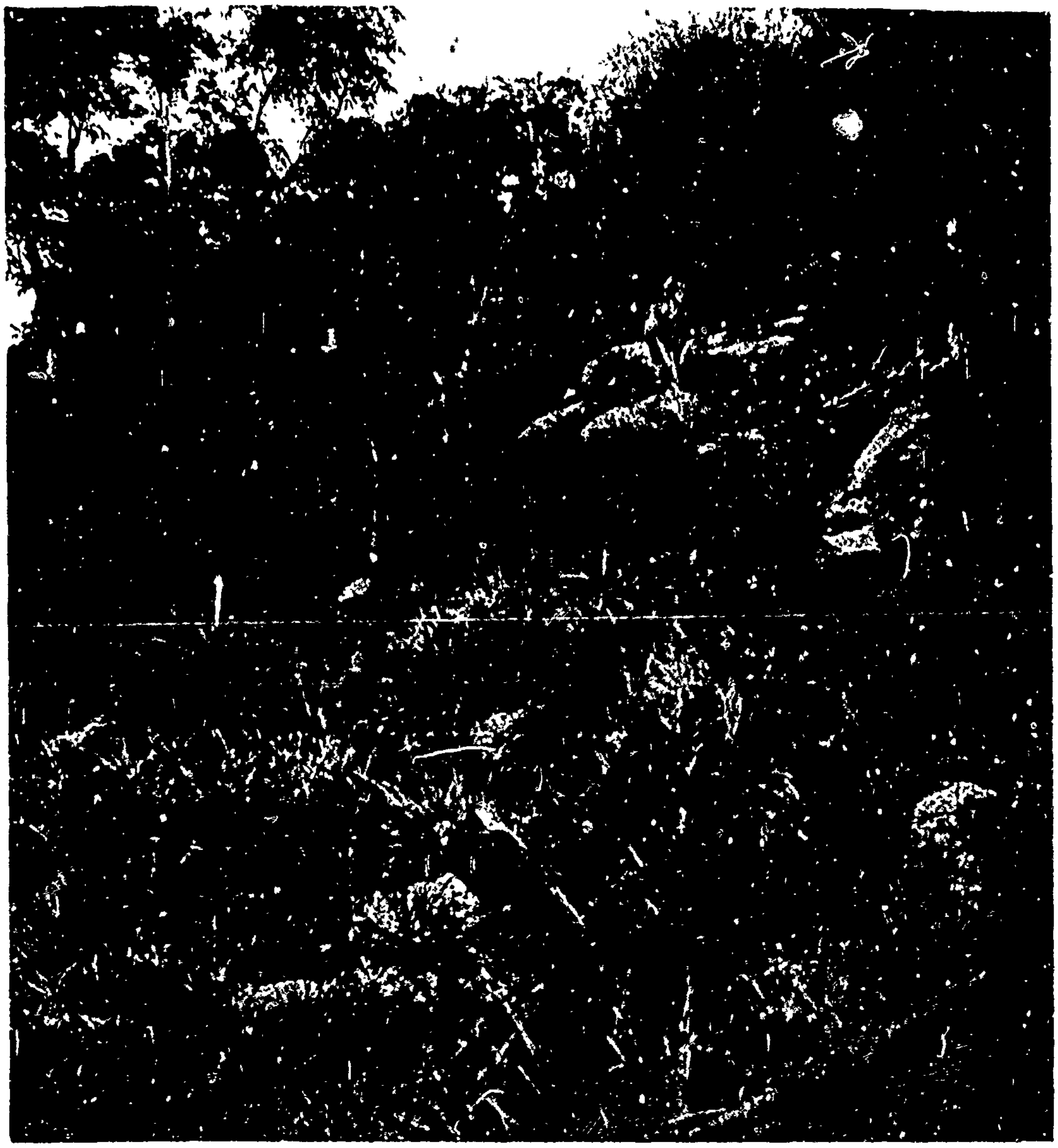


Figure 32. Hua Hin study area: Large rocks and outcrops on 18 degree slope segment. The majority of the rocks and outcrops range in size from a small suit case to a small size foreign car. The slope segment is near site #23 of traverse #73.

Figure 33. Hua Hin study area: Segment of slope covered with small sandstone rocks. Twenty-three degree gradient slope segment nearly 100 percent covered by small rocks between sites #25 and #26 of traverse #15. This slope had recently been burned over. Many of the rocks had fresh surfaces where they had been split open by the intense heat of the fire.

less than 10 degrees to over 30 degrees. The author suspects that ground vehicles of the latest off-road designs could not negotiate these slopes (Figs. 28, 29, 30 and 31), or at best could traverse them with great difficulty and great risk of damaging the vehicles and injuring the crew. Moreover, traversing slopes like those shown in Figures 34, 35 and 36 are difficult and slow for men, especially if carrying equipment, and impossible for present off-road vehicles.

No cave-like sites or caves such as those in the Khorat and Kanchanaburi areas were encountered in the Hua Hin study area. Most of the Hua Hin study area, however, could be kept under close surveillance with relatively few men strategically located on selected points in the linear complex of hills and mountains.

The Hua Hin topography is less suitable for guerilla ambush and harassing activities than the other study areas. There is no dense forest cover; roads are on rolling to flat terrain with few streams. In much of the Hua Hin study area, if a road or bridge is blown up, it is not much of a problem to detour off the road around the problem. It is unlikely that the Hua Hin study area would be a guerilla stronghold because the topography does not favor their type of operations.

Ranong Study Area

This study area is a small part of the mountain complex of ranges that extend southward from northeastern Thailand to the southern part of the Malay Peninsula (PLATE IV). In the study area, the topography on the west side of the main highway is different from that on the east side. On the west side of the highway, the coastal side, the topography consists of coastal flats and scattered, low rounded hills with relief ranging between 50 to 800 feet (Fig. 37). A mile or so to the east of these scattered, low rounded hills, the topography changes to a high, rugged mountain complex. Here the relief ranges from about 100 to 2,000 feet (Figs. 38 and 39).

Mountain streams flowing westerly out of the mountains have incised deeply. The resulting stream valleys are narrow with steep slopes which are rarely less than 20 degrees at the bottom of the valley sides. These stream gradients are steep, and the channels are filled with large boulders.

Figure 34. Hua Hin study area: Large rocks and discontinuous cliffettes on a 34 degree slope segment. Picture shows surface features on slope between sites #9 and #10 of traverse #21.

The area has been folded and metamorphosed to varying degrees. The Phuket series which includes sedimentary, igneous and metamorphic rocks underlie the area. Shale, sandstone and quartz outcrops were observed on the traverses on the west side of the highway. Granite outcrops and rocks were the only rock type observed on the traverses on the high rugged mountains east of the highway.

Figure 35. Hua Hin study area: Large granite blocks, outcrops, and discontinuous vertical to nearly vertical cliffettes on a 31 degree slope segment. Picture shows surface features at site #6 of traverse #76.

Figure 36. Hua Hin study area: Massive quartz ridge crest with nearly vertical to vertical and overhanging sections. Narrow quartz ridge crest between traverse #77 and #78.

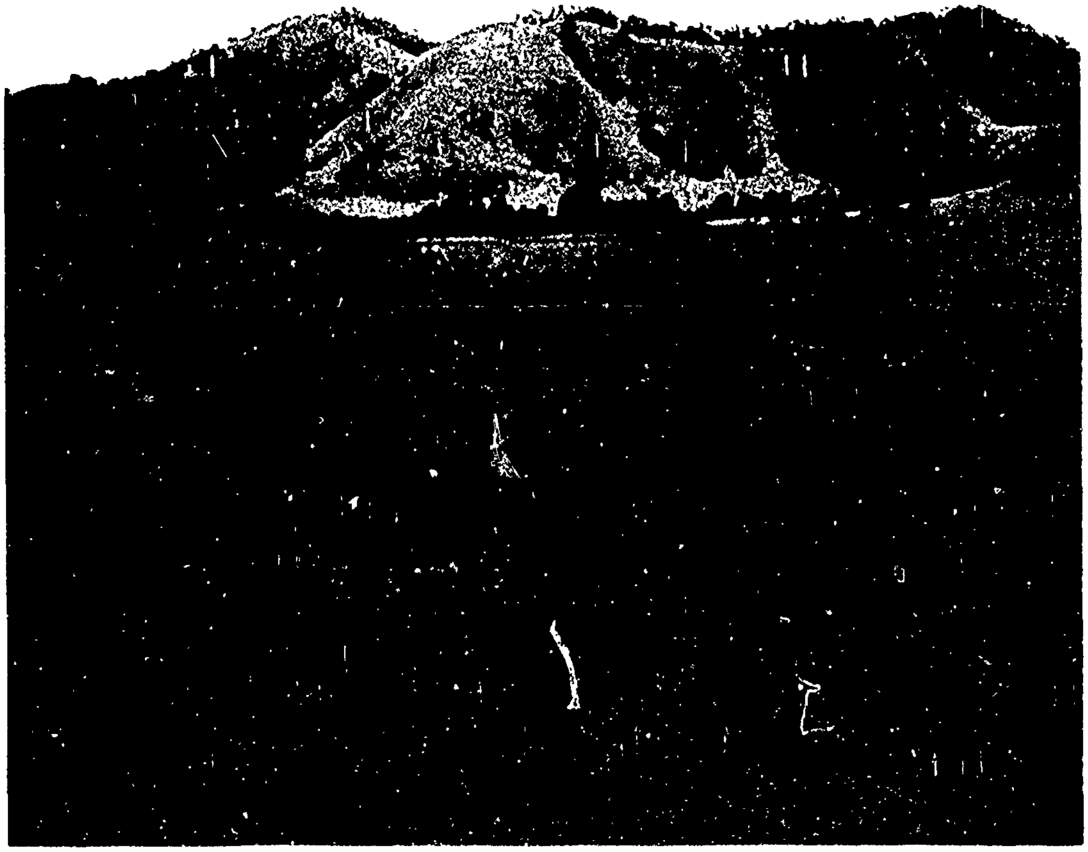


Figure 37. Ranong study area: Low rounded coastal hills west of Ranong airport. Foreground is a grass covered runway of a World War II airfield. During the 1969 field season, part of the runway was being used for a golf course. Hills in the background are location for traverses #1 and #2.

Figure 38. Ranong study area: Mountain slope with granite surface and tropical rain forest vegetation. Picture shows part of traverse #61; bedrock surface is near site #13, and the gradient is around 15 degrees through this section.

Selected Militarily Significant Features

The area is ideal for guerilla strongholds and activities:

(1) Its slopes have commanding views of the entire length of the one highway through the area.

(2) Tropical rain forest covers the hills and mountains, and mangrove and nipa palm blanket much of the coastal and estuary areas.

(3) It is a border area with Victoria Point, Burma.

(4) The area is richly endowed with large resources of tin and timber.

Figure 39. Ranong study area: Steep hill slope with terracettes on west side of the main highway. Terracettes on a 29 degree slope at site #36 of traverse #1. Mountains in background are granitic and on the east side of the main highway.

Excellent ambush locations are almost unlimited along the one and only highway through the area. The dense forest is within five to ten feet along much of the highway Also many sections of the road are cut into the side of a hill or mountain slope which can afford excellent vantage points. In addition, there are many short bridges spanning the streams from the high mountains to the east, and longer bridges spanning the estuaries in the flat coastal area.

This highway and its many bridges are next to impossible to make secure against destruction. A landslide or a bridge destroyed fore and aft of a column of vehicles could produce an excellent trap. The adjacent slopes are too steep to go around the slides or destroyed bridges. There are no connecting side roads for detouring. The trapped vehicles are easy targets from the overlooking hill and mountain slopes.

There is a major difference between the Ranong study area slopes and the three study areas described earlier in this report. In contrast to the first three areas, the Ranong study area slopes are relatively free of large rock blocks (Figs. 37, 38 and 39).

It has been pointed out that this border location area and its natural resources mentioned above are militarily significant, but these points are not further discussed because this report is limited to selected aspects of topography.

Chiang Mai Study Area

This area is part of the northern and western folded mountain ranges. There are marked differences in the hills and mountains on the east and west sides of the Mae Nam Ping flood plain (PLATE V). The mountains to the west are higher and have greater relief. To the west of the flood plain, the higher peaks are between 4,000 and 5,000 feet high, and the relief ranges from about 100 feet to around 2,500 feet (Fig. 40). The higher peaks to the east of the valley are between 2,000 and 3,000 feet and their relief ranges from about 100 feet to around 1,500 feet. Figures 41 and 42 are typical hills along the western side of the valley at Chiang Mai.

Figure 40. Chiang Mai study area: Granitic mountains at western margin of Chiang Mai Valley.

Figure 41. Chiang Mai study area: Quartzitic hills with marked break-in-slope at base of hill on eastern margin of Chiang Mai Valley.

Figure 42: Chiang Mai study area: Quartzitic hills with marked break-in slope at base of hill on eastern margin of Chiang Mai Valley.

On both sides of the valley, many hills and mountains have an abrupt break-in-slope with the valley flood plain or river terraces (Figs. 41 and 42). The break-in-slope shown in Figures 41 and 42 is from about 8 degrees along the edge of the flood plain to about 20 degrees for the lower segments of the hill slopes.

Rock units in the area include the Kanchanaburi series, injected gneisses and schists, and older granites (PLATE VI and APPENDIX I). There is a large number of rock types in the Chiang Mai area, but only three types were encountered: (1) granite, (2) quartzite, and (3) meta-quartzite. Granitic rocks were most common along the traverses on the west side of the valley; whereas, quartzitic rocks were most common along the traverses on the east side of the valley.

Outcrops and rocks are present on some of the Chiang Mai study area slopes, but they are not nearly as common as they are on the Khorat, Kanchanaburi, and Hua Hin study areas slopes. Moreover, there is considerable difference in the frequency of outcrops and rocks on the slopes underlain by granitic and quartzitic rock in the Chiang Mai study area. Frequency of rocks is much greater on the quartzitic slopes than on the granitic slopes. Figures 43, 44 and 45 show the size and frequency of outcrops and rocks that are typical on the quartzitic slopes that were traversed.

Gully development has reached major proportions on some of the deeply weathered granitic slopes west of the main highway. No water was in the gullies at the time the traverses were made. Slopes on which traverses numbered 53, 54, 65, 66 and 67 were made are good examples of gullied slopes. Gullies on the slope for traverses 53 and 54 are 10 to 20 feet deep and 10 to 30 feet across the top. The gully side slopes are 30 to 60 degrees. The gullies on the slopes for traverses numbered 65, 66 and 67 are smaller; they are 5 to 10 feet deep, 5 to 15 feet across the top, and have 30 to 60 degree side slopes. All of these gullies have steep headwalls, as steep or steeper than the side slopes.

These gullies do not join the drainage net of the area. They vary in length from 30 to about 80 yards At some distance from their head, they regress by diminishing in depth, width, and side wall gradient until they have merged with the adjacent surface and are no longer present.

This area is ideal for guerilla strongholds and activities. Ambush sites and conditions are similar to those in the Ranong area. Chiang Mai area has very limited highway and railroad connections with the rest of the country. The study area is almost completely forest covered. The hills and mountains are rugged terrain. Both the main highways and the railroad could be destroyed in several places within the steep mountainous areas. Here, it would be impossible to detour. Moreover, there are railroad tunnels and at least one high bridge vulnerable to destruction, which would stop passage for months.

Figure 43. Chiang Mai study area: Quartzitic outcrops and rocks on a 20 degree slope segment. The majority of the outcrops and rocks on this slope segment range in size from about 6 inches square to about 5 feet square.

Figure 44. Chiang Mai study area: Quartzitic outcrops and rocks on a 25 degree slope segment. The majority of the outcrops and rocks on this slope segment range in size from a large suitcase to a standard size government office desk. This slope segment is near site #21 of traverse #61.

Figure 45. Chiang Mai study area: Five feet high quartzitic cliffettes on a 41 degree slope segment. This slope segment is near site #6 of traverse #62.

ANALYSIS OF FIELD-MEASURED SLOPE GRADIENT DATA

Bekker[1] (1969) a leader in terrain vehicle research wrote the following on slope distribution:

> To accomplish this, surface profiles must be traced and the frequency of slope distribution defined.
>
> Depending on the mission and its operational requirements, two approaches are useful: one relates slope distribution to the sampled area, the other to the sampled distance . . .
>
> Distribution may be defined either directly by field measurements or from the map.

This report presents field-measured data rather than map-measured data[2], using two approaches:

(1) Percent occurrence of slope gradients (TABLE 2 and Fig. 46).

(2) Percent and cumulative percent of total traverse distance by slope gradients (TABLE 3 and Fig. 47).

Some of the figures (histograms) and tables contain the same information. The histograms, however, are better than tables of numbers for visually comparing several sets of data. The tables are included because it is not possible to extract accurate data from small size bar graphs. All the field data are not presented; they are too voluminous. It is, however, on file at Earth Sciences Laboratory, U.S. Army Natick Laboratories, Natick, Massachusetts.

---

[1] Bekker, M.G., op. cit., p. 268.

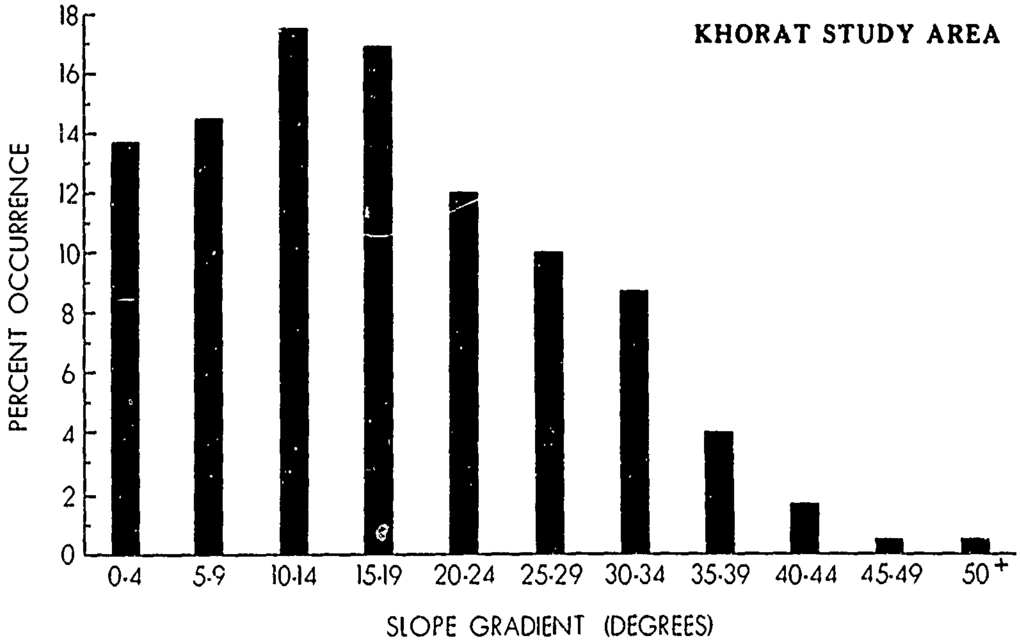
[2] APPENDIX II is included to show the difference between field and map-measured slope data for the same traverse.

