A STUDY OF TERRACETTES IN THE SOURIS RIVER VALLEY WITH REFERENCE TO PROCESS AND MORPHOLOGY

A Thesis

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by

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ABSTRACT

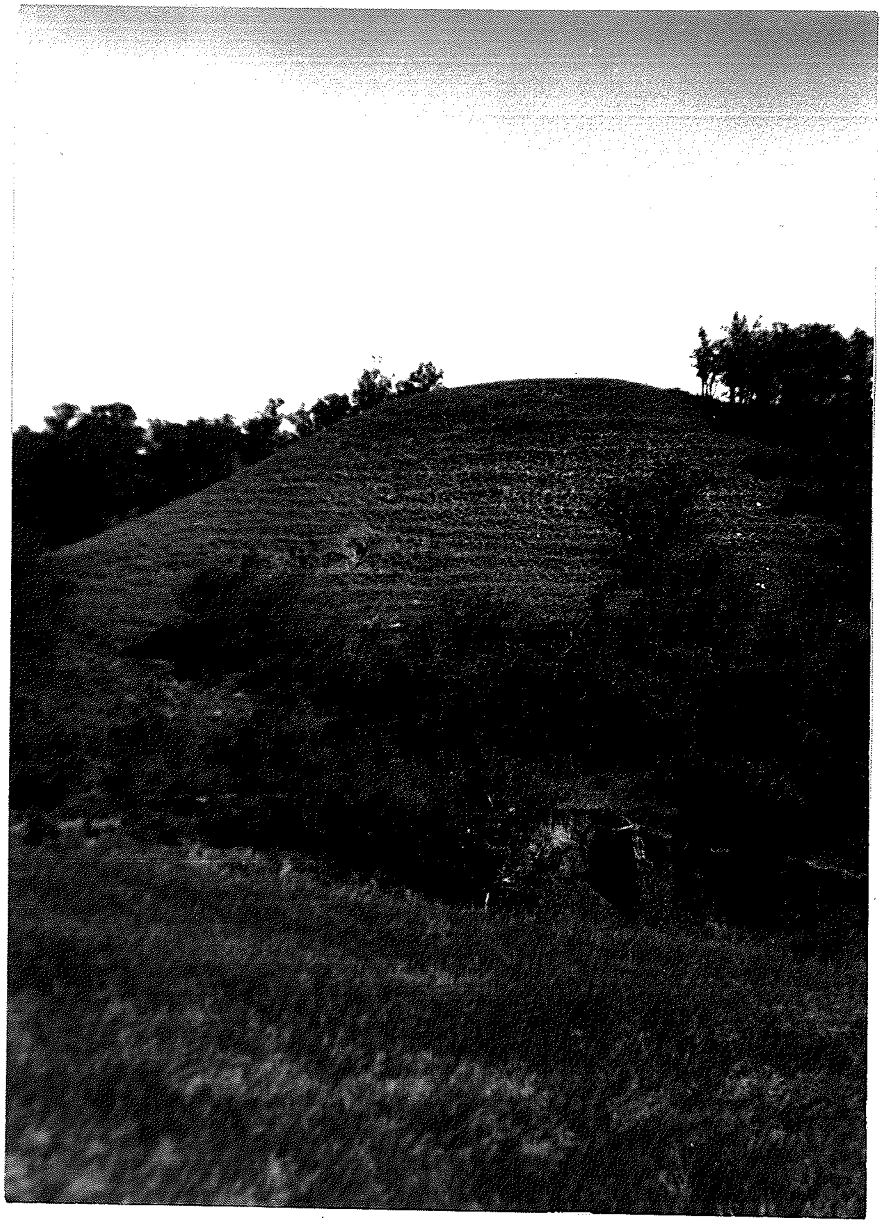
Terracettes may be defined as nearly parallel steps which follow along a hillside, giving it a tiered appearance similar to a bleacher. Although the morphology of the phenomenon is widely recognized, confusion exists in the literature as to its causal process.

In this thesis, a method has been originated for classifying the development of terracettes at a site. Conditions existing at the site which could influence the development of the phenomenon were referred to as location factors. These factors are aspect, type of material, vegetation type and density, overall slope angle, and evidence of animal usage. By comparing the terracette development with the location factors several relationships were discovered which revealed the site conditions conducive to terracette formation and maintenance. Of the many terracette sites examined, two showed no evidence of cattle usage. Therefore, it is possible for terracettes to form without faunal influence. However, the majority of the phenomena are either formed by cattle trampling or have their origin greatly influenced by this faunal process.

In an attempt to detect any recent or accelerated rates of rotational slumping or soil creep, root profiles were constructed. As the direction of root growth can be affected by several pedological variants, caution must be exercised when interpreting the root patterns.

A statistical expression was chosen to quantitatively represent the vertical irregularity in tread profiles. This irregularity was found to be greater for terracettes of a non-faunal mass movement origin than for cattle produced phenomena. The causal processes of terracettes at a particular site as interpreted from the value of the statistical expression agrees with the originating processes determined by examination of the actual field location. Therefore, this application of the statistical measurement is deemed worthy of further consideration.

The results of field study have shown that terracettes can be formed by either faunal or non-faunal mass movement processes as well as combinations of both types. Therefore, it is felt the word "terracette" should have morphological implication only. Process should be implied by adjectival modification of the term.



Terracettes in the Souris River Valley
two miles south west of Wawanesa

DEDICATED TO

NOREEN, MICHAEL

DAVID, AND JOANNE

ACKNOWLEDGEMENTS

I am most grateful to Dr. T. R. Weir who has made it possible for me to undertake this study. I also wish to thank Dr. W. J. Brown for his help and guidance particularily in the writing of this thesis but also during parts of the field work. I wish to express my gratitude to Mr. John Green who spent several hours helping me with the translation of the more difficult passages in Hilmar Odum's writings. I have benefitted from discussions on vegetation with Dr. A. K. Storgaard, and on certain climatic topics with Dr. A. J. W. Catchpole. Finally, I wish to show my appreciation to Mr. P. J. Lockett for surveying assistance, and Mr. H. L. Driedger for his help during the computer analyses of the field data.

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INTRODUCTION

The author first observed terracettes[≠] several years ago in an area twelve miles west of Cartwright, Manitoba. The phenomenon appeared as treads and risers forming long step-like features along the pastured slopes which brought to mind the bench-pattern of a bleacher. The first attempt at explaining their occurrence was the speculation that someone had ploughed along the contours of the slope and then abandoned the project. However, the "furrows" should have broken down with time and blended into the slope surface as the vegetation at the site indicated several years of non-cultivation.

In 1922, Hilmar Odum (Odum, 1922) wrote what may be considered as the first comprehensive account of the morphology, distribution, and origin of terracettes. Since that time, very few serious attempts have been made to understand this phenomenon although casual mention of the feature is found in most introductory textbooks of geomorphology. The lack of serious research would be more easily understood if the phenomenon were limited to a few areas of the globe but, as the following paragraph will show, the feature is quite widespread.

By personal observation Odum (1922) reports terracette occurrences in Denmark and the Faroe Islands. He cites accounts of the phenomenon as observed by other writers from Scotland, Iceland, Lapland, Spitzbergen, Sumatra, Norway, the

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[≠] The term "terracette" as used in this thesis will have a morphological implication only, unless specifically stated otherwise.

Faroe Islands, and Denmark. Andre Meynier (1951) mentions examples in France, and Jean Tricart (1963) refers to a terracette location in Vorarlberg, Austria. In the United States, D. A. Rahm (1962) writes of examples found on many of the steeper slopes of the Columbia Plateau in the state of Washington, C. F. S. Sharpe (1960) reports the occurrence of the phenomenon in Iowa. The feature has been recorded in England by G. H. Dury (1966) and A. S. Thomas (1959), and in New Zealand by M. J. Selby (1967) and C. A. Cotton (1948). Examples have been reported in Africa in Gitega province of Burundi by G. B. Unger (personal interview). Personal observation has revealed their widespread occurrence across the southern parts of the Prairie Provinces.

Despite the fact that terracettes are found in many parts of the world and are recognized as distinctive landform features, a very limited amount of field research has been done on their distribution and formation. Moreover, a critical examination of the literature reveals considerable disagreement as to the processes that have produced and maintained the terracette morphology. This thesis will examine the morphological characteristics of this phenomenon in part of south-west Manitoba, and will attempt to determine its causal processes.

An examination of literature on terracettes suggested that the following site factors should be considered in the study: slope orientation, slope gradient, lithology, vegetation cover, and animal utilization. Furthermore, the values of each site factor should vary. There should be a large variety of vegetation covers, a wide dispersion of slope angles formed on different types of materials, an abundance of present and derelict pastures on slopes, and slopes orientated in many different directions. The Souris River Valley between the town of Souris and the village of Treesbank was chosen for the study because many different combinations of the location factors occur throughout the region.

CHAPTER I

A REVIEW OF TERRACETTE LITERATURE

A general morphology for terracettes is usually recognized in the literature, but these forms have been attributed to a wide variety of processes and represented by numerous terms. This chapter will attempt to show the agreement among authors on a typical morphology for terracette-like features. The terminology applied to these features and the theories relating to their causation will also be examined.

a. Morphology

From photographs and descriptions in accounts of terracettes, it is apparent that there is a general accordance of view regarding their appearance. The main characteristics could be summarized by stating that terracettes are expected to exhibit alternating treads and risers, as on a staircase, and having a certain degree of parallelism, horizontality, longitudinal continuity, and a fairly constant vertical distance between treads.

Sharpe's photograph of terracettes in Monona County, Iowa, shows a tread and riser pattern similar to the one in Cotton's example from the province of Auckland, New Zealand.[1,2] The expected terracette characteristics of

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[1] C. F. S. Sharpe, Landslides and Related Phenomena (New Jersey: Pageant Books, Inc., 1960), plate VII B facing p. 68.

[2] C. A. Cotton, Landscape (New York: John Wiley and Sons, Inc., 1948), p. 17.

horizontality and parallelism are evident in Sharpe's photo of terracettes north of Yakima, Washington,[3] and Odum's photograph of a site near Voxlev.[4] A. S. Thomas' photographs of Knap Hill, Giant's Grave, Walker's Hill, and Oliver's Battery in Wiltshire, England,[5] display terracettes with similar morphological characteristics to those in Tricart's photograph of a site in Vorarlberg, Austria.[6]

Descriptions of terracettes by various authors show that similar morphologies are being considered. When describing terracettes, Dury states, "On very many steep slopes, a kind of ribbed pattern appears on the surface of the creeping waste, with little steps a foot or two in height running horizontally. These little steps are called terracettes."[7] Odum refers to terracettes as small shelves or ledges on steep slopes which, "gives these slopes an extremely characteristic appearance, not unlike grooving on a washboard."[8]

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[3]Sharpe, op. cit., plate III A facing p. 36.

[4]Hilmar Odum, "Om'Faarestiernes' Natur," trans. by John W. Carley, Dansk Geologisk Forening Meddelelser, VI, No. 7, (1922), p. 6.

[5]A. S. Thomas, "Sheep Paths," Journal of the British Grassland Society, XIV, No. 3, (1959), Illustrations facing pp. 162-163.

[6]Jean Tricart, Géomorphologie des Régiones Froides, trans. by John W. Carley, (Paris: Presses Universitaires de France, 1964), illustration facing p. 145.

[7]G. H. Dury, The Face of the Earth, Penguin Books (England: Hunt Barnard and Co., 1966), p. 13-14.

[8]Odum, op. cit., p. 3.

Meynier uses the term "gradin" ('step' or 'bench')[9] while Tricart prefers the term "sol-a-gradin" (soil in steps).[10] Charles Darwin referred to terracettes as "ledges of earth on steep hillsides."[11]

Some authors have given a range of values for the width of treads and the heights of risers. (Table 1.1) The ranges of values for tread width fall between the limits of 0.5 and 4.0 feet. The ranges given for riser heights lie between 0.1 and 5 feet. An overlapping of the ranges of values occurs for both the width and height measurements. Considering that these authors did not observe the same terracettes, it may be said that there is reasonable agreement on the dimensions that treads and risers should have.

The liberty has been taken when mentioning the above examples to compare any terracette-like features, while giving no consideration to the particular author's choice of nomenclature for them. For instance, an example Sharpe refers to as "terracettes" has been compared to a phenomenon Thomas refers to as "sheep tracks" and to one termed "sheep-paths" by Odum.

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[9]André Meynier, "Pieds de Vache et Terrassettes," trans. by John W. Carley, Revue de Géomorphologie Dynamique, 1951, II, No. 2, p. 81.

[10]Tricart, op. cit., p. 94.

[11]Charles Darwin, The Formation of Vegetable Mould Through the Action of Worms, with Observations on Their Habits, (New York: D. Appelton and Co., 1890), pp. 279-283, quoted in C. F. S. Sharpe, Landslides and Related Phenomenon (New Jersey: Pageant Books, Inc., 1960), pp. 71-72.

Author	Mean Tread Width (feet)	Mean Riser Height (feet)	Length	No. of Examples
Dury (1966) p. 14		1-2		
Odum (1922) p. 9	2.8 (0.85)			9
Macar and Pissart (1964) p. 78	1.4-2.0 (0.4-0.6)	2.2-2.8 (0.7-0.85)	330 and greater (100)	400
Rahm (1962) p. 65	0.5-2.5	0.1-4.0	3-300	
Sharpe (1960) p. 73	2-4	few inches to 4-5 feet		
Thomas (1959) p. 157	1 or less			
Tricart (1964) p. 94	1.0-2.6 (0.3-0.8)	0.7-3.3 (0.2-1.0)		
Overall Range	less than 4	few inches to 5 feet		

Table 1.1

It has been assumed that the measurements given by the above authors for the treads and risers are not the surface distances but actually the true horizontal and vertical displacements. As some authors used the metric system of measurements, their results, in meters, are shown in brackets. The overall range refers to minimum and maximum mean values that would accomodate the range of values of every author.

In spite of a generally accepted morphology, there is disagreement and even confusion among workers with regard to terminology and processes of formation.

b. Process

Although there is general agreement concerning the typical morphology of terracettes, the former does not exist with regard to the processes by which they are produced. The difficulty of establishing the types of process which produce terracettes is confounded by an unsatisfactory nomenclature. At present a variety of terms are being employed, some of which imply process and others which are non-genetic. Some terms imply a process according to one author, but have a purely morphological connotation when used elsewhere. However, it is apparent that while the problem may be aggravated by inadequate nomenclature, there are basic differences of opinion about the types of process responsible for terracette production.

Some theories state that terracettes have been produced by a purely geologic process while others favour a faunal origin. Additionally, some authors believe a combination of these types of process is responsible for the production of terracettes.

The purely geologic origins are propounded by Dury, W. D. Thornbury, and A. K. Lobeck. Dury states that terracettes are a phenomenon associated with soil creep on many steep slopes.[12] Although he recognizes "sheep tracks" as an alternative name for terracettes, he claims that the title is misleading on two accounts. First, terracettes can be found where no sheep have ever been, and, second, authentic sheep tracks which run obliquely upslope do not take the

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[12] Dury, _op_. _cit_., pp. 13-14.

form of steps. Dury has dismissed the possibility of terracette production by sheep on rather slim evidence. Moreover, his statement of upslope obliquity for sheep path patterns is in direct contrast to the almost horizontal and parallel paths that Cotton[13] and Thomas[14] labelled "sheep tracks."

Both Thornbury[15] and Lobeck[16] attribute terracettes to slumping, and neither mentions the effect that fauna could have in either producing the features or emphasizing their shapes.

Odum quotes correspondence from Dr. James Ritchie in Scotland who does not credit sheep with the ability to produce paths that are straight and regular.

> .....In the first place the ridges often show no signs whatever of having been used by sheep; in the second place the ridges are too close to have been formed by sheep, because these animals are very conservative and always follow a few well-defined paths; in the third place the ridges are too regular and parallel to have been formed by sheep, for it is almost characteristic of a sheep's track that it is almost unnecessarily irregular in direction.[17]

Although Dr. Ritchie did not state a definite origin for

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[13]Cotton, op. cit., p. 16.

[14]Thomas, op. cit., illustrations facing pp. 162-163.

[15]W. D. Thornbury, Principles of Geomorphology (New York: John Wiley and Sons, Inc., 1954), p. 92.

[16]A. K. Lobeck, An Introduction to the Study of Landscapes (New York: McGraw-Hill, 1939), p. 93.

[17]Odum, op. cit., p. 5.

terracettes, he was against the possibility of sheep having the ability to produce straight regular paths. Since he did not state whether or not he believed cattle could produce terracettes, he cannot logically be classed with other writers who proclaim a geologic process for the phenomenon. He does, however, appear partly opposed to a faunal origin.

Odum and F. J. Monkhouse[18] favoured the dominance of geologic processes in the formation of terracettes, but admitted that animals could make terracettes more distinctive by using them as paths.

Odum proposed a theory of terracette formation by small multiple slumping, and regards the feature as surficial. Figure 1.1 shows Odum's sketch of the slumping process he imagined and referred to as "self-produced."

> Processes start on a lower part of the slopes and begin with the turf splitting apart horizontally in shorter or longer pieces. Below this crack, the loose earth with some sod a few decimeters wide sinks a little, thus the flakes at the same time make a feeble rotation about a horizontal axis, parallel with the slope surface. Moreover, the sinking of the flakes gives the surface sod because of the rotation an inclination, which is a little less than the inclination of the overall slope. Turf above the first crack is now deprived of part of its support, and a strip of earth loosens itself a little higher, and this sod-flake performs the exact same movement. And etc. etc. In want of a better short designation, you could possibly describe the phenomenon of the surface being broken up into small flakes as "self- produced."[19]

Odum mentions an example of terracettes in a slope north

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[18]F. J. Monkhouse, A Dictionary of Geography (London: Edward Arnold, Ltd., 1965), p. 305.

[19]Odum, op. cit., pp. 10-11.

of Voxlev where the limestone bedrock had separated into vertical series of blocks. The columns had then begun to

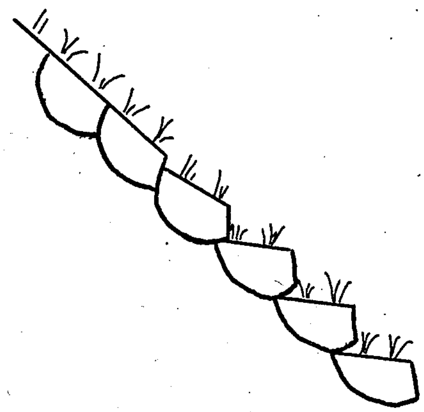

Figure 1.1

Odum's "self-produced" terracettes (After H. Odum, 1922)

tip downslope and in doing so had caused vertical cracks to open. Some surficial material had seeped into these cracks thereby influencing the location of terracettes on the surface.[20] However, on a slope west of Horup Beach, Grejsdalen, in fluvially deposited sand and gravel material, the familiar tread and riser pattern of terracettes was observed but no trace of any columns or special structuring of the soil could be found in the sub-stratum.[21] Thus the location of terracettes on a slope may be influenced by bedrock structure, but these will still form without such an influence.

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[20] Ibid., pp. 6-9.

[21] Ibid., pp. 9-10.

Odum realized that the trampling of animals across a slope could increase the distinctness of the terracettes.

> However, in order to give the sheep complete justice, it must be added that they by their travels can contribute to emphasizing the steps, but, mind you, only when these were formed beforehand. As animals usually put their feet on existing flat levels, where relief gives footing, they could in the course of time tread into it more of an impression, but moreover, the vegetation on the ledge surfaces would suffer by this (treading) and would be suppressed, but would thrive more strongly along the extreme edge and help to a large degree to make the path more noticeable.[22]

Thus Odum believes that terracettes were formed mainly by geologic processes but that faunal processes could emphasize the terracette pattern.

Monkhouse associates terracettes with a slope where soil creep is prevalent. He states that whereas it is not likely that animals could produce terracettes, they no doubt would use them as paths once formed.[23]

Some writers are in favour of an organic origin for the terracettes that they studied. Rahm, working in the Snake River Valley of Washington, proclaims a purely faunal origin for its terracettes. He has determined, from personal communications with an older citizen of the area, that the appearence of terracettes there coincided very closely with the introduction of cattle. Rahm adamantly states, "The terracette, long believed to be a slump block, is probably a cow path in most cases. At least this appears true for

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[22] Ibid., p. 15.

[23] Monkhouse, op. cit., p. 305.

the Columbia Plateau. Those who continue to believe otherwise must assume the burden of proof."[24]

Thomas studied the phenomenon at Wiltshire, England.[25] He attributes terracettes to sheep or cattle, but at the same time notes that the paths themselves often move downslope intact, as though they are being influenced by a form of soil creep. He cites a case at Kingsley Vale where the path has moved downslope two feet in four years even though the gradient is only 13°.

E. Warming and C. H. Ostenfield both entertain the idea that the terracette pattern on a slope is due to the action of sheep. Warming, when discussing beach sand dunes, states, ".....they serve at present a grazing place for sheep, which have formed no end of paths, nearly parallel to one another, running along slope sides."[26] Ostenfield says about the Faroe Islands, "As a rule the grass slopes are much destroyed by sheep. .....The surface is consequently traversed by many sheep paths, which run in parallel lines nearly at right angles to the slope, and from a distance give the hillside a

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[24] D. A. Rahm, "The Terracette Problem," Northwest Science, XXXVI, No. 3 (1962), p. 80.

[25] Thomas, op. cit., p. 163.

[26] E. Warming, 1906: Dansk Plantevaekst, 1. Strandvegetationen, S. 30, cited by Hilmar Odum, "Om 'Faarestiernes' Natur," trans. by John W. Carley, Dansk Geologisk Forening Meddelelser, VI, No. 7 (1922), p. 3.

rippled appearance."[27]

The majority of writers acknowledge both geologic and organic processes for the formation of terracettes. Meynier and Tricart both favour a separation of the phenomenon into two classes according to the type of process responsible for its production. Meynier employs "terracette" and "cattle paths" to designate examples produced by geologic and faunal processes respectively.[28] Tricart refers to terracettes formed by geologic processes as "natural" and those by faunal ones as "artificial."[29] However, both authors do recognize the fact that either type of process could form a terracette-like feature. They differ in that Tricart believes block sliding to be the geological process responsible, while Meynier favours micro-faulting.

Sharpe considers a range of causal processes grading from purely geological to completely faunal ones. He states, "Field observation of these hillside forms show all gradations from true paths with no subsurface movement to miniature fault blocks in the origin of which animals have played no part."[30] From his geological viewpoint, Sharpe has put forward four major proposals involving slumping, one of which

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[27] C. H. Ostenfield, 1908, "The Land-Vegetation of the Faroes." Botany of the Faeroes, Part III, S. 963, cited by Hilmar Odum, "Om 'Faarestiernes' Natur," Dansk Geologisk Forening Meddelelser, VI, No. 7, p. 4.

[28] Meynier, op. cit., pp. 81-83.

[29] Tricart, op. cit., p. 95.

[30] Sharpe, op. cit., p. 71.

was first proposed by Odum. (Figure 1.2) All of Sharpe's own theories require a major slip plane and basal undercutting of the slope (Figure 1.2, A, C, and D).

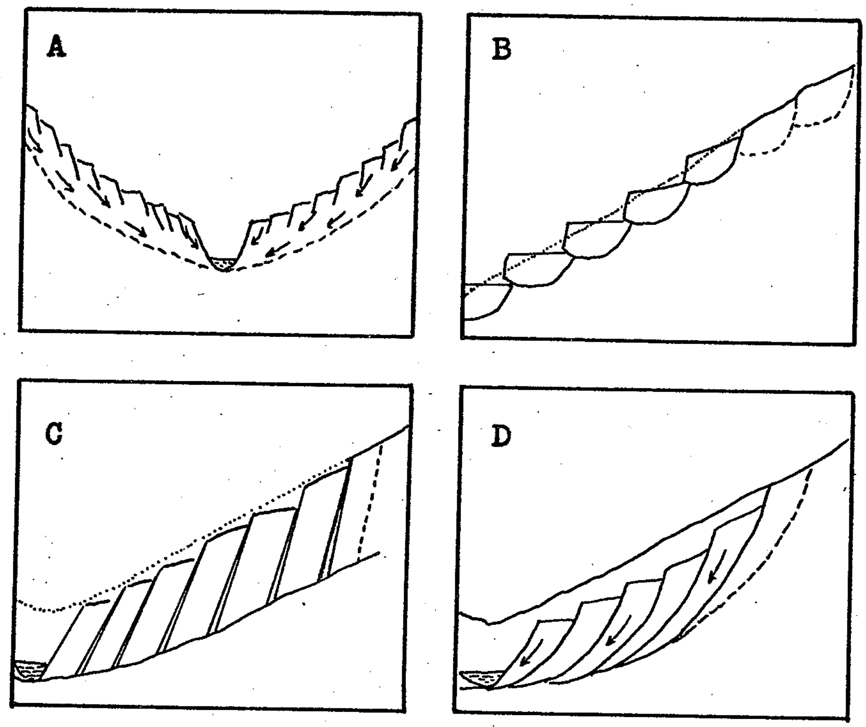

Figure 1.2

Sharpe's theories of terracette development are shown in A, C, and D. The multiple slump theory of Odum is illustrated in B. (After C. F. S. Sharpe, 1960)

On the other hand, Sharpe realizes the great influence cattle can have on the morphology of a slope, particularly if slope material is quite stable.

> By close grazing and the repeated use of certain paths, animals expose the soil which is then subject to rill wash and wind erosion. The weight of the animals com-

> presses both the vegetation and soil. Sharp hoofs cut into the hillslope, producing bare scars on the uphill side of the path.[31]

Sharpe then goes on to explain how under normal conditions of soil stability, a combined form of process is likely to result.

> Unless the soil is unusually firm, however, it seems probable that the continued walking of cattle on hill-side paths will aid in the development of small slip planes, and terracettes of combined organic and tectonic movement will be the result.[32]

Selby, in writing of the greywacke ranges which border the lower and middle Waikato Basins, New Zealand, expresses the opinion that terracettes are caused by both tectonic soil creep and cattle treading.[33] P. Macar and A. Pissart recognize the role of both geologic and faunal processes in the production of the terracette-like features found north-east of Liege, Belgium.[34] They refer to those features produced by geologic processes as "terrassettes naturelles" (natural terracettes), and those formed by faunal processes as "sentiers-de-vache" (cow paths). Cotton also reconizes

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[31]Ibid., p. 72.

[32]Ibid., pp. 72-73.

[33]M. J. Selby, "Aspects of the Geomorphology of the Greywacke Ranges Bordering the Lower and Middle Waikato Basins," Earth Science Journal, I, No. 1 (1967), p. 45.

[34]P. Macar and A. Pissart, "Etudes récentes sur l'évolution des versants effectuées à l'Université de Liège: Les terrassettes du Pays de Herve," trans. by John W. Carley, Zeitschrift für Geomorphologie, Supplementband V (1964), p. 78.

that either process could produce terracette-like features.[35]

The foregoing review of the literature on terracettes reveals that considerable disagreement exists as to the type of process or combination of processes responsible for the production of terracettes. It is most probable that Sharpe's idea of terracettes showing "...all gradations from true paths with no subsurface movement to miniature fault blocks in the origin of which animals have played no part" is nearest to being correct.

c. Terminology

When Odum published his classic paper on terracettes in 1922, he made a review of the contemporary terms used to describe the phenomena. Since Odum's review has been used by Sharpe and alluded to by many others, it is felt necessary to quote it here.

> Obviously "sheep-path" is an awkward name for an actual geological phenomenon, so this alone is reason enough to find a better designation for this peculiar feature. Jonsson used the expression "wrinkles" and Bjorlykke the word""horizontal wrinkles", but both must be considered as misleading as they give a false impression about the phenomenon's origin; the same applies to Bjorlykke's "lines of equal pressure", which, moreover, demands a lengthy translation into a foreign language. Oyen's "mill surface" is certainly neutral with regards to explanation, but it does not give any impression of the path's straight, horizontal course, and too, presents a linguistic difficulty. As a neutral, but completely descriptive designation for the paths, I would like to call them "terracettes", and a surface with paths a "terracette-surface" or "terracette-slope."[36]

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[35]Cotton, op. cit., pp. 15-16.

[36]Odum, op. cit., pp. 25-26.

Had the term "terracette" been allowed to remain the neutral, descriptive one that was intended, much of the controversy and confusion which today surrounds this word would not exist. But no sooner had the term been established than attempts were made to give it a genetic connotation. In fact, Odum himself, although he positively states the term to be neutral, strongly implies that terracettes were formed by "a settling of the loose outer stratum of earth."[37] Sharpe more or less allows the term to remain solely descriptive by recognizing that terracettes may be produced by all combinations of geologic and faunal processes.

Tricart recognizes two forms of terracettes, those formed by geological processes which he refers to as "natural" and those that are formed by cattle as "artificial." Although he recognizes the two processes, he proposes the term "sol-a-gradin" for both types of terracettes and also includes solifluction phenomena in the same term.[38] Macar and Pissart use the terms "sentiers-de-vache" and "terrassettes naturelles" for faunal and geologic types respectively.[39]

Cotton seems to be one of the first authors to use "terracettes" to designate the phenomenon with a geologic origin only.[40] For the sheep-formed variety, he uses the

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[37] Ibid., p. 24.

[38] Tricart, op. cit., p. 94.

[39] Macar and Pissart, op. cit., p. 78.

[40] Cotton, op. cit., pp. 15-16.

term "sheep paths." Thornbury defines terracettes genetically, attributing them to slump processes.[41] Monkhouse also explains the term with a genetic implication of slumping.[42] Dury associated them with a creeping waste surface not in any way connected with the action of animals.[43] Selby uses the term to apply to either a geologic or an organic formation.[44]

Meynier has borrowed Odum's term but will not accept the neutrality that Odum has given it. Meynier states, "We believe that under the same word has been grouped two different phenomena."[45] He then assigns the term "terracettes" to geologically produced features, and "cattle tracks" to faunally produced ones. As Odum intended the term to be used as a descriptive tool, he implies no recognition of process. Thus Meynier has helped defeat Odum's original intention.

Had the term always been given the same genetic implication, i.e. either geologic or organic, less confusion would have resulted. Unfortunately, such is not the case. While "terracette" is used most frequently with geological implications, some authors, for instance Rahm, have used the term to apply to cattle-formed features. Not only do

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[41]Thornbury, op. cit., p. 92.

[42]Monkhouse, op. cit., p. 305.

[43]Dury, op. cit., p. 14.

[44]Selby, op. cit., p. 45.

[45]Meynier, op. cit., p. 81.

different authors use the term to imply different genetic processes, but Rahm has changed his mind as to which process the term should refer to. He applied the term "terracette" to the product of a purely geologic process in 1961[46] but uses the same word in 1962[47] to imply a faunal process.

Should a landform term have only a morphological connotation, or should it also imply genesis? The word "terracette" was devised as a simple, neutral term for morphologically descriptive purposes. However, many authors have used the term genetically. Consequently, the attempt to make the expression more meaningful by giving it a genetic implication has actually made it less efficient as a geomorphic term.

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[46] D. A. Rahm, "Terracettes--an Index of Erosional Environment of Slopes," Northwest Science, Abstract, XXXV, No. 4 (1961), p. 164.

[47] Rahm (1962), op. cit., p. 80.

