A SLOPE PROFILE ANALYSIS OF A VALLEY IN SOUTH WEST MANITOBA

A THESIS

presented to

the Faculty of Graduate Studies and Research

University of Manitoba

In partial fulfillment

of the Requirements for Degree

Master of Arts

---

by

John Alan Hodgson

May 1968

" A properly conducted statistical investigation has all the spirit of the chase, amplified by the forward-pressing human curiosity in the search for knowledge, which in success brings great and rewarding satisfaction."

W. J. Reichmann, Use and Abuse of Statistics, Methuen & Co. Ltd., 1961 p. 24.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge the many individuals who have helped in the preparation of this thesis.

In particular, thanks is due to Dr. J. M. Brown, Geography Department of the University of Manitoba who gave freely of his time and valuable advice, and to the University of Manitoba for the research grant, without which the field work and computor programing would have been impossible.

Valuable advice was also given by Dr. E. H. Schludermann, Psychology Department of the University of Manitoba, regarding interpretation of the factor analysis program results, and Mr. K. Carpenter of the Computor Center for assistance in the computor programing.

The writer is also indebted to Mr. R. M. Sanderson, editor of the Souris Plaindealer for providing the weather records of the town of Souris, Manitoba. Special thanks to Mr. and Mrs. J. V. Hodgson, Dand, Manitoba, for their hospitality, and to numerous residents in the Dand-Souris area.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Slope profiles were measured at systematic intervals along the sides of a former glacial spillway in south west Manitoba. The profiles were grouped according to their location or relation to various physical conditions. A normal distribution analysis of the frequency of occurrence of the maximum angles present in each profile of each group, plus an analysis of the variance between the means of these groups enabled the variables which had influenced the development of the valley slopes to be determined.

The results indicated that the profiles located on lake bordered (riparian) slopes were significantly different from those profiles on slopes which are not adjacent to lakes. Within the riparian profile group, those profiles which are orientated towards either the prevailing wind or the secondary wind are significantly different from those profiles not facing these wind directions.

A statistical analysis of selected profile parameters revealed that i) there are basic correlations between parameters and these correlations are common to all the measured profiles, and b) that each of the significant profile groups have correlations which are unique. It is likely that these results may apply in other landscape conditions, but the universality of these conclusions requires further investigations.

CHAPTER 1

THE PROBLEM AND DEFINITION OF TERMS

This thesis is a quantitative study of selected geomorphological characteristics of the valley sides of a former glacial spillway in southwest Manitoba.[1]

1. THE PROBLEM

Delimitation of the Problem

The objectives of the study were, 1) to measure profiles of the sides of the valley, 2) to apply standard statistical techniques in the analysis of the data to determine what relationships and differences exist in the morphometry of the valley sides, 3) to attempt to relate any significant differences found within the data to possible slope forming processes or other causal factors.

Importance of the Study

Quantitative methods and the use of statistics as a tool in the analysis of data is a recent development in geomorphological studies.[2] The aim of these new techniques is to express the relation of process to landform development.[3] Systematic measurements of the landforms are necessary if

---

[1] See the location map, page 2.

[2] Ian Burton, "The Quantitative Revolution and Theoretical Geography," Canadian Geographer, V11,4,1963,p.154-155.

[3] Arthur N. Strahler, "Davis' Concept of Slope Development Viewed in the Light of Recent Quantitative Investigations," Ann. Assoc. Am. Geog., 40, 1950, p. 209.