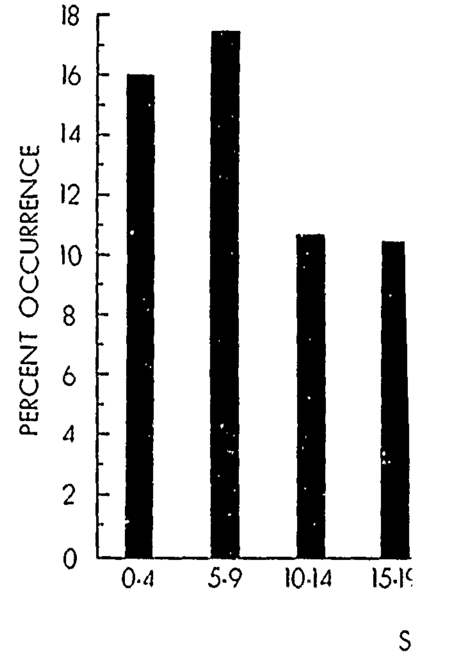
TABLE 2

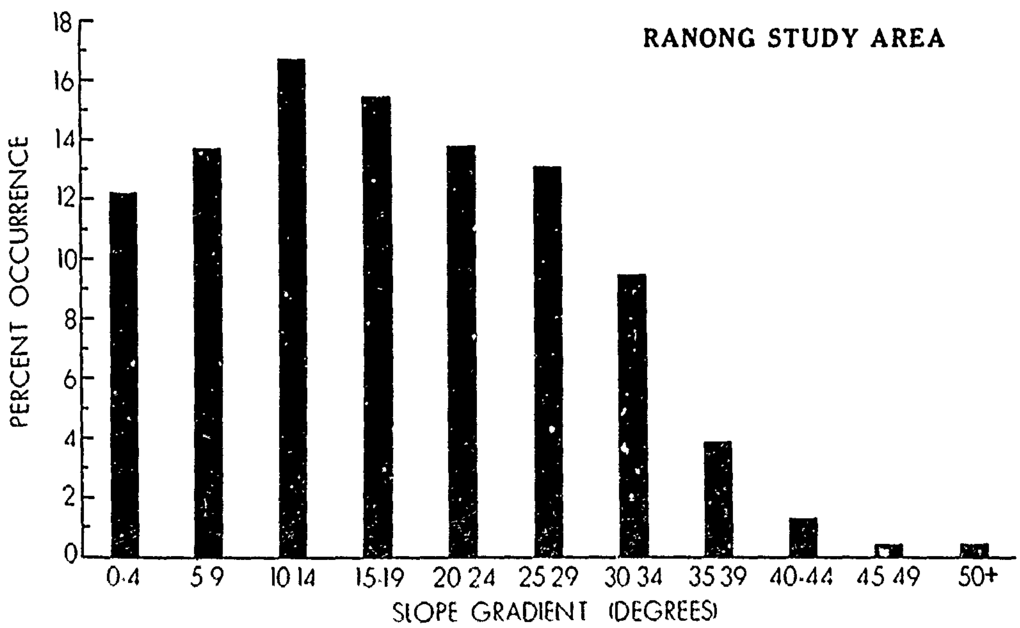
Number and percent occurrence of slope gradients by study area and for all study areas combined.

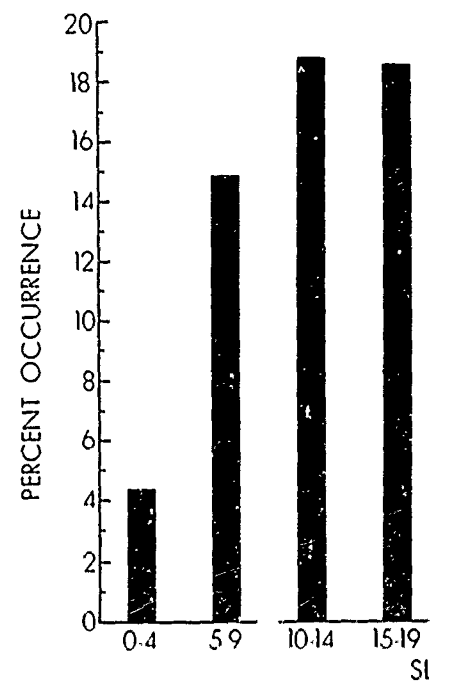
Slope gradient (degrees)	Khorat		Kanchanaburi		Hua Hin		Ranong		Chiang Mai		All Studied Areas Combine		
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	Cum %
0-4	55	13.7	98	16.0	84	10.2	65	12.2	19	4.4	321	11.5	11.5
5-9	58	14.5	107	17.5	126	15.3	73	13.7	64	14.9	428	15.3	26.8
10-14	70	17.5	66	10.8	120	14.6	89	16.7	81	18.8	426	15.2	42.0
15-19	68	16.9	64	10.5	115	13.9	82	15.4	80	18.6	409	14.6	56.6
20-24	48	12.0	77	12.6	137	16.6	73	13.7	72	16.8	407	14.5	71.2
25-29	40	10.0	85	13.9	129	15.7	69	13.0	62	14.4	385	13.8	84.9
30-34	35	8.7	69	11.3	75	9.1	50	9.4	31	7.2	260	9.3	94.2
35-39	16	4.0	33	5.4	27	3.3	20	3.8	8	1.9	104	3.7	97.9
40-44	7	1.7	11	1.8	6	0.7	7	1.3	9	2.1	40	1.4	99.4
45-49	2	0.5	0	0.0	5	0.6	2	0.4	1	0.2	10	0.4	99.7
50+	2	0.5	1	0.2	0	0.0	2	0.4	3	0.7	8	0.3	100.0

PERCENT OCCURRENCE OF SLOPE GRAD









GRADIENTS BY STUDY AREA AND ALL STUDY AREAS C

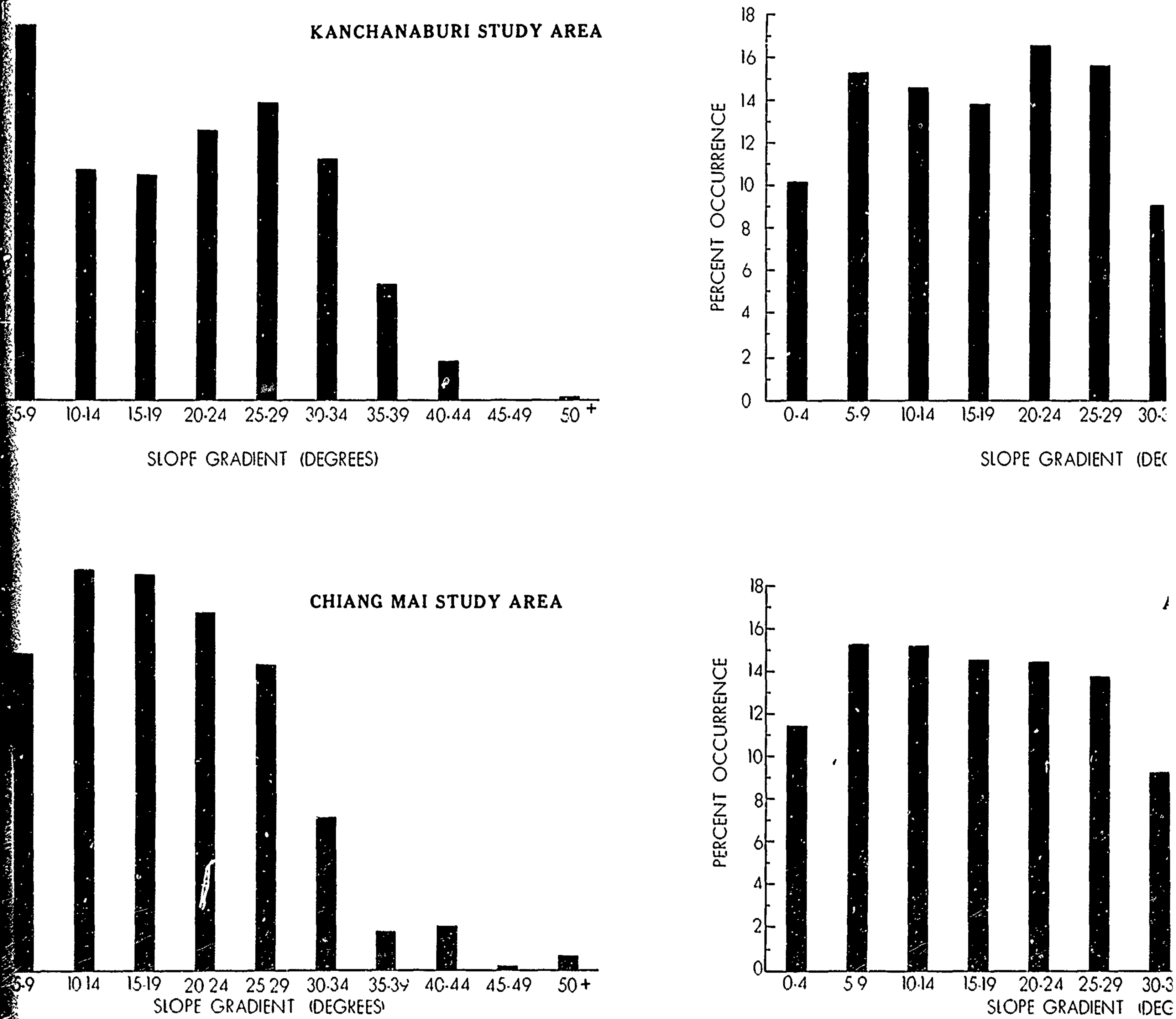
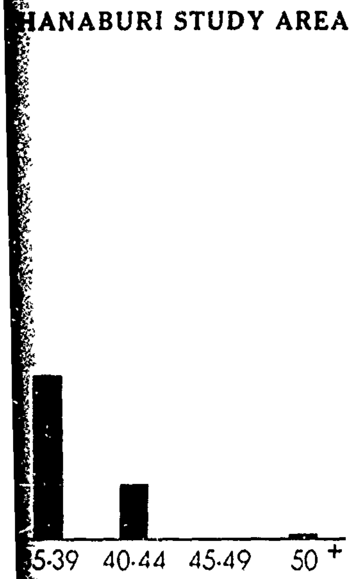
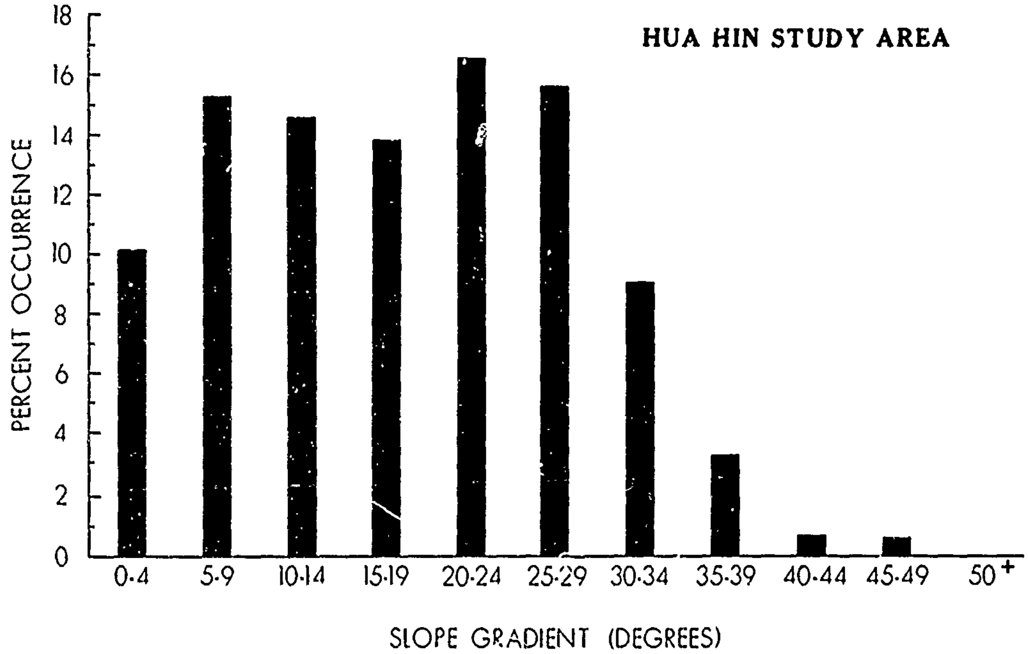
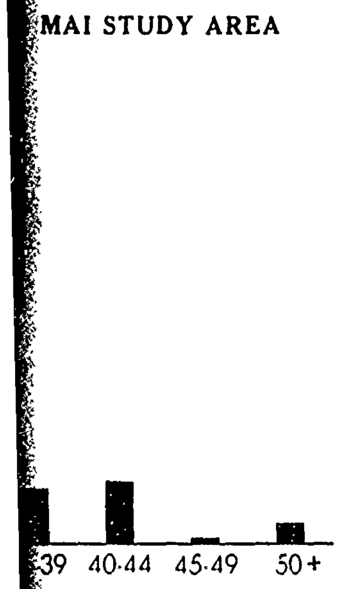


Figure 46

TUDY AREA AND ALL STUDY AREAS COMBINED







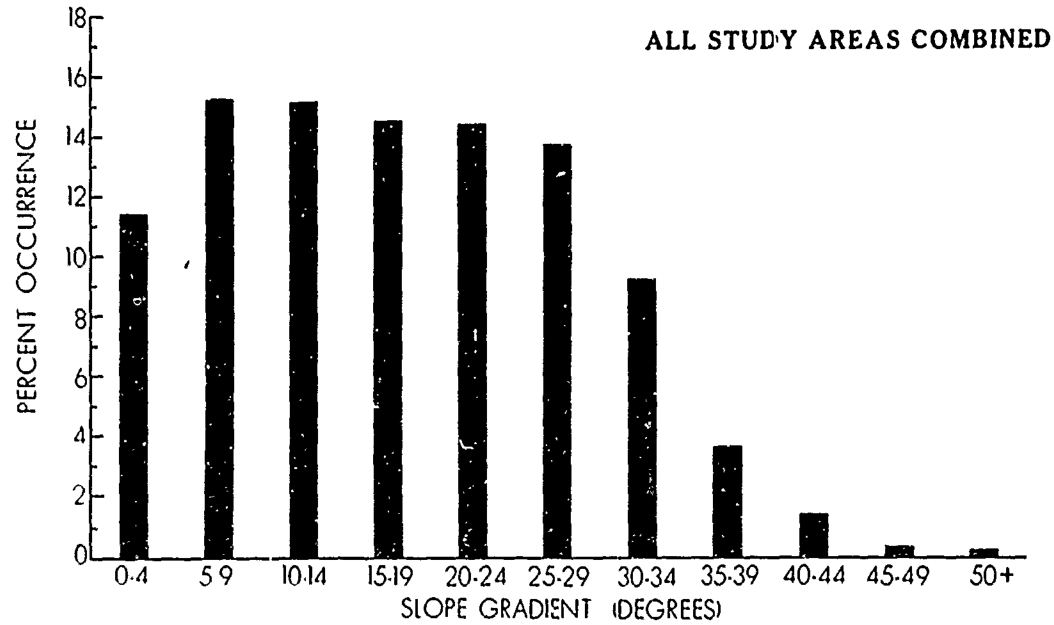
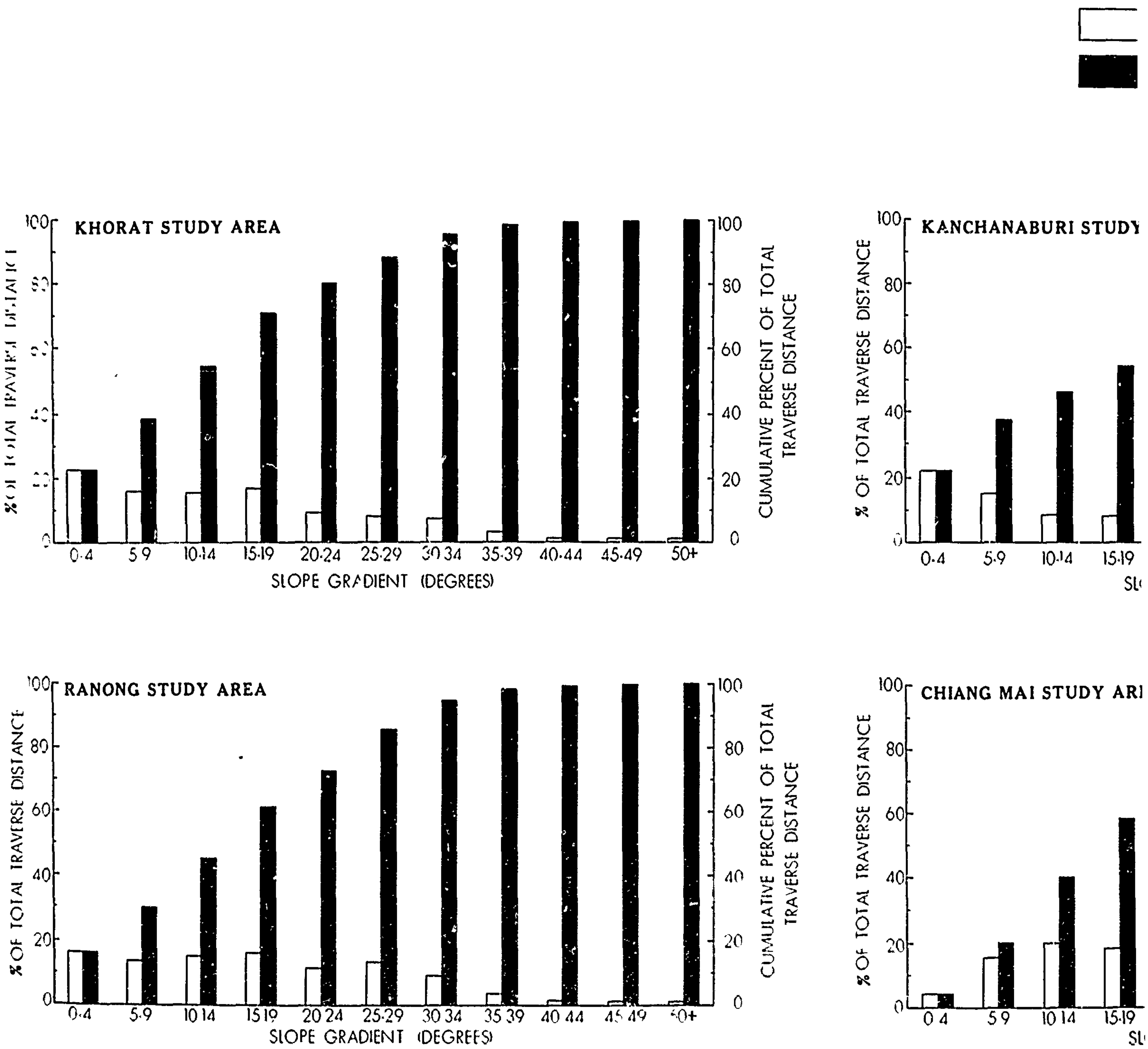


TABLE 3

Percent and cumulative percent of total traverse distance by slope gradients for each study area and for all study areas combined

Slope gradient (degrees)	Khorat		Kanchanaburi		Hua Hin		Ranong		Chiang Mai		All study areas combined	
	A	B	C	D	E	F	G	H	I	J	K	L
	%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %
0-4	22.9	22.9	22.4	22.4	14.2	14.2	16.2	16.2	4.2	4.2	16.3	16.3
5-9	16.0	38.9	15.2	37.6	17.0	31.2	13.5	29.7	15.8	20.0	15.6	31.9
10-14	15.3	54.2	8.5	46.1	12.0	43.2	15.4	45.1	20.0	40.0	13.7	45.6
15-19	16.6	70.8	8.2	54.3	12.4	55.6	16.1	61.2	18.2	58.2	13.8	59.4
20-24	9.3	80.1	11.2	65.5	15.9	71.5	11.3	72.5	16.0	74.2	12.9	72.3
25-29	8.0	88.1	14.1	79.6	16.2	87.7	13.2	85.7	15.3	89.5	13.7	86.0
30-34	7.1	95.2	12.8	92.4	8.4	96.1	9.0	94.7	7.0	96.5	9.0	95.0
35-39	3.3	98.5	5.6	98.0	3.0	99.1	3.4	98.1	1.4	97.9	3.4	98.4
40-44	0.9	99.4	1.9	99.9	0.5	99.6	1.3	99.4	1.8	99.7	1.2	99.6
45-49	0.3	99.7	0.0	99.9	0.4	100.0	0.4	99.8	0.1	99.8	0.3	99.9
50+	0.3	100.0	0.1	100 0			0.2	100.0	0.2	100.0	0.1	100.0