CHAPTER II

CLASSIFICATION OF TERRACETTE DEVELOPMENT

In preparation for more intensive field work, the total study area in the Souris River Valley was first covered extensively by car and short walking traverses to familiarize the author with its general characteristics. From this preliminary survey it became apparent that many of the terracette sites were inaccessible by car. Since the aim of the study was to examine the complete terracette population of this area, an intensive investigation had to be carried out on foot to minimize the possibility of overlooking important sites. Both sides of the Souris valley and several tributary valleys were then scrutinized, with about 90% of the total traverse being covered on foot.

During this intensive survey, notes were made not only of the areas displaying terracettes but also of those locations which seemed favourable to terracette development but did not possess such features. Although the foregoing might seem to imply that this part of the field work was carried on with preconceived ideas, such was not the case. However, when an area devoid of terracettes was observed adjacent to a site displaying an abundance of fine examples, and when both locations appeared to be very similar, it became imperative to record the physical condition of the barren site.

It was necessary to introduce several new morphological terms to facilitate discussion of the phenomenon. Figure 2.1

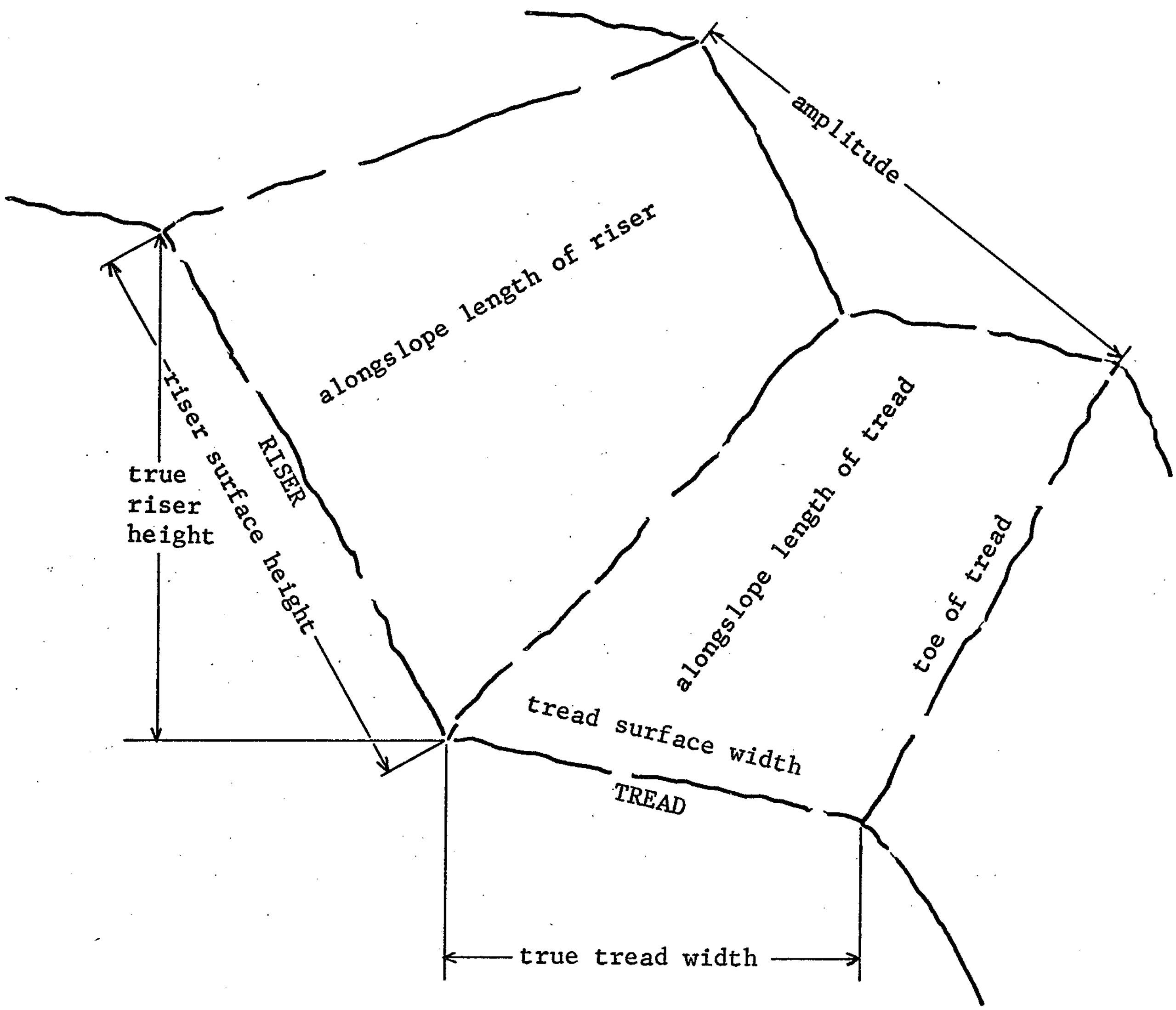

Figure 2.1

Illustration of terms applied to the terracette phenomenon illustrates this new nomenclature as well as several terms that have appeared previously in terracette literature.

Possible determinants of terracette development were recorded as site factors. As stated in the Introduction, these determinants are aspect, slope gradient, vegetation, soil material, and animal activity. In order to evaluate the strength of the influence of these factors in the production of terracettes, the latter had to be classified according to their degree of development. Terracettes that showed well-defined treads and risers with considerable alongslope length would be considered to have a good degree of development. Examples of variation in terracette development can be seen by comparing Plates 2.1 and 2.2. Poorly developed terracettes have their treads and risers weakly demarcated and are segmented alongslope. Only four classes of terracette development were chosen to ensure a sufficient number of occurrences in each. The requirements for each of these four categories of development will be given in the following paragraphs.

Sites with good potential for terracette development but currently devoid of them were classes as "barren". Comparisons involving site frequencies cannot include this class as its members are chosen occurrences. However, use will be made of this class when the site factors of slope, vegetation, and animal evidence are being discussed later in Chapter III.

The following terracette characteristics, illustrated

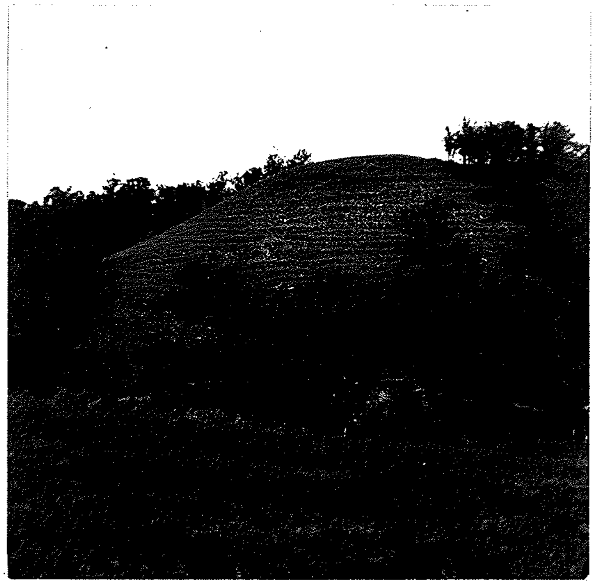

Plate 2.1

Well developed terracettes

Plate 2.2

Poorly developed terracettes

in Figure 2.1, were recorded during field work: alongslope length of tread, alongslope length of risers, tread surface widths and gradients, riser surface heights and gradients, and vegetation. Amplitude, that is, the downslope distance between the distal limits of successive treads was also measured. Tread surface width is defined as the distance from the front edge to the rear limit of the tread, and is not the true horizontal dimension. Likewise, riser surface height is the distance from the top to the bottom of the riser as measured along the surface, and is not the true vertical height. The tread and riser angles were measured by brunton compass and a 42" hardwood rod (Plate 2.3). The difference between the tread and riser angles was termed the tread-riser angle (Figure 2.2). The alongslope lengths of the terracettes were determined by pacing off the distances. Although a steel tape was used initially, it soon became apparent that alongslope limits of terracettes are often too indefinite to warrant such precise measuring equipment. Other characteristics were considered such as degree of horizontality and parallelism of adjacent terracettes, but these showed little variation from site to site, and therefore would not serve as parameters for evaluating terracette development.

Amplitude, vegetation on treads and risers, surface tread widths, and surface riser heights provide no basis for determining degree of development. The value of amplitude at a site with well developed terracettes could be

Plate 2.3

Method of measuring tread angles. A similar method was used for riser angles.

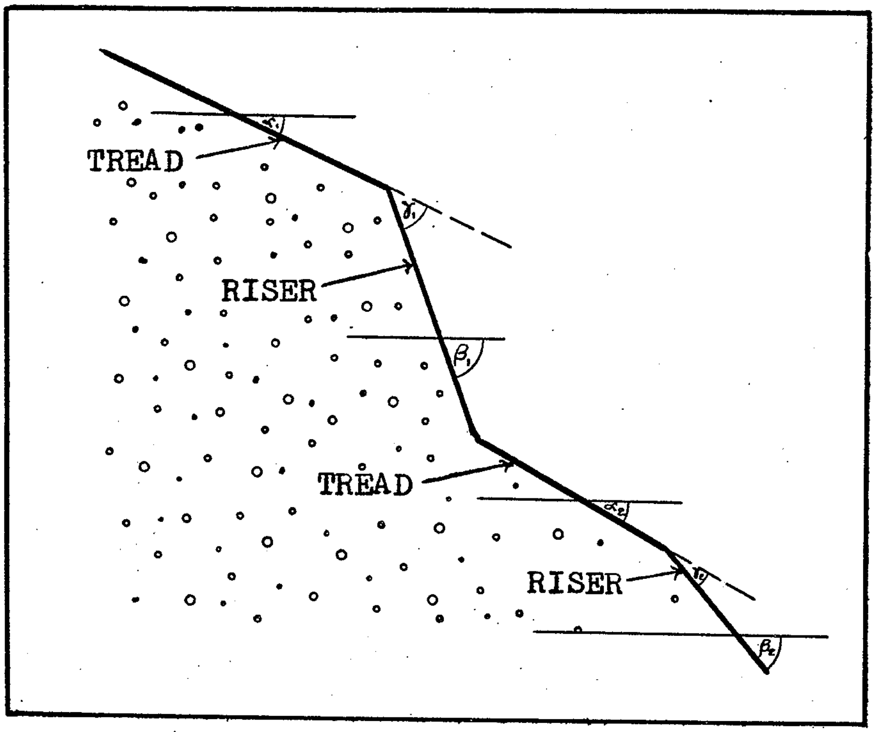

Figure 2.2

Tread-riser angle(γ) = riser angle(β) - tread angle(α)

γ_1 and γ_2 are examples of large and small tread-riser angles respectively. The larger the tread-riser angle, the more prominent the terracettes appeared.

exactly the same as that for poorly developed examples. Comparisons of types of vegetation with degree of terracette development show no definite relationships. Furthermore, considerations of density of vegetation are no help in evaluating the degree of development of terracettes, as well developed features can be found where there is a thick, moderate, or sparse vegetation mantle. Lastly, a large tread surface width and great riser surface height may be characteristic of either well- or poorly-developed terracettes.

The tread-riser angle has more influence on the prominence of the terracettes than have the tread surface width and riser surface height. Thus the tread-riser angle is regarded as a meaningful criterion for judging the degree of development of terracettes. The tread-riser angles in the survey area were found to vary from 71° to 17° with the greatest majority of values in the 50° to 20° range. Limits of tread-riser angles for good, medium, and poor terracettes were arbitrarily defined as 30° and greater, 16-29°, and less than 16° respectively. The actual values of tread-riser angles and alongslope lengths chosen to delimit the classes of terracette development are not critical to this thesis. It is rather that the terracettes must be classed according to quality in order that variations in degree of development may be compared with variations in site factors.

It did not seem reasonable that terracettes with similar tread-riser angles should be regarded as having the same degree of development if their alongslope dimensions were quite different. Therefore, alongslope length was chosen as a complementary criterion for class definition. Terracette lengths in the survey area varied from 6 feet to over 100 feet, with the majority of examples in the 10 to 50 feet range.

Figure 2.3 shows the various values of alongslope lengths that have been combined with the divisions of tread-riser angles to define the classes of degree of development of terracettes. The chart is used in the following manner.

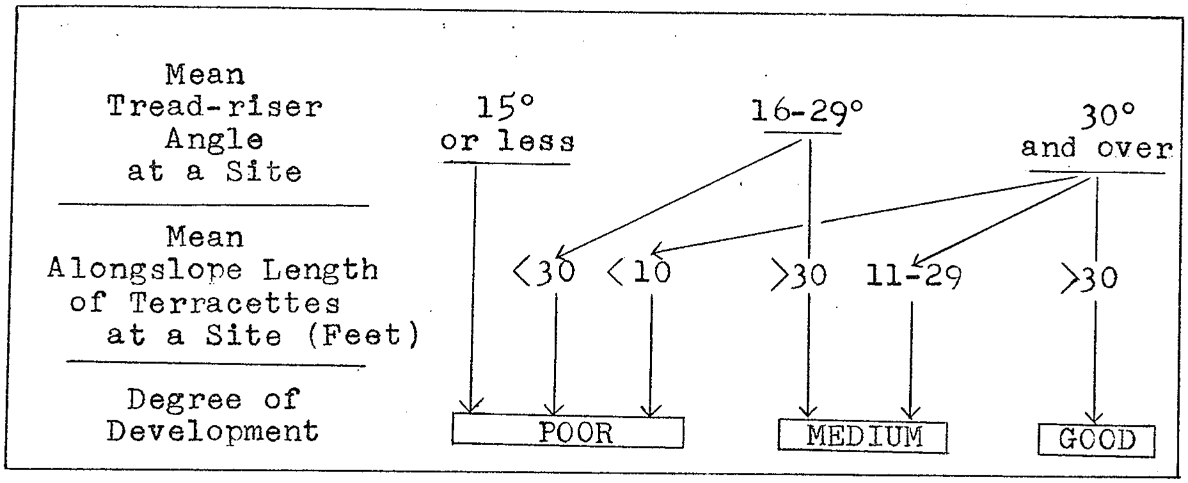

Figure 2.3

Chart for determining the degree of development of terracettes

After computing the values of the tread-riser angles and the alongslope lengths for all the terracettes at a particular site, the mean tread-riser angle and mean alongslope length may be determined. By reference to the chart, these two means indicate the average degree of development for the terracettes at that site. The variations in this average degree of development from site to site can then be compared to the variations in the importance of particular site factors.[1]

So far in this study, no maximum values have been established for tread surface widths or riser surface heights. Without such dimensional limits, huge slumps could be termed terracettes, as the criteria established thus far are tread-riser angle and alongslope length. Riser surface heights

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[1] The term "degree of development" when applied to the quality of terracette development at a site will always refer to the average development.

in the study area were found to vary from 1-12 feet, with values usually between 2-5 feet. Features with values of 8-12 feet were recorded as terracettes because they occur in conjunction with other examples having a more usual riser surface value. Tread surface widths are usually from 1 1/2-2 1/2 feet, with the extreme value being approximately 5 feet. As shown in Table 1.1, the maximum typical tread surface width recorded in the literature was four feet. In order to be sure not to exclude any terracettes, it was decided that an area would be classified as a terracette site whenever the widths of the tread surfaces were less than five feet. As there are only one or two cases where this limitation has had to be applied in the study area, the choice of five feet for the limiting tread surface width value is not a critical decision.

The resulting classification of terracette sites corresponds remarkably well with that made on a purely subjective basis during field work. This accordance strengthens the validity of the classification system adopted here. Since the sites are now categorized according to their degree of development, an examination can be made of the relationships between the site factors and the degree of terracette development.

CHAPTER III

RELATIONSHIPS BETWEEN SITE FACTORS AND TERRACETTE DEVELOPMENT

The chapter discusses not only the relationships existing between site factors and degree of terracette development, but also considers the inter-relationships of the former. Each site factor will be presented in a separate section.

a. Aspect

A compass bearing was taken with a brunton compass from the approximate mid-point of the alongslope length of each surveyed site. As the survey area has an east-west dimension of less than 30 miles and a north-south distance of less than 20 miles, magnetic declination was assumed constant throughout. True bearings were obtained by subtracting the declination value of 3° from each magnetic compass reading. Since the one compass was used consistently in the field work, any error due to instrument variance was avoided.

In Table 3.1, the true bearings are grouped into classes of 10° intervals. The frequencies of poor, medium, and good terracette sites in each of these 36 classes are shown in the table. From the table, three important facts emerge.

1. Thirty-five percent of the terracette sites have aspects within the 156-185° direction range.

2. The maximum number of terracette sites in any one

Aspect	Degree of Development			Total
	Poor	Medium	Good	
356-005	1			1
006-015				
016-025	1			1
026-035				
036-045				
046-055				
056-065				
066-075		1		1
076-085			1	
086-095	1	2	1	4
096-105	1			1
106-115	1	1		2
116-125				
126-135		2	1	3
136-145		1	2	3
146-155	1			1
156-165	2	2		4
166-175	2	1	2	5
176-185	6		4	10
186-195		2		2
196-205				
206-215	2	1		3
216-225				
226-235	2			2
236-245		1		1
246-255				
256-265	2			2
266-275	1	2		3
276-285		1	2	3
286-295				
296-305	1			1
306-315	1			1
316-325	1			1
326-335				
336-345				
346-355				
Total	25	17	13	55

Table 3.1

Distribution of poor, medium and good terracettes according to aspect class, constituting approximately 20% of the total, occurs in the 176-185° group.

3. Poor terracette sites are found through almost the entire range of the compass bearings. Medium ones are widely distributed through the 76-285° range. Good sites occur entirely within the same range of compass bearings as medium ones but show a concentration in the 176-185° class.

From these results, it is apparent that a southerly exposure is conducive to the formation of terracettes. The results might have been biased if the survey area consisted of a straight valley running directly through the region. However, that part of the Souris Valley under consideration consists of two fairly straight sections connected by a 90° elbow. As well, tributary valleys enhance the opportunity for slope aspects to cover all points of the compass.

Aspect, through its control of the intensities, durations, and frequencies of some processes, affects the development of terracettes indirectly. For example, in the study area a south facing slope will receive more direct solar radiation than a north facing one. The greater amount of insolation is due to the longer period of exposure to the sun and to the higher angle of incidence of its rays to the slope's surface. The result will be greater amounts of heating and evaporation on the south-facing slope than on its counterpart.

Heating and drying will affect the stability of the soil and regolith on which terracettes occur or are forming. As drying occurs, the cohesive force between soil particles diminishes and soil creep processes are accelerated. Furthermore, the intensities of heating and drying will influence the density and type of vegetation present, which in turn will also affect the stability of the slope surface. A dense vegetation mantle will retard the process of soil creep.

Cattle grazing is also affected by aspect at certain times of the year. In the spring, these animals will search out the fresh grasses which naturally will occur first on the south-facing slopes. At that time, the soil is least consolidated because the frequent freeze-thaws of the early spring have disturbed the soil particles. Thus, cattle, in search of early forage, leave hoofprints deeply impressed in the slope surface by virtue of their heavy weight and the incoherent condition of slope materials.

Type and density of vegetation and cattle activity have been pointed out as ways in which aspect indirectly influences the degree of development of terracettes. The factors of vegetation and cattle activity will be discussed in detail later in this chapter.

b. Slope gradient

A gradient angle was determined at each site by measuring, with a Suunto clinometer, that section of the slope that displayed the best terracettes. This angle was designated the overall slope angle to distinguish it from tread and riser angles. The values of this angle were then processed to find the mean, median, upper quartile, and lower quartile for each of the poor, medium, and good classes of terracette development (Table 3.2). The mode was not determined as its significance would be limited by the small number of overall slope angles for medium and good terracette sites. A composite dispersion diagram of overall slope angles was then constructed for the degree of terracette development categories (Figure 3.1).

The dispersion diagram shows a direct but weak relationship between overall slope angles and degree of terracette site development, i.e. when gradient is steeper, the terracettes tend to be better developed. The relationship is most noticeable when lower limit and lower quartile values are considered. The mean, median, and upper quartile values for good development are much higher than those for medium and poor degrees of development. Extreme maximum overall slope angles vary very little.

The direct relationship between overall slope angle and degree of terracette development is most strongly evidenced by the fact that each value for good development given on the dispersion diagram is larger than its corresponding value at medium and poor sites, with the exception of the upper limit of the latter.

There is a much greater variation of overall slope angles on slopes that have a poor degree of terracette development than on medium or good sites. The degree of

	Degree of Development		
	Poor	Medium	Good
	17	23	25
	18	24	30
	18	26	30
	19	26	30
	19	29	33
	20	30	34
	22	30	36
	24	30	37
Overall	26	30	40
Slope	28	30	40
Angles	29	32	41
	30	32	42
	30	32	42
	30	33	
	30	35	
	32	36	
	32	40	
	32		
	33		
	34		
	37		
	38		
	39		
	41		
	42		
Mean	$\overline{29°}$	$\overline{30.5°}$	$\overline{36°}$
Median	30°	30°	36°

Table 3.2

Means and medians of overall slope angles for the three degrees of development

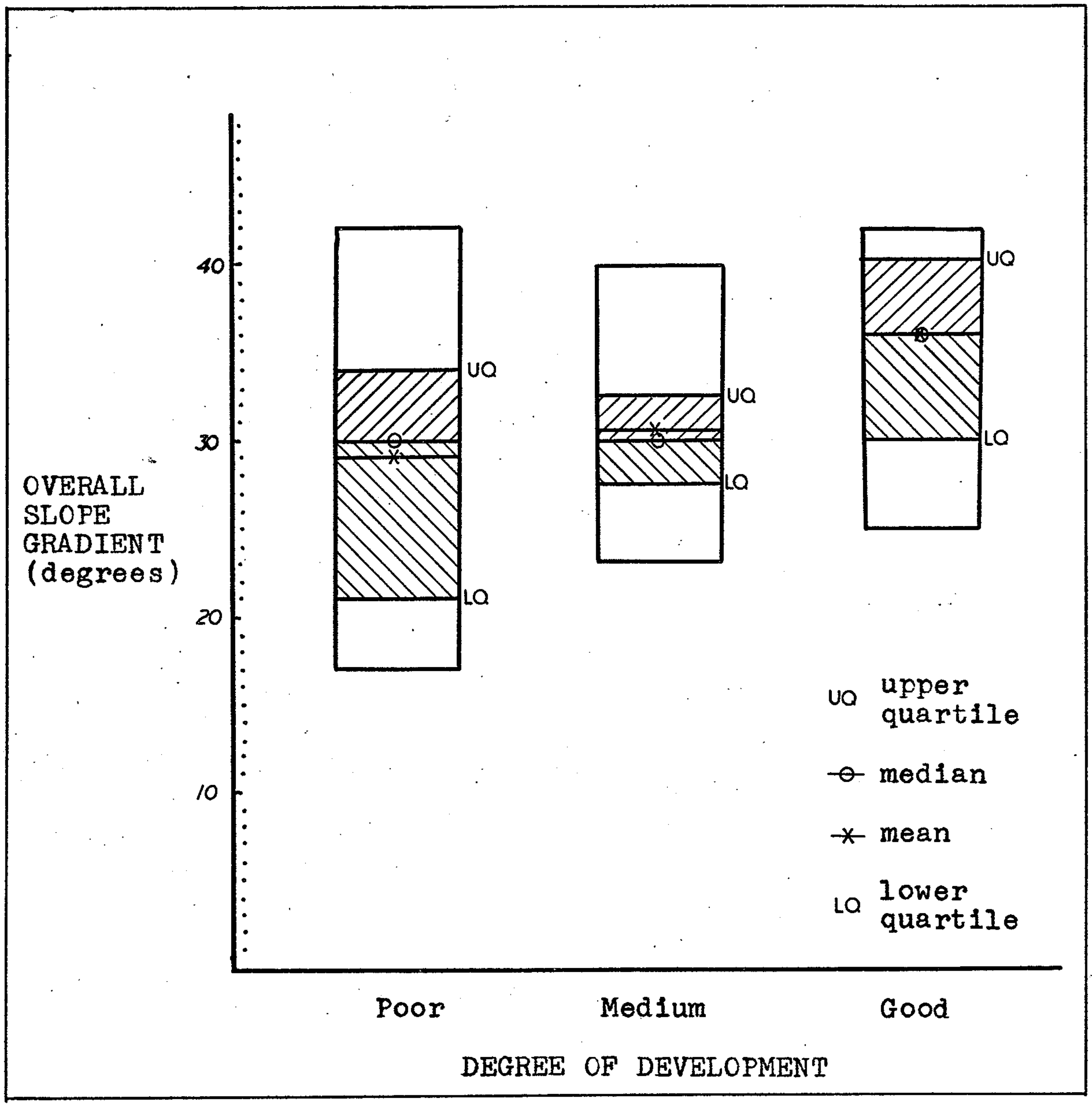

Figure 3.1

Frequency of overall slope gradient for each degree of development dispersion of values for the category of medium development is surprisingly low. It is noteworthy that approximately one-third of poorly developed terracette sites have overall gradients that are less than the lowest angle recorded on a medium development site. At least as significant is the fact that the interquartile range of values of the good development category is above the medians of the two other groups. Summarily, it is clear that the larger the overall slope angle, the better developed are the terracettes at a site.

There were no instances of terracettes existing on slopes with overall angles of less than 17°. The one example (site #8) of an overall slope angle of 17° was classified as poor.

The largest overall angle of a slope with terracette development was found to be 42° for the survey area. This value occurs at three terracette sites, one of these being poorly developed and the others well developed. This angle could be the maximum for slopes over which cattle are willing to move. Also, steep slopes tend to be subject to rapid erosion unless covered by thick vegetation. The good developments at 42° slope occur at sites #54 and #57. Both have a thick mantle of grasses which would help prevent rapid downsliding of material. The 42° slope with poor development is at site #39, an actively eroding river cliff where large blocks of turf have been moving downslope with backward rotation (Plate 3.1). In this case, the site is currently

Plate 3.1

A large turf block approximately two feet thick

Plate 3.2

Vegetation densities: sparse (a), moderate (b), and heavy (c) inaccessible to cattle. The river cutting at the base of the cliff has been removing shale material very rapidly, thereby making the top portion of the cliff unstable. Thus large pieces of soil and roots have slid down the steep cliff face. This, of course, raises the question of whether these features are terracettes or not, but since their dimensions meet the arbitrarily specified requirements, they will be regarded as such for the present.

The range of overall slope angles at terracette locations is 17-42 degrees. Since the greatest percentage of the barren sites occur on slopes with gradients within this range, factors other than overall slope angles must be responsible for these places remaining devoid of terracettes.

In summary, an analysis of the composite dispersion diagram indicates that a relationship, not a particularly strong one, exists between overall slope angle of a terracette site and the degree of development of the phenomenon. Furthermore, terracettes do not appear to develop on slopes of less than 17° or greater than 42° under conditions found within the survey area.

c. Vegetation

Vegetation can influence the ease with which terracettes form by virtue of the ability of the root system to hold soil together. It is common knowledge that a piece of turf with its complex interwoven roots will not disintegrate as easily as a mass of root-free soil material (Plate 3.1).

Roots may either hinder or promote the development of terracettes. They could be a hindrance in that they may hold the soil so firmly that the terracette-forming processes cannot operate properly. On the other hand, the terracettes, once formed, could be preserved by the root systems, in spite of erosive agents such as wind, rain, and running water.

A method was devised to classify the density and type of vegetation at each terracette site. Vegetation density was considered to fall into one of four classes, described as bare, sparse, moderate, and heavy. The classification was carried out in the field using the following guidelines:

bare--no vegetation except for occasional plants widely scattered over the site,

sparse--approximately 1/3 of the site covered by vegetation,

moderate--approximately 2/3 of the site covered by vegetation,

heavy--no soil readily visible due to vegetation cover.

Examples of three of these vegetation density categories are seen in Plate 3.2.

The type of vegetation cover was divided into three classes: grasses, shrubs, and trees. As root systems are greatly influenced by their environment,plants at the same site would tend to have similar root systems.[1] No useful purpose could be seen in having a separate class for each

[1]John E. Weaver, Root Development in the Grassland Formation, (Washington: Carnegie Inst. of Washington, 1920), p. 15.

plant species, for differences in the holding powers of roots would not be significantly large. Therefore, flowering plants, weeds, and grass were included in the grasses category.

Very often the vegetation at a site consists of more than one type. Whenever this situation was encountered, the percentage proportions of each type were recorded. Vegetation density and type were recorded in the shorthand form of "density/ % grass/ % shrub/ % trees". For example, if a site were moderately vegetated with grass making up 40% of the vegetation, shrubs 50%, and trees 10%, the site was recorded as "moderate/40/50/10".

Root systems were excavated and their profiles drawn in an attempt to discover recent mass movements such as slumping or soil creep.

(i) Vegetation type and aspect

Vegetation type was found to have a definite relationship to aspect. This was very noticeable in the field, particularly in small east-west valleys tributary to the Souris Valley. Most of the north-facing slopes of these valleys possess a tree cover, whereas the south-facing ones have chiefly grasses with a mingling of shrubs (Plate 3.3). Air photos clearly reveal this response of vegetation to aspect (Plate 3.4).