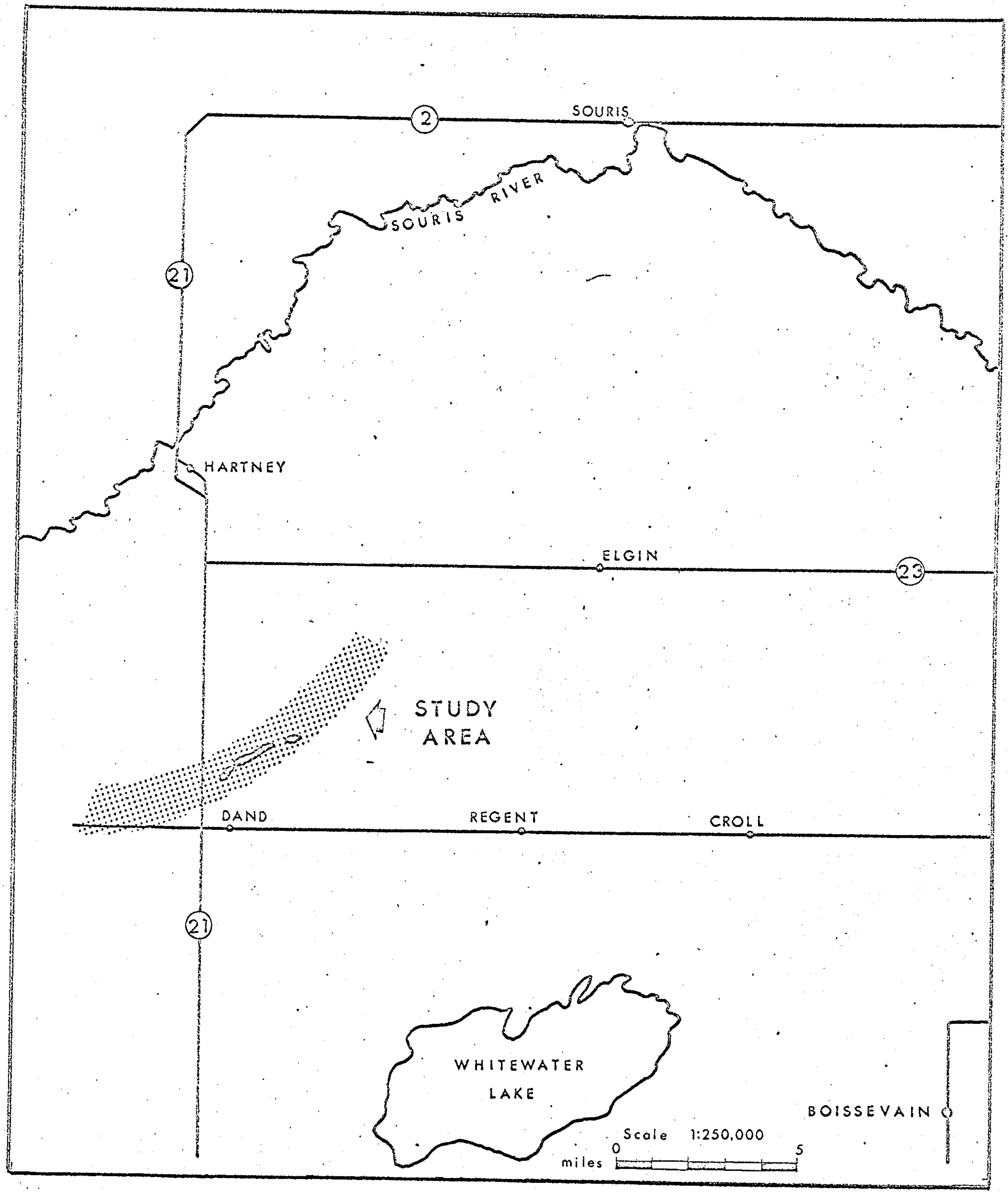


Fig. 1

Location Map

reliable comparisons are to be made between the different parts of the landscapes.

It is hoped that the results of this study will provide some insight into the relationship which exists between process and landform development in southwest Manitoba.

2. DEFINITION OF TERMS

The following definitions are adapted from those of Anthony Young,[4] R. A. Savigear,[5] or R. S. Waters,[6] unless otherwise noted.

Slope segment. A slope segment is the rectilinear portion of a slope profile.

Slope element. A slope element is the curved portion of a slope profile and may be either convex or concave.

Micro segment or micro element. These are segments or elements which are too small to be represented on the field base map.

Slope profile unit (or slope unit). A slope unit is either a slope segment, a slope element, or a micro element or micro segment.

---

[4] Anthony Young, "Some Field Obsevations of Slope Form and Regolith, and Their Relationship to Slope Development", Trans. & Papers, Inst. Br. Geog., 32, 1963, p.3.