PERCENT AND CUMULATIVE PEI
SLOPE GRADIENT FOR EACH STUI



Preceding page blank

LATIVE PERCENT OF TOTAL TRAVERSE DISTANCE BY EACH STUDY AREA AND ALL STUDY AREAS COMBINED

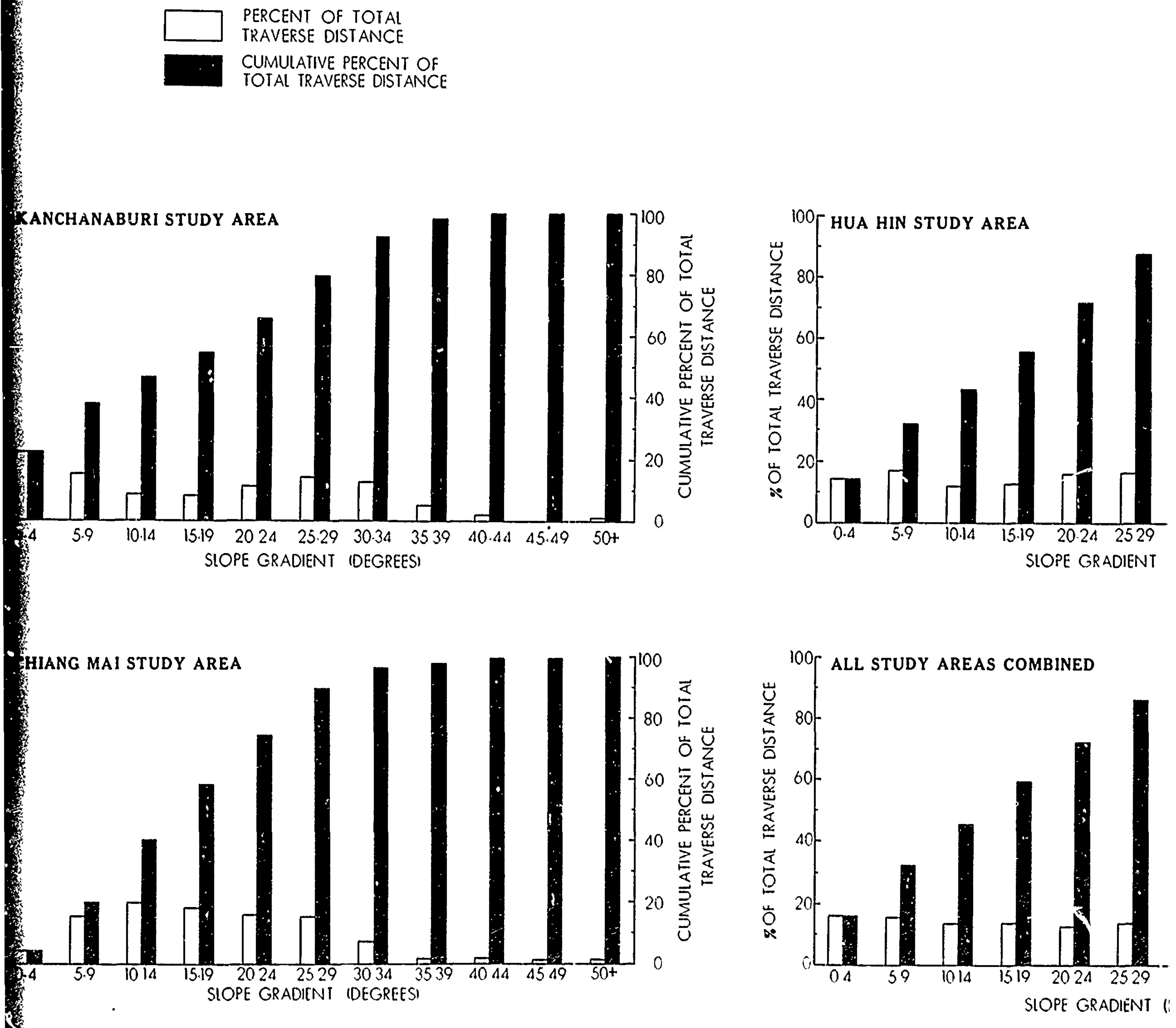
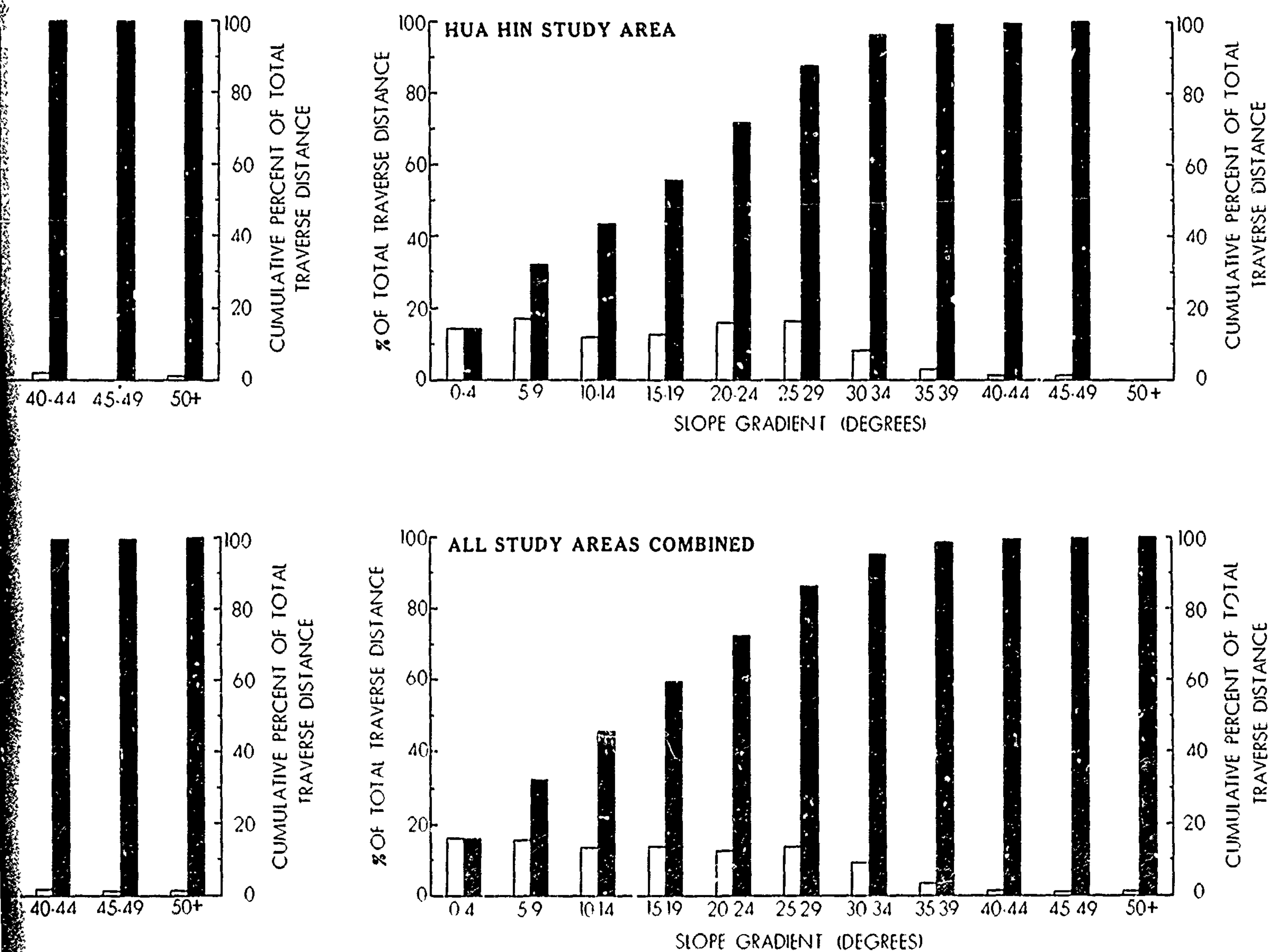


Figure 47

OTAL TRAVERSE DISTANCE BY

D ALL STUDY AREAS COMBINED



The 1967 and 1969 slope gradient samples were compared and found to be very similar: only one of their gradient class intervals had a difference greater than 10 percent. It was 15.5 percent. Seven class intervals had 5 to 9 percent differences. The great majority (35), however, were less than 4 percent. This suggests that both samples are fairly representative. In order to improve the representativeness of the data for the study areas, the 1967 and 1969 samples were combined into composite samples for each study area. Figures 46 and 47 and Tables 3 and 4 present composite (1967 and 1969) data.

Percent Occurrence Of Slope Gradients

Figure 46 includes histograms of the percent occurrence of slope gradients for each study area (I through V), and for all study areas combined (VI). Several points are evident from these histograms (Fig. 46):

(1) Three of the five distributions (Fig. 46 - I, IV, and V) are unimodal, and two weakly suggest bimodal distributions (Fig. 46 - II and III).

(2) All six of the distributions are positive skewed (Fig. 46 - I through VI).

(3) When all study areas are combined, 2,798 gradient measurements, the distribution is platykurtic (unusually flat or broad humped), positive skewed, and it has no suggestion that frequency of slope gradients has a tendency to group into several narrow preferred ranges, i.e., polymodal[1] (Fig. 46 - VI).

(4) Occurrence of slope gradients decreases rapidly with increasing gradients above 30 degrees (Fig. 46 - I through VI).

---

[1] Slope gradient distributions for Yuma Test Station, Arizona, and Fort Knox, Kentucky differ radically from the Thailand distribution. The distributions for Yuma and Fort Knox parallel each other remarkably well, so well that both distributions peak and valley at four identical values. Both areas show marked peak values for the following slope gradient angles: 11.3, 21.8, 30.9 and 38.8 degrees whose corresponding tangent values are 0.2, 0.4, 0.6 and 0.8. This is a very systematic quadri-modal frequency distribution. Is this coincidence, or has a bias been introduced by some inherent feature of the maps, instruments, templates, or whatever was used to make the measurements?

TABLE 4

Cumulative percent occurrence of slope gradients and cumulative percent of total traverse distance by slope gradients for all study areas combined

All study areas combined

Slope gradient (degrees)	A Cumulative percent occurrence of slope gradients	B Cumulative percent of total traverse distance
0-4	11.5	16.3
5-9	26.8	31.9
10-14	42.0	45.6
15-19	56.6	59.4
20-24	71.2	72.3
25-29	84.9	86.0
30-34	94.2	95.0
35-39	97.9	98.4
40-44	99.4	99.6
45-49	99.7	99.9
50+	100.0	100.0

Positive skewness is no surprise; it is common for other geologic and geomorphic parameters. The positive skewness is a result of the fourth point listed above The angle of repose for unconsolidated material explains this rapid decrease.

The great majority of slopes are covered with unconsolidated material. Unconsolidated material establishes an angle of repose which is primarily dependent on the moisture content of the unconsolidated mass and the shape and size of the particles. It has been shown experimentally that the maximum angle of repose for most unconsolidated material is around 30 to 35 degrees. Therefore, if the majority of slopes are covered with unconsolidated material, the majority of slope gradients will be less than 35 degrees.

Considering Thailand or the world as a whole, the frequency of slopes greater than 35 degrees is small. They are very frequent in areas having certain materials and conditions. Clays, clayey sands, clayey loams, marls, cap rocks, or other capping material under certain conditions will develop slopes greater than 35 degrees. A common condition is undercutting of the above material by springs, streams, or waves. It is not uncommon for slopes developed on the above named materials and conditions to have some slopes nearly vertical to overhanging. The mass of unconsolidated material or capping material fractures along planes of weakness or fracture joints.

Areas where slope gradients greater than 35 degrees are found include the following:

(1) hills and mountains with bedrock surfaces,

(2) escarpment and dissected areas with cap rocks or a capping material that gives a caprock effect,

(3) narrow bands (channel side banks) along sections of stream channels, and

(4) clayey, shaley, and marly regions in arid and semi-arid areas. Badlands are an example.

The Khorat escarpment study area is an example of number (2) above.

Furthermore, in some places steep slopes (over 35 degrees) are encountered where there is a soil cover. In these places the soil is only a thin veneer - a few inches at the most. The thin soil cover on the bedrock is similar to a thin dusting of snow on a sloping roof. In both cases the thin soil veneer and the thin dusting of snow merely copy the gradient and pitch of their respective underlying surfaces. Thus, thin veneers of unconsolidated materials do not develop a true angle of repose.

Percent And Cumulative Percent Of Total Traverse Distance By Slope Gradients

TABLE 3 and Figure 47 present the slope gradient data that are pertinent to total traverse distance. There is much similarity between the percent frequency of slope gradient distributions and the percent of total traverse distance by slope gradients (Figs. 46 and 47). The second, third, and fourth general statements made for the percent occurrence of slope gradient distributions can also be stated for the traverse distance - slope gradient distributions. Only the first statement needs some modification:

(1) One of the six distributions (Fig. 47 - V) is truly unimodal: four distributions weakly suggest bimodal distributions (Fig. 47 - I through IV).

(2) All six distributions are positive skewed[1] (Fig. 47 - I through VI).

(3) When all study areas are combined, 2,798 gradient-distance measurements (Fig. 47 - VI) the distribution is platykurtic, positive skewed, and it shows no tendency to concentrate into several narrow preferred ranges, i.e., polymodal.

(4) The percent of the total traverse distance decreases rapidly with increasing gradients above 30 degrees (Fig. 47 - I through VI).

---

[1] The positive skew is related to the angle of repose of unconsolidated material which has been presented in the previous section on percent occurrence of slope gradients.

The platykurtic distribution is very evident by the percentage values for the first through the sixth class interval: 16.3, 15.6, 13.7, 13.8, 12.9, and 13.7 percent (TABLE 3, Column K, and Fig. 47 - VI). The remaining class intervals show the positive skew very well; the five percentage values are 9.0, 3.4, 1.2, and 0.3 and 0.1. The platykurtic distribution (Fig. 47 - VI) for the five combined Thailand study areas shows no tendency to concentrate into several narrow modal ranges of slope gradients.

Useful slope gradient information on each of the five Thailand study areas and on the composite of the five study areas can be combined from TABLES 2 and 3 to make TABLE 4. Tables like TABLE 4 can be made from TABLES 2 and 3 for each of the five study areas. The following are examples of statements that can be made from TABLE 4 for the combined Thailand study areas.

(1) Slopes less than 25 degrees occur 71 percent of the time, and they comprise 72 percent of the total traverse distance.

(2) Slopes greater than 24 degrees occur 29 percent of the time, and they comprise 28 percent of the total traverse distance.

(3) Slopes less than 35 degrees occur 94 percent of the time, and they comprise 95 percent of the total traverse distance.

(4) Slopes greater than 34 degrees occur 6 percent of the time, and they comprise 5 percent of the total traverse distance.

The type of information in the above four statements is useful for design engineers and tactical planners. Based on information like the above, they may decide that it is not necessary to have ground vehicles that can negotiate slopes greater than 39 degrees, especially if their frequency is only 2 percent and comprise only 2 percent of the total traverse distance. With data such as are in TABLE 4, the engineers and planners will know what "slope gradient risk" they are accepting when they design or request ground vehicles with specific slope gradient capabilities.[1]

Similarity Of Values For Percent Occurrence Of Slope Gradients And Percent Of Total Traverse Distance

Extracting data for TABLE 4 and writing the four statements on page 71 on the frequency of occurrence and percent of total traverse distance pointed out to the author an unsuspected phenomenon. The values for each of the following sets of data are remarkably similar:

(1) Percent occurrence of slope gradients and percent of total traverse distance by degree class intervals (TABLE 5).

(2) Cumulative percent occurrence of slope gradients and cumulative percent of total traverse distance by degree class intervals (TABLE 4).

Using columns A, B and C of TABLE 5 it is easy to compare the percent values for frequency of occurrence and percent of total traverse distances for each slope gradient interval. The first class interval (0-4 degrees) has the greatest difference; it is almost 5 percent. The other 10 sets have very small differences. There is less than 2 percent difference for each of the other ten sets of percent values. In fact, seven of the ten have less than 1/2 percent difference.

In TABLE 4, compare columns A and B. The first two classes (0-4 and 5-9 degrees) both have differences of around 5 percent, but the great majority have differences ranging from about 1/2 to 3 percent. The author did not expect this remarkable similarity, but did expect the following two trends:

(1) frequency of slope gradients to decrease as gradient increased

(2) segment length to decrease as gradient increased.

---

[1] In addition to the percent occurrence of slope gradients and percent of total traverse distance, the spatial distribution (long linear or short discontinuous) of steep slopes is very important. Many other parameters besides slope gradient are factors which influence vehicle capability to negotiate slopes. Slope gradient, however, is so basic that it should be included for all vehicle cross-country mobility and vehicle design studies.

TABLE 5

Percent occurrence of slope gradients and percent of total traverse distance by slope gradient for all study areas combined

A	B	C	D	E	F
Slope gradient (degrees)	Percent occurrence of slope gradients	Percent of total traverse distance	Number of slope segments	Average segment Length (ft.)	Traverse distance (ft.)
0-4	11.5	16.3	321	131	41,968
5-9	15.3	15.6	428	94	40,133
10-14	15.2	13.7	426	83	35,156
15-19	14.6	13.8	409	87	35,601
20-24	14.5	12.9	407	82	33,263
25-29	13.8	13.7	385	91	35,164
30-34	9.3	9.0	260	89	23,104
35-39	3.7	3.4	104	85	8,804
40-44	1.4	1.2	40	76	3,036
45-49	0.4	0.3	10	69	692
50+	0.3	0.1	8	43	343

The Thailand data, in a general way, agrees with the two trends mentioned above. Listed below, however, are several deviations which are obvious in TABLE 5, columns D, E, and F.

(1) There are less slope segments for the first class interval (0 to 4 degrees) than the next five higher class intervals (TABLE 5, column D).

(2) There are irregular and relatively small decreases in the number of occurrences for the second through the sixth class intervals (TABLE 5, column D).

(3) Note the increasing and decreasing nature and relatively small decrease of the average segment length for the third through the sixth class intervals (TABLE 5, column E).

The first deviation is probably due to the following two reasons:

(1) As noted earlier in the introduction, level to gentle slope areas which are part of the lowlands along some roads and cart trails were excluded for traverses.

(2) Roads and trails are frequently located at the base or just below the abrupt break-in-slope of hills and mountains. In these cases the number of low gradient (0 to 4 degrees) slopes is reduced considerably. This is because the distance to the steeper slopes above the break-in-slope is limited.

A scatter diagram including all the 2,798 slope segment lengths and their gradients was made to see if a relationship exists between them. The general outline of the points is a "V" rotated counter clockwise almost 90 degrees so that the open end faces the ordinate axis. This axis is used for "segment length." By computer the best fit linear regression equation is

$$Y = 106.67 - 0.83X$$

and the standard error of estimate (Syx) is, 70.77, and the coefficient correlation (r) is 0.33.

The Syx is at least 75 percent as large as 11 of the 12 average segment lengths (TABLE 5, column E). The large Syx and the low coefficient of correlation indicates that there is a very poor relationship between segment length and segment gradient for the Thailand slope data.

SUMMARY

Several recent U.S. Army reports stress the need for field-measured slope parameters. Ground vehicle designers, operational test evaluation agencies, tactical and strategic planners, logistic groups, and military geographic intelligence agencies are a small sample of the different types of users of slope data.

The major objective of this study was to field measure slope segment lengths and their gradients in five selected representative hill and mountain sample areas of Thailand. These areas are physiographically different. Another objective was to determine if slope gradients could be predicted for larger geographically related areas. Other objectives included the testing, the storage, the sorting, the quick retrieval, and the mathematical computations of the data by computer.

Information obtained includes 2,798 field-measured slope segment lengths and their gradients from 157 traverses totaling 49.3 miles. Brunton compass, steel tape, optical rangefinder, and Abney hand levels were used for measurements. Photographs and field descriptions were also used to complement the quantitative material.

Large and small caverns are numerous in the carbonate strata of the Kanchanaburi area. The caves in the carbonate areas and the cave-like sites along the base of the massive Khorat escarpment cap rock are excellent for guerilla and partisan forces. These caves and cave-like sites can be used for shelter, storage, observation and gun sites.

Accessibility is very poor due to the limited road and railroad network in these mountainous areas. Dense forest cover, especially in the tropical rain forest areas, is ideal for ambushes and disrupting and/or controlling foot troop and vehicle movement on the transportation routes.

Comparison of field-measured slope segment lengths and their gradients with map-measured slope segment lengths and their gradients were performed. The best available topographic maps, scale of 1:50,000, were used for the map measurements. All the comparisons reveal that the map-measured data is a gross misrepresentation of the ground-truth (field-measured) slope data.

Unfortunately, except for desert and very sparsely vegetated areas, the present state-of-the-art makes it necessary for researchers to rely on field measurements for ground-truth of micro surface features and reliable slope gradient data.