It is not surprising that aspect is a determinant of the vegetation type. In this area the amount of solar

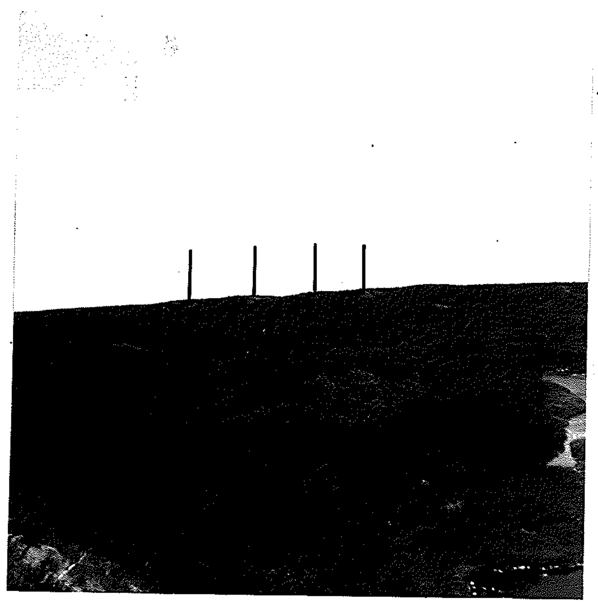

Plate 3.3

A view showing south west facing slopes (marked by black lines) near site #42

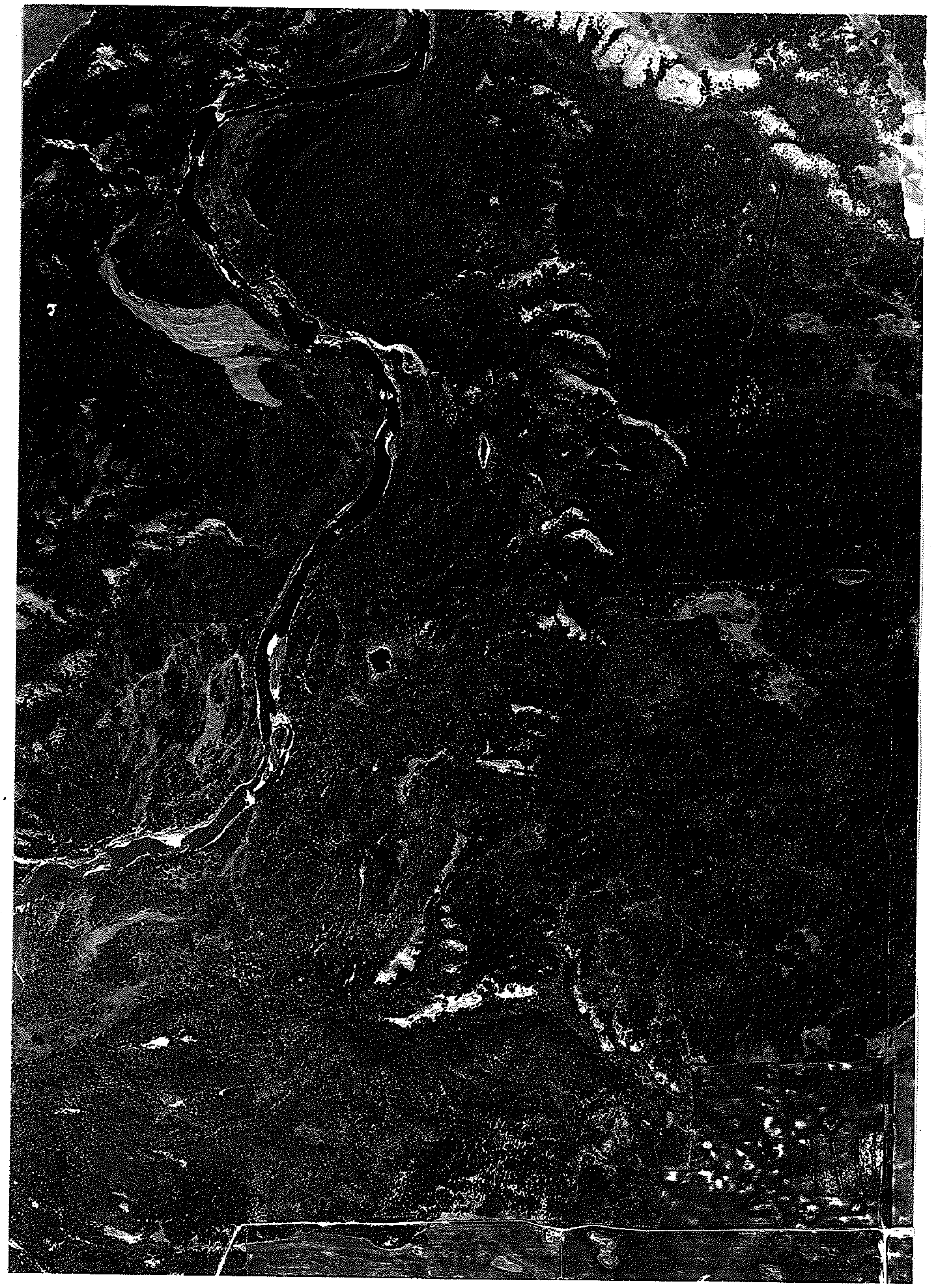

Plate 3.4

Air photo of area north of site #42 showing the response of vegetation to aspect. The light-colored areas are grass-covered slopes with a southerly aspect.

radiation received by a north-facing slope will undoubtedly be less than that received by a south-facing one. In the spring, the south-facing slopes will begin to thaw out during the day at an earlier date than the north-facing ones. However, during the nights, air temperatures will often fall below freezing point again. Thus the trees on south-facing slopes will begin to regenerate during the day only to suffer nocturnal freezing. At early stages of development this is most injurious to the plant.[2,3,4] As the season progresses, and freezing occurs less frequently at night, the north-facing slopes will begin to thaw during the day but by this time the nocturnal air temperatures will not be as low as they had been earlier in the season. When temperatures are warm enough to initiate tree growth on north-facing slopes, the nocturnal freezing will be less frequent and the trees will have a better chance of survival.

Undoubtedly, warm dry winds blowing over an area will produce a desiccating effect by enhancing evaporation. Wind is also significant in directing precipitation against

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[2]Ernest E. Hubert, _An Outline of Forest Pathology_, (New York: Wiley and Sons, Inc., 1931), p. 114.

[3]C. Abbe, "The influence of cold on plants--a resume." Exp. Sta. Record, VI, 1895, pp. 777-781, as cited by Ernest E. Hubert, _op. cit._, p. 120.

[4]F. J. Lewis and G. M. Tuttle, "Osmotic properties of some plants cells at low temperatures." Ann. Bot., XXXIV (1920), pp. 405-416, as cited by J. Levitt, _Frost Killing and Hardiness of Plants_, (Minneapolis: Burgess Publishing Co., 1941), p. 98.

exposed slopes. To attempt to relate the effects of winds to the local distribution of precipitation and dessication is a climatic study beyond the scope of this thesis. However, on level parts of this area with similar soil moisture retention capabilities, woodland predominates, suggesting sufficient precipitation for tree growth over most of the region. It is, then, probably the combined effects, on the south-facing slopes, of greater evaporation due to the more intense solar radiation and of a larger number of spring freeze-thaws that determine the restriction of the tree species, and not a difference in precipitation. As grasses and shrubs can survive with less moisture than trees, the south-facing slopes tend to be treeless whereas north-facing ones are usually tree-covered.

Some diseases are influenced indirectly by aspect. Sun scald, bark scorch, and heat cankers can affect both broadleaf and coniferous trees. Since the primary cause of these diseases is high temperatures, trees on the south-facing slopes would tend to be more affected than those on north-facing slopes.[5]

An analysis of vegetation type with aspect showed that 46 terracette sites have a covering of 90-100% grass. Of these, 23 have aspects defined by a magnetic bearing between 165° and 215° (Figure 3.2). Thus 50% of the grass-covered terracette sites have aspects that lie approximately within

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[5]Ernest E. Hubert, op. cit., pp. 122-124.

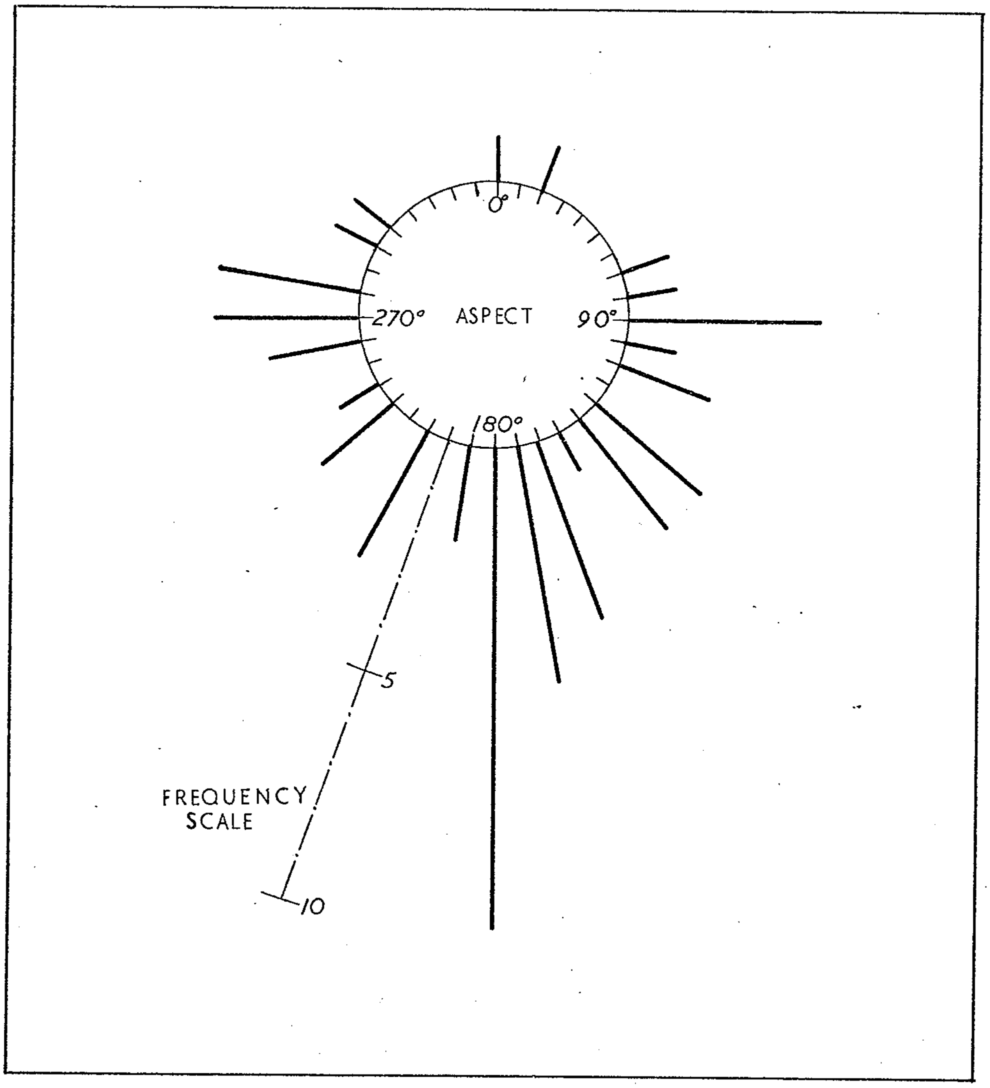

Figure 3.2

The rose diagram reveals the aspect frequencies of terracette sites. The majority of sites have an approximately south-facing aspect. However, one minor grouping of site aspects occurs in the 85-105° range, while another appears in the 265-275° group. These two minor concentrations may be a reflection of the valley orientation. There is, however, as much possibility for terracettes to occur on north-facing slopes as south-facing ones, as the valley sides are very close to being parallel. Therefore, the concentration of southern aspects for terracettes is deemed significant.

the range S.S.E. to S.S.W. The only terracetted slope chiefly tree-covered has a true bearing of 267°. Shrubs do not populate terracette sites to the same extent as grass. Wherever they account for over 50% of the vegetation cover at a site, the following slope aspects occur: 20°, 135°, 145° (2)[6], 185°, 235°, 260°, and 285° (2). From considerations of these slope bearings, it is seen that shrubs do not have preferences for aspect as strong as grasses do. In summary, there appears to be a definite relationship between aspect and type of vegetation, especially in that grass tends to be dominant on south-facing slopes. By contrast, shrub vegetation is more evenly distributed throughout the compass directions than grasses.

(ii) Vegetation density and aspect

A significant examination of vegetation density and aspect of terracette sites cannot be made as densities for all sectors of the compass are not well represented. For instance, only six terracette sites were discovered with an aspect in the 280-080° range. The barren sites could not be used since they were selected occurrences. Thus attempts to show comparison of density and aspect on a proportional basis would hardly be justified when only 6 terracette sites occur in 160° of compass direction while 49 occur in the remaining 200°. Even within this 200° range, no definite

[6] Figure in brackets refers to number of sites having that particular aspect.

relationship between aspect and vegetation density exists.

(iii) Vegetation density and overall slope angle

Vegetation is not strongly related to the overall slope angle of terracette sites. The material that composes the slope probably has more influence on the density of vegetation than the slope angle *per se*. Steep slopes in the area are often composed of shale beds and scree overlain by a thin cover of poorly developed soil. The shale debris does not form a very desirable environment for the establishment of well developed root systems necessary to impede the downslope movement of material. Sparse vegetation tends to be more characteristic of steep slopes where vegetation may have difficulty in becoming established. However, a dispersion diagram of overall slope angles of terracette sites for each of the density categories indicates that both heavy and sparse grass vegetation are found on similar slope angles (Figure 3.3). Moderately dense grass covers are found on lower slope angles than are either sparse or heavy ones. It is possible that the heavy grass density exists on steep slopes because these would be less frequently grazed by cattle. Grasses develop better when the above-ground portions are not frequently cut off as might occur in close grazing.[7,8]

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[7]John E. Weaver, *North American Prairie*, (Lincoln, Nebraska: Johnsen Publishing Co., 1954), p. 141.

[8]John E. Weaver, (1954), *op. cit.*, p. 146.

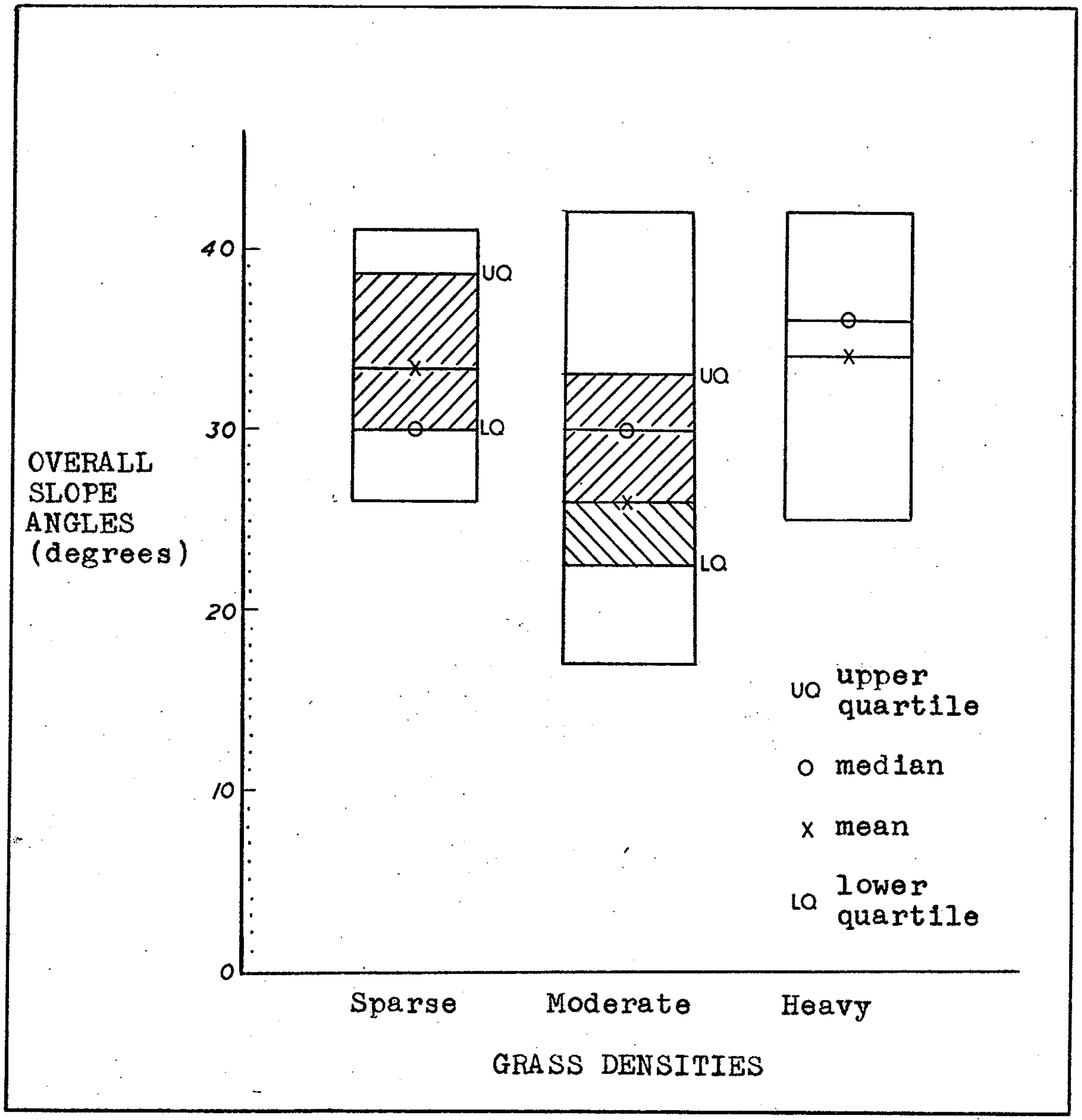

Figure 3.3

A comparison of the dispersion of mean overall slope angles for each of the three categories of grass densities. Due to the small number of sites with dense grass vegetation, the upper and lower quartiles were not determined for that category.

(iv) Type of vegetation and degree of development

As shown in Table 3.3, 81% of the terracette sites essentially had a grass cover, 17% were vegetated predominantly by shrubs, while only 2% were dominated by a tree cover.

The occurrence of grasses influences the frequency of occurrence of terracette sites more indirectly than directly. It will be shown later in this chapter that a strong relationship exists between cattle utilization of a slope and the appearance of terracettes. Cattle, then, in search of forage frequent these grassy slopes more than shrub- or tree-covered ones. Furthermore, in the spring, grass shoots appear first on the south-facing slopes, and so cattle are particularly attracted to these areas at the season when the slope material is most vulnerable to compaction. Thus the appearance of terracettes may be highly related to the presence of a grass-type vegetation through the latter's influence on cattle utilization.

Although shrub vegetation predominated at 17% of the terracette locations, grasses invariably were found as a strong sub-dominant type. Terracettes possessing a shrub cover would probably be due at least as much to the presence of grasses as to the predominance of shrubs. Medium and heavy density tree covers were not accompanied by terracette features. Trees effectively shade out much of the grasses, thus furnishing less forage for cattle, which then frequent such sites less often. Also, trees tend to act as

Degree of Development	Grass			Shrub			Trees			Total
	Sp.	Mod.	H.	Sp.	Mod.	H.	Sp.	Mod.	H.	
Barren	1	17	6	2	5	1	0	0	0	32
Poor	2	16	1	0	3	0	1	0	0	23
Medium	5	8	2	1	1	0	0	0	0	17
Good	3	5	1	0	0	3	0	0	0	12
Total	10	29	4	1	4	3	1			52
Percent of Total Sites	19	55	7	4	7	6	2			100
Cumulative Percent of Each Vegt. Type		81			17			2		100

Table 3.3

Type and density of vegetation for various degrees of terracette development. The barren sites have been inserted for comparison purposes only, and therefore their values are not included in the percent figures. (Sp. = sparse; Mod. = moderate; H. = heavy.)

Grass Density	Degree of Development		
	Poor	Medium	Good
Sparse	11%	33%	33%
Moderate	84%	54%	56%
Heavy	5%	13%	11%
Total	100%	100%	100%

Table 3.4

Densities of grass cover occurring at each degree of development

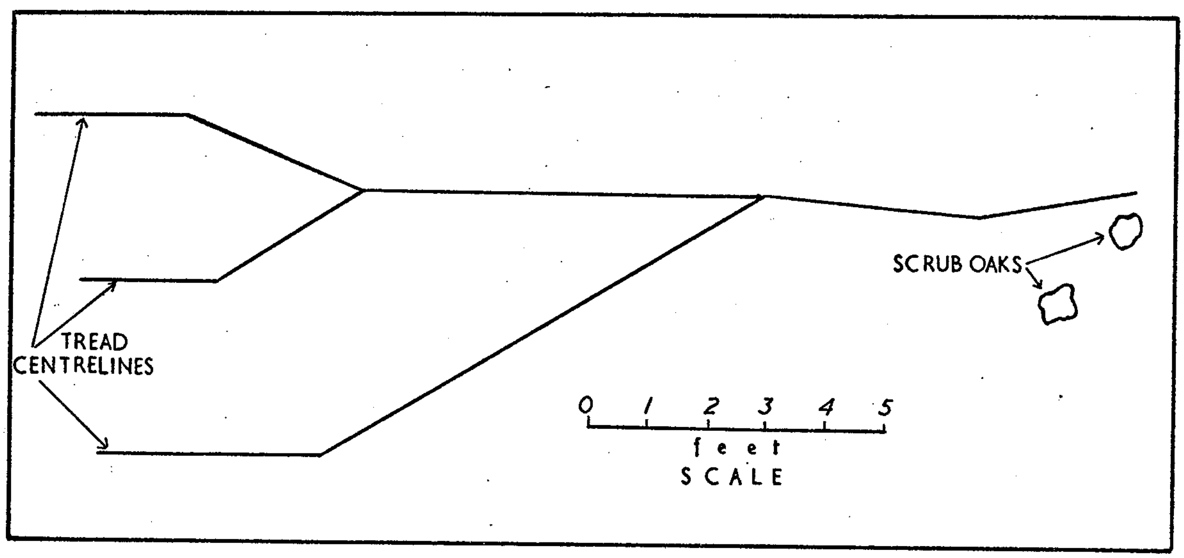

Figure 3.4

A plan of tread centrelines as viewed normal to the slope surface at site #63 obstacles to the alongslope continuity of terracettes. Terracettes forming by gravity influenced mass movement processes are not likely to occur in a tree-covered area. It was observed that whenever trees were involved in slumping or accelerated soil creep, the resulting features did not have a narrow, continuous form in the alongslope direction. Thus, it is doubtful if terracettes can be formed by mass movement processes in a markedly tree-covered area.

It is apparent that terracettes are strongly associated with a grass cover, and that the latter is a factor that operates indirectly by determining, to a large degree, the amount of cattle trampling there will be on a slope.

(v) Vegetation density and degree of development

Considerations of vegetation densities will be made solely for grass-covered sites, as only this type of vegetation occurred at a large number of terracette locations. Table 3.4 shows the percentage of each degree of terracette development having sparse, moderate, or heavy grass cover densities.

The lack of terracettes at heavily vegetated sites might be a reflection of dense grass roots holding the soil so firmly that the phenomenon could not develop. On the other hand, sites with sparse vegetation might not be able to preserve the phenomenon against the destructive action of erosive agents unless the slope were under the constant influence of terracette forming processes.

The relationship between grass density and degree of development is definitely complex. Furthermore, since vegetation is inter-related with several other site factors, isolating the exact effect of grass densities on terracette development is at best quite speculative.

As the sites devoid of terracette development were selected phenomena, consideration of their percentage occurrences with each of the vegetation types is not justified. However, it is interesting to note that all four vegetation densities were found in the barren class.

Vegetation can make terracettes more conspicuous. For example, risers are often too steep to be vegetated while the tread may support plant growth. These alternating bands of vegetated and non-vegetated material produced contrast which enhances the appearance of the terracettes (Plate 3.5). A similar effect, although usually less pronounced, can be produced by alternating bands of vegetation of different densities.

The above-ground portions of plants affect the terracette pattern on a slope, for a large shrub or tree can indirectly cause the convergence of two terracettes. Figure 3.4 shows a diagram of terracette treads at the eastern extremity of site #63. The dashed lines represent the centre line of each tread. Since this site has had considerable cattle usage, the terracette pattern should show the influence of their treading. In order to avoid the trees, the cattle have brought their paths together. Although

Plate 3.5

The vegetation on the downslope edge of the cattle path contrasts sharply with the bare tread surface. In a similar fashion, vegetation can accentuate terracettes.

scrub oaks were responsible for terracette coalescence at this site, large groups of shrubs were observed to produce a similar effect at other locations in the survey area.

(vi) Vegetation as an indicator of mass movement

Since slumping and soil creep have been proposed as possible causes for terracette development,[9] the detection of these types of mass movement was attempted by digging into a terracetted slope. Site #63 was chosen as it possesses well-formed terracettes and is readily accesible. (See frontispiece.) It is at the end of a spur with a Souris River cliff on one side and a tributary valley side on the other. Number 2 highway was constructed along the axis of this tributary valley, but the spur had not been disturbed as a close examination of the foot of the slope showed willows which predated the road. Also, the soil development on the slope could not have occurred in the short period of time since the highway was constructed. As this slope, with an overall slope angle of 32°, is too steep for cultivation, it can be stated that it was in an undisturbed state except for the influence of natural processes including cattle activity.

To observe terracette cross sections, a pit was excavated, in the direction of steepest slope, approximately halfway up the hillside at site #63. This excavation extended horizontally into the slope a distance of six feet

[9]Chapter I, pp. 8-11.

giving a depth of approximately five feet at the uphill end. Although a careful examination was made of the pit sides, no trace of mass movement was detected.

The detection of slow slumping or soil creep in a homogeneous material can be very difficult unless some phenomenon is used as an indicator of movement. There were present in the sides of the pit numerous roots from grasses and flowering plants which penetrated beyond the depth of the pit. If there had been strong mass movement, such as rotational slumping, to produce the well-developed terracettes at the surface, the displacement of the soil would most probably have disturbed the roots. Botanists use a method of examining plant roots whereby a pit is dug to their maximum depth, and every branch of the root system of a particular plant is carefully mapped for several inches into the pit face.[10] However, in the current study, all the roots did not have to be from the same plant, for distinct changes in direction of all roots would indicate the presence of recent or of accelerated rates of mass movement. If the movement was slow and gradual, the older roots would show more displacement than the newer ones.

A four inch "slice" of earth was marked off along the west side of the pit (Figure 3.5). The positions of the larger roots in this bisect were carefully recorded in full scale on a large sheet of paper as the soil was being

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[10]Weaver, Jean, and Crist, _Development and Activities of Roots of Crop Plants_, (Washington: Carnegie Inst. of Washington, 1922), p. 6.

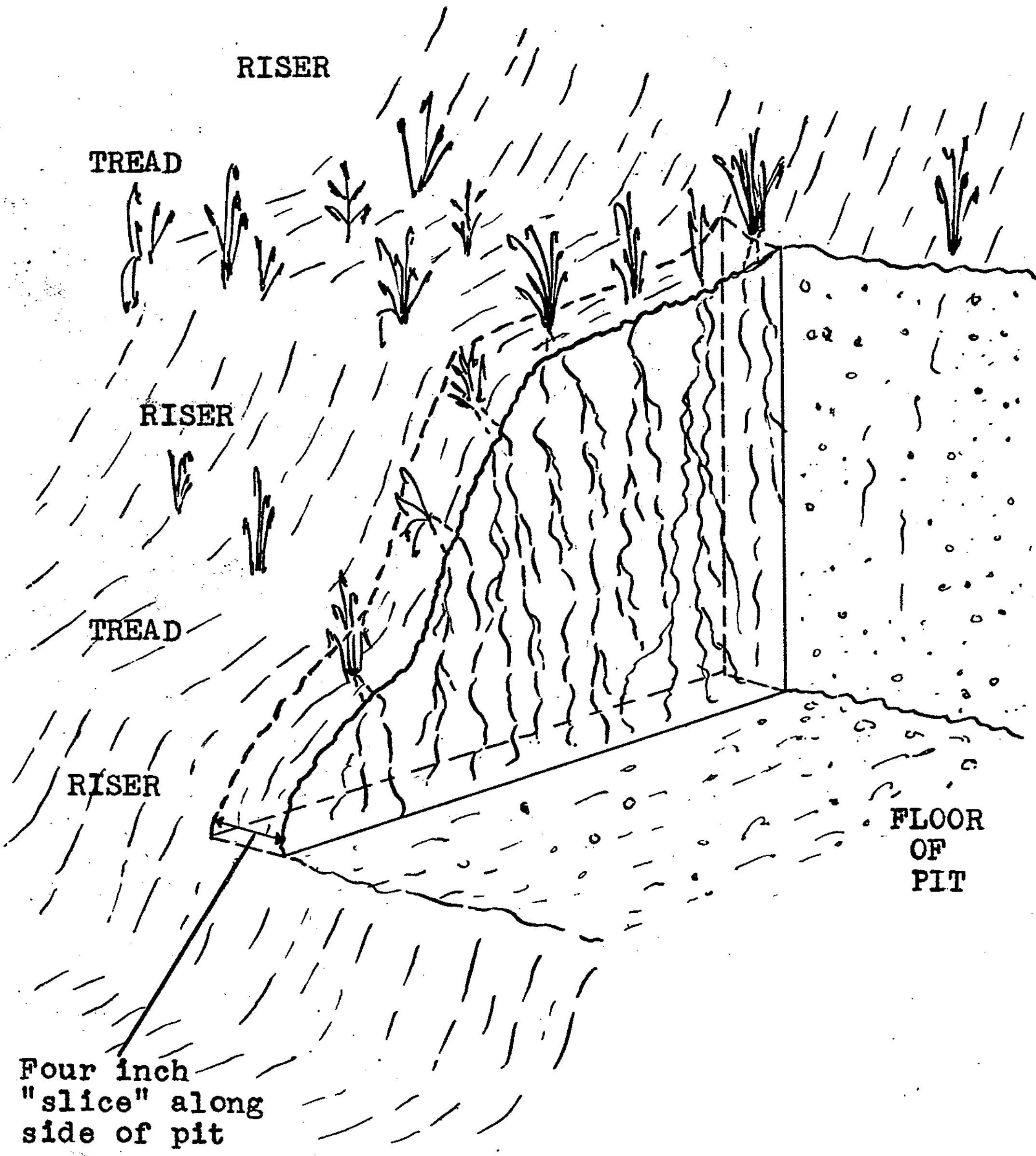

Figure 3.5

A schematic diagram showing the four inch slice of earth used to obtain the root profile shown in Plate 3.7

picked away with a knife point. A vertical rod and offset stakes were used to maintain a high degree of accuracy when locating the roots on the profile (Plate 3.6).

The root-pattern which appeared on the constructed profile did not reveal any strong indications of either slumping or soil creep (Plate 3.7). A close examination of the lower right of Plate 3.7 will show the roots sloping to the left or in other words towards the surface of the slope. This is not the type of displacement that might be expected from either slumping or soil creep. Rotational slumping would cause the roots to appear bent into the slope along the slip plane. Soil creep would show the uppermost portions of the roots being dragged downslope by the faster moving surface soil. The patterns these two processes would be expected to produce are shown in Figure 3.6.

Although the evidence gained from the root profile at site #63 is considered fairly conclusive for that site, soil creep and slumping cannot be entirely dismissed as possible processes for terracette formation. The upper left of Plate 3.7 shows an area of roots almost horizontal at the downslope extremity of the tread. This is possibly due to a combination of two factors. First, the soil containing the roots has slowly rotated over the edge of the tread due to the influence of erosive processes or mass movements. Second, previous animal burrowing has produced mellow, aerated soil which will promote root growth.[11]

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[11] John E. Weaver, (1920), op. cit., p. 147.

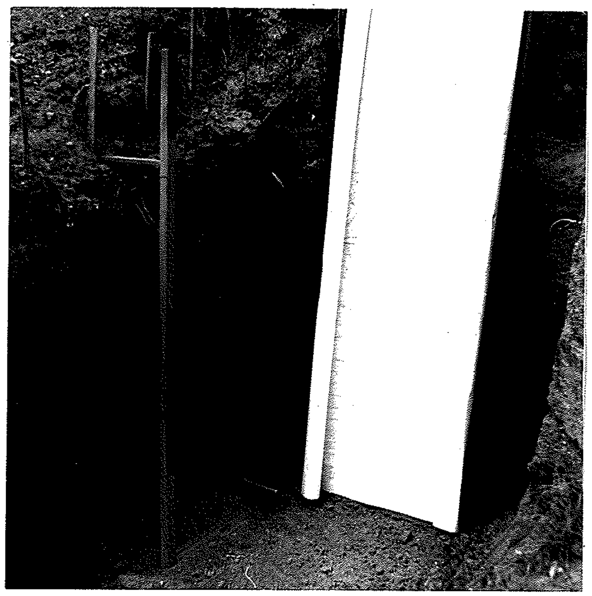

Plate 3.6

The partially completed pit at site #63 showing the equipment used to obtain the root profile.