[5] R. A. Savigear, "A Technique of Morphological Mapping", Ann. Assoc. Am. Geog., 55, 1965, p. 517.

[6] R. S. Waters, "Morphological Mapping", Geography, 43, 1958, p. 13.

Maximum slope unit (maximum slope). The maximum slope unit or maximum slope is the unit in a profile which contains the steepest angle in that profile.

True slope. The true slope of a slope unit is the direction and/or the angle of slope which is measured perpendicular to the contour lines.

Break of profile slope. The break of profile slope is an angular discontinuity between slope units.

Change of profile slope. The change of profile slope is a curved discontinuity between slope units.

Riparian.[7] The term riparian, as used in this study, refers to the portion of the valley sides which are adjacent to the small lakes found along the valley bottom.

Non-riparian. Non-riparian in this study refers to the portions of the valley sides which are not adjacent to the lakes found within the valley.

3. ORGANIZATION OF THE THESIS

The text of the thesis is in general divided into three parts. The first section deals with the introductory material and includes the location, physical characteristics of the study area, and the methods used in collecting the slope data. The second part describes the methods used in preparing the data for statistical analysis by computer, and the theoretical

---

[7] Note that Webster's New Collegiate Dictionary (Thomas Allen Limited, Toronto, Ontario, 1960) defines riparian as "of, pertaining to, or living on the bank of a river, of a lake, or of a tide water".

justification for the statistical tests used in the analysis of the data. The final chapters of the thesis contain the results, a discussion of the results, and the conclusions.

CHAPTER II

DESCRIPTION OF THE STUDY AREA AND THE FIELD TECHNIQUES

This chapter includes a description of the location, the general conditions of soil, geology, climate of the study area, and a complete discussion of the methods which were used in the measurement of the profiles.

1. DESCRIPTION OF THE STUDY AREA

Location and general features

The valley is located just to the north of the small town of Dand in south west Manitoba.[1] The former spillway is twelve miles long and approximately a quarter mile wide. At the present time there are only intermittent streams flowing into it via tributary gullies. There is a minor discontinuous channel cut in the valley floor. It is understood from talks with the local residents that water flows in this channel and in the tributary gullies only during the spring run-off.

Within the valley are found four small lakes which are known locally as the Chain Lakes.

Selection of the Study Area

A portion of the valley about eight miles long was chosen for the study because it met the following conditions.[2]

---

[1]See Fig. 1, page 2.

[2]See Fig. 4, page 12 for the extent of the valley considered in the study.

a) it is an area in which the bedrock is essentially uniform,[3]

b) it is an area which has one predominant soil type,[4]

c) the relief of the valley appears to be fairly constant on a 1:50,000 scale topographic map,[5, 6]

d) the vegetation in the valley is mainly grasses and low shrubs which would allow easy measurement of the valley side profiles,[7]

e) there is enough variation in the orientation of the valley to allow an examination of the effect of aspect on the formation of the valley slopes.

It was important that there should be uniformity in the variables of lithology, soil, vegetation, climate and relief since in a small region "slopes tend to approach a certain equilibrium angle appropriate to those controlling factors".[8]

---

[3] For the general geology of the area see Map 1166, Geology Assiniboine River Sheet, Geological Survey of Canada, 1965.