Many segments in some of the study areas are partially to completely covered by rocks (pebbles to large blocks). Negotiating these slopes is difficult and slow for men on foot. For ground vehicles, many of these same slopes would present a "no-go-situation." For example, the massive cap-rock zone of the Khorat escarpment area presents vertical cliffs ranging from 10 to 15 feet in some places and large rock blocks in other places.

Slope gradients and micro surface conditions vary considerably on slopes with the same type of bedrock, and there are apparent differences in slope gradients on different types of bedrock in the five study areas. In the Khorat escarpment area, the gradients on the sandstone cap-rock slopes are steeper than gradients on the less resistant rock units below the cap rock. In the Kanchanaburi study area, the gradients on granite, limestone, and marble slopes are generally steeper than gradients on slopes underlain by shale and phyllite. Unfortunately, the small number of slope gradients for which the underlying bedrock is known precludes making any quantitative statement. The above generalizations support but add nothing new to several past studies.

Percent occurrence of slope gradients for the 1967 and 1969 samples of the same areas were compared and found to be very similar. These were combined into composite samples for each study area. The percent occurrence of slope gradients for the Thailand study areas show the following:

(1) Three of the five study area distributions are unimodal, and two weakly suggest bimodal distributions.

(2) The distribution is platykurtic and positive skewed when all the study areas are combined into one composite. There is no suggestion that frequency of slope gradients has a tendency to group into several narrow (polymodal) ranges of slope gradients. This distribution differs radically from two earlier reports on slope gradient distributions prepared for the U.S. Army.

(3) The occurrence of slope gradients decreases rapidly with increasing gradients above 30 degrees.

The percent of total traverse distance by slope gradient distributions are summarized as follows:

(1) One of the five study area distributions is unimodal, and the other four weakly suggest bimodal distributions.

(2) The distribution is platykurtic and positive skewed when all study areas are combined into one composite. There is no suggestion that traverse distance has a tendency to group into several narrow polymodal ranges of slope gradients.

(3) The percentage of traverse footage decreases rapidly with increasing gradients above 30 degrees.

There is a remarkable similarity of values for each of the following sets of data:

(1) Percent occurrence of slope gradients and percent of total traverse distance by 5 degree class intervals.

(2) Cumulative percent of slope gradients and cumulative percent of total traverse distance by 5 degree class intervals.

The following two statements are examples that can be made using the frequency distributions in this report:

(1) Slopes less than 25 degrees occur 71 percent of the time and comprise 72 percent of the total traverse distance.

(2) Slopes greater than 34 degrees occur 6 percent of the time and comprise 5 percent of the total traverse distance.

The range of segment lengths for each degree of gradient is large, and the linear equation of the relationship between the segment lengths and their respective gradients is

$$Y = 106\ 67 - 0.83X.$$

The standard error of estimate (Syx) is 70.77, and the coefficient correlation (r) is 0.33.

CONCLUSIONS

The requests by various military groups for ground-truth gradient data is justified. The slope data measured from the best topographic maps scale as large as 1:24,000, inherently have many major gradient errors. These maps were not designed for micro gradient studies. Map data is good for developing methodology, hypotheses, and generalizations. These, however, must be tested using field data before they are accepted and used for making important decisions.

At present, the author knows of no systems, including radar and laser, which can penetrate dense vegetation, especially tropical rain forests, and register slope variations with an accuracy equivalent to that achieved with the Abney hand level. Unfortunately, until airborne or satellite instruments are available which can measure terrain parameters such as relief, gradient, and rock size and their percent of surface coverage at micro levels, conventional ground field methods and instruments must be used when terrain-truth data are required.

Field sampling which is completely acceptable by statistical theory is difficult to impossible for certain areas of the world. Even for politically accessible areas, the available time, monies, and personnel can pose severe limitations on what sampling methods can be used.

For practical purposes, the histograms show that the differences among the slope gradient occurrence distributions for the five Thailand study areas are insignificant. It is concluded that this close similarity of gradient occurrence is basically due to the great heterogeneity of each area.

The physiographic regions of Thailand are large; they are heterogeneous in several aspects. These aspects include structure, rock type, stage and process of erosion, climate and vegetation. In addition, slope form is influenced by its original form and the relationship between the rate of disintegration of its underlying strata and the rate of removal of the disintegrated rock and soil from the slope and base of the slope

Depth of soil influences hill and mountain slope gradients. Hill and mountain slopes with no or thin soil cover have a greater incidence of steep (greater than 35 degrees) gradients than thick soil-covered slopes. A thin soil cover does not develop a true angle of repose which is generally less than 35 degrees. A thin soil cover merely parallels and veneers the underlying bedrock which can be considerably steeper than 35 degrees.

Climate influences vegetation which in turn influences the rate of removal of the disintegrated rock and soil from the slope. The amount and intensity of rain and the infiltration capacity of the soil influences the runoff. Runoff influences development of streams which are the most important agent for removing material from the base of the slopes.

It appears that all kinds of hill forms and slope gradients are found in all kinds of climates. Specific climates do not produce unique hillslope forms or gradients. What is known is that specific factors vary in relative importance in different climatic environments.

Understanding slope form development and gradient frequency distributions are difficult. Similar hillslope forms and gradients may be the results of totally different factors. Many aspects of slopes, including gradients, are the composite results of today's influencing factors and the past geologic and climatic factors. This for some regions can be considerably different than the present factors. The present factors have not completely obliterated the results of the past factors. The almost unlimited number of present and past combinations of climate, vegetation, soil, lithology, structure, jointing, tectonic movements, processes of weathering, and agents of erosion, all of which can change considerably through geologic time, act as normalizers.

The similar percent incidence of slope gradients for the five hill and mountain study areas of Thailand are attributed to the above unlimited combinations and heterogeneity of large, soil-covered physiographic regions. Moreover, the similar gradient distributions support the idea that similar hillslopes and gradients develop in different climates.

Using the findings and conclusions from this study and general knowledge of land forms and slopes it is possible to postulate on slope gradient distributions. Most gradient frequency distributions will have at least a small percentage of their slope segment gradients at both ends (0 and 90 degrees) of the scale. The distribution of the bulk of the segment gradients, however, will have marked differences (Fig. 48).

It is postulated that thick soil-covered hills and mountains anywhere in the world, having heterogeneity of strata, structure, processes of weathering, and agents of erosion will have a platykurtic, positive skewed gradient frequency distribution. It is also postulated that hills and mountains with bedrock surfaces, rather than thick soil horizons, with heterogeneity of the same above mentioned factors will have a gradient frequency distribution similar to the thick soil-covered hills and mountains with some degree of the following modifications (Fig. 48, curve #2):

(1) a lower percent level for the platykurtic part of the distribution,

(2) a broader span of degrees for the platykurtic part of the distribution, and

(3) an increase in the percent occurrence of gradients greater than 35 degrees.

It is postulated that for plains the distribution would be unimodal at the 0 to 5 degrees range and positive skewed with very low percentages for gradients above 10 degrees (Fig. 48, curve #3). Additional distributions could be postulated for sand dune areas and other types of topography. The few distributions mentioned are sufficient to stimulate thought and discussion on gradient frequency distributions. With field measurements in each physiographic province and subprovince, percent and cumulative percent frequency of gradient and percent and cumulative percent of total traverse distance by gradient could be established for militarily significant areas of the world.

POSTULATED GENERALIZED SLOPE GRADIENT FREQUENCY DISTRIBUTIONS

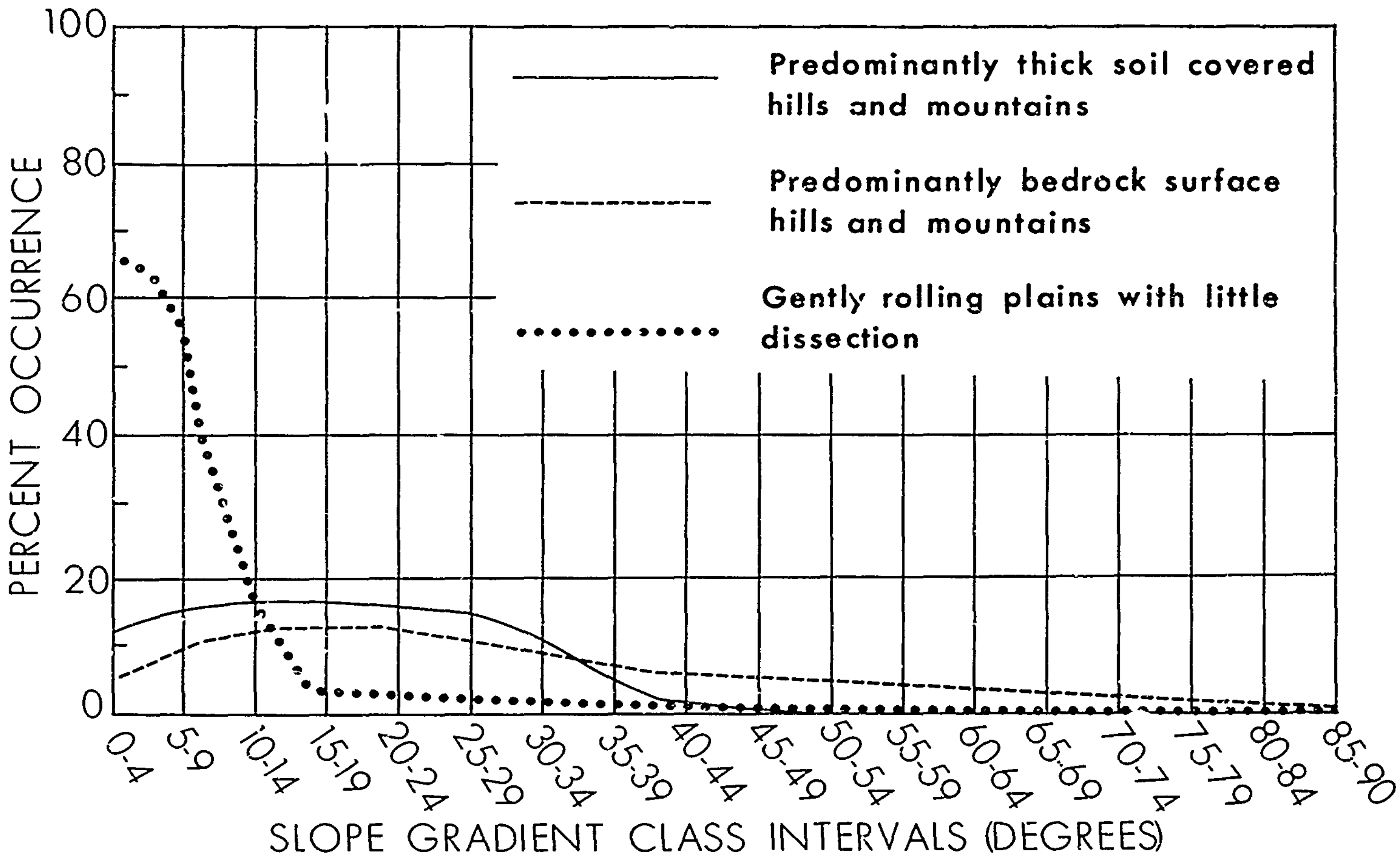


Figure 48

RECOMMENDATIONS

Several recommendations can be made as a result of this study. All the recommendations are important, but with the exception of the first one, no attempt is made to list them in their order of importance.

The development or airplane and/or satellite borne instruments which can duplicate the reliability of field-measured environmental parameters should be very high on the priority list for support funds.

Until suitable airplane or satellite instruments are developed, research should be conducted for establishing constants which will equate map-measured data from topographic maps of different scales to field-measured data.

A similar field study of predominantly soil-covered hills and mountains in a humid meso-thermal or humid micro-thermal climate should be done to check and verify or refute the findings and conclusions for the soil-covered hills and mountains in the tropical climates of Thailand. If the findings and conclusions are correct, similar studies could be undertaken to establish gradient frequency and traverse distance by gradient distributions for other militarily significant types of topography.

Atlases showing cave and potential cave or tunnel areas should be prepared. These could include carbonate rock areas. Outcrop areas of massive strata underlain by less resistant formations such as those along the top edge of the Khorat escarpment should be mapped. Areas having favorable soil types and hydrologic conditions for man-made caves and tunnels should also be indicated.

Areas where the frequency and size of small rocks and rock blocks present problems to men and vehicles should be mapped.

Maps and information on selected drainage parameters should be obtained. Frequency of channels and their cross sections are needed. Seasonal depth and temperature of water, average thickness of ice on water channels and lakes, and the potability of surface and underground water are needed for military purposes.

Preceding page blank

Soil depth and soil engineering qualities should be mapped so that the effectiveness of different types of explosives may be determined. Minerology and particle size of soils should be determined to establish their potential for silt and dust concentrations from natural and induced causes near the surface of the earth.

REFERENCES

1. Bekker, M.G., Introduction to Terrain Vehicle Systems, The University of Michigan Press, Ann Arbor, Michigan, 1969.

2. Brown, G.F. and Others, Geologic Reconnaissance of the Mineral Deposits of Thailand, Geologic Investigations of Asia, Geological Survey Bulletin 984, U.S. Government Printing Office, Washington, D.C., 1951.

3. Committee for Proposed AMC Mobility Research Program, Proposed AMC Mobility Research Program, U.S. Army Engineer, Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss., 11 April 1969.

4. Dornbush, Jr. W.K., Mobility Environmental Research Study: A Quantitative Method for Describing Terrain for Ground Mobility, Vol. III, Surface Geometry, U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss., Sept. 1967.

5. Krenkel, Peter A., Application of Terrain Descriptive Techniques to Fort Knox, Kentucky, Contract No. DA-22-079-eng-300, Department of Civil Engineering, Vanderbilt University, Nashville, Tenn., 30 April 1962.

6. The 2d AD HOC Working Group, Adverse Effects of Slopes on Military Operations, U.S. Army Advanced Materiel Concepts Agency, Washington, D.C., 20315, 20 Sept. 1968.

7. U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Handbook A Technique for Preparing Desert Terrain Analogs, Technical Report No. 3-506, 1959.

APPENDIX I

Preceding page blank

APPENDIX I

SUMMARY OF CURRENT (1950) KNOWLEDGE OF THAI STRATIGRAPHY*

Age	Rock unit	Character	Thickness (meters)	Principal areas or changwats where rock unit occurs: Southern Thailand (between latitude 5°-12°N)	Central Thailand (between latitude 12°-16°N)	Northern Thailand (between latitude 16°-21°N)	Economic value
Quaternary		Unconsolidated silt, clay, sand, and gravel of stream channels, flood plains, and terraces; beach and estuarine deposits; raised coral reefs and marine terrace deposits; residual lateritic deposits.	0-300+	Songkhla, Phuket, Phangnga, Surat Thani.	Central plain of Mae Nam Chao Phraya and Tributary rivers.	In the basins of Mae Fang, Mae Rin, Lampang, Amphur Pai, Mae Sot and others.	Important alluvial and tin placers in southern Thailand; eluvial and colluvial tin and tungsten placers in southern and central Thailand; alluvial gold placers in many localities; gemstone placers in eastern Thailand; small lateritic iron deposits; good water-bearing beds in alluvial valleys and the flood plain of Mae Nam Chao Phraya.
	Krabi series	Semiconsolidated fluviatile, estuarine, or marine deposits of clay, sand, gravel, marl, bituminous shale, lignite, gypsum, and marine limestone.	0-175+	In eight structural basins lying in southern Peninsular region.	Not recognized	Not recognized	Contains potentially important lignite beds in several places; gypsum and oil shale deposits of doubtful value.
Tertiary	Mae Sot series	Semiconsolidated fluviatile and lacustrine deposits of clay, sand, gravel, marl, oil shale, lignite, gypsum, and fresh-water limestone.	0-430+	Not recognized	Mae Sot basin	In basins of Mae Fang, Mae Rin, Mae Moh, Lampang, Amphur Pai and others	Contains potentially important oil shale deposits in Mae Sot basin; a small oil-bearing bed in Mae Fang basin; lignite and gypsum deposits of minor value.
	Andesite and rhyolite porphyry	Andesite porphyry in stocks and dikes by younger rhyolite porphyry in dikes and flows; in places intrudes or overlies basalt or diorite.		Chumphon	Chanthaburi, Sara Buri	Tak, Petchabun Uttaradit Chiang Rai	In places used for road ballast.
Tertiary (?)	Basalt	Basalt in flows, dikes and plugs; nepheline and spinel in some localities, intrudes Korat series.		Not recognized	Kanchanaburi, Chanthaburi, Trat, Lop Buri, Buriram, Sisaket.	Tak, Lampang, Chiang Rai	Yields sapphires, rubies, and topaz to eluvial and alluvial placers in Changwats Chanthaburi, Trang and Kanchanaburi.

SUMMARY OF CURRENT (1950) KNOWLEDGE OF THAI STRATIGRAPHY

(Cont'd)

Age	Rock unit	Character	Thickness (meters)	Principal areas or changwats where rock unit occurs: Southern Thailand (between latitude 5°-12°N)	Central Thailand (between latitude 12°-16°N)	Northern Thailand (between) latitude 16°-21°N)	Economic value
	Diorite and quartz diorite.	Diorite and quartz diorite in dikes, bosses, stocks, and small batholiths; intrudes Korat series and other rocks.		Not recognized	Lop Buri	Phetchabun, Chiang Rai.	Associated with gold lodes and placers of Tha Tako, Krabin, and other localities; also the contact-metamorphic iron deposit of Khao Thap Khwai.
Late Cretaceous	Younger granite	Muscovite-biotite granite with hornblende generally present, and zircon, apatite, and tourmaline common accessories; in dikes, stocks, and elongate batholiths.		All of Peninsular region.	Western frontier area.	Mae Sariang area.	Associated mineralized zones yield important deposits of tin and tungsten from lodes or eluvial and alluvial placers in western and Peninsular Thailand.
Jurassic and Triassic	Korat series with Kamawkala limestone.	Sandstone, conglomerate, and shale, with some thin marly or concretionary limestone locally metamorphosed to quartzite, phyllite, and slate; massive gray impure Kamawkala limestone intercalated with Korat series in Mae Sot region.	366-2,000+	Southern Peninsular Thailand, Surat Thani, Chumphon.	South-eastern Thailand, Korat Plateau.	Northern and north central region, Mae Sot region, Korat Plateau.	Associated with most of Thailand's manganese deposits; also contains salt deposits in the Korat Plateau; hard sandstones used for building stone and abrasives.
Triassic (?)	Older granite	Hornblende-biotite granite, with subordinate muscovite; in dikes, stocks, and elongate batholiths.		Narathiwat	Chanthaburi, Chon Buri, Nakhon Nayok, Korat region, western region.	Chiang Mai, Chiang Rai, western region.	Associated mineralized zones contain gold, copper, molybdenum, iron, antimony, lead, and zinc ores. Gold lodes are characteristic, and locally antimony, lead, and zinc deposits. Apparently tin mineralization rare or absent.

SUMMARY OF CURRENT (1950) KNOWLEDGE OF THAI STRATIGRAPHY

(Cont'd)

Age	Rock unit	Character	Thickness (meters)	Principal areas or changwats where rock unit occurs: Southern Thailand (between latitude 5°-12°N)	Central Thailand (between latitude 12°-16°N)	Northern Thailand (between latitude 16°-21°N)	Economic value
	Mafic and ultra-mafic rocks.	Diorite, gabbro, pyroxenite, and minor perknites in dikes, small plugs, and stocks.		Not recognized	Not recognized	Chiang Rai, Uttaradit.	Serpentinized zones in Changwat Uttaradit contain small asbestos deposits.
Permian and Carboniferous?	Rat Buri limestone	Massive light gray limestone interbedded with sandstone and shale in Peninsular and northern Thailand; fossiliferous cherty beds and thin-bedded limestone occur locally.	752-2,350+	Scattered through Peninsular region.	Phet Buri, Rat Buri, Kanchanaburi, Nakhon Sawan, Prachin Buri.	Scattered through northern region.	Important as a source of lime, road and railroad ballast.
Pre-Permian (?)	Gneiss and schist	Biotite-muscovite para and orthogneiss and associated mica schist in injected bodies in Kanchanaburi series.		Surat Thani	Prachuap Khiri Khan, Chon Buri.	Chiang Mai	Limited use for building stone and kitchenware.
Early Carboniferous (?), Devonian (?) and Silurian.	Kanchanaburi series	Shale, sandstone, and sandy shale, in many places metamorphosed to phyllite, argillite, quartzite, and slate; thin beds of limestone locally present.	1,000-2,900+	Southern Peninsular region.	Western and southwestern region	Northern and northwestern region.	
Ordovician (?)	Thung Song limestone.	Dark gray limestone, with disseminated crystals of pyrite and thin stringers of brown calcareous material.	2,740±	Ron Phibun, Nakhon Si Thammarat, Satun.	Kanchanaburi, Chon Buri.	Not recognized	Limited use for road and railroad ballast; small scale use of dolomitic limestone of Koh Si Chang for refractory pruposes.
Cambrian (?)	Phuket series	Dark colored pebbly shale, shale, and fine-grained sandstone, in many places metamorphosed to schist, slate, quartzite, and argillite; pebbles of quartz, quartzite, slate, and granite in pebbly shale may be pre-Cambrian.	1,220±	Central and western zones of Peninsular region	Not recognized	Not recognized	

* Source: Brown, G.F. and others, Geologic Reconnaissance of the Mineral Deposits of Thailand, Geologic Investigations of Asia, Geologic Survey Bulletin 984.