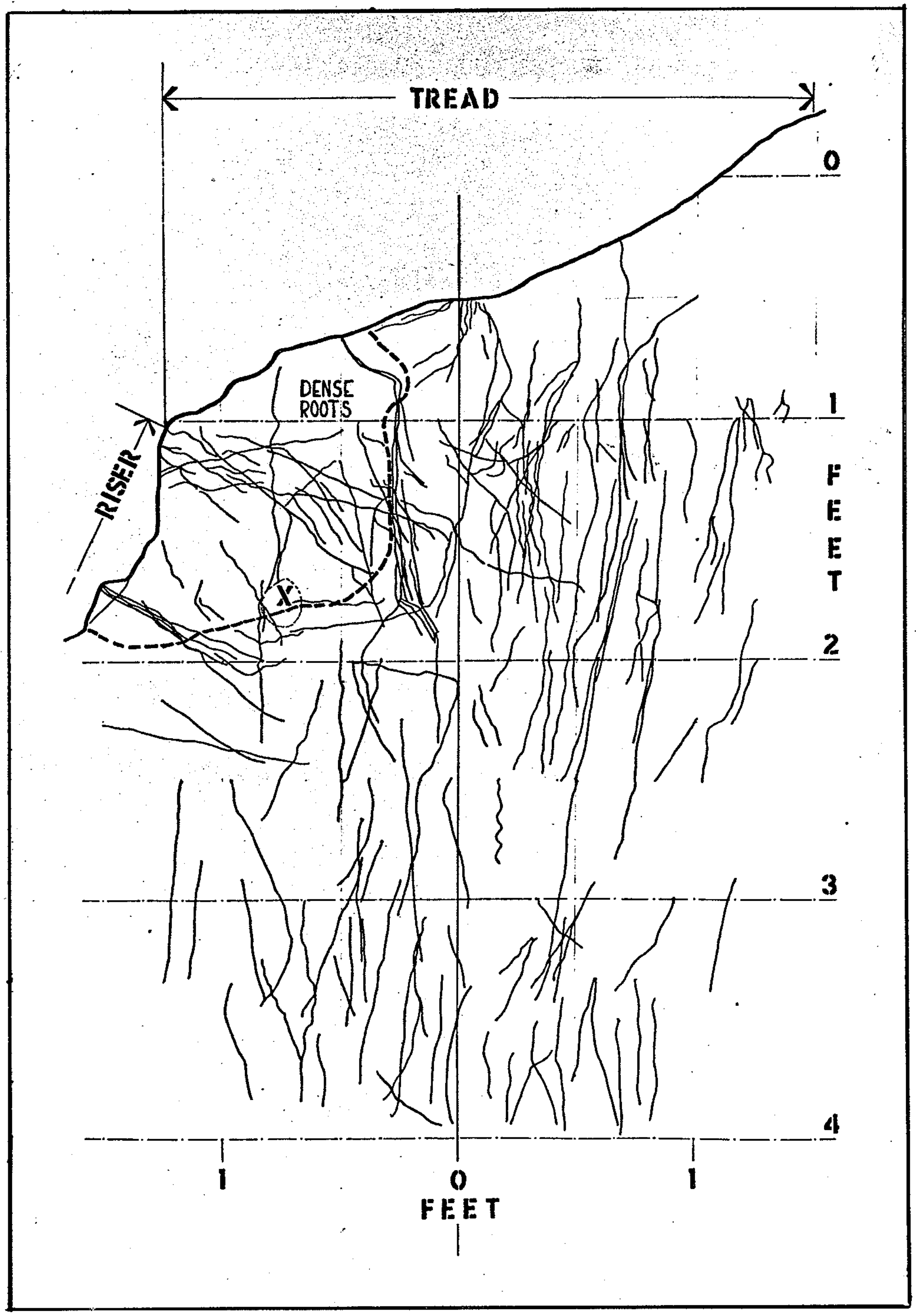

Plate 3.7

Root profile. The dense root zone in the upper left corner of the profile is caused by burrowing animals aerating the soil. An abandoned burrow is marked at "X".

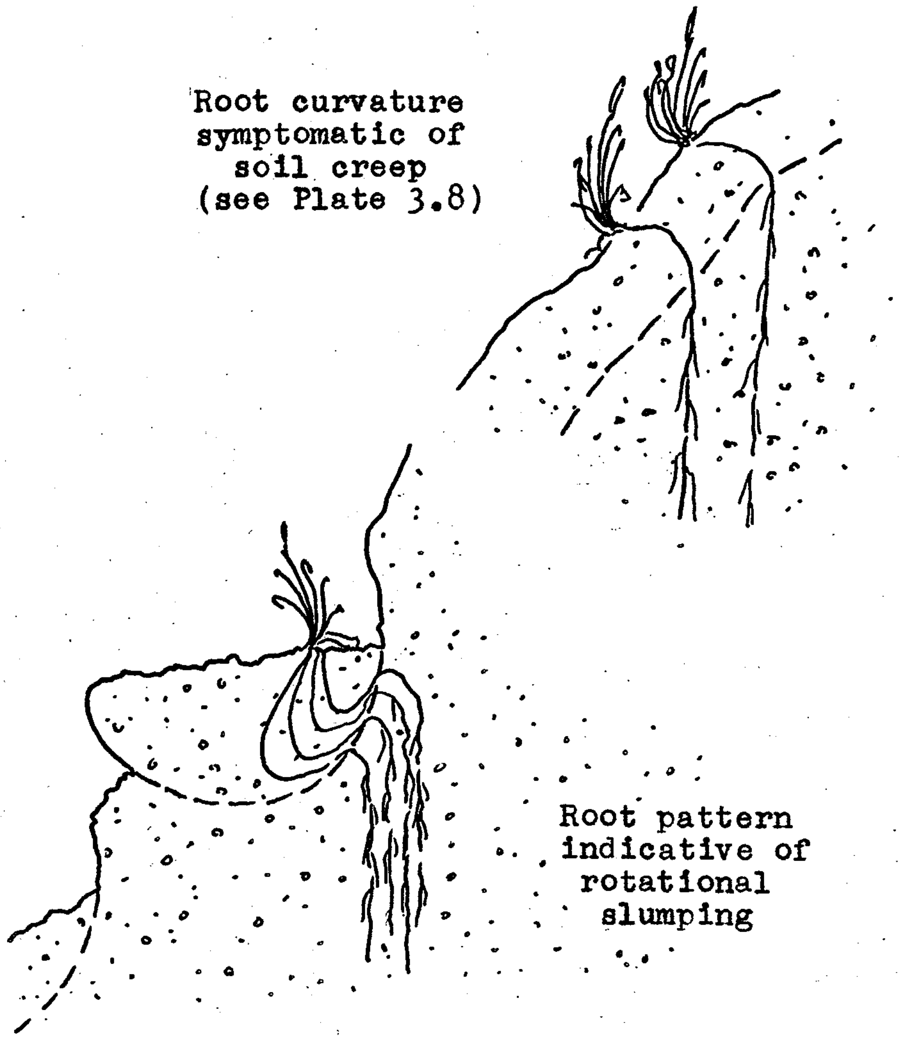

Figure 3.6

Root profile curvatures expected for slumping and soil creep

Some surficial soil creep at this site is indicated by the root pattern in Plate 3.8. This example is situated further up the slope from the pit area. Although the stems of these small shrubs are inclined as much as 60° from the vertical, an examination of their root profiles showed the soil creep process to be surficial, extending only 8-12 inches below the surface (Figure 3.7).

Plant roots were examined to a depth of one foot at random locations at site #63. In each case, any deformation of the normal root pattern extended only a few inches below the surface of the slope. From the evidence presented by root profiles, very little slumping or soil creep is responsible for the terracettes formed at site #63.

It has been shown earlier in this chapter how differences in tread and riser vegetation densities can increase the conspicuousness of terracettes. The differences may also help to indicate the process or processes which formed these phenomena. Whenever the tread vegetation density was less than that of the riser, the difference could usually be attributed to cattle using the treads as paths. Only six sites had a greater vegetation density on the treads; one of these is site #51, shown in Plate 3.9. At this site, the turf, overlying fine silt material, has become broken into long, horizontal, parallel pieces. Influenced by an overall slope angle of 42° and unconsolidated silts for sub-surface material, these sods moved downslope with a backward rotation, i.e. slumped, causing their vegetated

Plate 3.8

Several inches of soil were removed in order to show the curvature of the roots.

Plate 3.9

Terracettes on loose silts. Note the projecting tread with fringes of dead vegetation at the toe. Notebook is 7" wide.

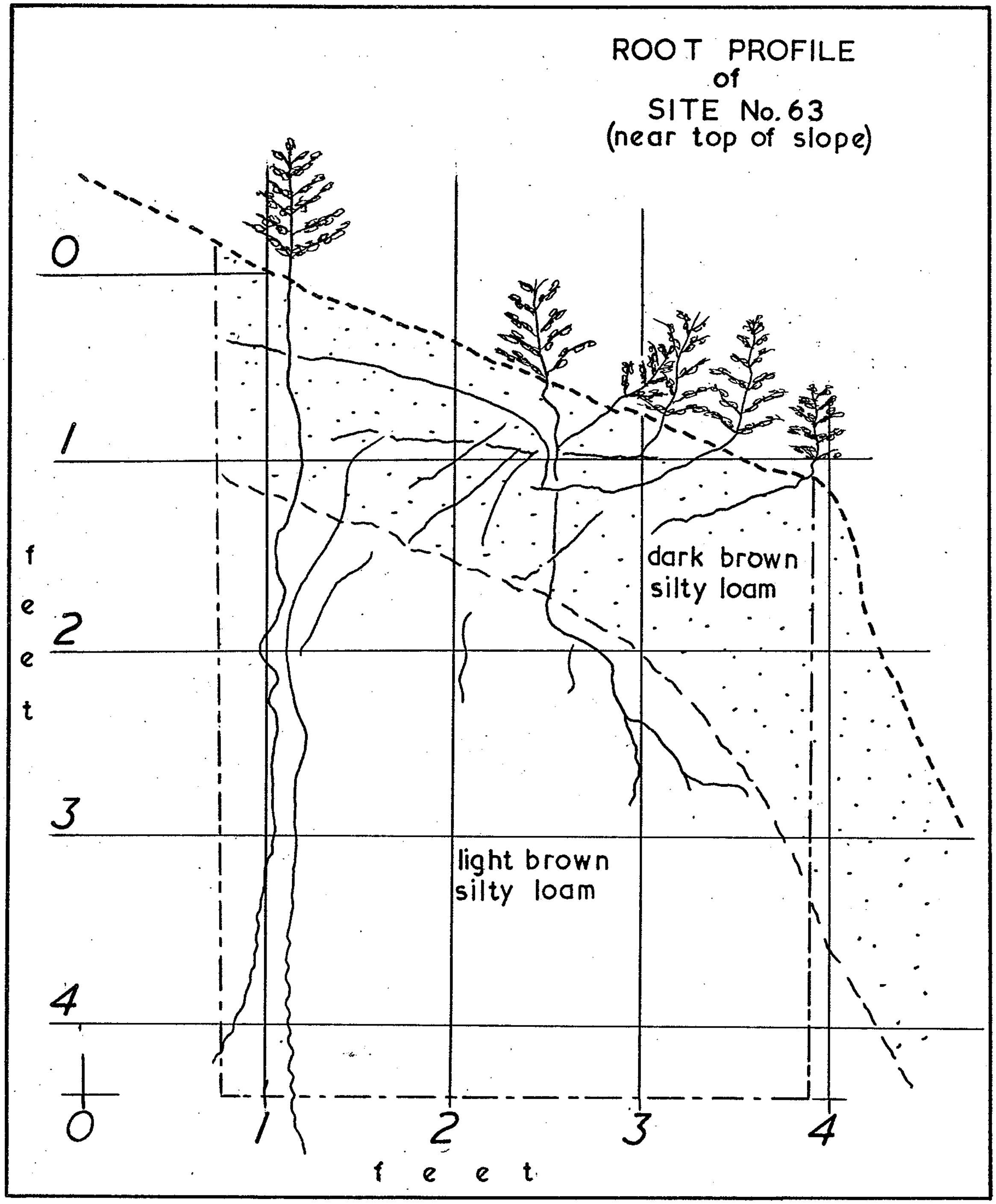

Figure 3.7.

Profile of roots showing soil creep along toe of tread surfaces to become treads. Despite the steep slope and unconsolidated material, there is no large amount of detritus at the foot of the slope. A small drainage channel with an intermittent stream exists about 20 feet from the base of the slope, but is heavily vegetated with shrubs and trees and shows no signs of being instrumental in undercutting the slope or carrying away appreciable amounts of downslid material. It appeared that although the small slumps had been quite strongly developed by backward rotation, the downslope movement of material was relatively weak. The silty material beneath each tread had been exposed to erosional agents and had been rapidly removed to produce projecting treads in several instances. Since the slope's southern exposure should cause a rapid drying of the silty subsoil, it is probable that wind erosion may have played a significant role in the removal of this material. The vegetation on the overhanging portion had died and, as seen in Plate 3.9, had formed a fringe of dead plants hanging from the toe of the tread. If the breaking of the sods was random, there should have been very little longitudinal development of the feature. However, the terracettes persisted up to lengths of 45 feet which seems to imply that processes besides slumping were operative at this site.

The other five sites with denser tread than riser vegetation also displayed easily eroded material that was being removed from below a segmented turf cover. The treads and risers thus formed usually show alongslope lengths of less than 10 feet. This seems to strengthen the speculation that slumping alone cannot produce well-developed terracettes. When terracettes with denser tread than riser vegetation have considerable alongslope length it is quite likely that rotational slumping is not the sole causal process.

In conclusion, type and density of vegetation do not seem to greatly affect the degree of terracette development. As vegetation is itself dependent upon other factors such as aspect and soil material, it follows that a distinct causal relationship between vegetation and degree of terracette development would not necessarily occur. However, with no vegetation, the slope would have to be under the influence of a continuous terracette forming process if the features were to be maintained against the onslaught of destructive agents.

The use of a root profile technique has been helpful in looking for mass movements at site #63. The profile has given a good indication of the depth of soil creep processes and the absence of rapid slumping. Whenever terracettes have been produced or are being maintained by rotational slumping processes, the vegetation density will usually be greater on treads than risers.

d. Material

The surface material at each site was classified according to its approximate proportions of clay, silt, sand, gravel, boulders, or eroded shale. A separate class was warranted for eroded shales because, although they could, on the basis of size only, be classed as gravel, their plate-like structure produces a different slope stability. The determination of the clay, silt, and sand content was achieved by hand texturing the material from several places at each site during field work.

Literature on the area provides little help in the classification of the material, for most of the sites are simply designated as "eroded slopes complex" or "eroded complex". However, a close examination was made of exposed materials in gullies or river cliffs immediately adjacent to a terracette site. Soil or subsoil brought to the surface by burrowing animals was also of value in determining the general nature of the surficial material.

Occasionally a terracette site possesses only one type of surface material, but up to four different types occurred at some locations. Whenever several materials are present, the same importance cannot be attached to each of these components as to a single one making up an entire site. For example, the clay fraction of a slope material, when accompanied by other types, should not receive as much emphasis as when clay makes up the entire slope. In order to make a more precise evaluation of the relationship between material and terracette formation, a method of weighting was devised. The method is simply to assign 12 points to each site to be divided among the various material types found there. Since up to four different types of material may occur at a site, the value twelve was chosen for the factor as it is the lowest number which would eliminate fractional expressions in the calculations. Thus if a certain site has both silt and sand, each would be weighted with a factor of six. If a site has only a single type of material, e.g. silt, this would be weighted with a factor of twelve. In this fashion the relative importance of each type of material has been obtained for each degree of development of terracettes.

(i) Types of material and degree of development

The results of examining proportions of different materials at sites with different degrees of development are presented in Table 3.5 and Figure 3.8. Clay, silt, and sand together comprise a higher proportion of the slope material at sites with good degree of terracette development than where there is poor development. As a corollary, gravels, eroded shale, and boulders combined constitute a progressively smaller percentage of material as degree of terracette development improves. It has been shown that terracette development is related, at least in part, to vegetation. Clay, silt, and sand offer better rooting environments for vegetation than gravel, eroded shales, or boulders. A change in vegetation density is often reflected in a change in cattle activity, although the latter may also induce the former. Furthermore, it will be shown in Section (e) of this chapter that cattle activity has a very

Deg. of Dev.	Size Fraction	Weight Factors (w)	Σw	w/W	%
	Clay	6 4 4 4 4 6	28	28/228	12%
P	Silt	6 4 4 4 4 6 4 4 3 4 6 6	55	55/228	24%
O	Sand	12 4 4 3 4	27	27/228	12%
O	Gravel	6 6 6 6 6 6 4 4 3 4	51	51/228	22%
R	Boulders	4 6 4 4	18	18/228	9%
	Eroded Shale	12 4 6 6 6 6 3 6	49	49/228	21%
					100%
		W = total (Σ w) =	228		
M	Clay	6 6 4 6 4	26	26/180	14%
E	Silt	6 12 4 4 12 4 6 6 4	58	58/180	33%
D	Sand	6 6 4 4 6	26	26/180	14%
I	Gravel	6 6 6 6 4 6 6 4	44	44/180	25%
U	Boulders				
M	Eroded Shale	4 12 6 4	26	26/180	14%
					100%
		W = total (Σ w) =	180		
	Clay	4 4 4 6 4 6	28	28/156	18%
G	Silt	4 6 4 4 4 6 4 6 12 6 12	68	68/156	44%
O	Sand	4 4 6 12 12	38	38/156	24%
O	Gravel	4 6 4 4	18	18/156	11%
D	Boulders				
	Eroded Shale	4	4	4/156	3%
					100%
		W = total (Σ w) =	156		

Table 3.5
Percent of material type in each degree of development

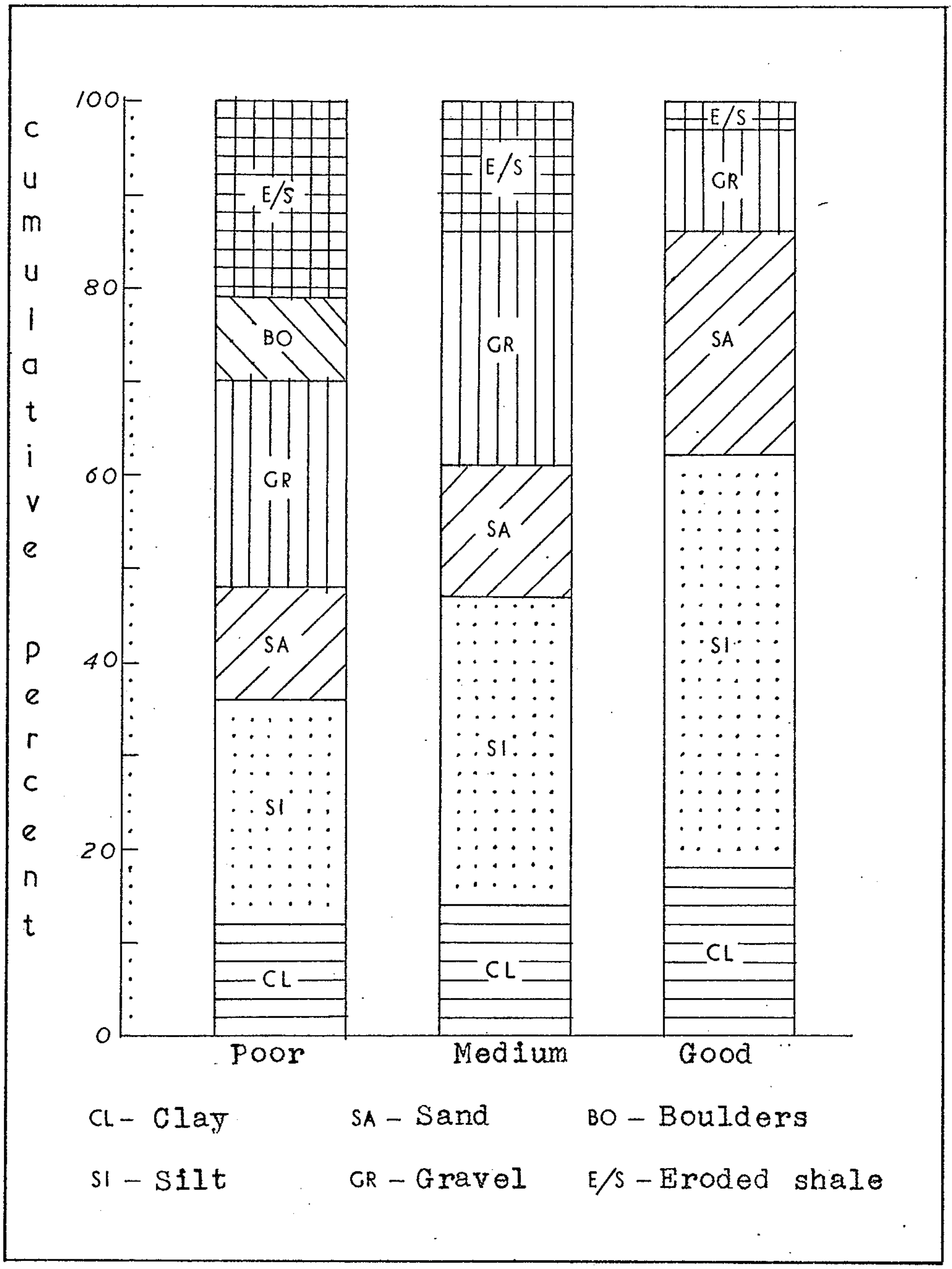

Figure 3.8

Graph showing changes in type of material with changes in degree of development high direct relationship with terracette development.

Thus a sequence of influences is established, in which the type of surficial material influences the type of vegetation, which in turn, helps determine cattle activity, which affects the degree of terracette development. This rather extreme example not only shows a way in which degree of development can be influenced by type of material, but also indicates the complexities encountered in attempting to relate site factors to degree of terracette development.

At the proper moisture content, clays, silts, and even sands are capable of maintaining a given ground surface morphology. It is more probable that sands in particular show an increased occurrence with an increase in terracette development because cattle will naturally seek out the soft sandy places rather than gravel or eroded shale areas. The increased cattle traffic on sands would aid in improving the degree of terracette development.

It is doubtful if gravels would either support much vegetation or have the ability to retain the terracette shape once the feature had formed. Plate 2.2 shows terracettes that have been interrupted by boulders that are _in situ_. Since a considerable alongslope length was one of the necessary requirements for well-developed terracettes, boulders will have a detrimental effect on their development. Eroded shales such as seen at site #6 (Plate 3.10) afford little encouragement to the establishment of the terracette feature. Plate 3.11 shows a close-up of

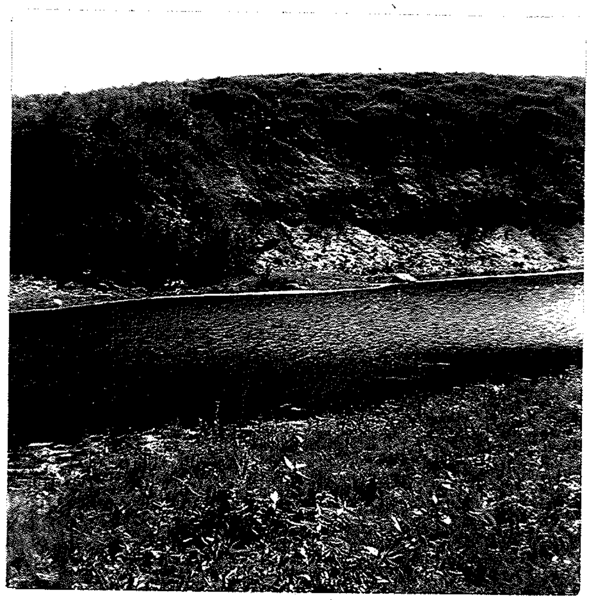

Plate 3.10

Eroded shale material overlying shale beds at site #6

Plate 3.11

Eroded shale material found on upper part of slope at site #6 weathered and eroded shale material. When this material becomes lubricated it is extremely unstable. Plate 3.10 shows poorly developed terracette features near the top of the cliff but a lack of them below. The eroded shales have not been able to support the projection of material required for terracettes.

(ii) Effects of stratification on terracettes

It is not unreasonable to postulate that stratification of slope material may have an effect on terracette development. However, in the survey area none of the three types of stratification that were encountered seemed to be directly influencing terracette formation. One example of stratification occurs in shale bedrock. Wherever the shale bedrock was exposed, it was usually so severely weathered and eroded that it merely presented an irregular, near-vertical face. Where unexposed, the bedrock was overlain by debris, soil, and plant material slipping downslope over the shale. Because of the slow but constant soil movement, the profile of the underlying bedrock has little influence on the formation of terracettes at the surface.

A second type of stratification was formed by lacustrine deposition. The deposits are particularily noticeable on the east side of the Souris River Valley from a few miles north of the elbow northeastward as far as Treesbank. From a distance, the deposits appeared as one unstratified layer but closer examination showed them to be composed of many thin strata. Several strata often occur within a vertical distance of one foot, and the material within a stratum is homogeneous. Such thin strata of lacustrine deposits do not have any detectable influence on the amplitude or degree of terracette formation.

A third type of stratification has been produced by river deposits. This is noticeable north of the town of Wawanesa, in some very large meander cutoffs. Plate 3.12 shows an example of cross-bedded river deposits overlain by coarse eroded shale and gravel material. The short irregular lengths of the river-deposited strata would do little to promote horizontal elongation in terracettes.

At site #63, an example of stratification was thoroughly examined (Plate 3.13). The layers seen in the photo are the only ones found at this site. Plate 3.14 shows the lowest stratum dipping into the hillside. Although it changes direction abruptly, there does not seem to be evidence of recent bending, for the apex of the fold is quite sharply defined and shows no fracturing. If recent bending had occurred, one may expect to find fractures at the top of the bed near the axis of fold. The middle stratum becomes very much thicker from this point in toward the hillside. This increase in thickness suggests that the bending of the bottom stratum pre-dated the deposition of the middle stratum.

A sketch of the strata in relation to the position of the terracette is given in Figure 3.9. Fine material is

Plate 3.12

Discontinuous fluvial deposits
1/2 mile east of site #68

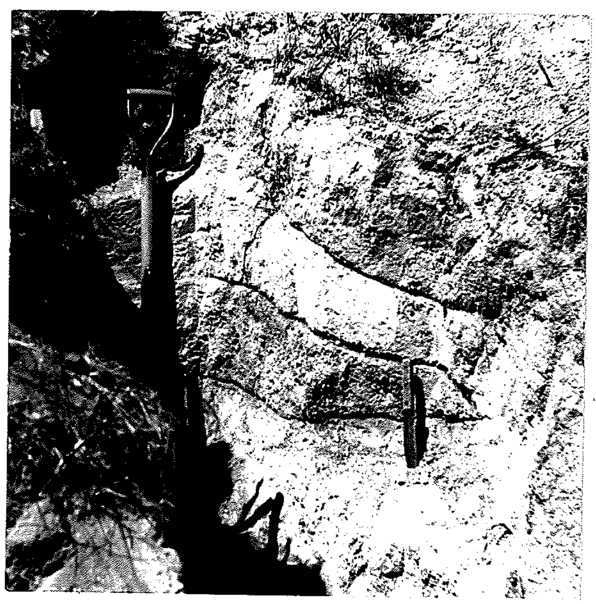

Plate 3.13

Strata in pit at site #63

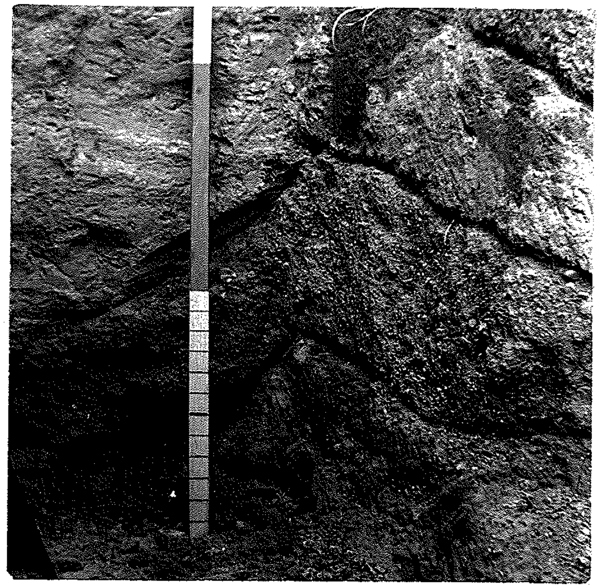

Plate 3.14

View looking into the pit at site #63. The layer in the centre of the photo dips sharply into the hillside.

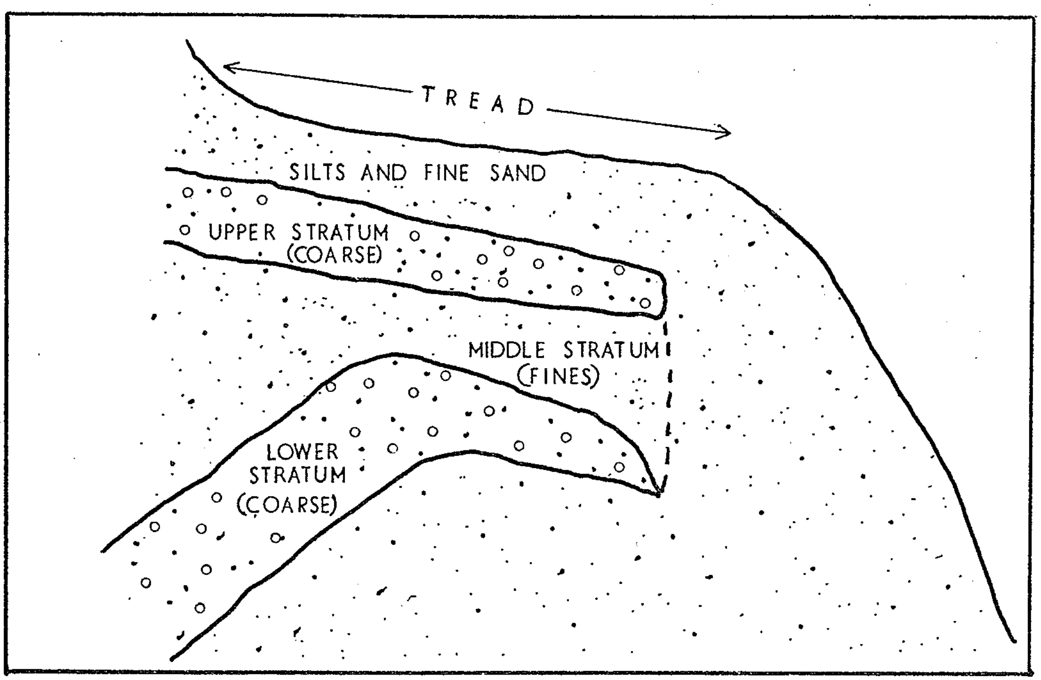

Figure 3.9

Three strata at site #63 shown in Plates 3.13 and 3.14. The bending of the bottom stratum appears to have pre-dated the deposition of the middle and upper strata.

present below each of the coarse strata. This produces two coarse-fine sequences of material. It is apparent from Figure 3.9 that the dip of the uppermost coarse stratum accords generally with the dip of the terracette tread. This might suggest that the development of the tread is due to coarse material. However, if the upper stratum has been instrumental in the development of this tread, then another tread should occur at the lower coarse stratum as the two coarse-fine sequences of material are similar.

Another excavation was made into a well-developed terracette further up the slope. No evidence of stratification was found except for a slight layering effect of the material caused by soil-forming processes. Therefore, well-developed terracettes can form in homogeneous, non-stratified material. If rapid soil creep were prevalent on the slope, some of the material would have to be supplied from this upper slope area. The fact that soil horizons were developing indicates that this form of mass movement was not very active. Conclusive proof that terracettes can form on unstratified material was found at site #81. Many cubic yards of straw had been dumped over the valley edge, and had gradually disintegrated into a porous, homogeneous material which covered the slope to a depth of about 12 inches. On the surface of this material medium development of terracettes had occurred. When this material was scraped aside, no signs of terracette-like features could be seen on the underlying soil surface. The area surrounding the site was pastured by sheep, and these animals in their travels had walked across the disintegrated straw many times. Plate 3.15 shows these terracettes formed by the sheep. Undoubtedly, this material is very susceptible to forces of erosion and the features may be almost destroyed during storms. However, their existence proves that terracettes can form without the presence of stratification.