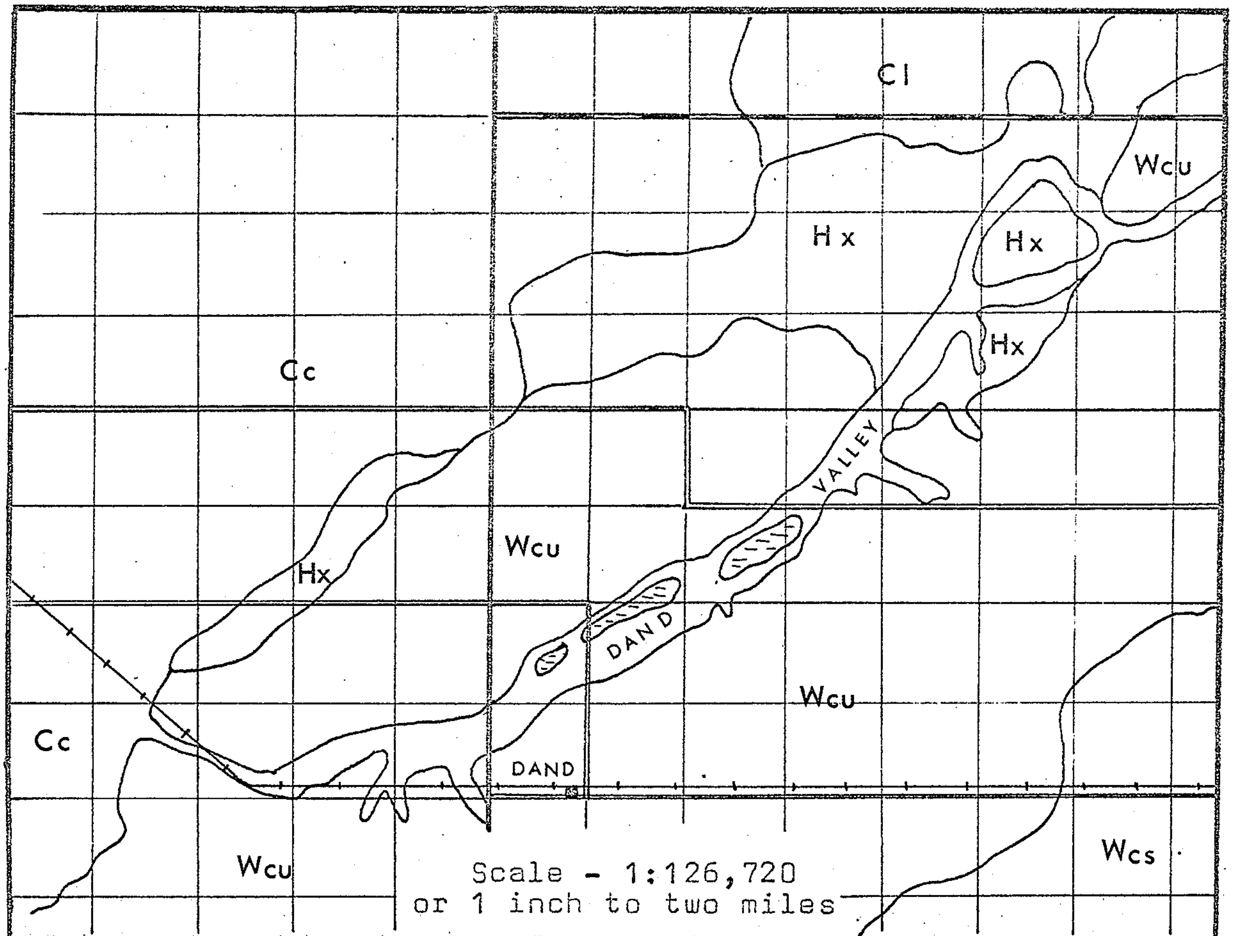
[4] See Fig. 2, page 8.

[5] National Topographic Series, Maps 62F/7 East (Hartney) and 62F/8 West (Elgin).

[6] Subsequent analysis of the valley side heights has shown that there is no significant difference between the means of the various portions of the valley. See page 55 for the results of this analysis.

[7] See Fig. 3a and 3b, page 9.

[8] Arthur N. Strahler, "Equilibrium Theory of Erosional Slopes Approached by Frequency Distribution Analysis, Am. J. Sci., 248, 1950, p. 681.



LEGEND*

Dark Brown soils developed on till

- Wcu - Waskada Heavy Loam to Clay Loam (undulating phase)
- Wcs - Waskada Clay Loam (smooth phase)

Black Earth soils developed on Mixed Till and Water Deposits

- Hx - Heaslip, (gravelly water worked till and weathered shale)

Lacustrine Soils

- Cc - Carroll (clay loam to fine loam)
- Cl - Carroll (very fine sandy loam)

*After the Reconnaissance Soil Map of South-Western Manitoba.

Fig. 2

Soil Map of the Dand Valley and Surrounding Area.