APPENDIX II

APPENDIX II

COMPARISON OF FIELD AND TOPOGRAPHIC MAP-MEASURED SLOPE GRADIENTS

Slope gradient data is available from several sources: (1) topographic maps, (2) aerial photographs, and (3) field measurements. Each of these sources has advantages and disadvantages. All investigators have not in the past and will not in the future use the same source for their slope gradient data. Bekker (1969)[1] wrote the following on slope data source: "Distributions may be defined either directly by field measurements or from the map." Several things influence what source is used:

(1) availability of large scale topographic maps,

(2) availability of aerial photographs,

(3) available time to collect data,

(4) amount of money available for the study,

(5) degree of detail and/or reliability of data required,

(6) availability of office and/or field personnel,

(7) logistic problems of field work, and

(8) physical difficulty and related problems in the field.

Aerial photographs, which are the source material for modern topographic maps, and topographic maps are available for most of the world. Unfortunately, aerial photographs lack ground surface details for forested areas which means topographic maps also lack the same details. In all fairness, however, it must be pointed out that topographic maps are good for their intended purposes which do not include identification of micro surface features. Topographic maps depict within set limits of accuracy (1) relief, (2) contour of the land, and (3) selected cultural features.

---

[1]Bekker, M.G., op. cit., p. 268.

Contoured topographic maps, because of scale problems, must be generalized. Detail is lost in any generalization. Contour maps show the average slope gradient between any two adjacent contour lines. Whereas, the same slope segment measured in the field can include all the 1 degree variations between any two adjacent contour lines. With this little background on aerial photographs and maps, it is now appropriate to present a comparison of the measured slope segment gradients and lengths of the same traverse taken in the field and from the topographic map.

Comparisons between field source data and map source data for several traverse lines were made. They all show similar results, so only one set of surface profiles and data are presented. Field data for traverse #61 of the Chiang Mai study area and map-measured data along the same line are used to show what differences there are between the two sources of data. Traverse #61 was selected because the starting and stopping points are clearly visible on the map and in the field. The high point of the traverse is at the peak of the slope, and the low point is at the road at the eastern base of the slope (PLATE V). The map, scale 1:50,000, was enlarged 400% to facilitate making accurate map measurements. The field and map measurements are tabulated in TABLE 6, and the surface profiles are shown on Figure 49. A histogram of the percent of total traverse distance of slope gradients is shown on Figure 50.

On a cursory examination of the surface profiles (Fig. 49), one may think that the difference between field and map data are insignificant. Major differences, however, are evident in a listing of the two sets of data (TABLES 6 and 7) and on the histogram (Fig. 50) of the percent of the total traverse distance by slope gradient. The maximum number of gradient readings from the map is one less than the number of contour lines on the slope, or the same number as contour lines when the elevation of the peak is indicated. For the case in point, it is the latter, which has thirteen slope gradient readings. For the same traverse measured in the field there are twenty-seven slope gradient readings which indicate actual changes of at least 1 degree.

Even more important, the field data show slope gradient values that are not expressed on the map contours (Fig. 50). The field data show about 26 percent of the traverse distance having slope gradients between 4 and 11 degrees, but no 4 to 11 degree slopes are depicted by the contour lines on the map. The field data also show that there are no gradients over 31 degrees; whereas, the map data show about 5 percent of the traverse distance has slope gradients between 32 and 35 degrees. Other differences are also evident, but there is no need to belabor the point.

TABLE 6

Field and map-measured slope gradient data for Chiang Mai Traverse #61

Map *		Field	
Slope gradient (degrees)	Segment length (feet)	Slope gradient (degrees)	Segment length (feet)
Bottom of mt.		Bottom of mt.	
15	255	7	287
18	213	2	73
18	213	6	46
14	273	24	36
32	125	20	50
18	213	16	64
25	156	14	81
22	176	8	46
15	255	19	73
25	156	15	70
24	162	22	60
19	203	20	71
1	172	28	65
Top of mt.		31	53
		26	59
		20	83
		27	84
		30	80
		31	71
		25	110
		26	105
		17	106
		25	218
		21	142
		10	185
		13	135
		7	113
		Top of mt.	

* Original map scale (1:50,000) enlarged 4 X to 1:12,500 so that map could be measured more accurately.

PROFILES FOR CHIANG MAI TRAVERSE #61 FROM FIELD AND MAP MEASURED DATA

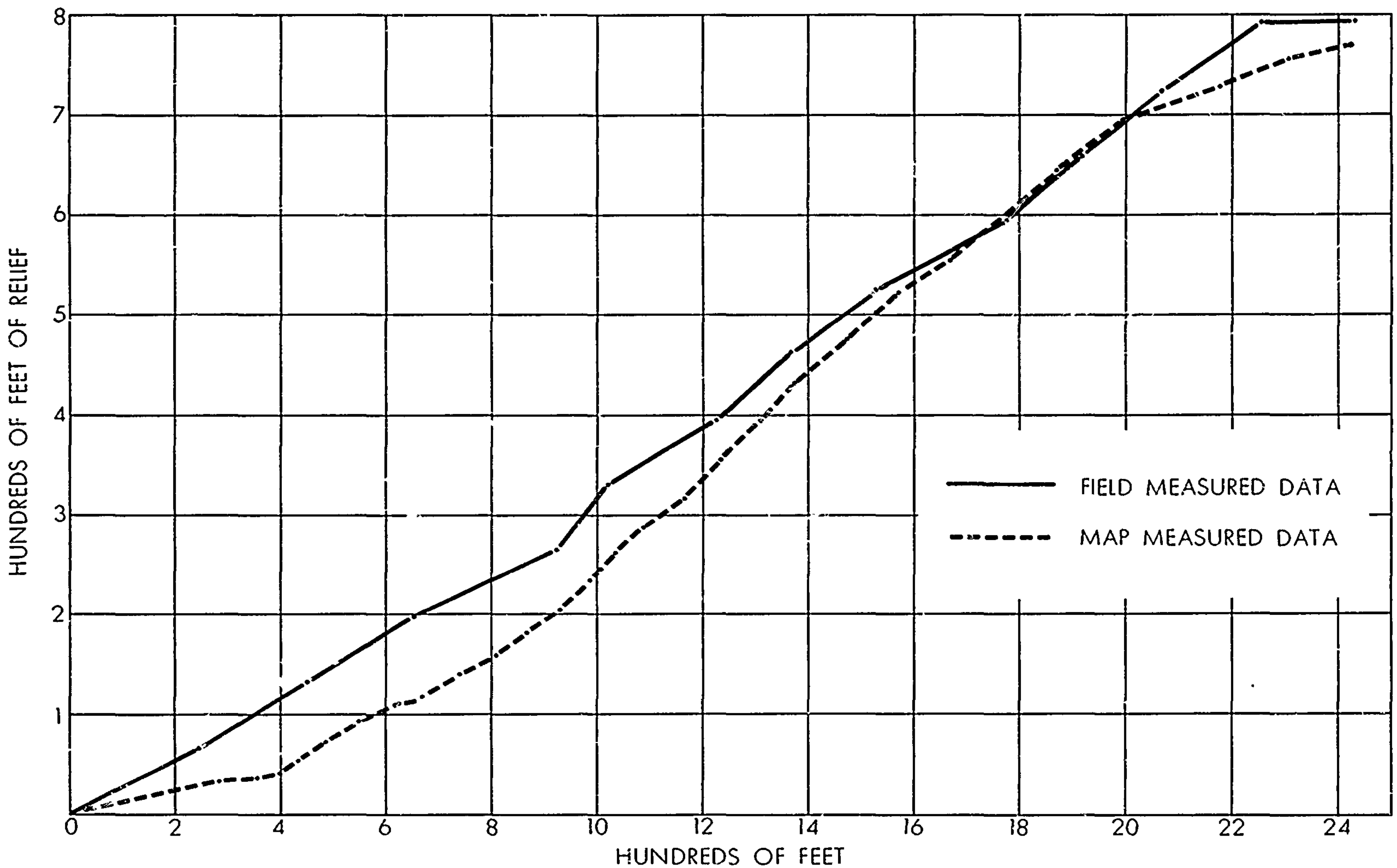


Figure 49

PERCENT OF TOTAL TRAVERSE DISTANCE OF SLOPE GRADIENTS FOR CHIANG MAI TRAVERSE #61

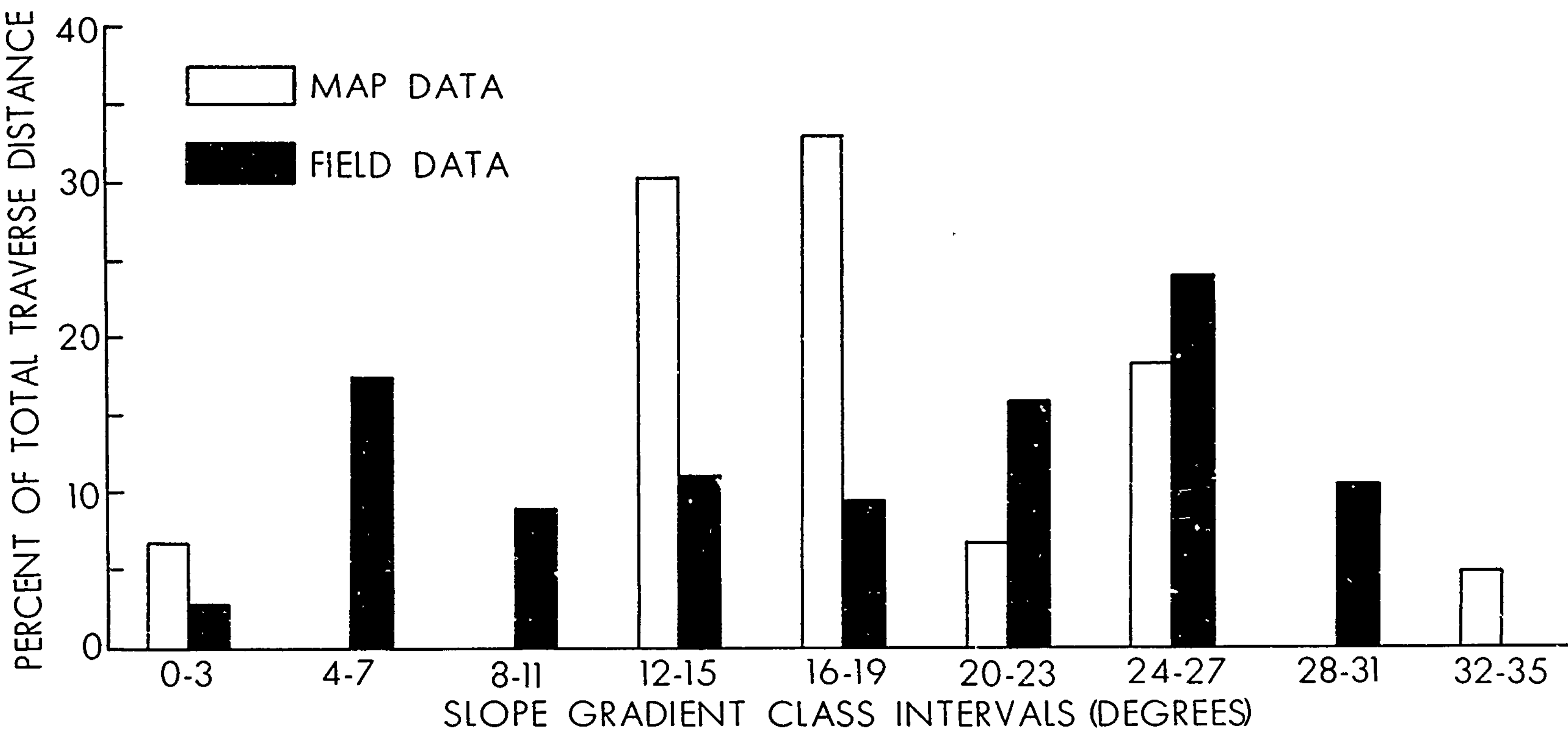


Figure 50

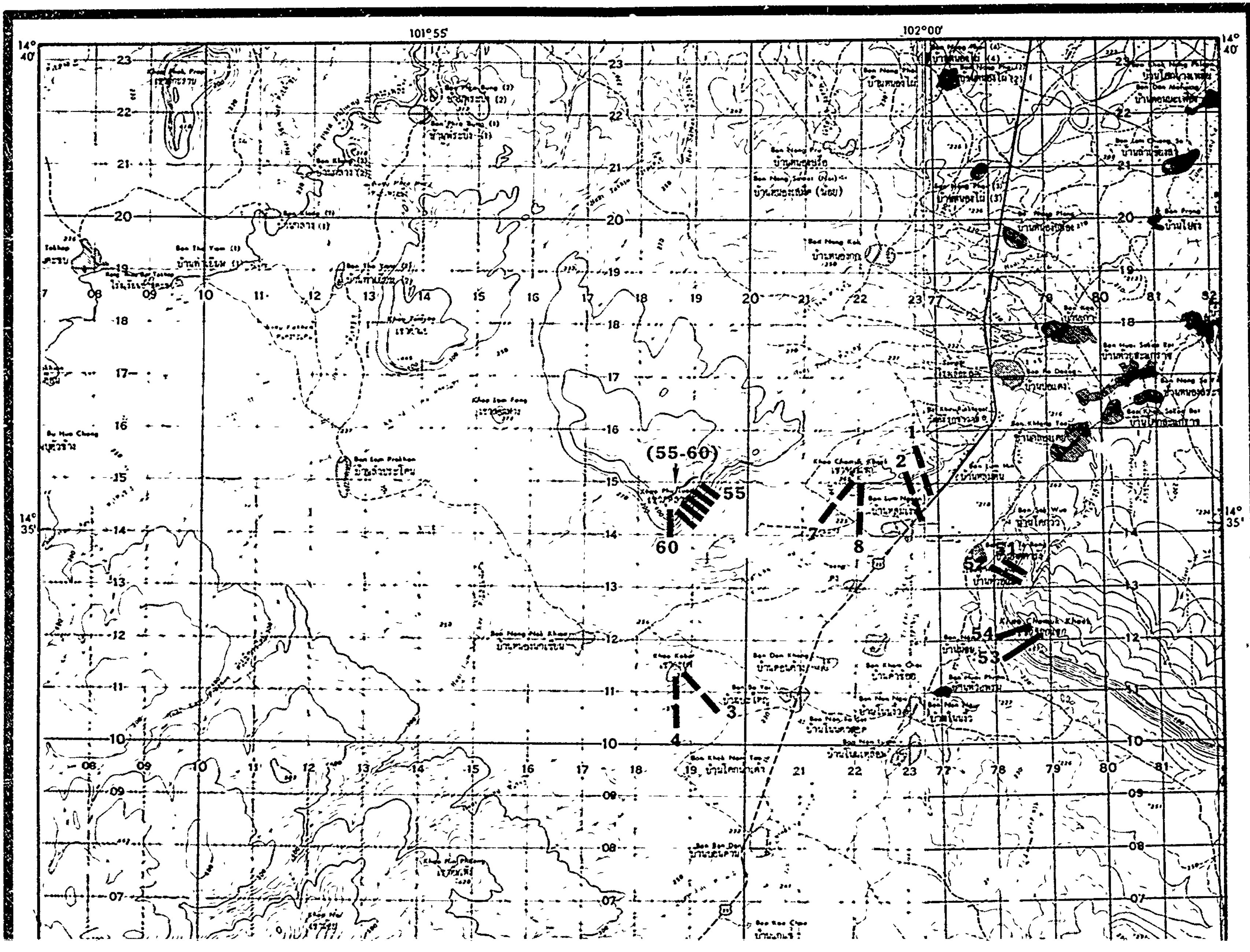
TABLE 7

Field and map-measured distance and percent of traverse distance by slope gradients for Chiang Main traverse #61

Class Intervals (degrees)	Map		Field	
	Distance (feet)	Percent of traverse distance	Distance (feet)	Percent of traverse distance
0-3	172	6.7	73	2.8
4-7	0	0.0	446	17.4
8-11	0	0.0	231	9.0
12-15	783	30.4	286	11.1
16-19	842	32.7	243	9.5
20-23	176	6.8	406	15.8
24-27	474	18.5	612	23.9
28-31	0	0.0	269	10.5
32-35	125	4.9	0	0.0
	2572	100.0	2566	100.0

It has been definitely established that there are major differences in slope gradient data obtained from the best available topographic maps and from field measurements. So, what data should be used? The map data may suffice for generalization, but for decisions involving millions of dollars for mobility models and vehicle and test course designs, the author believes data much better than that obtainable from the standard topographic map (1:50,000 and 1:24,000) are needed.