(iii) Summary

There can be little doubt that structural and textural characteristics of materials affect the degree of development of terracettes to some extent, even if through their influence on the amount and type of vegetation cover. Finer materials such as clay, silt, and sand aid in the formation of terracettes, whereas gravel and boulder material hinder good development. The type of material is important, as coarse fragments of eroded shales, because of their instability, will not support the same degree of development as gravels. Stratification could, in certain circumstances, promote terracette formation, but it is not necessary. The type of material also influences the type and density of vegetation, which can affect the degree of development of terracettes. Thus, both directly and indirectly, materials may be an important factor.

e. Animal evidence

Organisms may be very influential in the development of terracettes. Several authors have attributed the

Plate 3.15

Terracettes formed by sheep treading. Although not readily discernible from this photo, the tread-riser angles were quite distinct, having a mean value of 30°. The upright stakes mark the downslope edge of the risers.

formation of terracettes to animals, while others have been in favour of a geologic origin. During field work in the current study, each site was carefully examined for evidence that organic activities could contribute to terracette formation.

Much of the land on the Souris valley sides has been used for pasture, because rough and steep topography makes cultivation by heavy machinery difficult if not impossible. In addition, owing to recent agricultural trends toward grain farming and enlargment of farm units, many of the slope pastures are derelict. This provides ample opportunity to find sites with both recent and non-recent animal usage. Some areas, as far as could be determined, had never been pastured intensively, due to their relatively inaccessible location. Thus three categories of animal usage were set up:

recent--indications of animal usage during 1968,

non-recent--indication of animal usage, but prior to 1968,

absent--no indication of animal usage.

The animal influence was produced by cattle at all sites but one, where sheep were pasturing.

It became apparent during field study that cattle may induce mass movement processes such as soil creep and slumping. However, they are able to produce treads and risers in their own way. As they walk along the hillside their sharp hoofs cut into the upper side of the slope, loosening a little soil and displacing it slightly downslope. As the path is gouged into the slope surface, an accumulation of the loosened material forms the toe of the tread. Naturally, cattle will walk nearest the upslope side of the tread where the surface material is more stable. In this way their hoofs continually cut into the lower part of the riser and steepen its gradient. Furthermore, cattle feed on vegetation upslope from the tread on which they are standing. This will also induce them to walk as close to the riser as possible.

It has been shown earlier in this chapter that grasses predominate on south-facing slopes. Since much of the survey area along the Souris River Valley is tree covered, the cattle will rely on these grassy areas for food unless they have access to level pasture lands in the valley bottom or on the flatland above the valley rim. Thus aspect affects the distribution of cattle activity by helping to determine the type of vegetation found at the various points of the compass.

Vegetation growth begins earlier in the spring on the south-facing slopes. The soil material is less consolidated at this time of year, due to thawing processes. Cattle moving over loose soil in search of early grasses will readily create paths along the slopes. Such paths are emphasized by repeated treading, thus forming terracettes. Thus, degree of development will also depend on the time of the year that the slopes are exposed to cattle treading.

The relationship between cattle usage and degree of development is given in Table 3.6 and Figure 3.10. From this analysis it can be seen that cattle usage has a fairly strong relationship with the formation and maintenance of terracettes. Of the total number of terracette sites examined, 70% were found to have had recent cattle usage and

Animal Evidence	Degree of Development							
	Barren		Poor		Medium		Good	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Recent	17	55%	18	72%	11	65%	10	77%
Non-recent	5	16%	6	24%	6	35%	2	15%
Absent	9	29%	1	4%	0	0%	1	8%
Total		100%		100%		100%		100%

Table 3.6

Cattle evidence and degree of development

The barren class, being a subjectively chosen phenomenon, cannot be compared against poor, medium, or good terracettes. However, it is interesting to note that the barren class showed the greatest absence of cattle, i.e. 29%.

26% were found with non-recent use. Thus 96% of all terracette sites showed some evidence of cattle activity. Of all the analyses between site factors and degrees of development, animal usage shows the strongest relationship with terracettes.

Two of the sites, #54 and #39, showed terracette

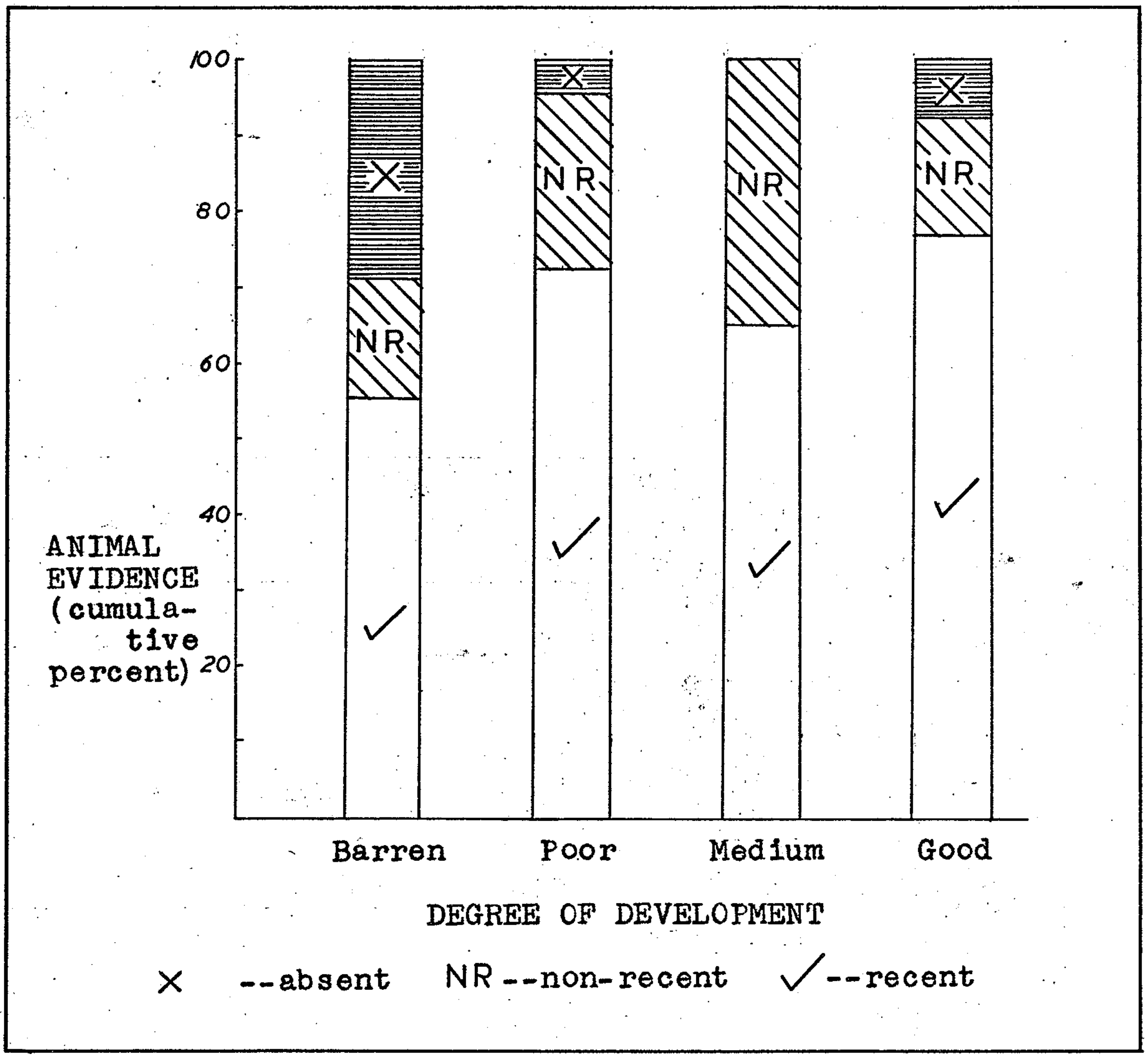

Figure 3.10

Bar graph of cattle evidence and degree of development

development but did not have evidence of cattle usage. Part of site #39 is shown in Plate 3.1; from the photograph it can be seen that non-faunal mass movements were largely responsible for the development. Figure 3.11 was drafted from field measurements and serves to illustrate the sporadic slump-block features found there. There is a striking contrast between the continuity and uniformity of size of

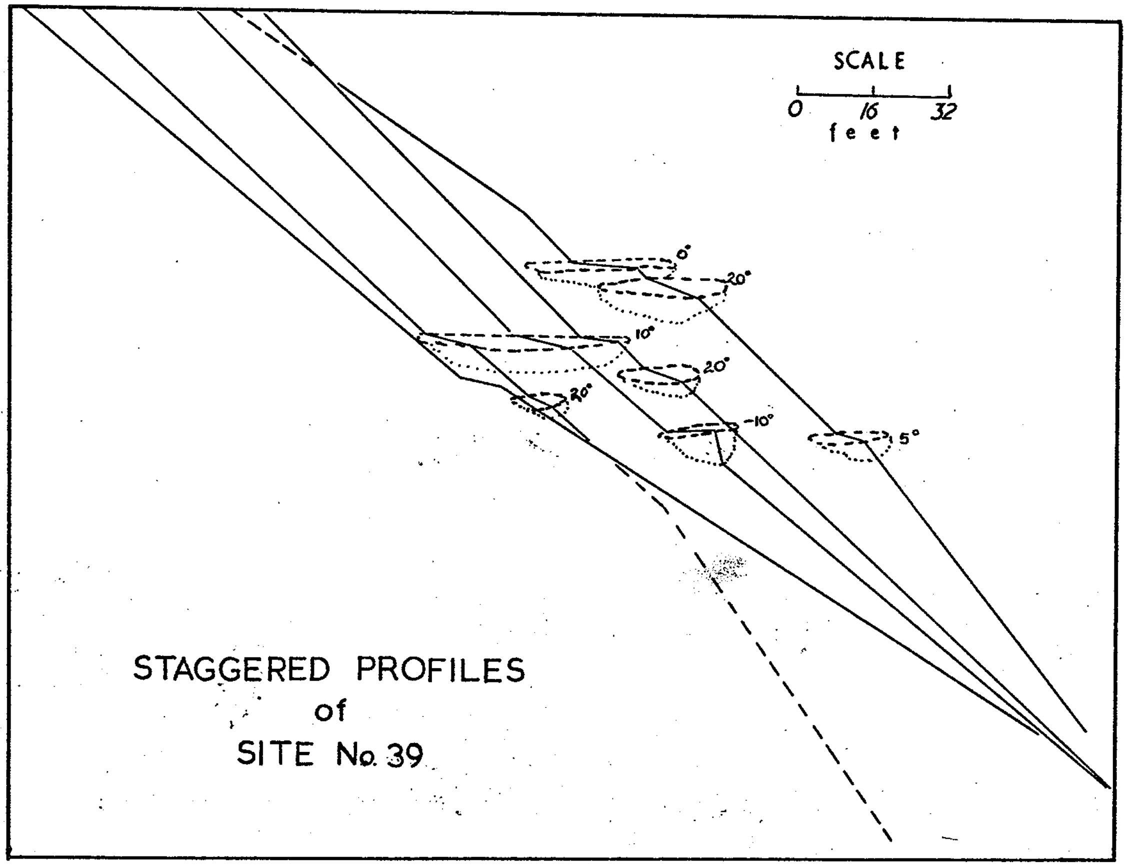

Figure 3.11

Profiles at site #39

the features at site #39 and the well-developed terracettes of site #63 (Appendix VII). Site #54 has two well-developed terracettes, but it did not display evidence of cattle activity; its terracettes appear to be narrow elongated horizontal slumps.

The question may be raised as to why these two examples, sites #54 and #39, were included if they had so much resemblence to a slump. The reason is simply that if certain sites had been rejected during field studies on the basis of their probable process, no analysis could be carried out to determine which factors had brought about the terracettes' formation. Since the morphology and dimensions of the features at sites #54 and #39 place the phenomena in the terracette class, as arbitrarily defined in this thesis, they were recorded as terracettes. Figure 3.12 is a sketch of the features found at site #54.

Of the 31 selected sites with no terracette development, 17 had evidence of recent cattle usage. This would seem to imply that cattle do not have much influence on the formation of terracettes if 55% of the sites with no development have evidence of recent cattle usage. However, 6 of the 17 sites had overall slope angles less than or just equal to the established minimum occurring value for the survey area, while another five were located in pastures where an abundance of level grazing area was available. Clearly, cattle treading would not be as frequent on the sloping areas of the pasture. The presence of large boulders and excessive soil creep were the detrimental factors at the other six sites.

It is apparent from Table 3.6 that more barren sites showed absence of cattle activity than did sites with poor, medium, or good development, notwithstanding the fact that barren sites were chosen occurrences. This somewhat strengthens the belief that the greater the cattle treading at a site, the better will be the degree of terracette development.

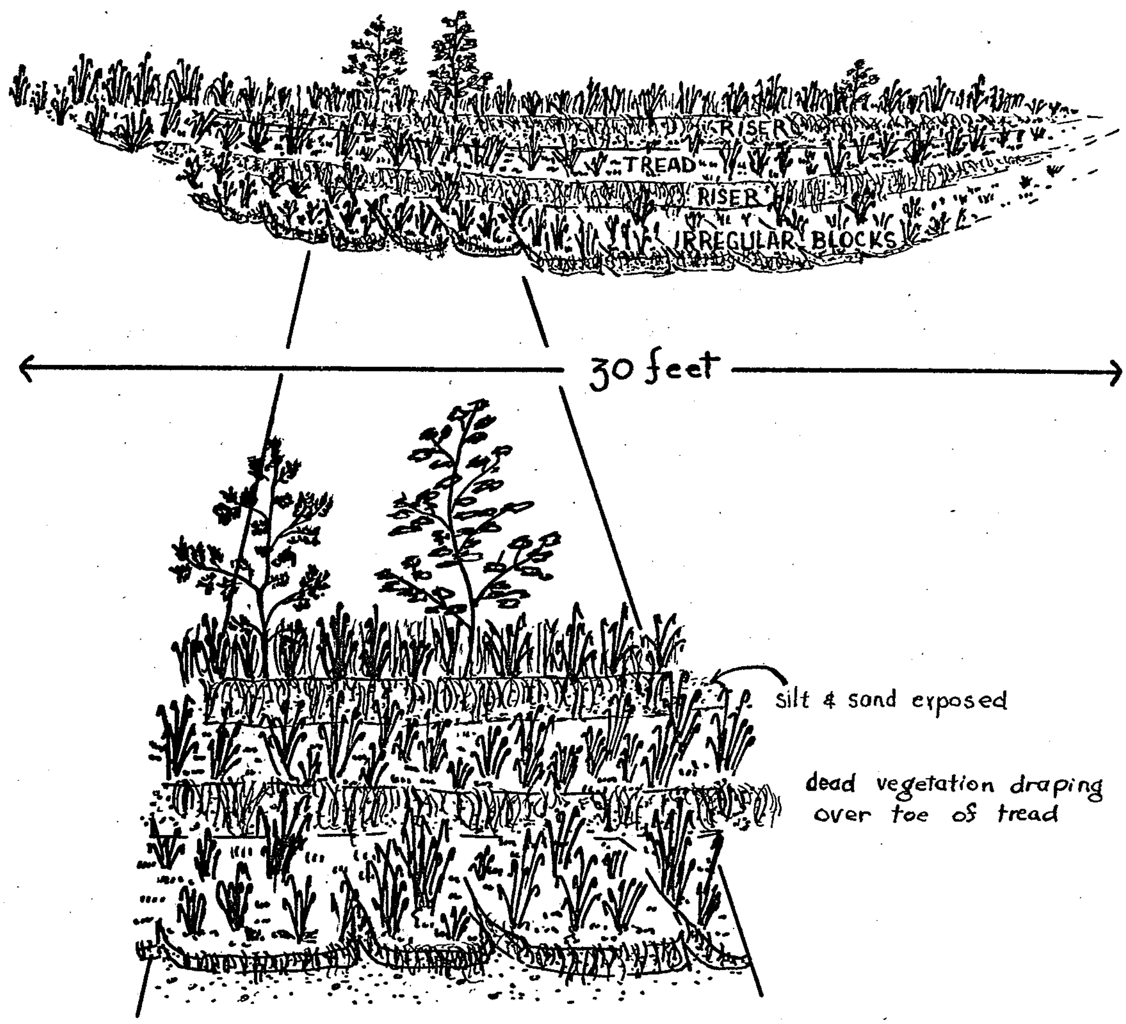

Figure 3.12

Showing site #54 as seen looking perpendicular to the slope. The tread-riser angle was extremely well defined, having a value of 55°.

If animals are to produce terracettes, they must have the ability to move at constant height along a crenulated slope. It has been determined, as Chapter IV will show, that cattle do possess the ability to follow a certain contour quite closely, even across rough terrain.

Another relationship of animal activity to terracette development was discovered at site #81. The animal influence here was entirely due to sheep. The amplitude of terracettes formed by sheep was discovered to have a mean of 23 inches, less than that where cattle had been. Although there was only one site which had been grazed solely by sheep, this single example is rather interesting as it suggests that the size of the animal may determine, to a large degree, the amplitude of terracettes.

Animal activity (the treading of cattle in particular) has the highest relationship to degree of development of all five site factors. Evidence of cattle treading is present at 96% of the terracette sites. Cattle usage of a slope is influenced by aspect, vegetation, and season. The greater the cattle usage during times when the slope is susceptible to compaction, the more readily will terracettes be formed and maintained.

f. Summary

This chapter is an attempt to examine the relationships which exist between terracettes and their environment. In many cases these factors of the environment, which have been designated site factors, are inter-related. The latter may be exemplified by the effect of aspect on type of vegetation density and type of material on overall slope angle.

The evidence accumulated in this study seems to indicate that the formation and maintenance of terracettes is assisted by the desirable site factors of a southerly aspect, a steep slope (approximately 30-40°), a heavy mantle of grass, treading of cattle, and clay, silt, and sand materials as opposed to gravels, boulders and eroded shales.

An analysis was made of the field data to determine how many of the desirable site factors were missing from the poor, medium, and good terracette sites. It was found that good terracette sites on the average were deficient in one of the desirable site factors; medium terracettes were deficient by two factors, and poor terracettes by three. This not only strengthens the conclusions reached in the preceding paragraph but also lends support to the degree of development classification system set up at the beginning of this chapter.

CHAPTER IV

THE ABILITY OF CATTLE TO PRODUCE TREAD PROFILES HAVING MINIMUM VERTICAL IRREGULARITIES

An attempt will now be made to evaluate the ability of cattle to produce paths and terracettes with tread profiles having a constant gradient. The tread profile is the longitudinal trace along a tread of a terracette or cattle path. Field study showed that visual judgment of such landscape properties as horizontality or continuity may be difficult. The first part of this chapter will show how certain terracette characteristics may be made deceptive in appearance. The second section will present the methods and results of precise surveys made at selected locations in order to mathematically evaluate the ability of cattle to produce a tread profile with minimum vertical irregularity. The vertical irregularity of this profile will be compared with that of an example formed by slumping.

a. Factors influencing the evaluation of terracettes

There are four frequently occurring factors which may mislead an observer when judging how well-defined certain terracettes are in the landscape. These deception factors are vegetation, viewing distance, viewing angle, and the incident angle of light onto the terracette surface.

It was frequently observed during field work that vegetation could emphasize or camouflage the morphology of terracettes. If the terracettes have been in frequent use by cattle, grass and shrubs usually form a fringe on the toe of the tread. The contrast between the vegetated and unvegetated part of the tread accentuates the terracette outline when viewed from an upslope position. The middle parts of the risers are often bare of vegetation due to their steep slope angles. When viewed from a distance, the bare risers contrast with the vegetated portions of the treads to emphasize the tread-riser sequence.

If the vegetation has not been grazed and is therefore able to grow to its normal mature height, tall stems and leaves tend to reduce the distinctness of the terracette outlines. A good example of this is found at site #63. This site was first observed in early May when the grass and flowering plants were just beginning to grow. The terracette features were quite prominent on the slope at that time. However, by mid-September the same site appeared to have a uniform surface, due to the presence of tall ungrazed vegetation.

Two somewhat related factors are viewing distance and viewing angle. Viewing distance is simply the horizontal distance between the observer and the base of the terracette slope, while viewing angle is the angular difference in a vertical plane between the observer's line of sight and the overall slope angle. The effects of these two considerations are shown in the sequence of Plates 4.1, 4.2,

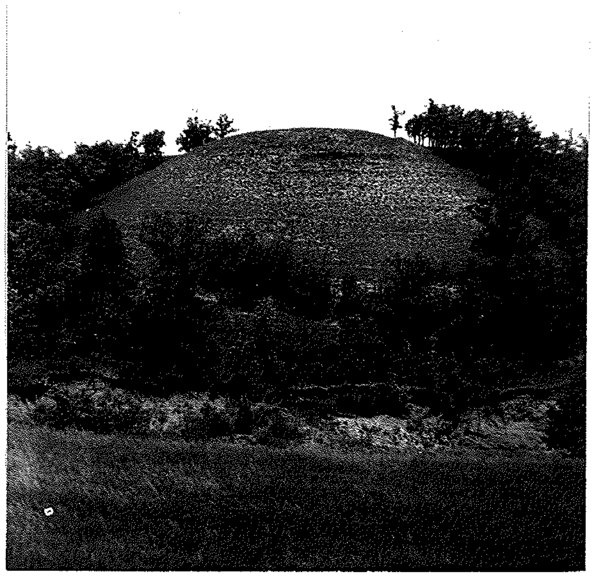

Plate 4.1

View of site #63 from a distance of approximately 100 yards from the base of the slope

Plate 4.2

View of site #63 from base of the slope

Plate 4.3

View of a terracette tread at site #63 as seen from a position on the slope and 4.3. Plate 4.1 shows the terracettes of site #63 as they appeared to an observer from a distance of approximately 100 yards from the base of the slope and reveals that they are relatively well-developed and continuous. As the foot of the slope is approached (Plate 4.2) the risers become less distinct and the terracette features seem to blend together to give the appearance of a uniform slope surface. It is difficult to say whether viewing distance or viewing angle has the greatest effect in this case, as both have changed considerably from the first position of observation. Finally, when the observer is standing on the terracetted portion of the slope, the well-defined tread-riser pattern observed at a distance of 100 yards is almost completely camouflaged by the confusion of plant growth and animal hoofprints (Plate 4.3). Quite often the two-dimensional medium of ground perspective photographs cannot show as exactly as desired the field situation which is three-dimensional. Nevertheless, the three above-mentioned plates show quite well the observational effects produced by varying viewing distance and viewing angle in the field. Such effects were very noticeable during the entire field study and necessitated a thorough examination of each slope so as not to misjudge the surface morphology of the terracettes.

The angle at which sunlight strikes the surface of a slope has a considerable effect on the distinctness of terracette appearance. When the angle of incidence of light with the overall slope is small, the tread and riser patterns contain greater contrasts of color and shadow than when the sun's rays approach the normal to the surface. Vegetation enhances this contrast by increasing the amount of shadow produced on certain parts of the tread-riser sequence.

Thus relatively simple factors such as vegetation, viewing distance, viewing angle, and incident angle of light can readily produce misconceptions of the morphological characteristics of terracettes in the mind of the casual observer.

b. Determination of vertical irregularities in selected tread profiles

Since a strong direct relationship has been found between the presence of cattle and the occurrence of terracettes, it is not unreasonable to suspect that these animals could be at least partly responsible for the apparent constant gradient of alongslope tread profiles. If this suspicion is true, cattle should possess an inherent ability to produce a continuous path, with little vertical deviation, across an undulating terrain. To aid in confirming or rejecting this idea, an examination of a cattle path was made to determine the vertical irregularity of its tread profile. There also arises the question of whether cattle are responsible for the production of a profile of nearly constant gradient or are just using a previously formed slump as a natural path. To aid in answering this question, the vertical irregularity of tread profiles of a cattle-produced feature and a non-faunally produced slump are compared. Since the examination of a site showing evidence of both processes should help to reveal the relative importance of the type of process to the amount of vertical irregularity of a tread profile, it was decided to select a total of three control sites.

Unlike the terracette sites, which were recognized on the basis of their morphology, the control sites were chosen with reference to the type of causal process. Site A was to possess a cattle path subject to minimal mass movements; site B was to have both cattle activity and mass movement processes induced by the usual geologic agents; and site C was to show treads formed only by non-faunal mass movement processes.

Site A was chosen on a river terrace north of Bunclody, (Figure 4.1). This terrace, which was being used as a pasture, is dissected by several shallow north-south drainage depressions directing intermittent run-off from the area above the valley rim into the east-flowing Souris River. These channels allowed ample opportunity for cattle to produce paths of constant gradient <u>around</u> them, if in fact they had the ability to do so. The very low transverse gradient of the terrace and the gently-sloping sides of channels would prevent slumping and retard the rate of creep. The channel selected was covered with thick but closely cropped

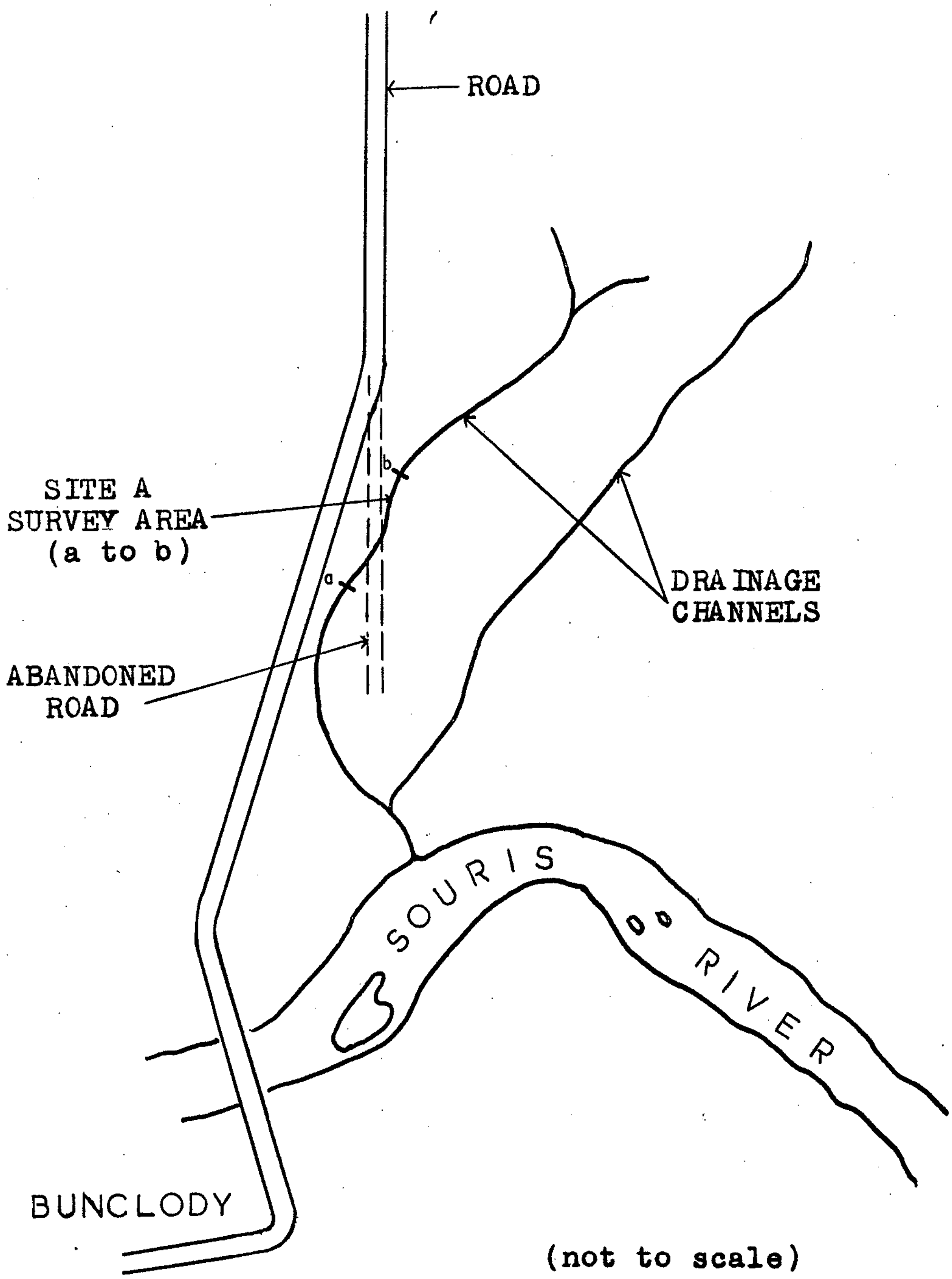

Figure 4.1

Control Site A
North-south extent of map is approximately one mile. See Map II in Appendix I for location of Site A in the study area.

grass, and possessed stable surface conditions. Along its west side, a path had been trodden by cattle in their travels to and from the river (Plates 4.4 and 4.5). As the entire channel had a perceptible slope toward the river, horizontality of the path was not expected. Rather, a constant tread gradient with minimum vertical irregularities would be anticipated.

Site B was located approximately one and a half miles north-east of the village of Margaret. This site showed evidence of slumping and soil creep with strong indications of livestock influence (Appendix I, Map IV). One of the terracettes was surveyed to obtain data representing the effects of both cattle and non-faunal mass movement activities.

The third site, C, was located approximately three miles north-west of Bunclody on a cliff that is actively being undercut by the Souris River (Appendix I, Map II). The undercutting of the shale cliff has induced slumping and earthsliding (Plate 4.6). Due to the instability of the material and the high overall slope angle, 45°, cattle have not frequented the slope. This site was accurately surveyed to acquire data on terracette-like features produced by the action of strictly non-faunal mass movement processes.

Since the amount of vertical irregularity in tread profiles could not be ascertained accurately with a hand clinometer, a tripod level and stadia were used. From

Plate 4.4

Control site A as seen from its northern-most limit, i.e. location "b" on Figure 4.1

Plate 4.5

Control site A as seen from its southern-most limit, i.e. location "a" on Figure 4.1

Plate 4.6

River cliff of site C

the survey data, a plan and a profile were drawn for the tread feature at each of the control sites (See Appendices II, III, and IV).

At site A, the tread follows a nearly constant gradient having only one major irregularity due to a small recent gully. As shown in Appendix II, two small dome-shaped features on the west side of the drainage channel direct intermittent run-off into the main drainage depression. The run-off has produced a small gully about 12-18 inches deep across the cattle path. If the cattle had followed a constant elevation around this five-foot wide gully, they would have been forced to make several abrupt changes in direction and to walk 35-40 feet in order to circumnavigate it. Instead, the gully was crossed directly, thus producing a large vertical irregularity in the vertical tread profile.

The profile derived from site A seems to indicate that cattle can follow a line of minimum vertical deviation as they travel across an undulating surface. The vertical irregularity of the tread profile is kept to a minimum at the expense of lateral deviation. These animals have allowed their path to become sinuous rather than expend energy rapidly in lifting their weight over these elevations. Measurements with a steel tape showed that the distance traversed by cattle would have been the same, or even less in some instances, if they had gone over the elevation rather than around it. Furthermore, there were no obstructions large enough to discourage the cattle from moving <u>over</u> the elevated portions of the terrace surface. This constant gradient of tread profile can possibly be regarded as a manifestation of a tendency to most efficient energy expenditure by cattle.