NAKHON RATCHASIMA (KHORAT) STUDY AREA TRAVERSE LOCATIONS



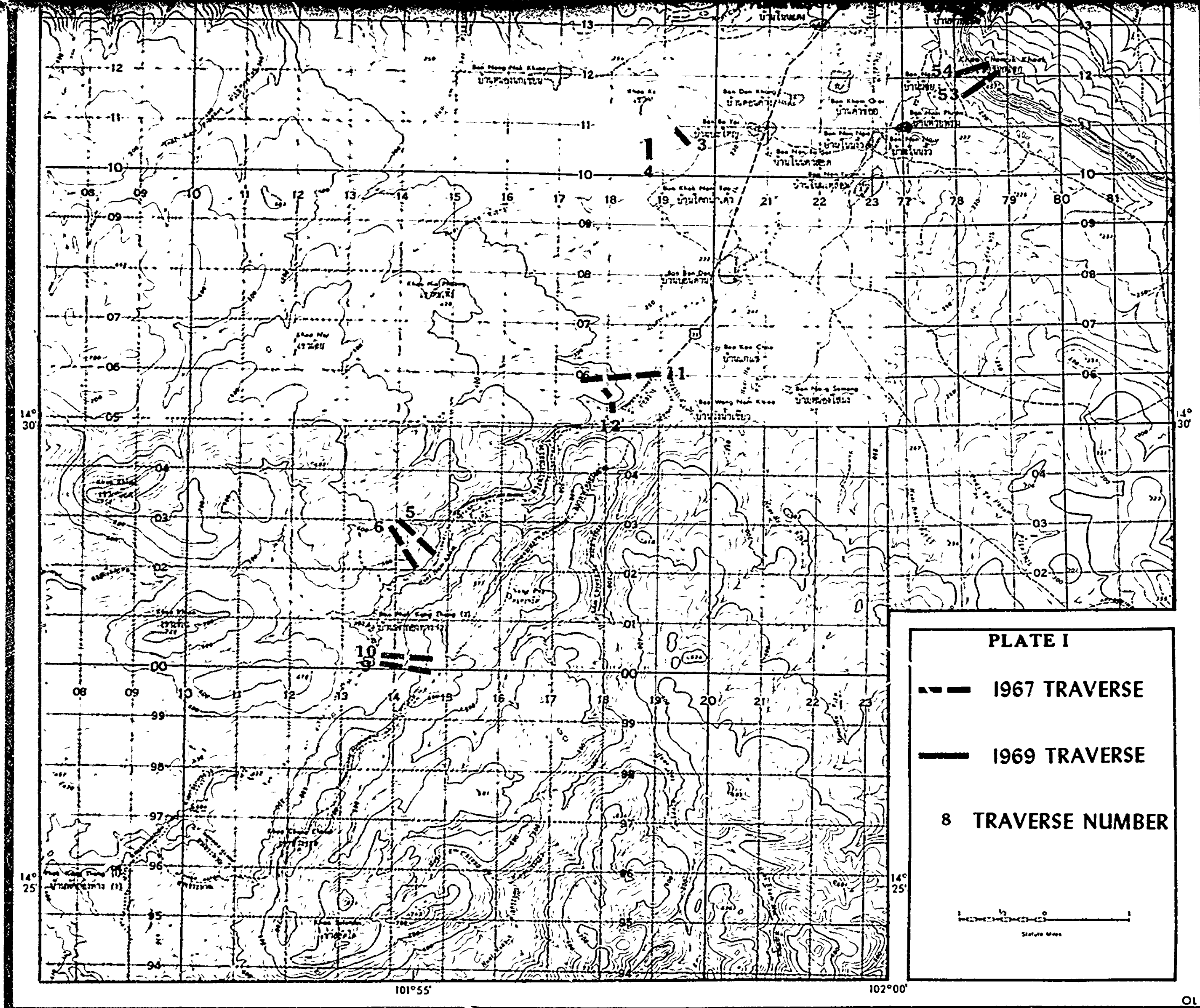
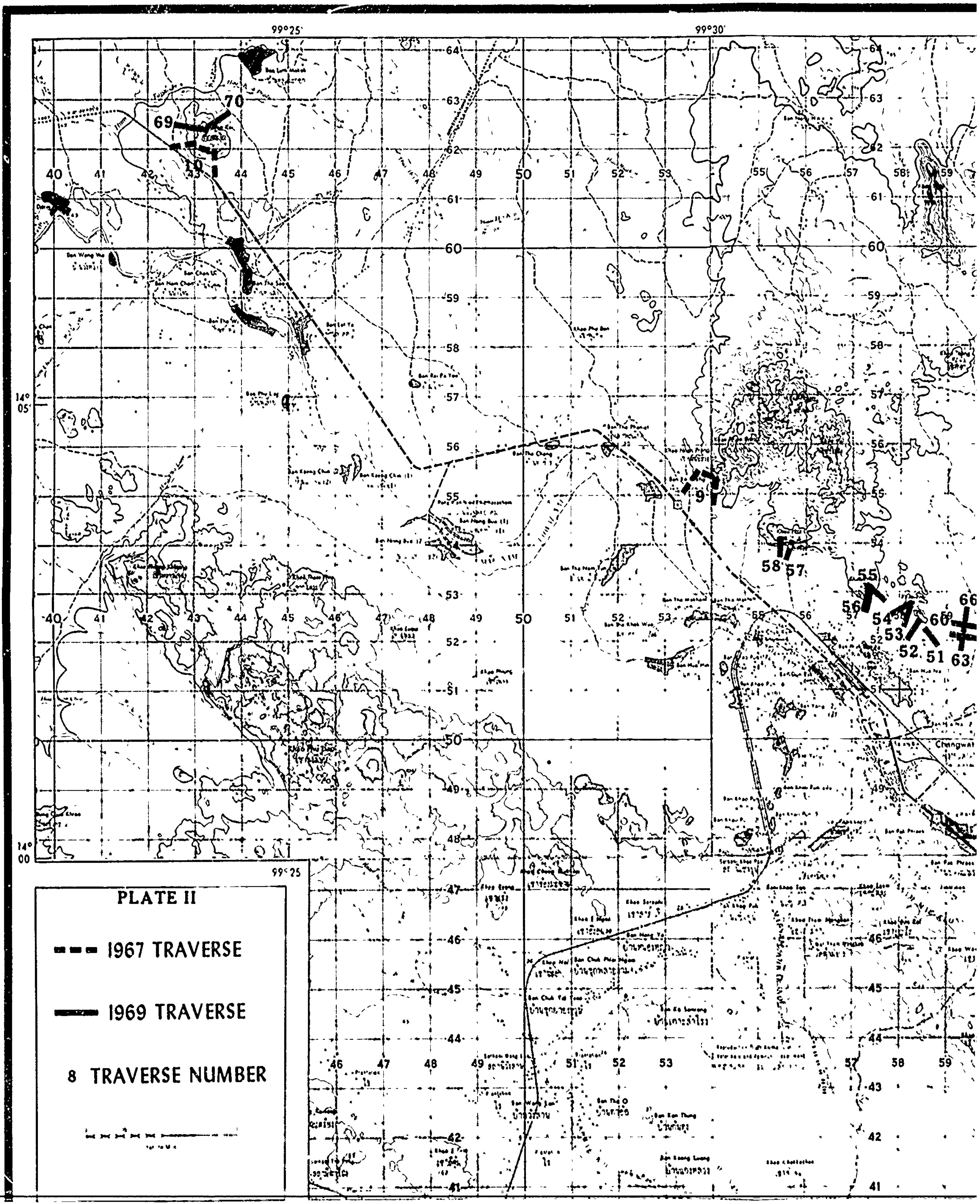
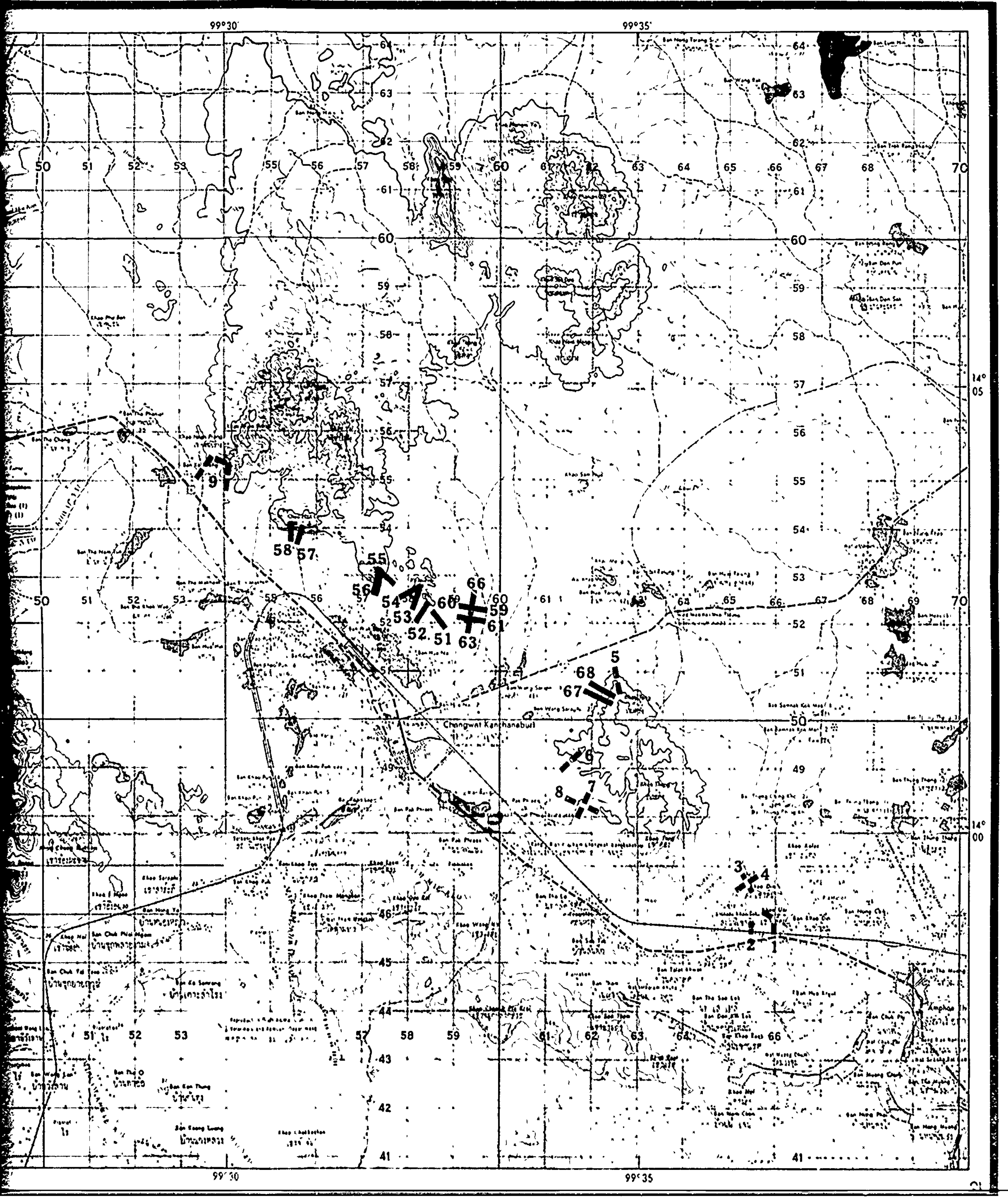


PLATE I
1967 TRAVERSE
1969 TRAVERSE
8 TRAVERSE NUMBER
Statute Miles
14° 30'
14° 25'
101°55'
102°00'
OL
APRIL 1971

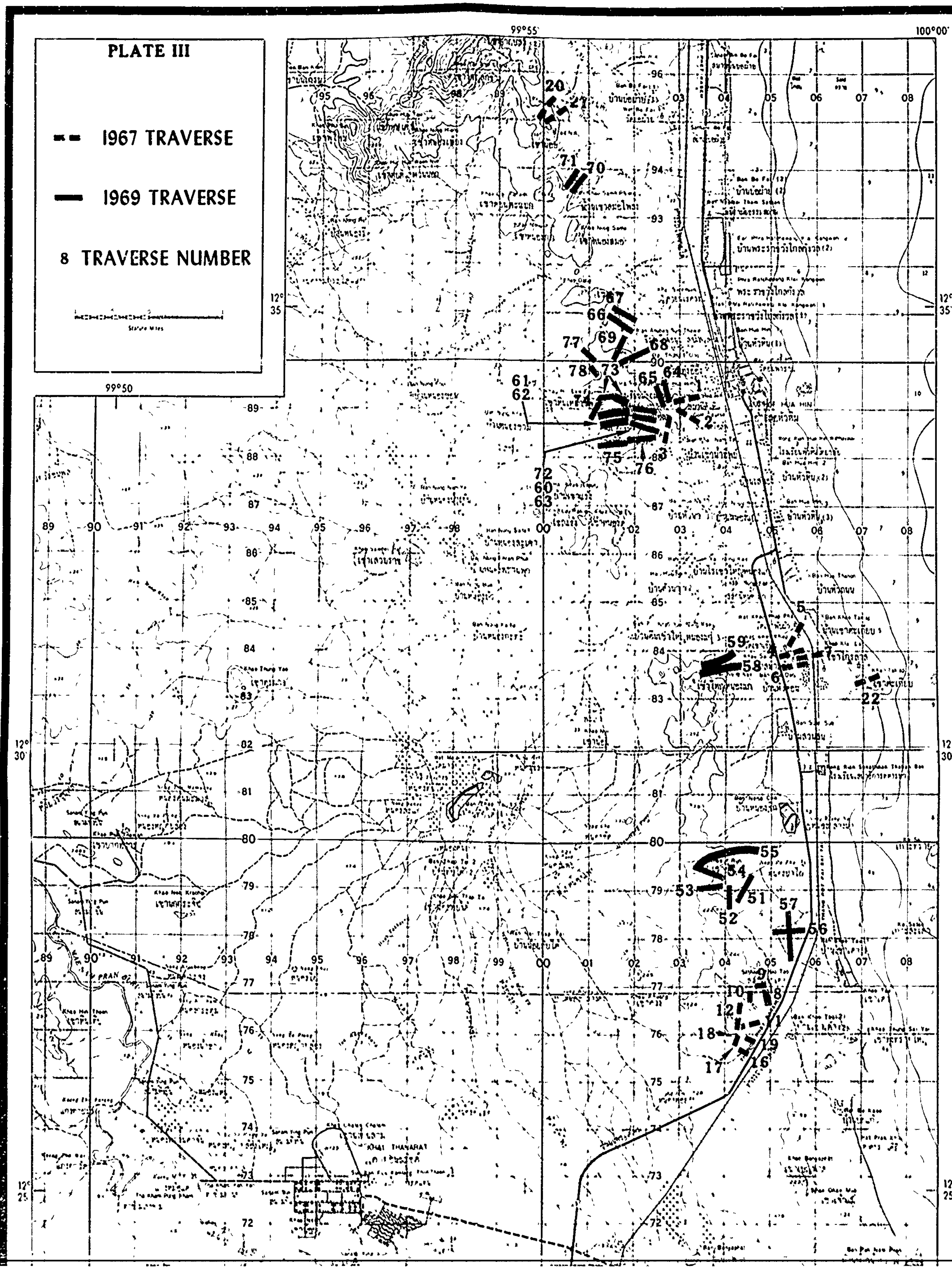
KANCHANABURI STUDY AREA TRA

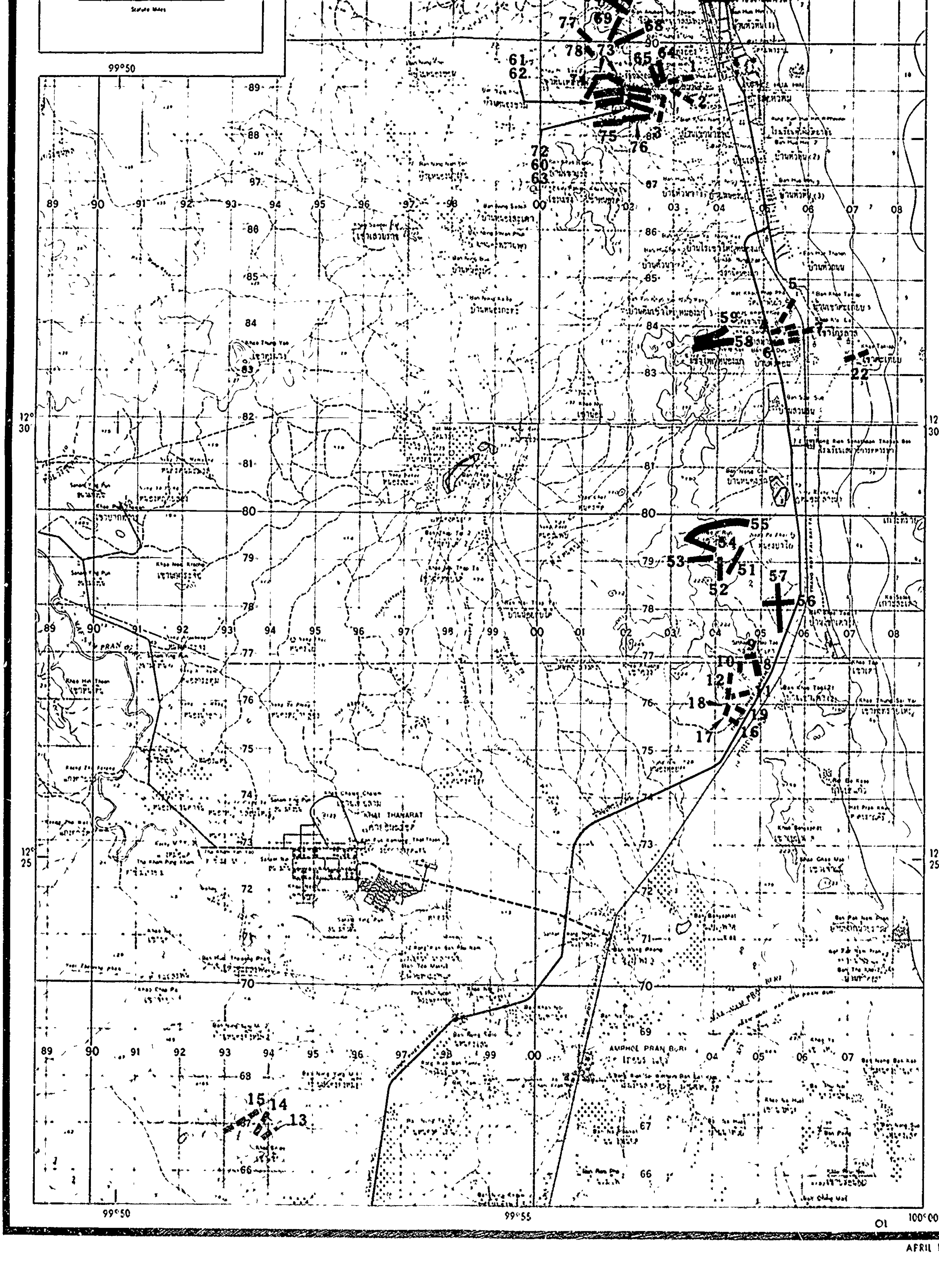


STUDY AREA TRAVERSE LOCATIONS



HUA HIN STUDY AREA TRAVERSE LOCATIONS

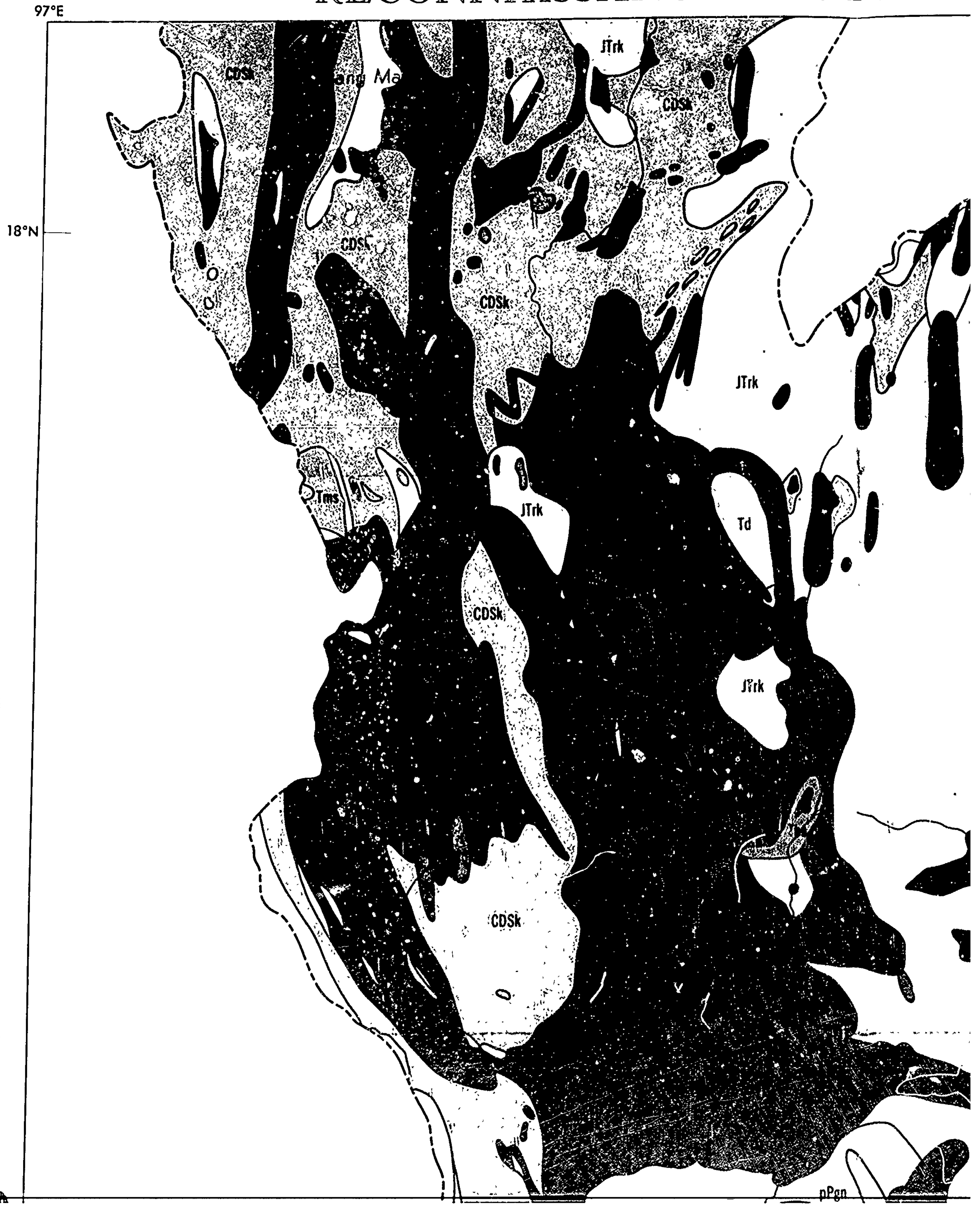




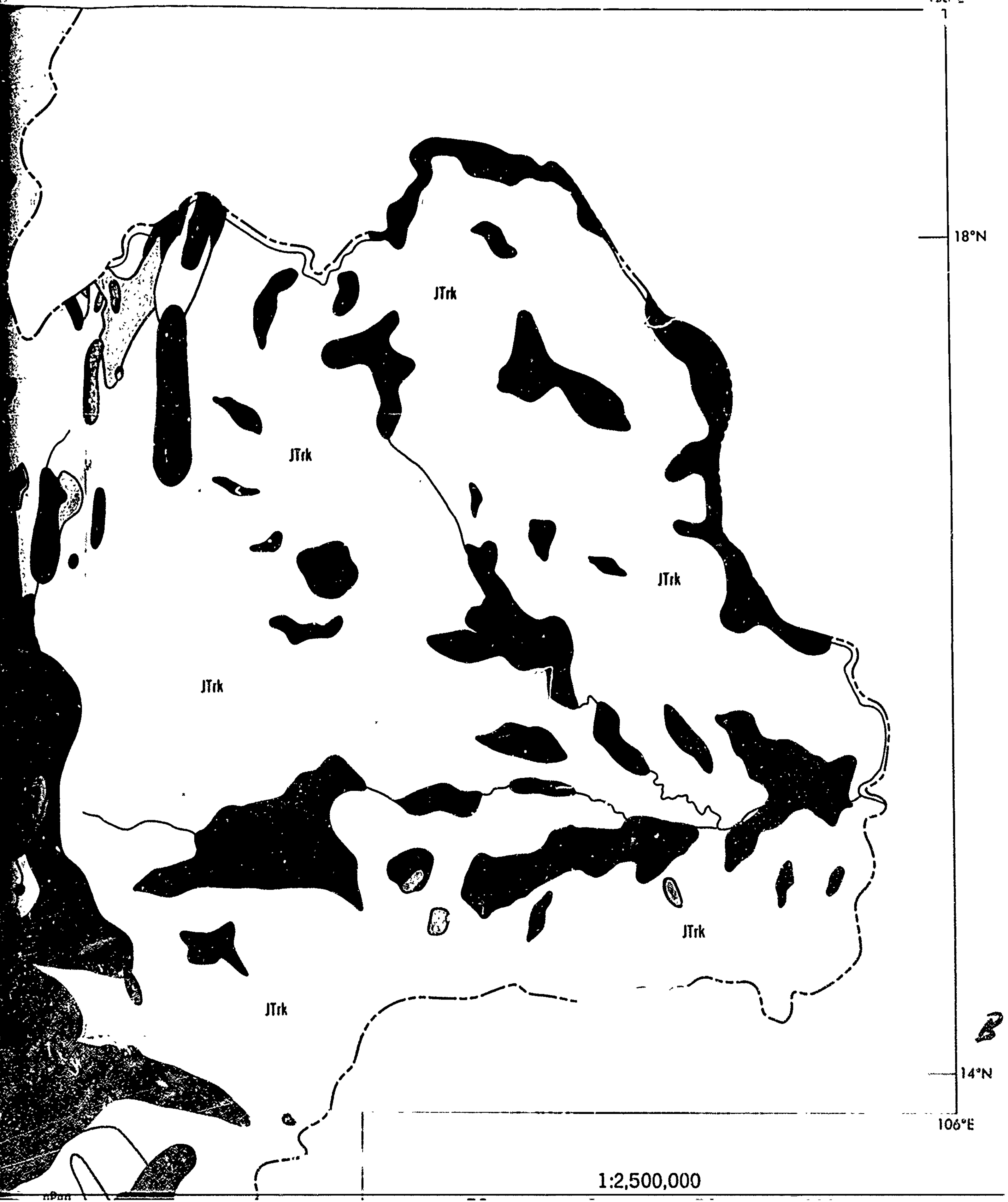
Statute Miles
99°50
12° 30'
12° 25'
99°55
100°00
KHAI THANARAT
AMPHOE PRAN BURI
PRAN

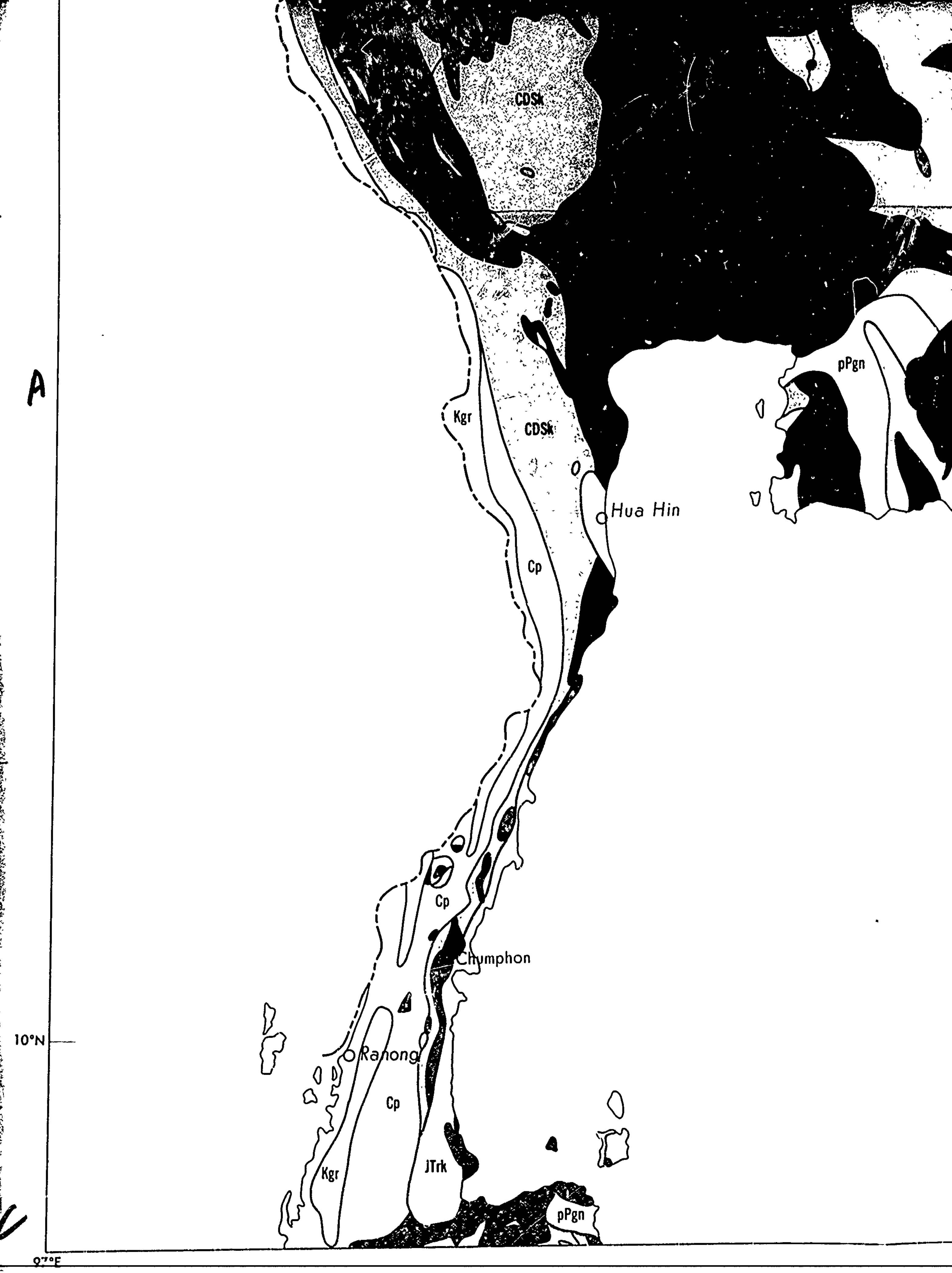
APRIL 19

RECONNAISSANCE GEOLOGIC

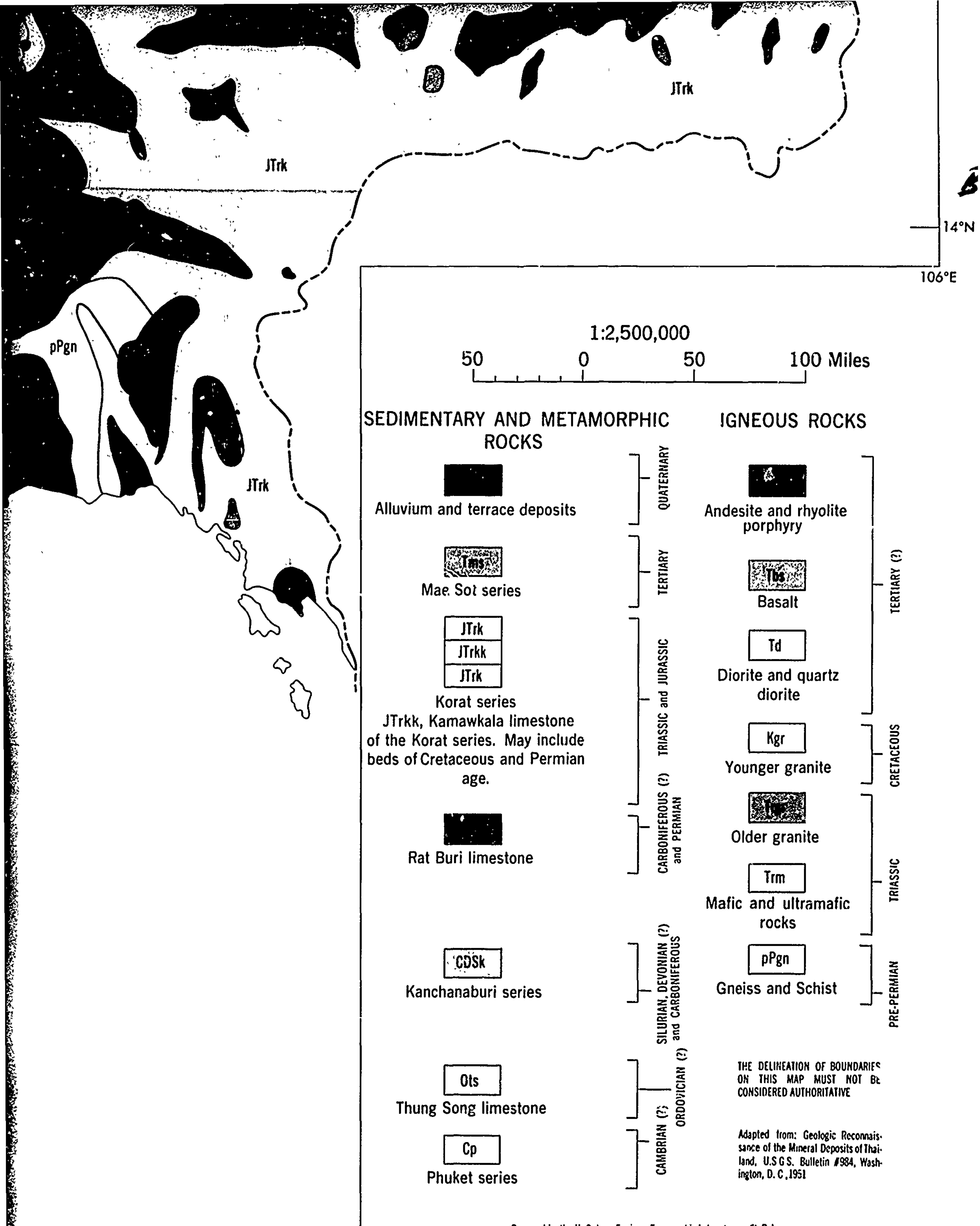


EOLOGIC MAP OF THAILAND





CDSk
pPgn
Kgr
CDSk
Hua Hin
Cp
Cp
Chumphon
10°N
Ranong
Cp
Kgr
JTrk
pPgn
97°E



1:2,500,000

50 0 50 100 Miles

SEDIMENTARY AND METAMORPHIC ROCKS

QUATERNARY
Alluvium and terrace deposits

TERTIARY
Tms
Mae Sot series

TRIASSIC and JURASSIC
JTrk
JTrkk
JTrk
Korat series
JTrkk, Kamawkala limestone of the Korat series. May include beds of Cretaceous and Permian age.

CARBONIFEROUS (?) and PERMIAN
Rat Buri limestone

SILURIAN, DEVONIAN (?) and CARBONIFEROUS
CDSk
Kanchanaburi series

ORDOVICIAN (?)
Ots
Thung Song limestone

CAMBRIAN (?)
Cp
Phuket series

IGNEOUS ROCKS

TERTIARY (?)
Andesite and rhyolite porphyry
Tbs
Basalt
Td
Diorite and quartz diorite

CRETACEOUS
Kgr
Younger granite

TRIASSIC
Older granite
Trm
Mafic and ultramafic rocks

PRE-PERMIAN
pPgn
Gneiss and Schist

THE DELINEATION OF BOUNDARIES ON THIS MAP MUST NOT BE CONSIDERED AUTHORITATIVE

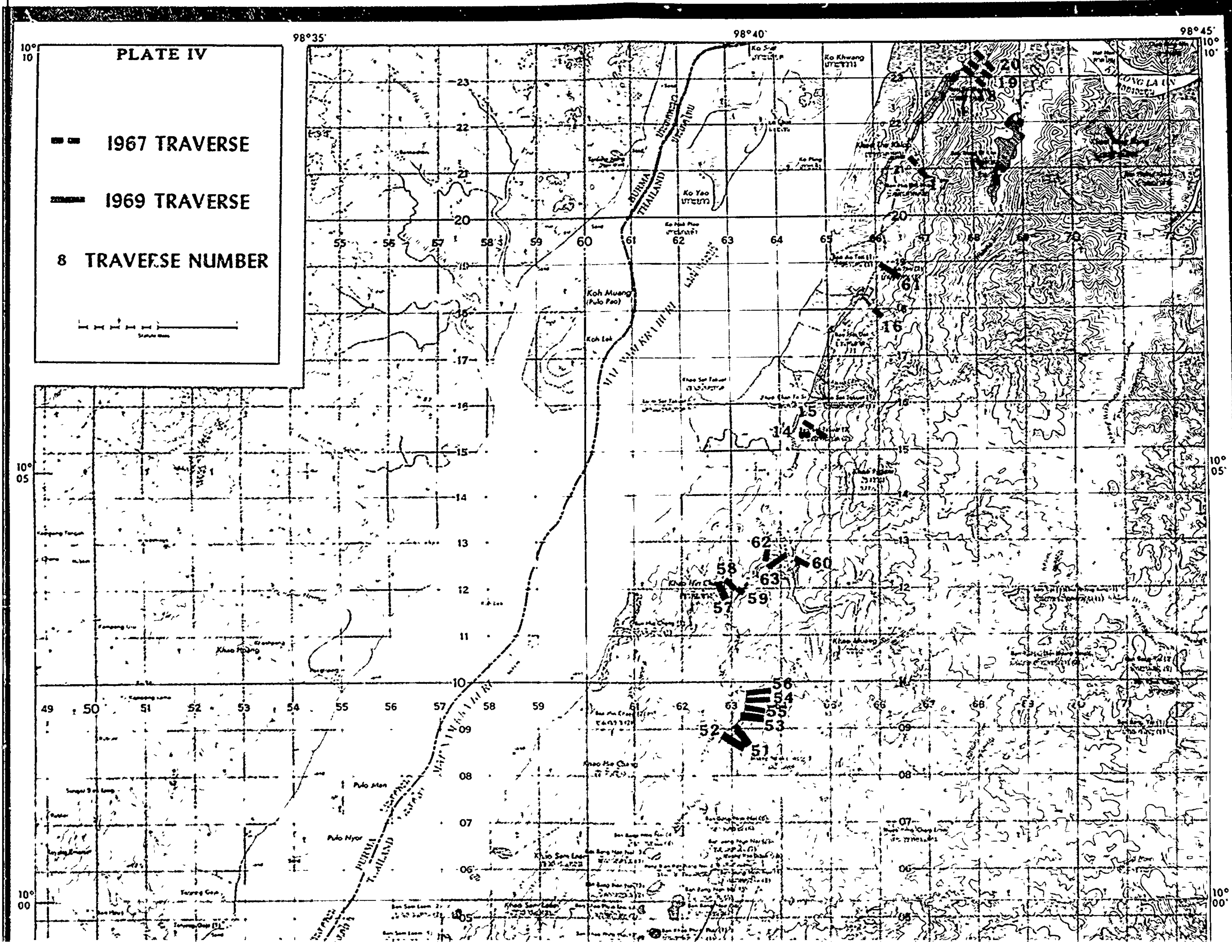
Adapted from: Geologic Reconnaissance of the Mineral Deposits of Thailand, U.S.G.S. Bulletin #984, Washington, D.C., 1951

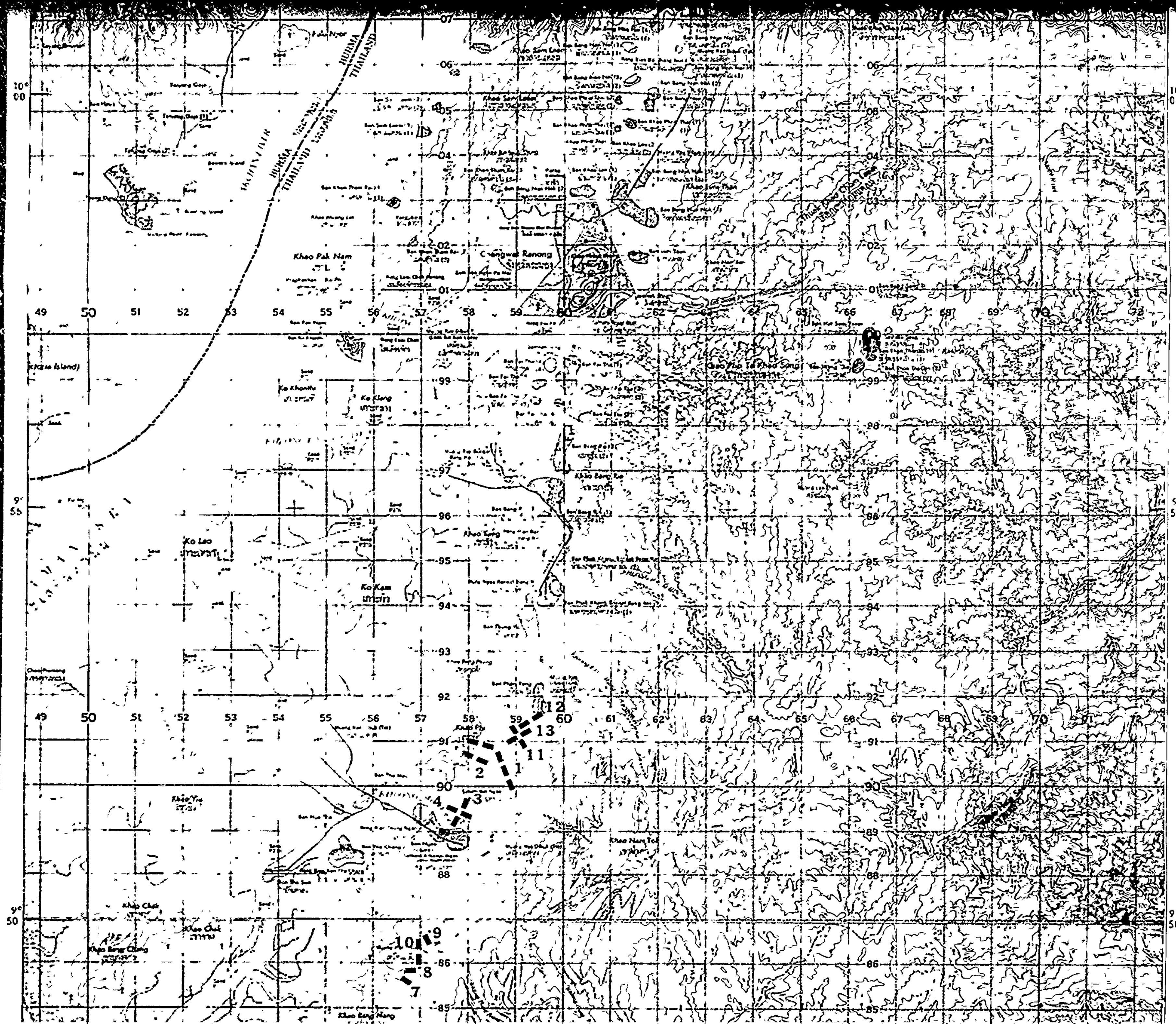
Prepared by the U. S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia 22060. Compiled October 1971