Field observation of the phenomenon at site A and exanination of the constructed tread profile (Appendix II) shows that cattle apparently have the ability to produce paths that have a relatively constant gradient.

At site B, (Appendix III), where features were formed by both cattle and non-faunal mass movement processes, the profile has several definite breaks and therefore is not as rectilinear as that at site A. These breaks can probably be explained best by considering the erosional history and surficial material of the hillside.

The upper half of the hillside on which site B occurs consists chiefly of unconsolidated silt and sand, and possesses large scars, having the arcuate and concave form generally associated with earth-sliding or slumping. Each of these scars reveals evidence of smaller subsequent slumps and earthslides. As the cattle move along the hillside, they travel on the crests of these smaller mass movement features, which are at different heights in each of the embayments. A comparison of the plan and profile of the tread (Appendix III) shows that several of the major breaks of gradient in the profile coincide with the occurrence of these recesses. Doubtless, some of the smaller mass movements in the recesses have been caused, at least in part, by the weight of the cattle. Nevertheless, a close examination of tread profiles from sites A and B shows that the former has a more constant gradient than the latter one. This may be a reflection of the higher percentage of cattle activity at control site A.

At site C, the tread profile (Appendix IV) of the slumped blocks, with earth slid material filling the interspaces, obviously does not show the constant gradient found at the other control sites. This is not unexpected as it is quite unlikely that a piece of sod, fifty feet long and of uniform width, should break away from its sub-surface at the same time along its entire length and then move downslope without fracturing. The tread profile displays the large irregularities that are usually associated with purely non-faunal mass movement processes.

Thus far, the statements of vertical irregularities in the tread profiles have been made from a visual examination of the drawn profiles and plans of the control sites. To provide a more accurate comparison of vertical irregularities of tread profiles at different control sites, a statistical analysis was made. In order to measure the amount of irregularity between the actual tread profile and a truly rectilinear one, the data for each control site was subjected to computer analysis. The data analysed was obtained from profiles of Appendices II, III, and IV. Co-ordinate points were selected approximately every five feet along the profiles. The elevation values are designated as the Y or dependent variable, and measurements of the horizontal distance along the profile are the X or independent variable.

From the analysis, a regression line was found for each set of data and plotted on the appropriate profile (See Appendices II, III, and IV). These regression lines are the plots that would be expected if the tread profiles had no vertical irregularities. However, as irregularities do exist, a measurement of this condition is required. The measure chosen for this purpose is the expression $(1 - \frac{\bar{S}_y}{\sigma_y})$,[1] where $\bar{S}_y$ is the adjusted standard error of estimate,[2] and σ_y is the standard deviation of Y. This particular expression is used so as to overcome the difficulties arising from comparing differing dispersions. If there were no deviations from the regression line, a value of 1 would be expected for $(1 - \frac{\bar{S}_y}{\sigma_y})$. However, values of 0.85, 0.45, and 0.15 are obtained for sites A, B, and C respectively. There appears to be more vertical irregularity[3] in the

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[1] H. Arkin and R. R. Colton, <u>Statistical Methods</u>, College Outline Series (New York: Barnes & Noble Inc., 1965), p. 79.

[2] Appendix VI(A) shows the method used to adjust the S_y values.

[3] S_y is the quadratic mean of the deviation about the line of regression. Since the regression lines are seldom horizontal, S_y is not always a vertical measurement. In this thesis, the amount of correction necessary is negligible as shown in Appendix VI(B).

tread profile of non-faunally induced mass movement phenomena (site C) than in cattle-produced one (site A). At site B, an intermediate value was obtained for the expression $(1 - \frac{\bar{S}_y}{\sigma y})$, reflecting the influence of the combined processes (Table 4.1).

A second assessment of the vertical irregularity of a tread profile is the examination of the adjusted correlation coefficient, $\bar{r}$, and its derivative, the adjusted coefficient of determination, $\bar{r}^2$.[4] Both $\bar{r}$ and $\bar{r}^2$ should show the same trend as $(1 - \frac{\bar{S}_y}{\sigma y})$, as these three statistical measures are inter-related mathematically. Since values of $(1 - \frac{\bar{S}_y}{\sigma y})$ change more rapidly than those of $\bar{r}$ or $\bar{r}^2$ for the same change in irregularity of profile, the first is more suitable for measuring the vertical irregularities of tread profiles. However, consideration will be given to $\bar{r}$ and $\bar{r}^2$, in that they offer alternate methods of measuring the irregularities in tread profile gradients.

The coefficient of correlation is a comparative measure of association between X and Y values of a particular series. If the r value is high, i.e. near 1, there is a good relationship between X and Y, although it may be inverse. The data analysis showed a change in the $\bar{r}$ values for sites A, B, and C such that $\bar{r}_A > \bar{r}_B > \bar{r}_C$. This indicates an increasing magnitude of irregularity between the actual

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[4]Appendix VI(C) shows the method of adjusting r and r^2.

STATISTICAL EXPRESSION	CONTROL SITE		
	A	B	C
Number of cases (N)	68	48	12
Standard error of estimate (S_y)	0.85	0.65	0.84
Adjusted standard error of estimate ($\bar{S}_y$)	0.85	0.66	0.92
Standard deviation of "Y" (σ_y)	5.52	1.19	1.08
$1 - \frac{\bar{S}_y}{\sigma_y}$	0.85	0.45	0.15
Correlation coefficient (r)	0.99	-0.84	0.67
Adjusted correlation coefficient ($\bar{r}$)	0.99	-0.84	0.63
Adjusted coefficient of determination ($\bar{r}^2$)	0.98	0.71	0.40

Table 4.1

Statistical characteristics of tread profiles at the control sites tread profile and the line of constant gradient given by the regression line as the influence of non-faunally induced mass movement processes increases.

The coefficient of determination, r^2, indicates the proportion of the variance of Y that can be attributed to its linear regression on X.[5] Thus site A with an $\bar{r}^2$ value of 0.98 has 98% of the variation in Y explained by the changing values of X in the linear regression equation. Thus only 2% of the variance in Y cannot be explained by consideration of the various X values. These findings relate with the plotted profile of site A, as nearly all the selected coordinate points along the profile are located on or extremely close to the regression line. This strengthens the initial suspicion that cattle can produce a linear tread profile with an extremely small magnitude of vertical irregularity.

In contrast to site A, site C has an $\bar{r}$ value of 0.63 and an $\bar{r}^2$ value of 0.40. The low $\bar{r}$ value shows that there is a poor association between the actual Y and X values which means that many of the points on the actual profile do not fall on the linear regression line. The $\bar{r}^2$ value is quite low, indicating that much of the Y variability cannot be explained by changes in X values. On the basis of the results from sites A and C, it appears that the tread profiles on non-faunally induced mass movements have a

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[5] Murray R. Spiegel, Theory and Problems of Statistics, Schaum's Outline Series, (New York: McGraw-Hill Book Co., 1961), p. 243.

greater total magnitude of vertical irregularity than those produced chiefly by cattle. An examination of Table 4.1 will show that the $\bar{r}$ and $\bar{r}^2$ values for site B occur between the values for sites A and C. This is to be expected, for site B was under the influence of both cattle and non-faunal mass movement processes.

The above analysis at the three control sites reveals, in a limited way, that a tread profile produced by cattle has smaller vertical irregularity than one formed by non-faunal mass movement agents. This was suspected intuitively during field work and was fairly apparent from drafted profiles of sites A, B, and C.

It is fully realized that definite conclusions cannot be based on the results of only three precisely surveyed control sites. Since this section of the thesis is only part of the main topic, time and cost factors did not permit the surveying of more than a few sites. For example, the results of the statistical analysis would have been much more dependable if the samples of different tread profiles had been larger. Despite the small number of control sites, there is considerable ground to suspect that the findings have validity for the following reasons. During field study, alongslope tread profiles appeared to have a more constant gradient wherever there was an abundance of cattle evidence. The profiles plotted from the survey data of the control sites also suggest a similar relationship of process and vertical irregularity. Now, the same conclusion is reached when the vertical irregularities of the tread profiles are measured by statistical analysis to eliminate any misconceptions that might have been present in the visual evaluation of profile gradient. Moreover, field observations of tread profile gradients were not limited to the control sites. Throughout the entire survey, many of these irregularities were roughly assessed by clinometer. At frequent intervals along a tread of a cattle path, a level site would be taken onto an upright object such as a tree or post. The height differences of the level sitings would give the approximate vertical displacement of the tread, usually from 1 to 1 1/2 feet per 100 feet of tread length. Furthermore, the increase or decrease in elevation along the path was usually continuous for considerable distances along the path.

Summary:

The true morphology of terracettes can be often disguised by such deception factors as vegetation, viewing distance, viewing angle, and incident angle of light. A steady increase of vertical irregularity of tread profile occurs with an increase in the evidence of non-faunally induced mass movement processes. On the other hand, cattle appear to have the ability to produce a nearly constant tread gradient with few vertical irregularities.

CHAPTER V

AN EXAMINATION OF TERRACETTE MORPHOLOGY AT SITE #63

An attempt will now be made to determine the horizontality and parallelism of terracettes, as well as to test at site #63 the applicability of the relationship, established in Chapter III, between type of process and vertical irregularity of tread profile.

"Horizontal" is a term that is often used to describe the manner in which terracettes appear to follow a constant elevation along a slope. The term "parallel" is often used to describe the way adjacent terracettes seem to extend for considerable distances along a slope without coalescing. However, it became evident during field study that many of the terracettes do not exhibit complete horizontality or parallelism. Moreover, the morphological appearance of this phenomenon is often deceptive, due to the existence of certain factors, mentioned in Chapter IV. To evaluate the degree of horizontality and parallelism of terracettes and to eliminate any possible visual deception, an accurate survey of site #63 was made with a tripod level and calibrated stadia rod.

An apparent relationship between the vertical irregularities in a tread profile and the predominant causal geomorphic process was established in Chapter IV, on the basis of three control sites A, B, and C. This relationship indicated that the vertical irregularity in tread gradient, as measured by $(1 - \frac{\bar{S}_y}{\sigma_y})$, $\bar{r}$, or $\bar{r}^2$, is less for phenomena produced by cattle than by non-faunal mass movement processes. The vertical irregularities of the alongslope gradients of terracette treads at site #63 have been represented by values for the expressions $(1 - \frac{\bar{S}_y}{\sigma_y})$, $\bar{r}$, and $\bar{r}^2$. The means for each of these expressions can be judged in terms of the values established for the three control sites. A prediction of the process or combination of processes responsible for tread formation at site #63 can now be made. As stated in Chapter III, the processes operating at this site have been carefully determined. Therefore, the prediction can be tested for accuracy by comparing it with the processes determined by field study. The relationship which seems to exist between vertical irregularity of alongslope tread profile and type of formative process will be more strongly identified if the type of process predicted agrees with that observed.

a. The horizontality and parallelism of terracettes

The gradient of the alongslope tread profile was examined at many of the different terracette sites during field study. Although this was usually too small to be measured accurately with a clinometer, virtually none of the treads showed complete horizontality. At some locations parallelism of terracettes seemed prevalent, while at other sites coalescence of the treads was evident. The decision was therefore made to accurately survey one site (#63) to permit a closer examination of the horizontality and parallelism of terracettes.

The data obtained from the survey of site #63 has been plotted in the form of staggered slope profiles (Appendix VII). Corresponding tread and riser limits on adjacent slope profiles are connected by means of dashed lines. In this manner a non-perspective, three-dimensional diagram of site #63 has been produced. The diagram reveals that the terracettes are not as horizontal or parallel as they appeared to be when viewed in the field from a considerable distance. Comparison of the frontispiece photograph with the staggered profile diagram of Appendix VII provides the same conclusion.

For a more objective evaluation of the horizontality and parallelism of these terracettes, the data obtained from the survey of site #63 has been subjected to a simple regression analysis. The alongslope centre-line of each tread was considered as a separate profile. The heights for each profile were determined at five-foot intervals <u>along</u> the centre line of the tread. These elevations were considered as constituting the dependent or Y variable, and the along-tread distances were regarded as the independent or X variable, analogous to the method used with the control sites in Chapter IV. Although the data from nine tread profiles was analysed, three of the latter (profiles #3,

Terracette No.	Slope Gradient	Slope Angle
1	+0.03	+1°43'
2	+0.02	+1°09'
4	-0.02	-1°09'
5	-0.04	-2°17'
6	-0.06	-3°24'
9	-0.02	-1°09'

Table 5.1

Gradients and slope angles of tread profiles at site #63

#7, and #8) had to be discarded as their respective levels of significance, as determined by the "F" test, were below 95%. The gradient of each of the profiles was indicated in terms of the respective coefficient of regression, i.e. gradient of its regression line (Table 5.1).

The gradients of the alongslope tread profiles, as represented by the regression coefficient, range from 0.06 to 0.02, but none of them show complete horizontality. Three of the treads have profile gradients as low as 1°09'. The largest deviation from the horizontal is 3°24'.

Since no two neighbouring terracettes have the same algebraic value for tread profile gradient, no adjacent parallelism exists. The closest example to adjacent parallelism occurs between terracettes #1 and #2, with an angular difference of tread profile gradient of approximately 1/2°. The least parallelism 5°07', occurs between the gradients of #6 and #1 treads which are non-adjacent. Non-adjacent parallelism occurs between terracettes #4 and #9. From observations in the field, parallelism is more obvious at site #63 than at many other locations. Therefore, it is quite probable that terracettes are not parallel in the majority of cases.

For general descriptive purposes, the terms "horizontal" and "parallel" are useful as they convey the impression of longitudinal continuity and the tiered nature of terracettes. However, it should be realized that the terracette features, as measured by their alongslope tread profiles, are not strictly horizontal or parallel in most cases.

b. Relationships of vertical irregularities in tread profiles to predominant geomorphic processes at site #63

The survey data from site #63 has been analysed for the standard error of the estimate (S_y), the standard deviation of Y (σ_y), and the coefficient of correlation (r). The values of S_y and r have been corrected, because of their small N values, and designated $\bar{S}_y$ and $\bar{r}$ respectively. The expressions $(1 - \frac{\bar{S}_y}{\sigma_y})$ and $\bar{r}^2$ have been calculated for each profile (Table 5.2). The values of $(1 - \frac{\bar{S}_y}{\sigma_y})$, which express the vertical irregularities of alongslope tread profiles, range from 0.77 to 0.20, with an average of 0.46. Terracette #6 has the value of 0.77 which, if compared

STATISTICAL EXPRESSION	TERRACETTE NUMBER					
	1	2	4	5	6	9
N	11	11	11	11	11	11
S_y	0.28	0.13	0.39	0.27	0.22	0.21
$\bar{S}_y$	0.31	0.14	0.43	0.30	0.24	0.23
σ_y	0.51	0.28	0.54	0.64	1.06	0.38
$1 - \frac{\bar{S}_y}{\sigma_y}$	0.39	0.50	0.20	0.53	0.77	0.39
r	0.86	0.90	-0.72	-0.92	-0.98	0.85
$\bar{r}$	0.845	0.889	-0.687	-0.914	-0.980	0.831
$\bar{r}^2$	0.714	0.791	0.472	0.835	0.96	0.692

Table 5.2

Statistical characteristics of tread profiles at site #63 with the control site values shown in Table 4.1, suggests a predominance of cattle activity. Terracette #4 has the lowest value, 0.20, implying a strong influence of non-faunal mass movement processes. An examination of Appendix VII shows that terracette #6 has only one minor vertical irregularity of tread profile while #4 has two major irregularities. Thus the relationship $(1 - \frac{\bar{S}_y}{\sigma_y})$ appears to be measuring the vertical irregularities in alongslope tread profiles as intended. Field study has indicated that the major irregularities of tread #4 were largely due to soil creep. Therefore, the relationship $(1 - \frac{\bar{S}_y}{\sigma_y})$ helps to predict when mass movement processes have been influential in producing or maintaining terracettes.

In Chapter IV, the value 0.45 was obtained for the expression $(1 - \frac{\bar{S}_y}{\sigma_y})$ when combined processes of cattle and non-faunally induced mass movements occurred. A similar combination of processes is predicted for site #63, because the mean value of the six tread profiles is 0.46. The processes determined at this site by intensive observation do not agree completely with those predicted. Fewer indications of non-faunally induced mass wasting processes were actually evident at site #63 than the value of 0.46 suggests. One of the difficulties of predicting the intensity of a process from Table 4.1 is the lack of intermediate values. Since the function between vertical irregularities of the tread profile and type of process is not fully determined, the inference of cause from values between the three control site values is very speculative.

The coefficient of correlation, $\bar{r}$, values range from 0.69 to 0.98, as shown in Table 5.2. Five of the values are 0.83 or over, indicating that elevations are increasing fairly uniformly with distance along each of the treads. The low $\bar{r}$ value of 0.69 relates to terracette #4, and indicates that considerable vertical irregularity of alongslope tread profile exists. A similar indication is given by the value for the expression $(1 - \frac{\bar{S}_y}{\sigma_y})$. Values of $\bar{r}^2$ are also given in Table 5.2, and reveal more distinctly the vertical irregularity of tread profiles in terracettes #1 and #9. A field examination of site #63 showed that more non-faunally induced mass wasting had occurred at terracettes #1 and #9 than at #2, #5, and #6.

The established relationships of Table 4.1 have been somewhat strengthened by the partial agreement of the predicted processes at site #63 with the observed ones. An increase in the number of control sites used to establish the values of Table 4.1 would permit a higher degree of accuracy in the prediction of the processes operating at a particular site when the vertical irregularity of the tread profile has been determined. However, the foregoing is not meant to imply that this analytical method has been designed solely to predict the type of process or combination of processes dominating a particular site. The method was formulated chiefly to obtain a better understanding of how the morphology of the terracettes might reflect the predominant geomorphic processes operating at a particular location.

Summary:

The morphology of terracettes can in general terms be described by the use of "horizontal" and "parallel" when referring to their characteristic tendency to follow a near-constant elevation along a slope in a non-coalescing manner. Actually the terracettes are very seldom either horizontal or parallel to each other. Since the terms "horizontal" and "parallel" help to communicate the general idea of terracette morphology, they are deemed satisfactory even though not exactly correct.

The terracettes of site #63 have been shown in Chapter III to have been produced chiefly by cattle activity. The application of the analytical method formulated in Chapter IV has predicted some degree of non-faunally induced mass movement processes also at work at this location. Soil creep, as pointed out in Plate 3.8 is most likely the dominant process of this type. The terracettes of site #63 are, therefore, mainly the result of cattle activity, but they have also been influenced by mass movement in the form of soil creep.

CHAPTER VI

CONCLUSIONS

As summaries have been given at the end of most sections or chapters, concluding statements will only briefly re-iterate the findings of this study and give a few final remarks on terminology.

Terracettes in the survey area exhibit a pattern of alternating treads and risers of considerable alongslope length. The dimensions of the treads, risers and alongslope lengths are generally similar to those described by the various authors in Chapter I. The tread and riser features do not have the exact parallelism and horizontality that might be imagined from a casual field observation. Careful observation and precise surveying have shown that adjacent treads are seldom parallel, and absolute horizontality rarely occurs. When judging the degree of development at a terracette site, an observer can be visually deceived as a result of the existence of factors such as viewing distance, viewing angle, vegetation, and the angle of incidence of light.

The vertical irregularity of alongslope tread profiles apparently bears a relationship to the dominant processes at a terracette site. The greater the irregularity, the more dominant the evidence of non-faunally induced mass movements that are encountered.

Definite relationships exist between several of the site factors and the degree of terracette development. In addition, the former are often inter-related. Aspect influences terracette development indirectly through its effect on type of vegetation and, in turn, on cattle activity. This is manifest in that 35% of the terracette sites occur on south-facing slopes, and that a greater proportion of the better developed sites than ones with medium or poor development possess this aspect.

In the survey area, the minimum gradient on which terracettes are found is 17°, while the maximum one is 42°. A higher percentage of good terracette sites occur on steep slopes than on medium or gentle gradients.

The area also reveals that the vegetation type is strongly influenced by aspect, as only south-facing slopes are mostly grass-covered. The density of vegetation appears to have little effect on the degree of development of terracettes. However, the type of vegetation has considerable influence on terracette development, for 81% of the sites where they occur are grass-covered.

Stratification of subsurface materials appears to have no influence on the development of terracettes. Materials composed of fine particles, i.e. clay, silt, and sand, are believed to be conducive to terracette development, while gravel, boulders, and eroded shales hinder the production and maintenance of the phenomenon.

Of the five site factors considered, cattle activity has the strongest relationship with degree of development.

Ninety-six percent of terracette sites in the area show some evidence of cattle usage. By precise surveying, it was determined that cattle do possess the ability to walk at a constant height along a crenulated slope, or to follow a constant gradient if their destination is at a different elevation. Although cattle usage is the predominant causal process at most sites, some evidence of non-faunally induced slumping or soil creep also exists. In addition, two sites are exclusively the result of slumping processes. Thus the effect of non-faunally induced mass movement processes should not be entirely omitted.

This study has found that the processes responsible for terracettes range from purely non-faunally induced mass movement to essentially faunally induced ones. These findings agree more completely with Sharpe's ideas than with those of the other authors mentioned in Chapter I.

Site conditions conducive to terracette development are: recent cattle activity; clay, silt, or sand material; slope gradients of approximately 30-40°; a southerly aspect; and a grass cover.

In this dissertation, three concepts of terracette study have been developed which may have merit as contributions to further research. The first is a system of classifying the degree of terracette development at a site (Figure 2.3). Initially, the limiting values for poor, medium, and good terracettes were selected intuitively. The degree of development of a certain terracette site, as determined by these limiting values, generally accords with the subjective evaluation of development made during field study. Also, after classification according to these values, it was found that the poorly developed sites have a mean deficiency of three site conditions conducive to terracette development, while those that are well developed have an average of only one deficiency.

A second approach to the study is the use of root profiles as an indicator of mass movements. Although a tedious and time-consuming method, it does serve as a detector of recent slumping or soil creep, or of the accelerated rates of these processes in homogeneous materials. Its shortcoming is that the plant root pattern also responds to moisture content and nutrient concentration in the soil which could mislead an unwary observer.

Thirdly, the statistical expression $(1 - \frac{S_y}{\sigma_y})$ has been proposed and used as an indicator of vertical irregularity of tread profile. This procedure appears to be valid, for the amount of irregularity shown by values of $(1 - \frac{S_y}{\sigma_y})$ corresponds with that observed from actual field study and examination of graphed alongslope tread profiles of carefully surveyed terracettes. The irregularity, as measured by the statistical expression $(1 - \frac{S_y}{\sigma_y})$, shows a relationship to the dominant type of process at a site. This relationship was corroborated when the processes predicted by the expression for site #63 accorded well with those determined by thorough field examination of that location.

It is not the purpose of this dissertation to challenge the entire concept of the genetic classification of landforms. However, from a critical review of the literature, there appears to be justification for leaving "terracettes" as the neutral, descriptive term Odum intended. The majority of authors mentioned in Chapter I have insisted that the word "terracette" should be morphologically descriptive and should have a genetic connotation. Unfortunately, the term is used to refer to forms that resemble one another but which are ascribed to dissimilar processes of formation. Thornbury, in defending genetic classification, states, "How much more illiminating are such terms as floodplain, fault scarp, sinkhole, sand dune, and wave-cut beach. Even though they are in part descriptive they have genetic implications."[1] Each of these terms (with the exception of "sand dune"), is composed of a "process" word, e.g. flood-, fault, sink-, wave-cut, and a "morphologically descriptive" word, e.g. plain, scarp, hole, and beach. Likewise, the morphologically descriptive term "terracette" should be modified by a "process" word to produce an expression that describes form and yet expresses the process of formation of the particular phenomenon. For example, if the terracettes have been caused chiefly by cattle treading, the

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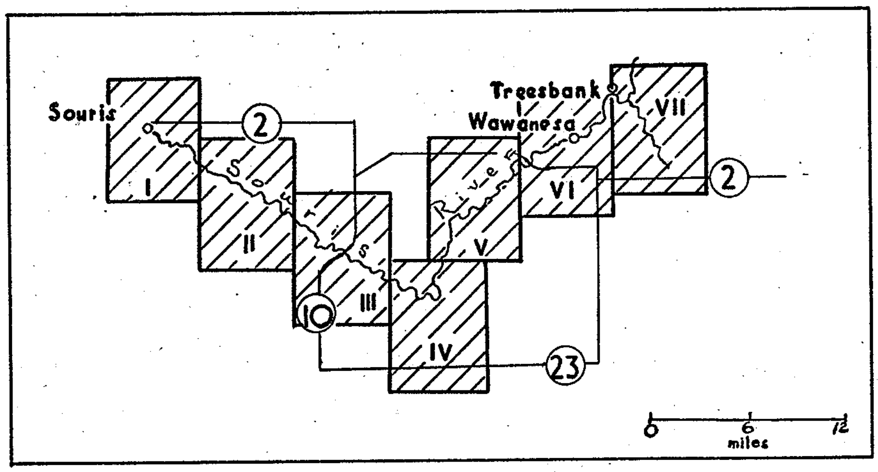
[1]W. D. Thornbury, Principles of Geomorphology (New York: John Wiley and Sons, Inc., 1954), p. 19.

expression "cattle terracettes" could be used; if mainly by a non-faunally induced slumping process, "slump terracettes" could be employed. One difficulty of this proposed scheme is the unwieldy groups of adjectives that may have to be added to the term "terracettes" if the phenomenon has resulted from a complex combination of processes. However, in such a case further description would be necessary even if the term "terracette" already implied one of the causal processes.

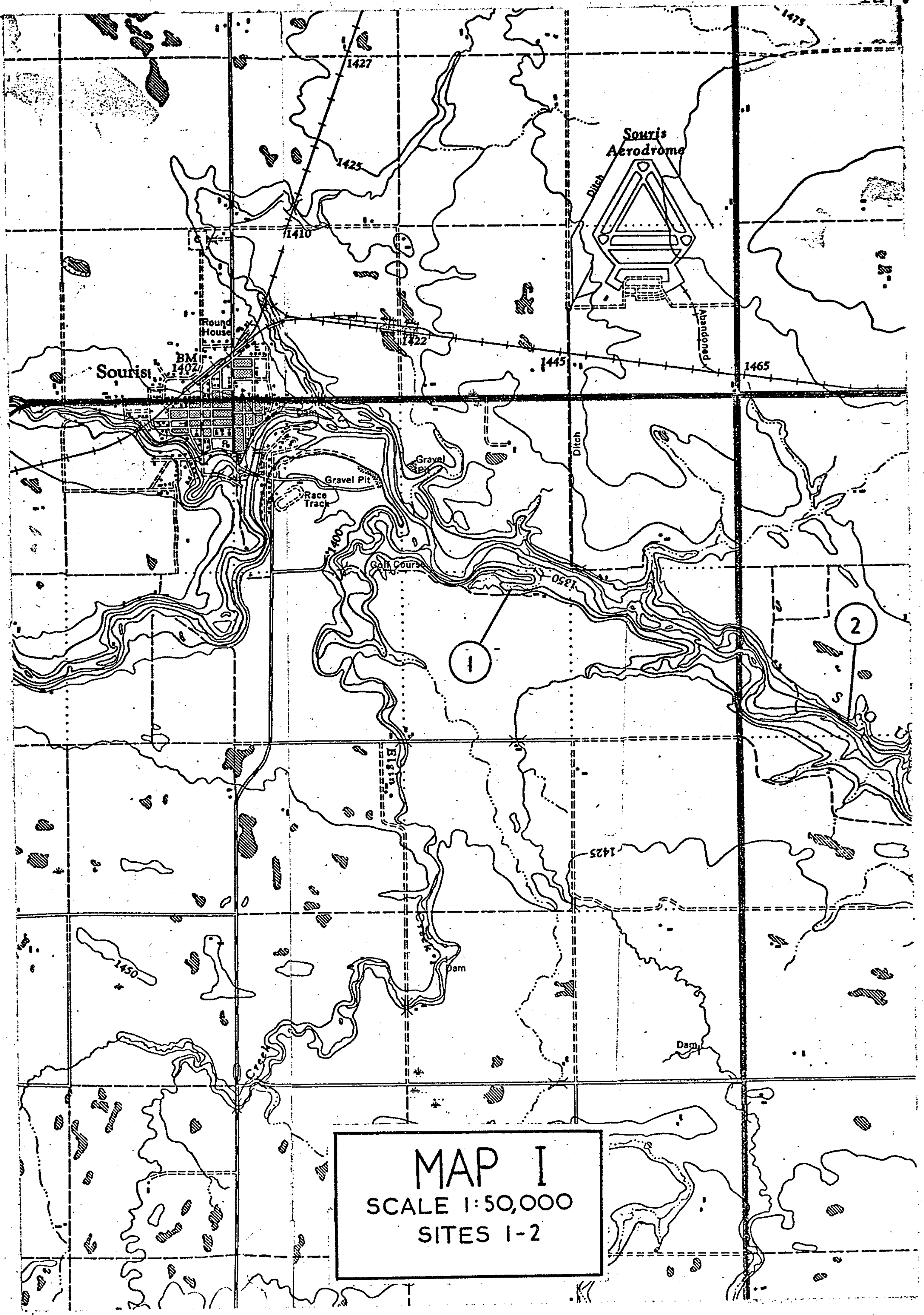
APPENDIX I

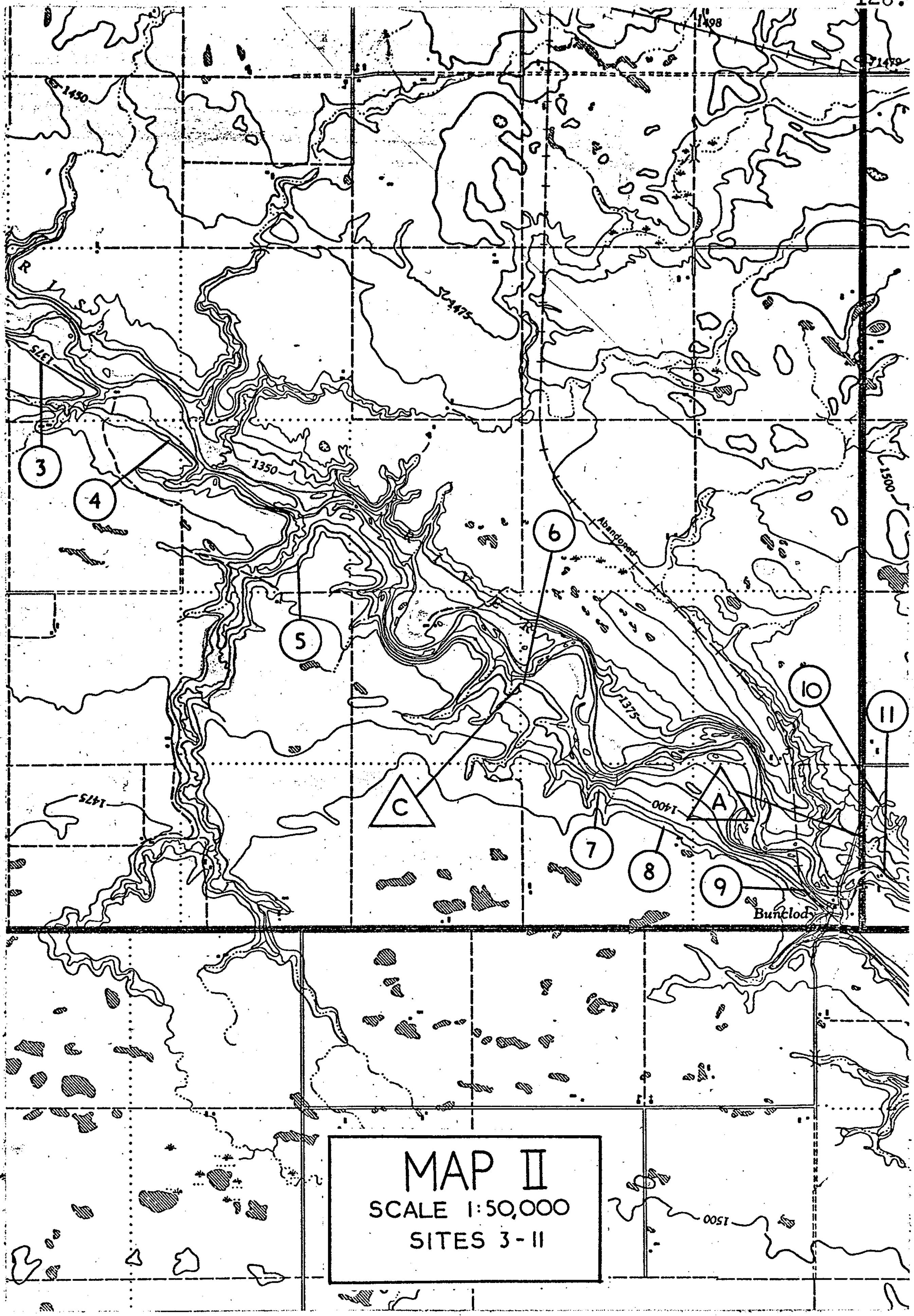
MAPS SHOWING SITE LOCATIONS

(Index Map)