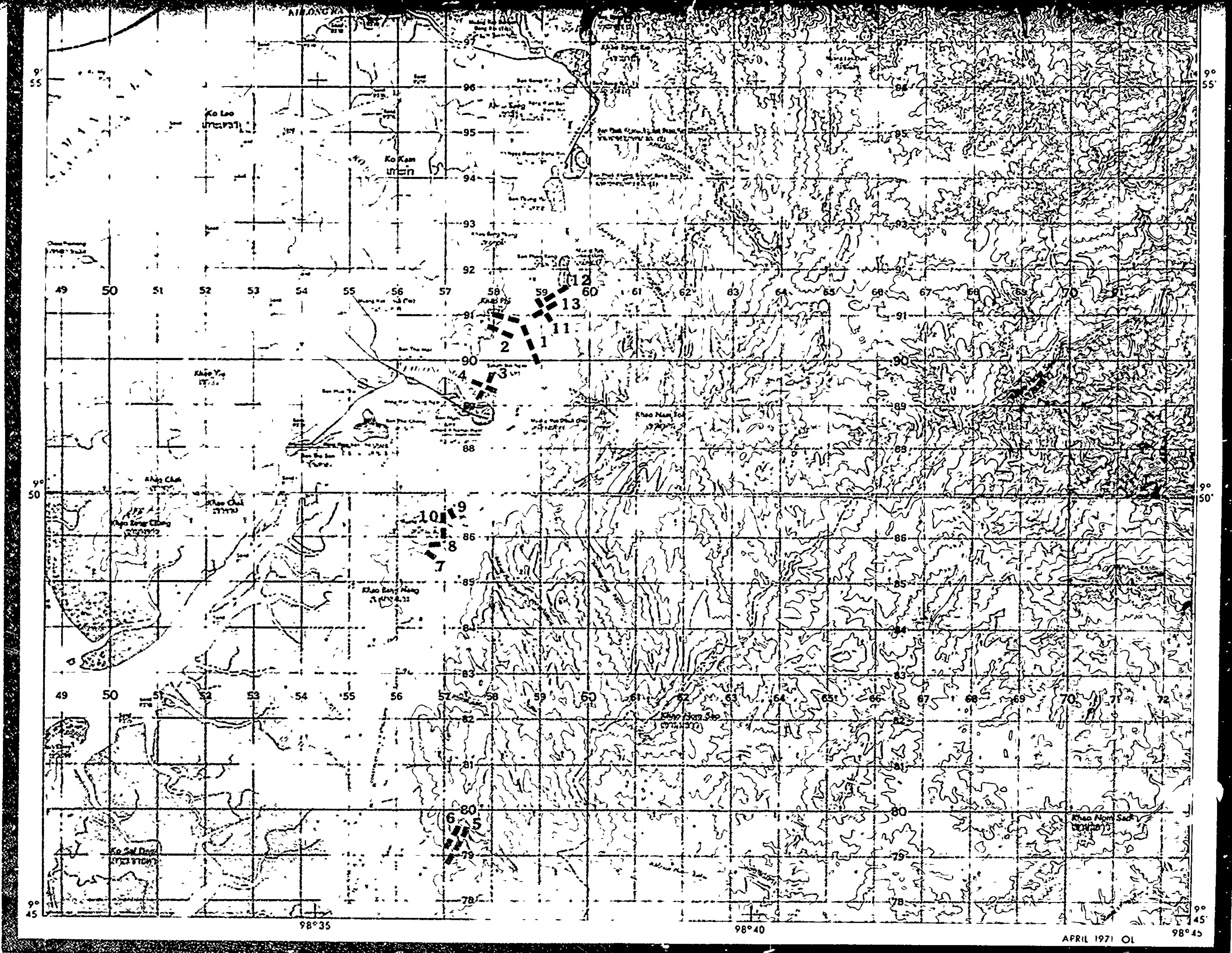
PLATE # VI

4-72 Printed by the U. S. Army Topographic Command

RANONG STUDY AREA TRAVERSE LOCATIONS

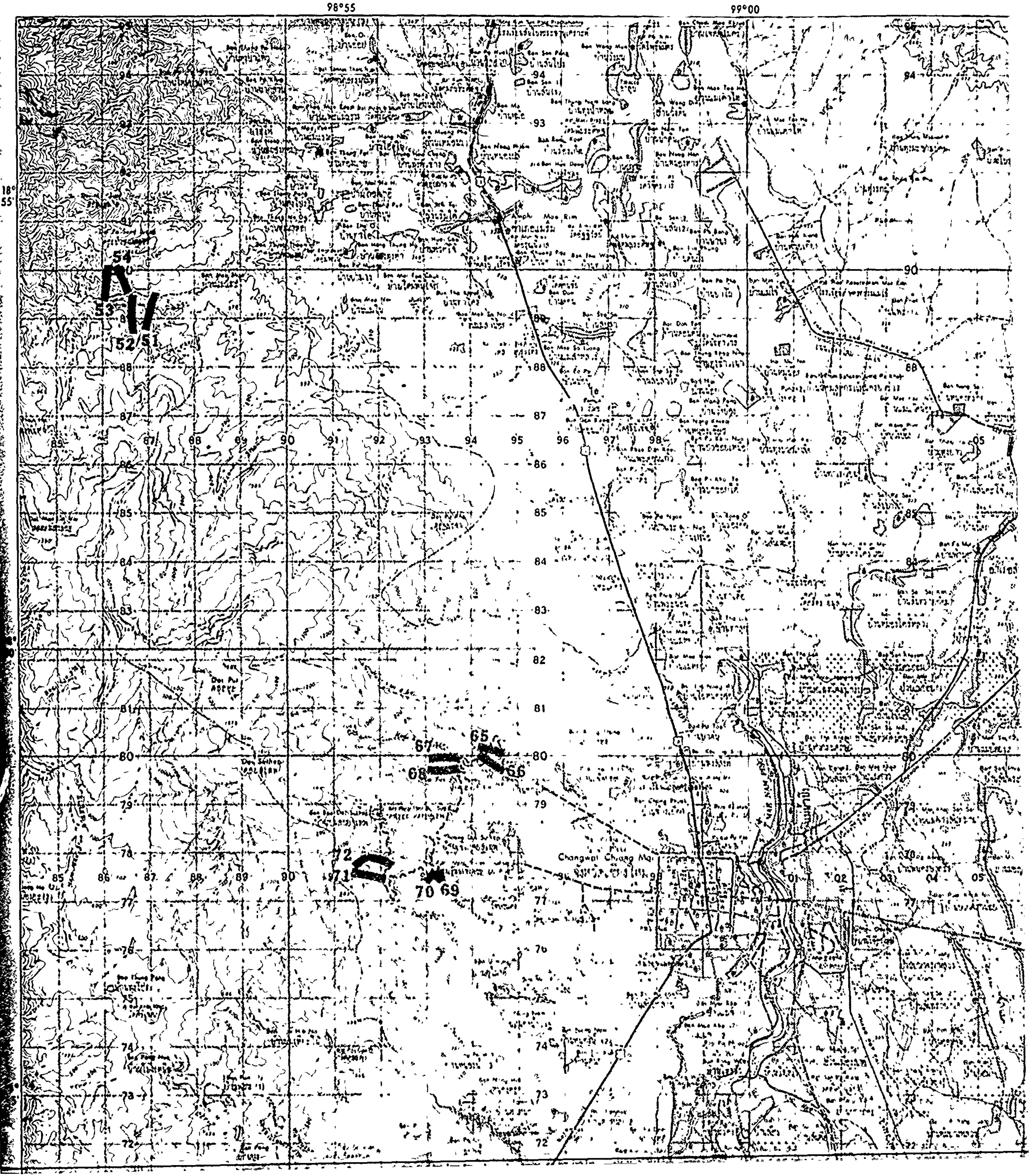



BURMA
THAILAND
Khao Pak Nam
Changwat Ranong
Ko Khonthi
Ko Klang
Ko Lao
Ko Kam
Khao Sang
Khao Yai
Khao Chuk
Khao Nam Tok
1
2
3
4
7
8
9
10
11
12
13

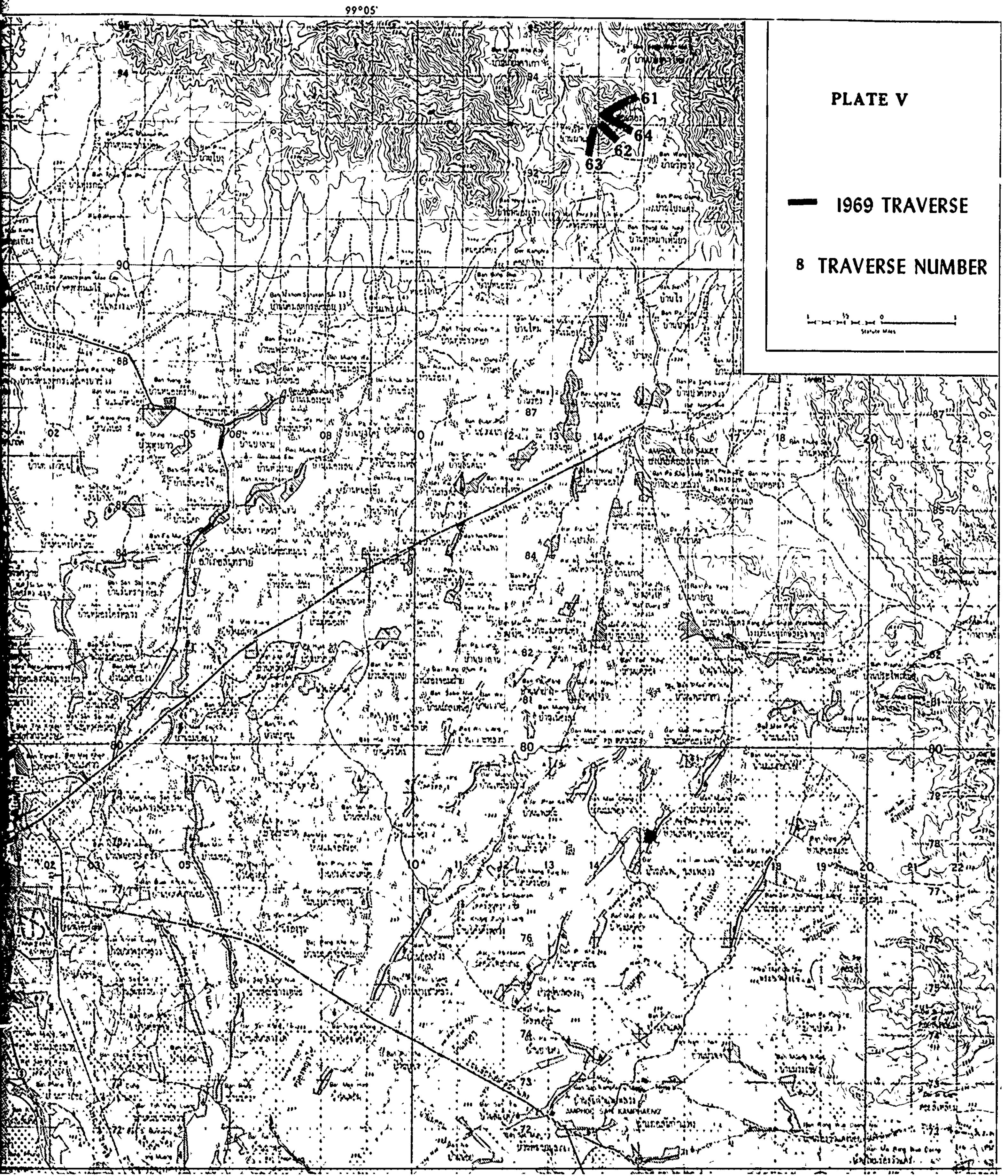


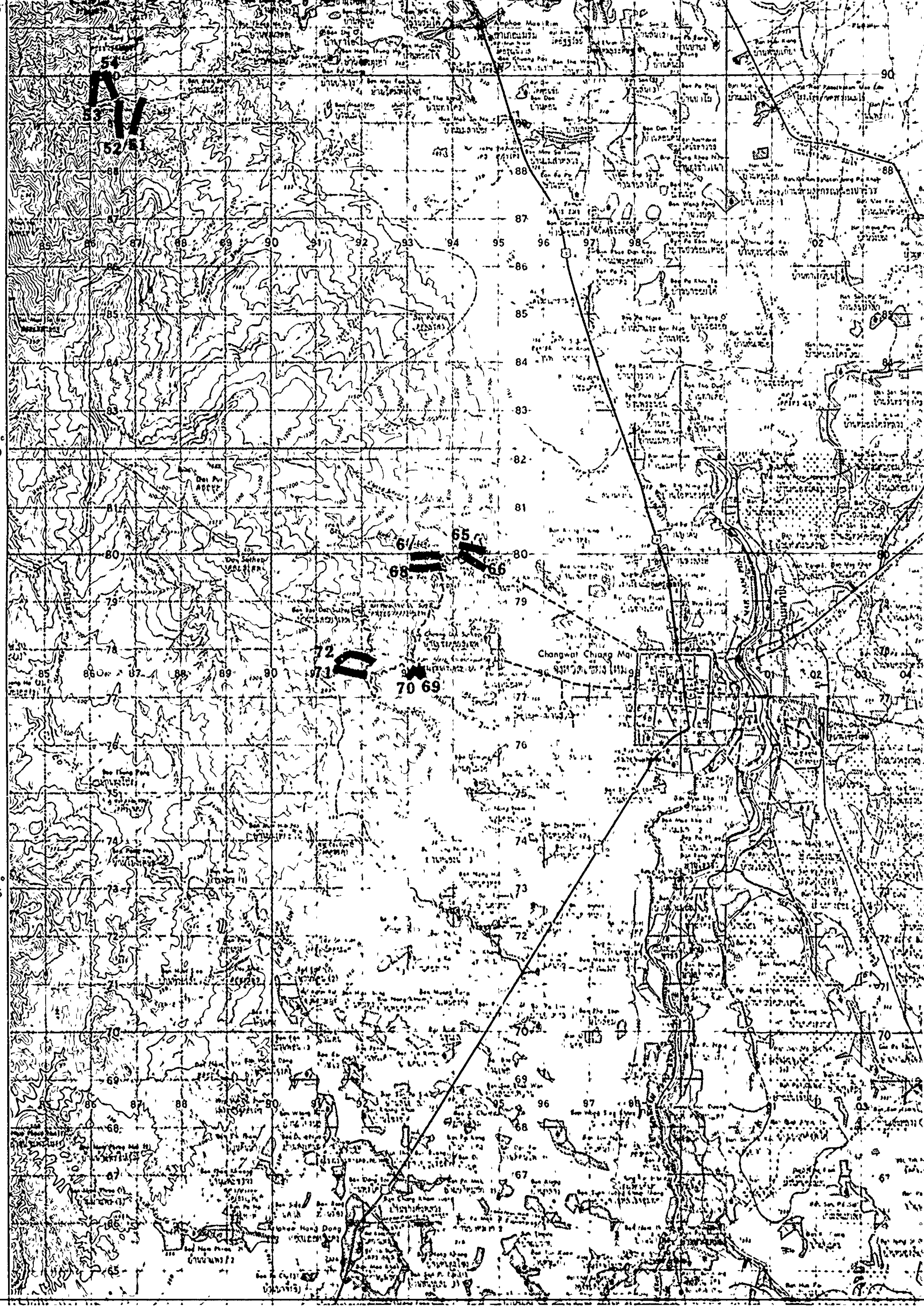
Ko Lao
Ko Kam
Khao Yai
Khao Nam Tok
Khao Chai
Khao Bang Nang
Khao Nam Sap
Khao Nom Sao
Ko Sai Dam
98°35
98°40
98°45
9° 55'
9° 50'
9° 45
1
2
3
4
5
6
7
8
9
10
11
12
13
APRIL 1971 OL

CHIANG MAI STUDY AREA T

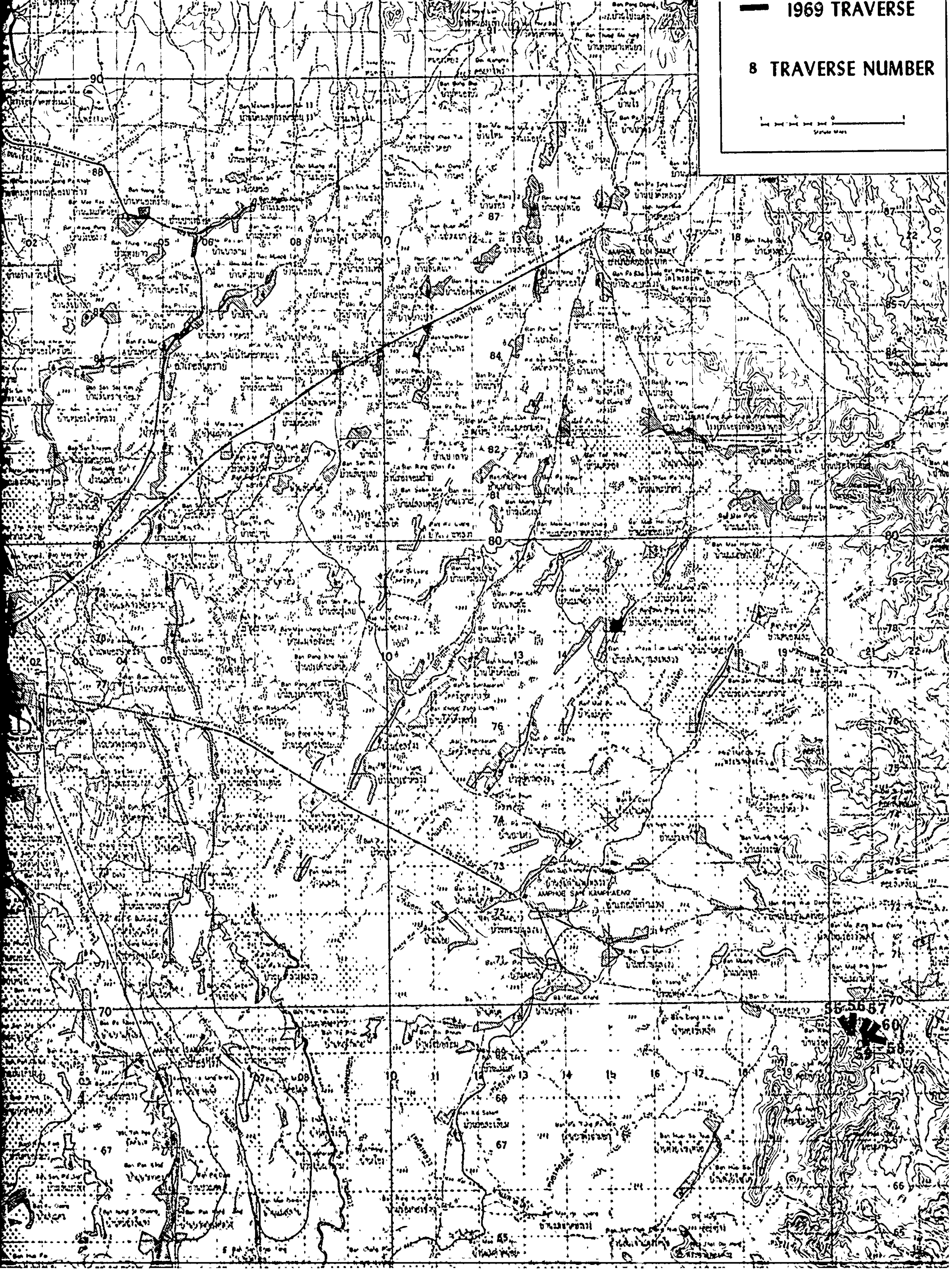


AREA TRAVERSE LOCATIONS





Changwat Chiang Mai
54
53
52
51
67
68
65
66
72
71
70
69
18° 50
18° 45



1969 TRAVERSE
8 TRAVERSE NUMBER
AMPHOE SAN KAMPHAENG