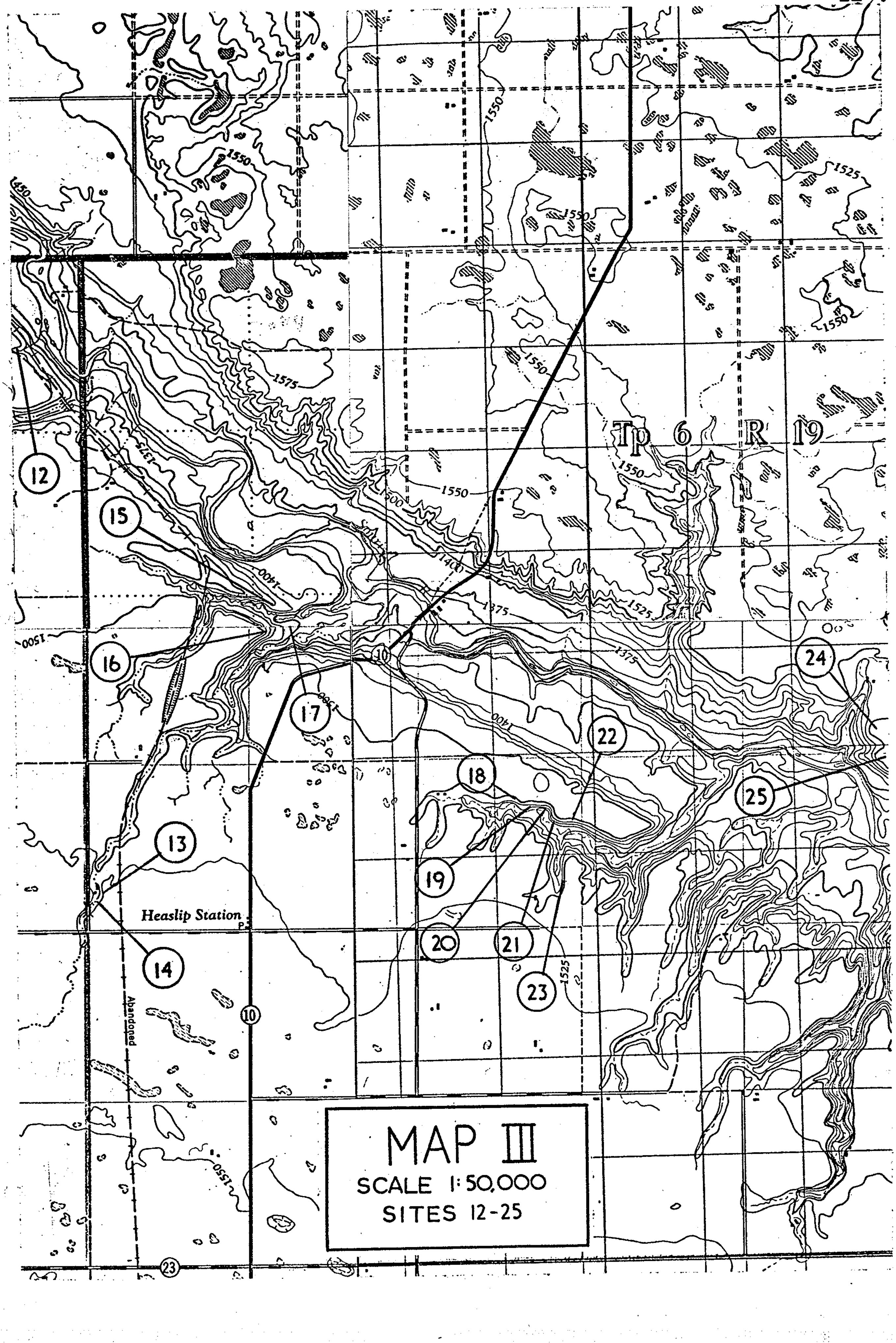


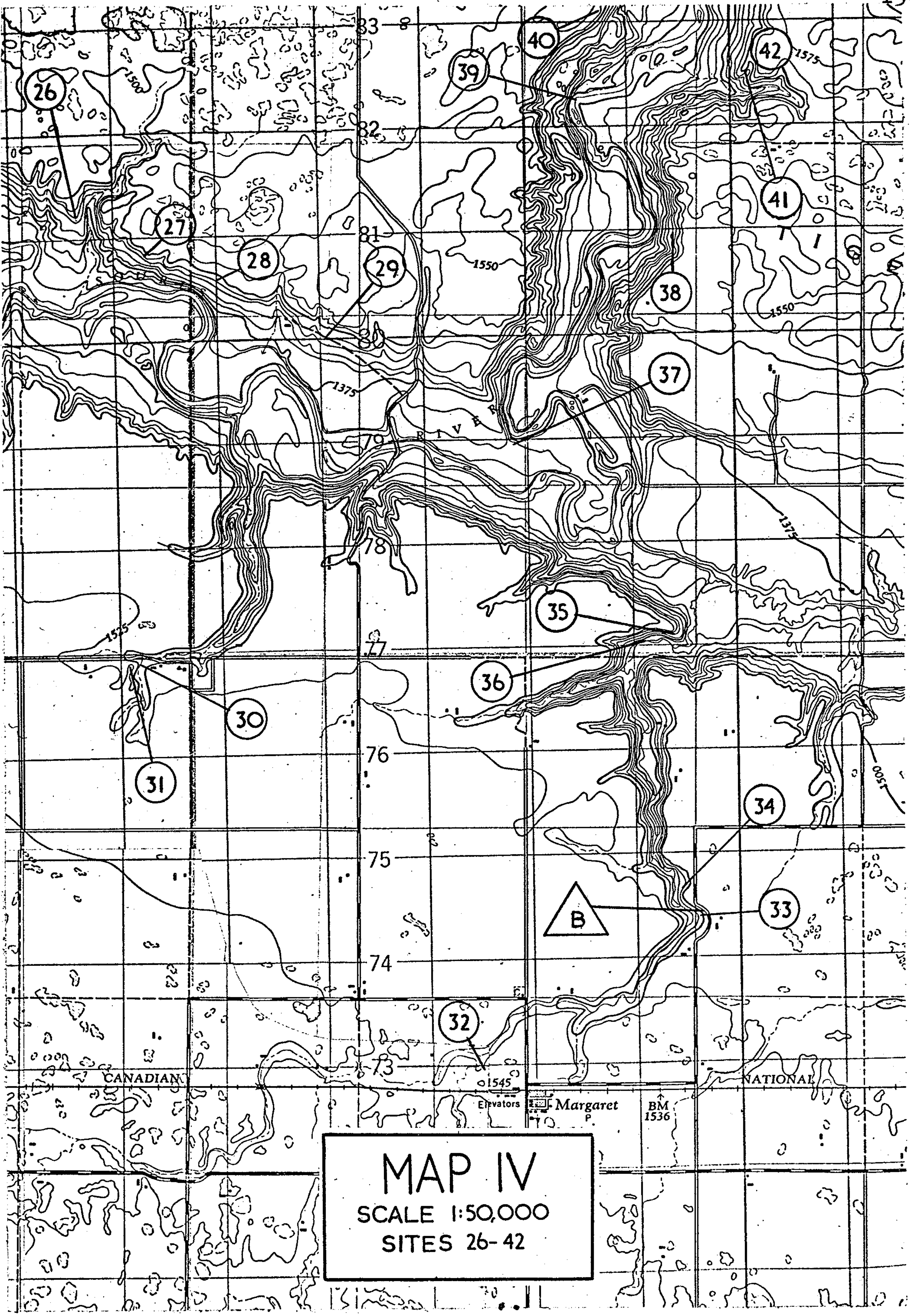
MAP NO.	SITE NOS. (symbol - ◯)	CONTROL SITES (symbol - △)
I	1-2	
II	3-11	A, C
III	12-25	
IV	26-42	B
V	43-55	
VI	56-74	
VII	75-87	


Souris Aerodrome
Souris
BM 1402
Round House
1427
1425
1410
1422
1445
1465
1475
Ditch
Abandoned
Gravel Pit
Race Track
Golf Course
1400
1350
1425
1450
Elgin
Creek
Dam
Dam
1
2
MAP I
SCALE 1:50,000
SITES 1-2

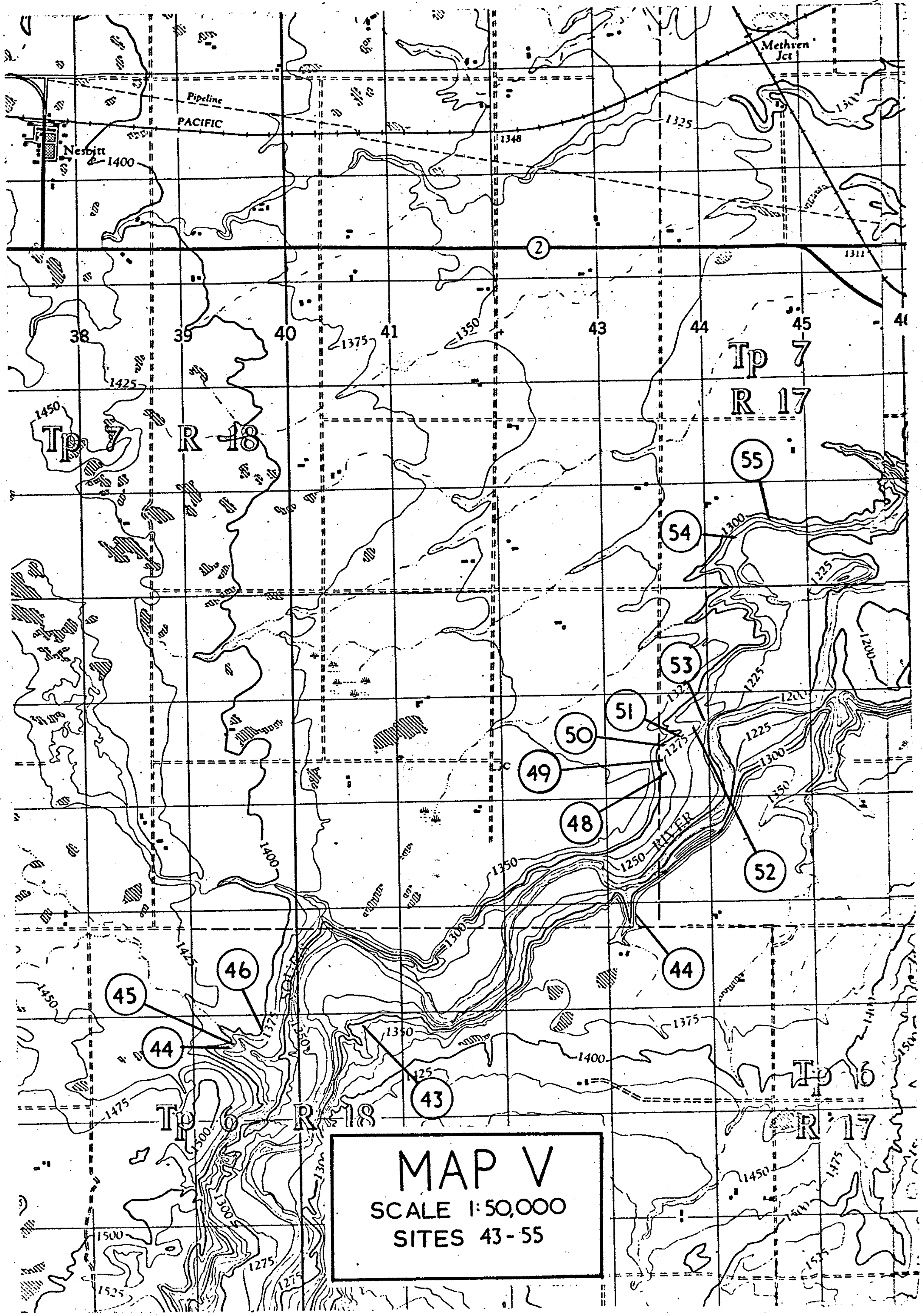


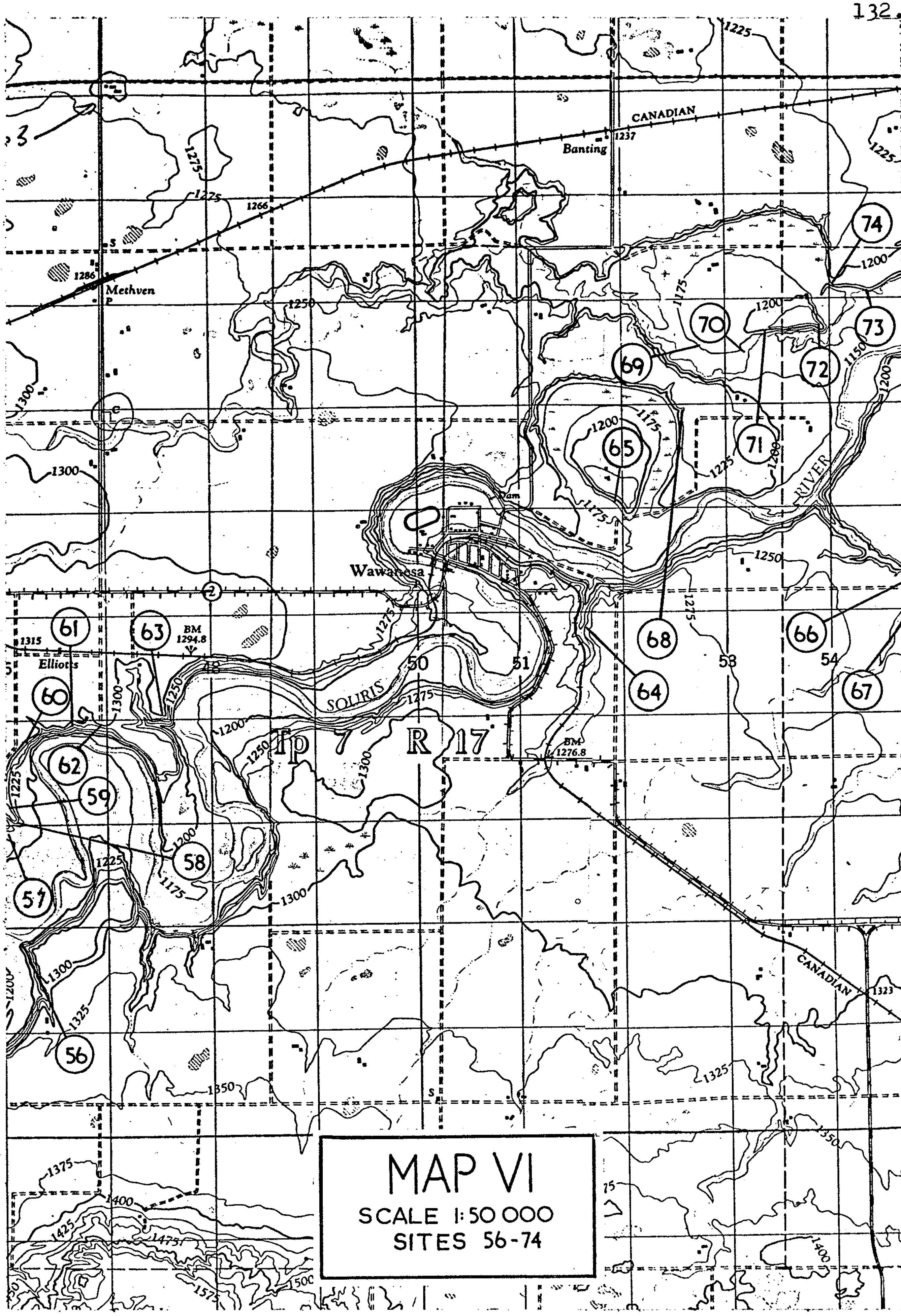
MAP II
SCALE 1:50,000
SITES 3 - 11


MAP III
SCALE 1:50,000
SITES 12-25
Tp 6 R 19
Heaslip Station
Abandoned
1550
1525
1575
1500
1400
1375
1450
10
23
12
13
14
15
16
17
18
19
20
21
22
23
24
25

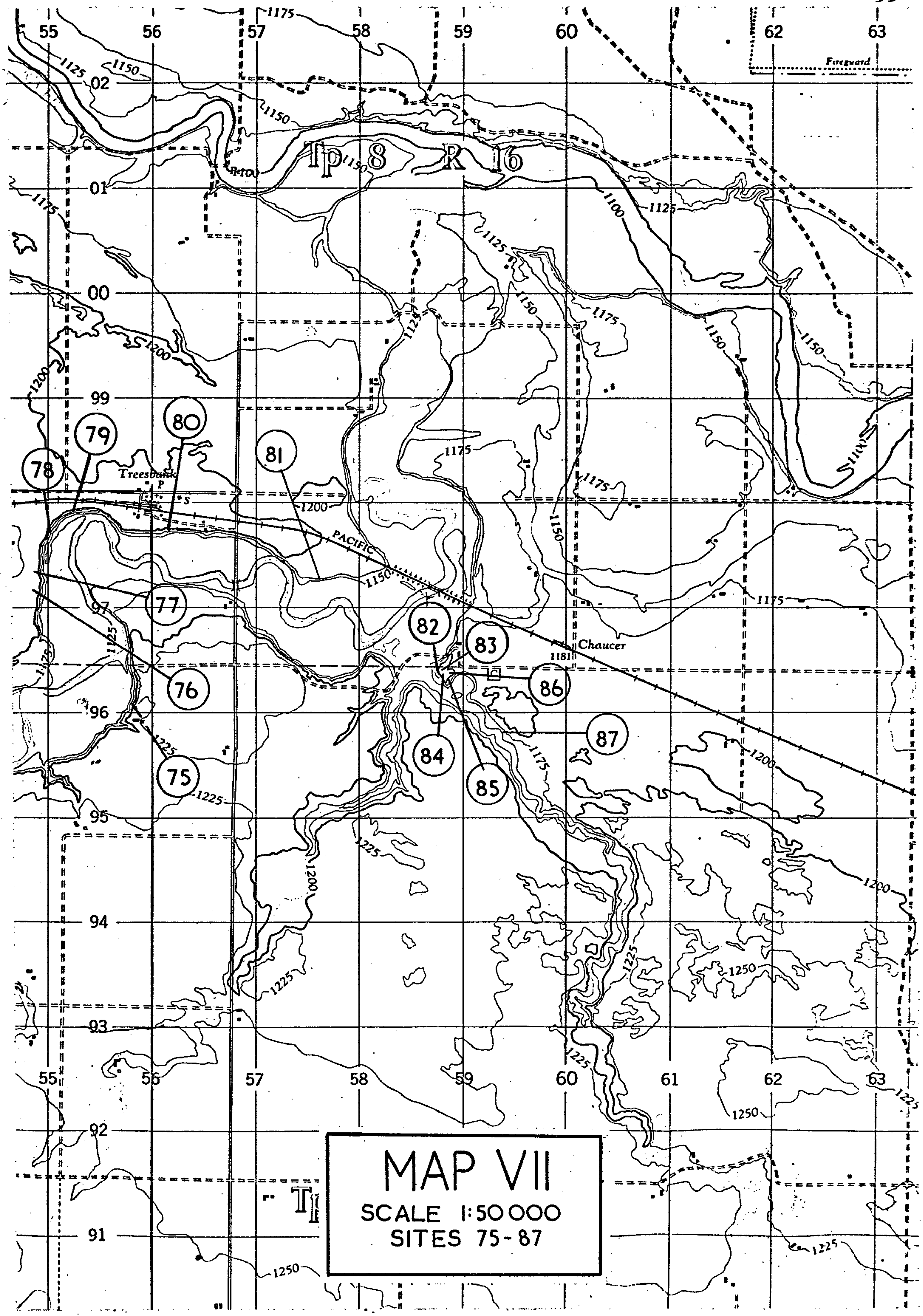


26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
B
83
82
81
80
79
78
77
76
75
74
73
1500
1550
1375
1575
1525
1545
RIVER
CANADIAN
NATIONAL
Elevators
Margaret
BM
1536
MAP IV
SCALE 1:50,000
SITES 26-42


MAP V
SCALE 1:50,000
SITES 43-55
Methven Jct
Pipeline
PACIFIC
Nesbitt
1400
1348
1325
1311
2
38
39
40
41
43
44
45
1375
1350
1425
1450
Tp 7 R 18
Tp 7
R 17
55
54
53
51
50
49
48
52
44
46
45
44
43
1300
1225
1200
1275
1250
RIVER
1375
1400
1475
1500
1525
Tp 6 R 18
Tp 6
R 17



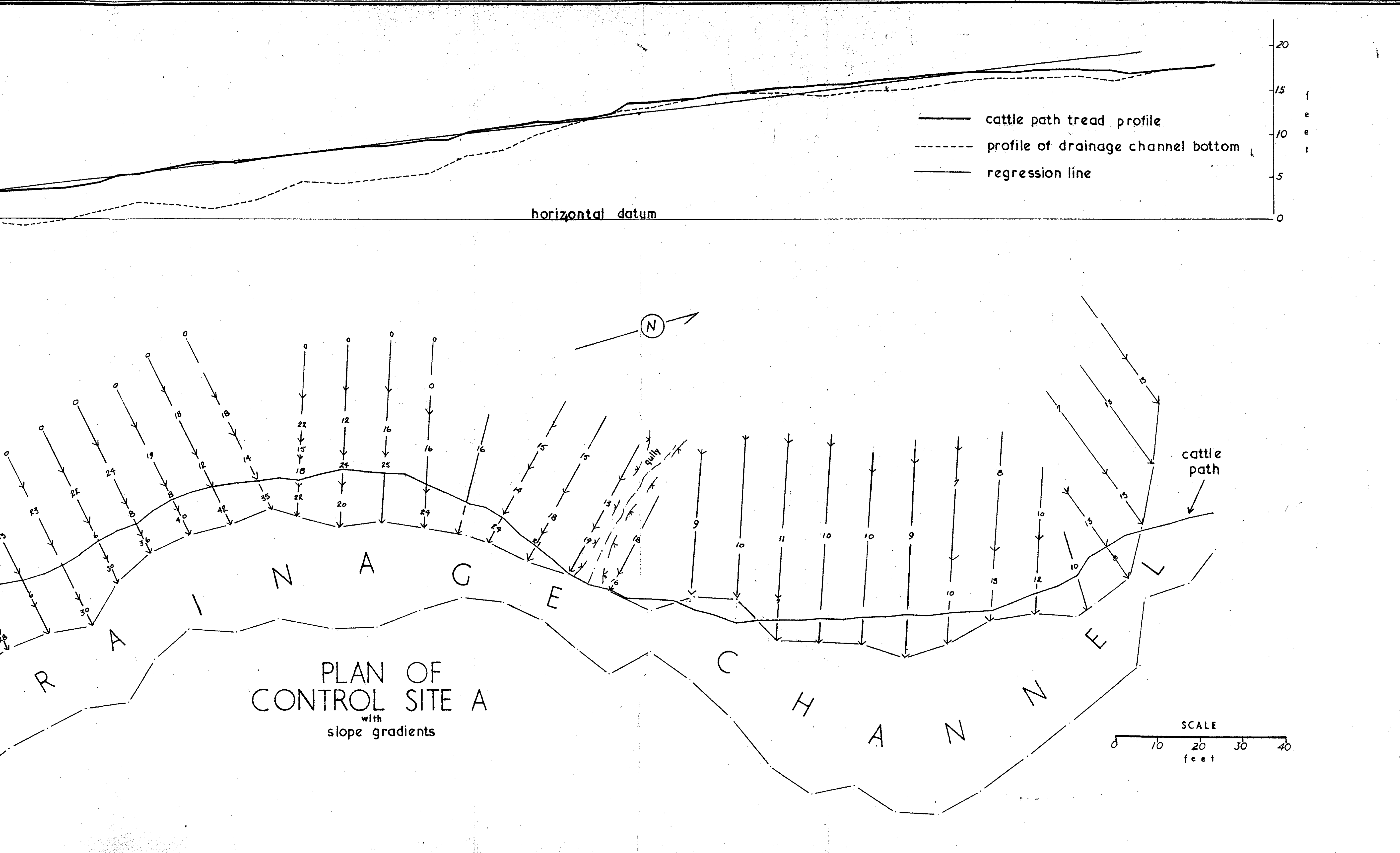
MAP VI
SCALE 1:50 000
SITES 56-74

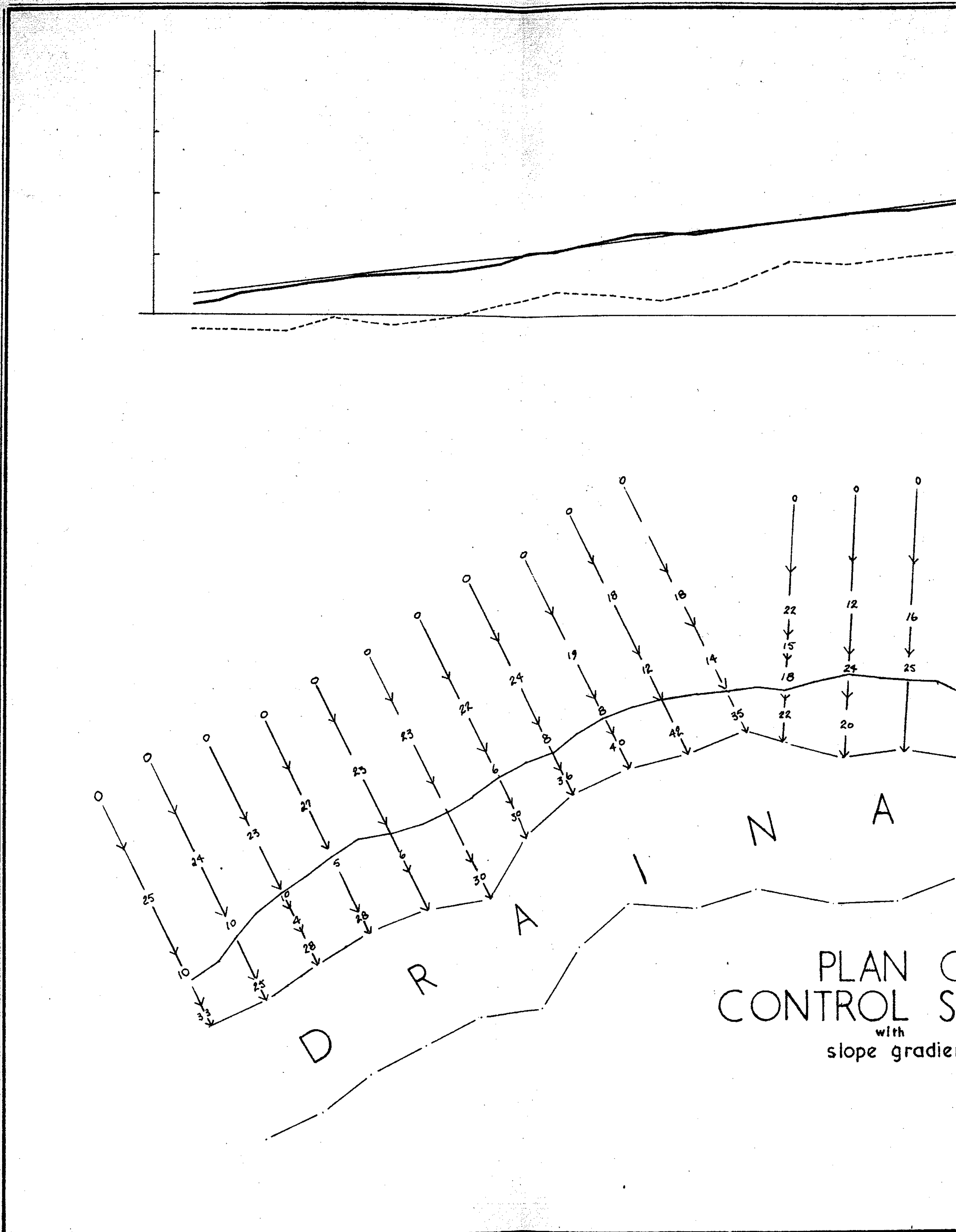


MAP VII
SCALE 1:50000
SITES 75-87

APPENDIX II

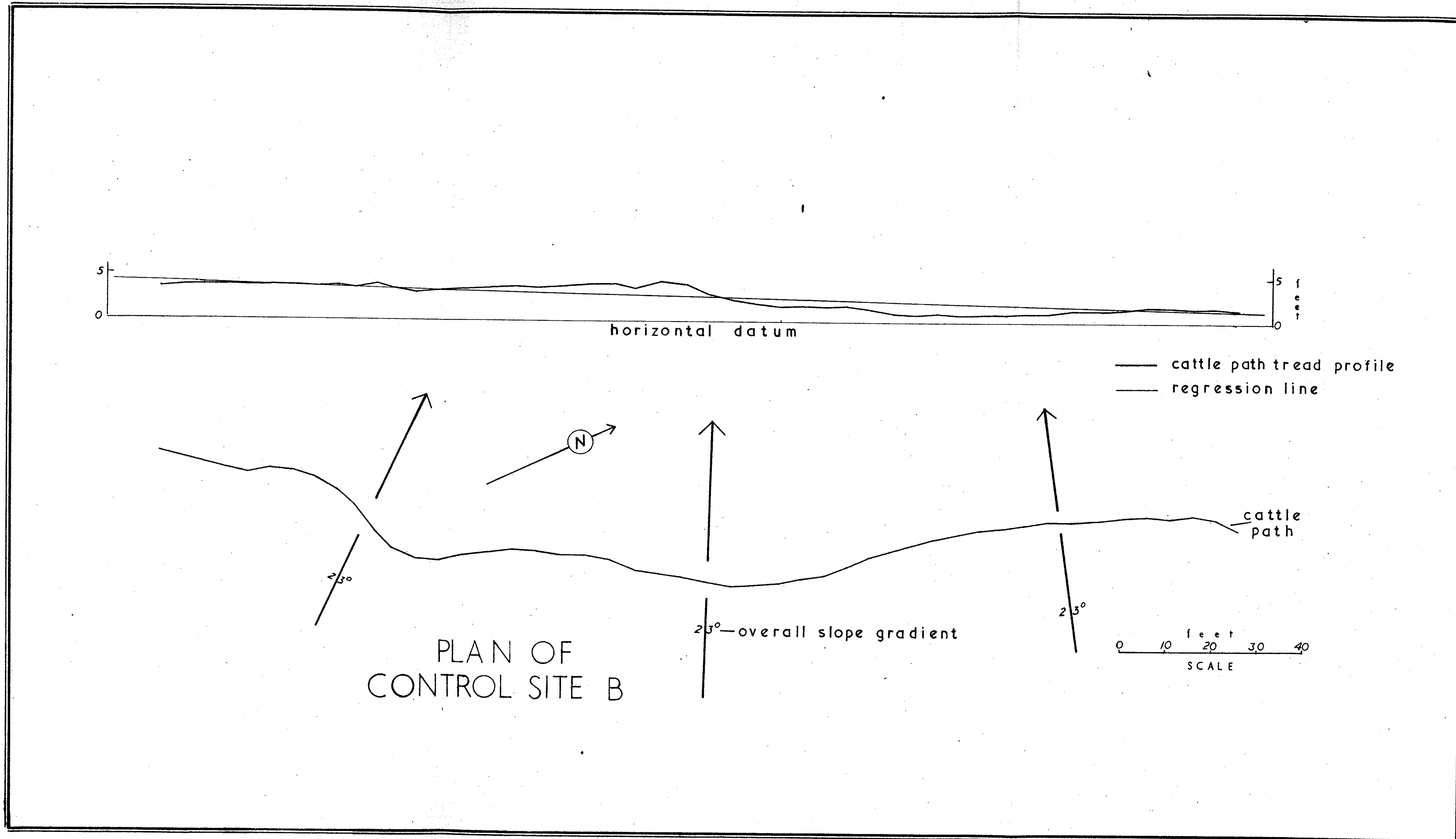
PLAN AND PROFILE
OF CONTROL SITE A


cattle path tread profile
profile of drainage channel bottom
regression line
feet
horizontal datum
N
cattle path
gully
DRAINAGE CHANNEL
SCALE
0 10 20 30 40
feet
PLAN OF
CONTROL SITE A
with
slope gradients


PLAN
CONTROL
with

APPENDIX III

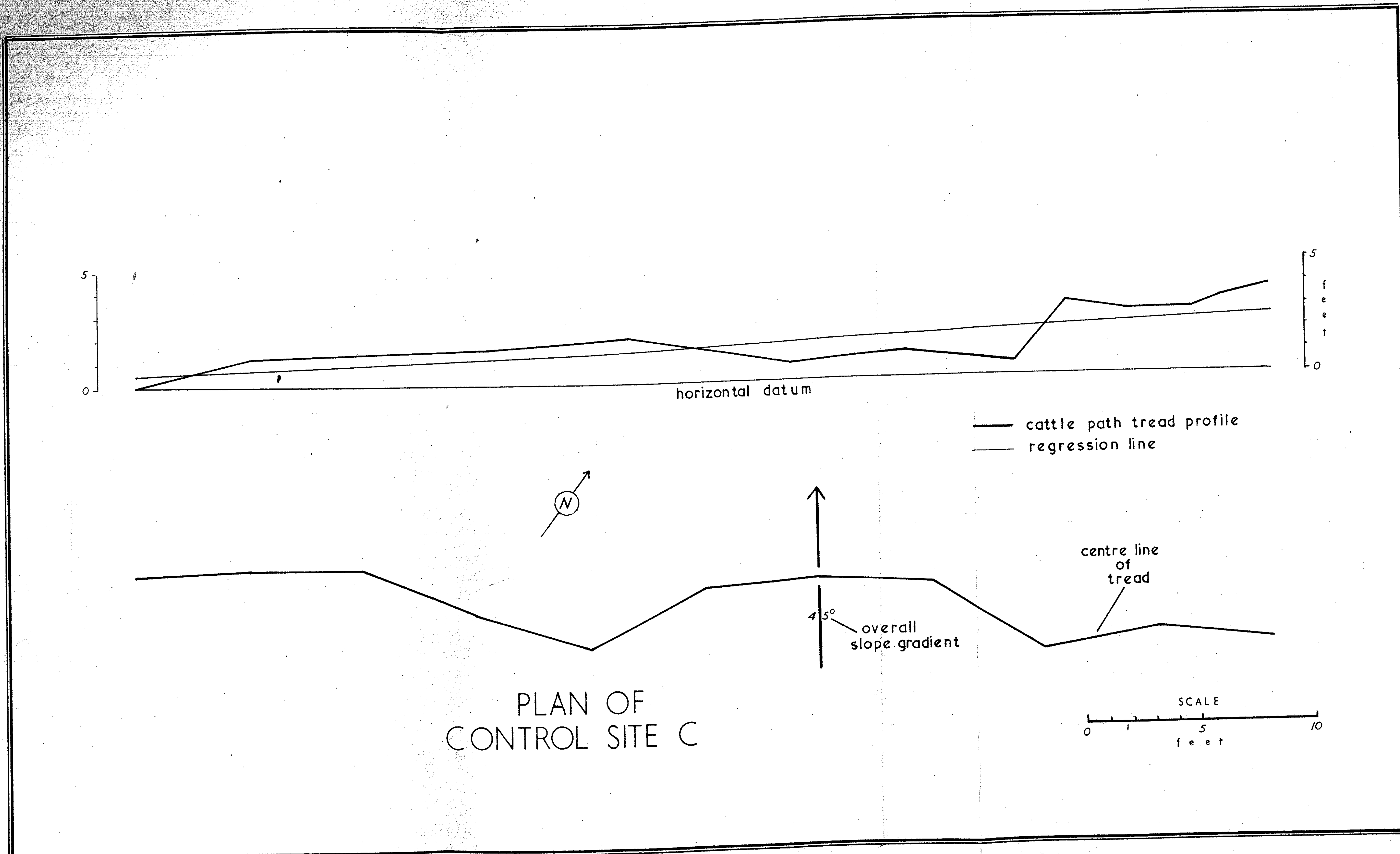
PLAN AND PROFILE
OF CONTROL SITE B


5
0
5
0
feet
horizontal datum
cattle path tread profile
regression line
N
cattle path
23°
23° — overall slope gradient
23°
0 10 20 30 40
feet
SCALE
PLAN OF
CONTROL SITE B

APPENDIX IV

PLAN AND PROFILE

OF CONTROL SITE C


5
0
5
f e e t
0
horizontal datum
cattle path tread profile
regression line
N
centre line of tread
4 5°
overall slope gradient
PLAN OF
CONTROL SITE C
SCALE
0
1
5
10
f e e t

APPENDIX V

DATA FOR COMPUTER ANALYSIS

OF

TERRACETTE SITE #63

AND

CONTROL SITES A, B, AND C

COORDINATES OF SELECTED POINTS ON THE TREAD PROFILES

CONTROL SITE A
(measurements from Appendix II)

X (feet)	Y (feet)	X (cont'd.)	Y (cont'd.)
0.0	0.8	154.0	11.1
4.5	1.1	157.8	11.3
8.0	1.6	161.8	11.7
11.0	1.9	166.2	11.8
15.5	2.2	170.5	12.2
19.5	2.5	174.5	13.3
23.8	2.7	181.0	13.7
27.8	3.0	186.0	14.0
33.0	3.2	191.0	14.2
37.5	3.2	196.0	14.4
42.5	3.6	201.0	14.7
46.5	3.9	206.0	15.0
51.0	4.4	211.0	15.3
55.0	5.0	216.0	15.4
59.8	5.1	221.0	15.5
64.0	5.4	225.5	15.7
68.0	6.0	231.0	16.1
72.8	6.5	236.0	16.4
77.8	6.7	241.0	16.7
83.0	6.6	246.0	16.9
88.2	7.0	251.0	17.0
93.8	7.3	256.0	17.1
98.2	7.6	261.0	17.2
103.2	8.0	266.0	17.2
108.5	8.3	271.0	17.4
113.2	8.6	276.0	17.6
118.2	8.8	281.0	17.6
123.0	8.9	284.5	17.5
128.0	9.0	289.0	17.3
133.0	9.4	292.5	17.2
137.0	10.0	298.0	17.2
141.8	10.4	303.5	17.5
146.0	10.8	308.5	17.7
149.2	11.0	313.5	18.0

CONTROL SITE B
(measurements from Appendix III)

X (feet)	Y (feet)	X (cont'd.)	Y (cont'd.)
0.0	1.1	121.0	3.5
5.0	1.3	126.0	4.0
10.0	1.4	131.5	4.1
15.0	1.5	136.0	3.8
20.0	1.7	141.0	3.6
25.0	1.4	146.5	3.4
30.0	1.2	151.5	3.3
37.5	1.2	156.5	3.4
41.8	1.0	161.5	3.4
47.5	1.0	167.0	3.3
52.0	0.8	172.0	3.1
57.5	0.8	177.5	2.7
61.8	0.8	182.0	3.2
66.5	0.8	186.2	3.5
71.8	0.6	190.2	3.5
76.8	0.7	195.0	3.6
81.8	1.1	199.0	3.6
86.5	1.3	204.0	3.6
91.5	1.3	209.0	3.6
96.0	1.4	214.2	3.5
101.0	1.4	219.0	3.6
105.5	1.8	224.0	3.6
111.0	2.2	229.0	3.5
116.0	2.8	233.8	3.4

CONTROL SITE C
(measurements from Appendix IV)

X (feet)	Y (feet)
0.0	0.0
5.0	1.2
15.3	1.6
17.8	1.8
21.6	2.0
29.0	0.7
34.0	1.2
38.8	0.6
41.0	3.2
43.6	2.8
46.7	2.9
47.7	3.2

SITE #63
(measurements from Appendix VII)

The locations of the numbered terracettes
are shown in Appendix VII

Terracette #1		Terracette #2		Terracette #3	
X (feet)	Y (feet)	X (feet)	Y (feet)	X (feet)	Y (feet)
0.0	0.0	0.0	0.6	0.0	0.9
5.0	0.0	5.0	0.6	5.0	1.3
10.0	0.3	10.0	0.6	10.0	1.2
15.0	0.0	15.0	0.9	15.0	1.2
20.0	0.2	20.0	0.9	20.0	1.3
25.0	0.9	25.0	0.8	25.0	0.6
30.0	1.1	30.0	0.8	30.0	0.6
35.0	1.3	35.0	1.1	35.0	0.8
40.0	1.0	40.0	1.2	40.0	1.0
45.0	1.0	45.0	1.3	45.0	1.0
50.0	1.0	50.0	1.3	50.0	0.9

Terracette #4		Terracette #5		Terracette #6	
X (feet)	Y (feet)	X (feet)	Y (feet)	X (feet)	Y (feet)
0.0	1.7	0.0	2.0	0.0	2.7
5.0	1.9	5.0	2.3	5.0	2.7
10.0	1.8	10.0	2.3	10.0	2.1
15.0	2.3	15.0	2.4	15.0	2.0
20.0	2.3	20.0	2.2	20.0	1.8
25.0	2.2	25.0	1.6	25.0	1.2
30.0	1.5	30.0	1.5	30.0	0.7
35.0	1.5	35.0	1.3	35.0	0.4
40.0	1.3	40.0	1.0	40.0	0.0
45.0	1.0	45.0	0.9	45.0	0.1
50.0	0.6	50.0	0.6	50.0	0.0

Terracette #7		Terracette #8		Terracette #9	
X (feet)	Y (feet)	X (feet)	Y (feet)	X (feet)	Y (feet)
0.0	0.5	0.0	0.1	0.0	0.0
5.0	0.7	5.0	0.7	5.0	0.0
10.0	0.6	10.0	0.8	10.0	0.4
15.0	0.6	15.0	1.4	15.0	0.4
20.0	0.4	20.0	1.3	20.0	0.8
25.0	0.6	25.0	1.8	25.0	0.6
30.0	1.2	30.0	2.1	30.0	1.0
35.0	1.0	35.0	1.4	35.0	1.0
40.0	0.8	40.0	1.2	40.0	0.6
45.0	0.7	45.0	1.1	45.0	0.8
50.0	0.4	50.0	1.0	50.0	1.1

APPENDIX VI

PROCEDURES USED TO ADJUST THE VALUES OF S_y, r, AND r^2

CLARIFICATION OF $1 - \frac{\bar{S}_y}{\sigma_y}$ AS USED TO MEASURE VERTICAL IRREGULARITIES OF TREAD GRADIENT

(A)

Adjusted Standard Error of Estimate

Due to the small number of cases, particularily at site C, the value of the standard error or estimate, S_y, for each control site had to be adjusted by applying the formula:[1]

$$\bar{S}_y{}^2 = S_y{}^2 \left(\frac{N}{N-2}\right), \text{ where } N = \text{number of cases.}$$

---

[1]H. Arkin and R. R. Colton, Statistical Methods, College Outline Series (New York: Barnes & Noble Inc., 1965), p. 85.

(B)

RELATIONSHIP BETWEEN NORMAL DISPLACEMENT (S_y) AND VERTICAL DISPLACEMENT (y) IN THE TREAD PROFILE

As the irregularities are measured statistically along a normal from a point to the regression line, the vertical displacement is not actually given in the results of the analysis. From Figure VI.1 it can be seen that the normal displacement (S_y) is related to the vertical displacement (y) by:

$$y = \frac{S_y}{\cos \alpha}$$

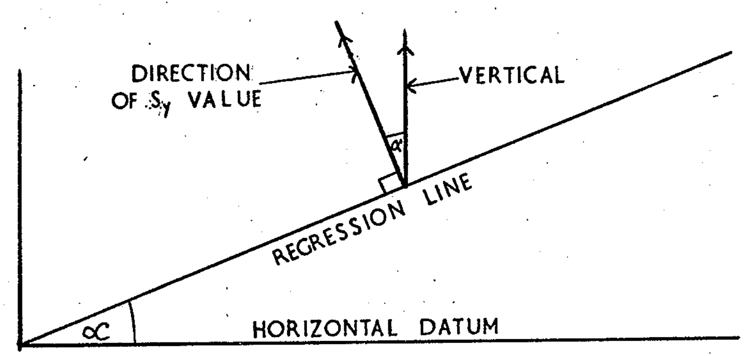


Figure VI.1

The largest slope value of the three regression lines was less than 3 1/2 degrees. When $\alpha = 3°30'$, $\cos \alpha = 1.0019$. Therefore, the vertical displacement = $\frac{\text{normal displacement}}{1.0019}$.

Since the conversion factor, 1.0019, is so near to unity, no attempt will be made to calculate the true vertical displacements. Moreover, it should be noted that the actual values of the vertical irregularities from the regression line are not being specifically considered, but only a comparison of the irregularities in the tread profile at each control site.

(C)

ADJUSTED CORRELATION COEFFICIENT, ($\bar{r}$), AND COEFFICIENT OF DETERMINATION, ($\bar{r}^2$)

The low frequency of data, particularily in the case of control site C, necessitated the use of adjusted r and r^2 values. The value $\bar{r}^2$ was obtained by application of the formula:[2]

$$\bar{r}^2 = 1 - (1 - r^2)\left(\frac{N - 1}{N - 2}\right)$$

where: r = coefficient of correlation,
N = number of cases.

The value of $\bar{r}$ was determined by taking the square root of $\bar{r}^2$.

[2]H. Arkin and R. R. Colton, op. cit., p. 85.

APPENDIX VII

STAGGERED PROFILES
OF SITE #63
(In Map Pocket)

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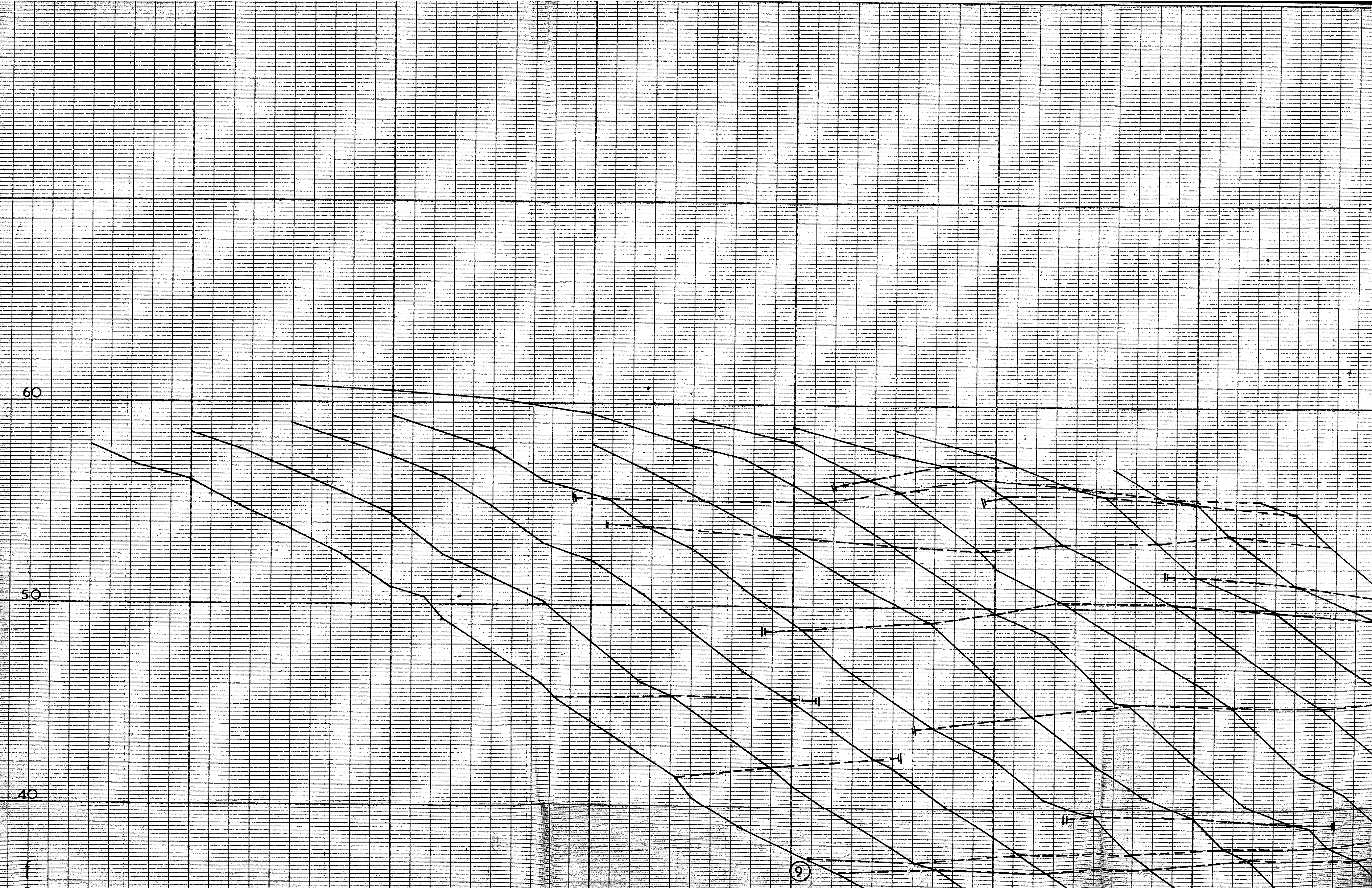
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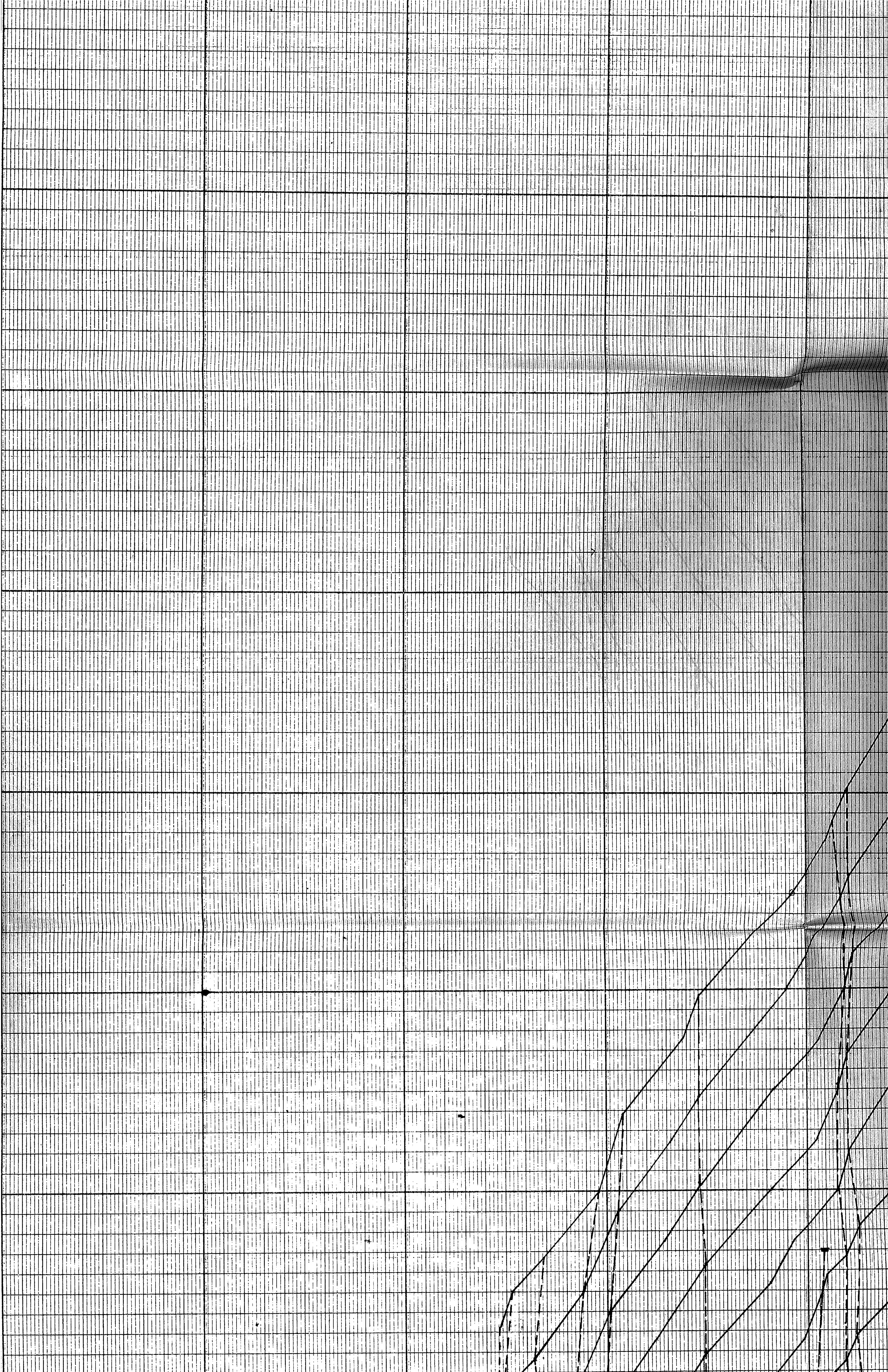
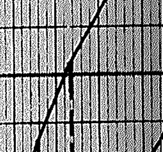
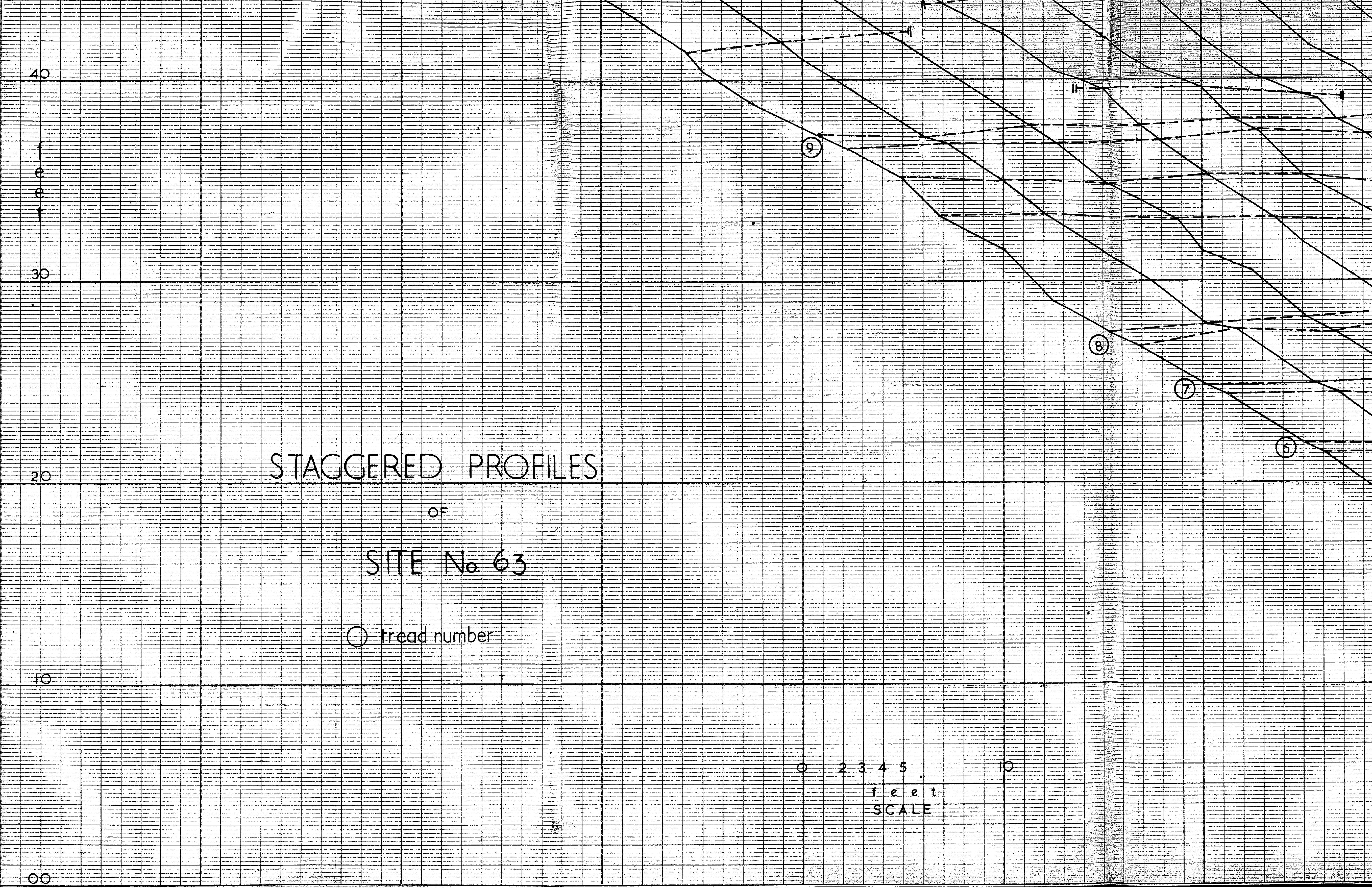
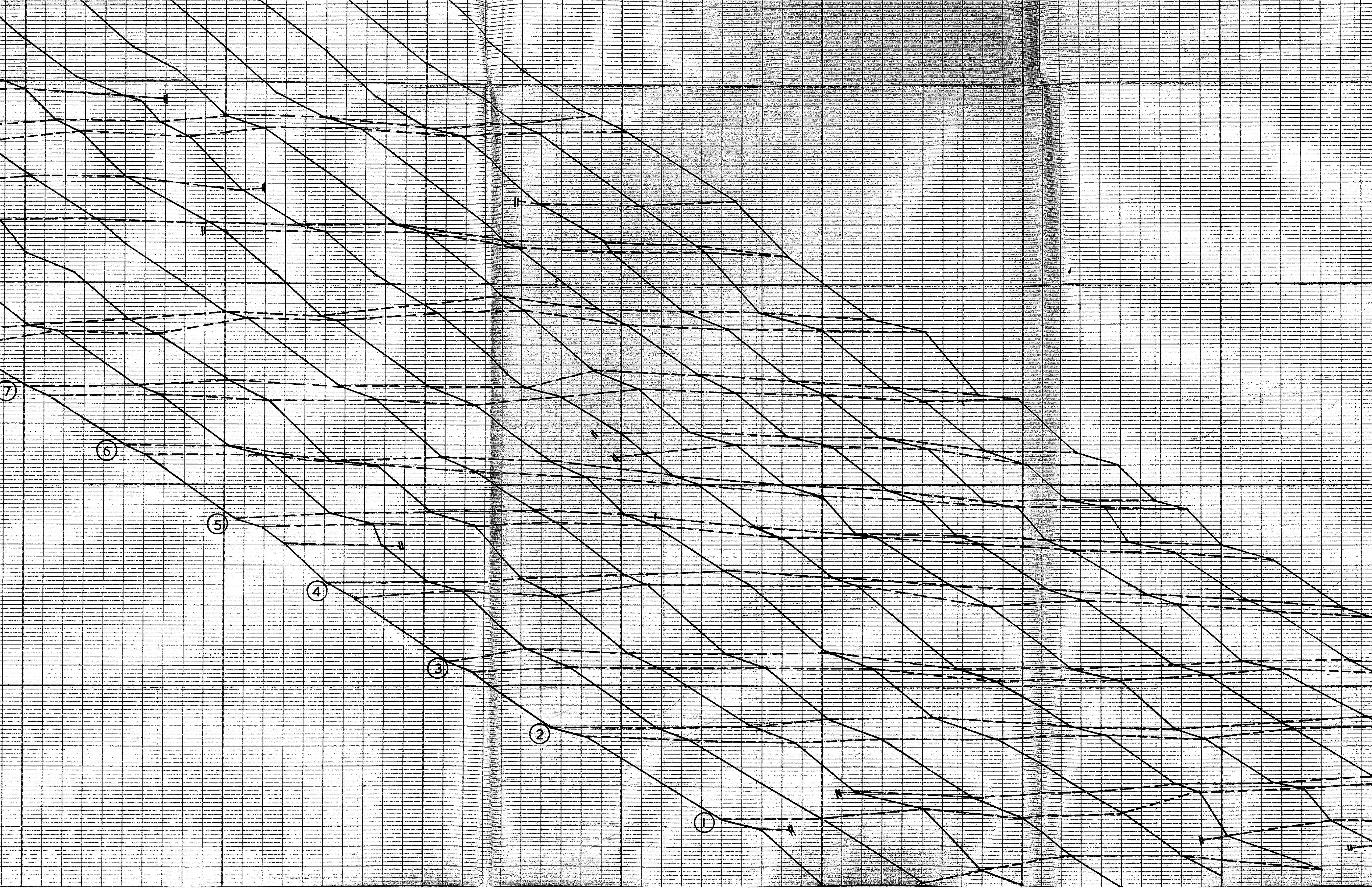






STAGGERED PROFILES
OF
SITE No. 63
○-tread number
feet
40
30
20
10
00
9
8
7
6
0 1 2 3 4 5 10
feet
SCALE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