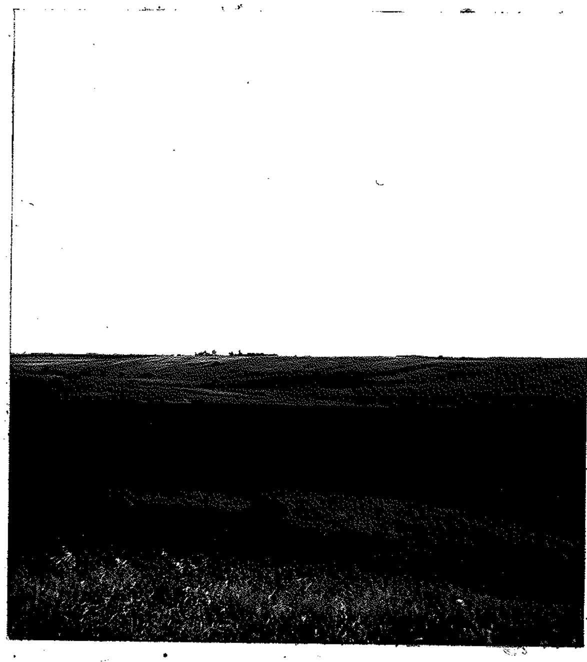


Fig. 3 (a). A view of the northeast part of the Dand Valley. Note typical vegetation.

Fig. 3 (b). Gully dissection on the north valley side.

The limits of the study area were determined by an inspection of the relief during the field work. The valley stops rather abruptly at the southern end and the boundary was easy to place. There is a section which has considerably lower relief in the northeastern end and the limit was placed before this section was reached.

Within the limits of the study area the profiles were measured regardless of the local relief. This was done in order to maintain a fairly uniform spacing between the profiles.[9]

Geology

The Dand Valley is located in an area which has glacial till overlying shale bedrock.

The shale is the hard siliceous Odanah beds of the Riding Mountain Formation, which also forms the cap rock of the Manitoba Escarpment.[10] Kirk states that, "with the exception of the underlying Riding Mountain Beds which are uncovered in the deep valleys of the Assiniboine, Souris and Pembina Rivers, and of overlying beds in the Turtle Mountain, the Odanah Shale is the only bedrock seen in the southwestern part of Manitoba."[11]

---

[9] See page 15 in the section on field techniques for a description on the spacing of the profiles.

[10] J.F. Davies, et al., Geology and Mineral Resources of Manitoba, Prov. of Man., Dept. of Mines and Nat. Resources, p.145, 1962.

[11] S.R. Kirk, "Cretaceous Stratigraphy of the Manitoba Escarpment", Geological Survey of Canada Summary Report, part B, p.126, 1929.

Near Dand these shale beds have a thickness of about five hundred feet[12] and have a fairly well developed joint system.

In general the Cretaceous shale beds have a strike of between N42W and N48W and have a very gentle dip to the southwest of approximately 8.8 to 9.3 feet per mile.[13]

The till overlying the shale is described as being a:

> concrete-like mixture of clay, silt, sand, gravel and boulders occurring as ground moraine, end moraine, and recessional moraine... The upper 20 to 30 feet of till is a greyish buff and is commonly known as 'yellow clay'. Beneath this is a more compact blue grey till commonly known as 'blue clay'. Both contain lenses of sand and gravel.[14]

A more detailed description of the surficial deposits is given by Elson on his map of the surficial geology of the Virden Map Sheet.[15] A summary of this is presented in Fig. 4, page 12.

According to Elson, the Dand Valley is situated in an area consisting mainly of ridged moraine.[16] He describes this deposit as being a sandy to silty till which is characterized by minor ridges 3 to 20 feet high.

---

[12] Personal communication, 1966, B. Bannatyne, Geologist, Manitoba Mines Branch.

[13] R.S. Kirk, op. cit., p.132B.

[14] R.A. Freeze, Ground Water Probability Map, Virden Sheet (east half), 1962.

[15] J.A. Elson, Surficial Geology, Virden Sheet, Preliminary series, Map No. 39-1961. See Fig. 4, page 12.

[16] Ibid.

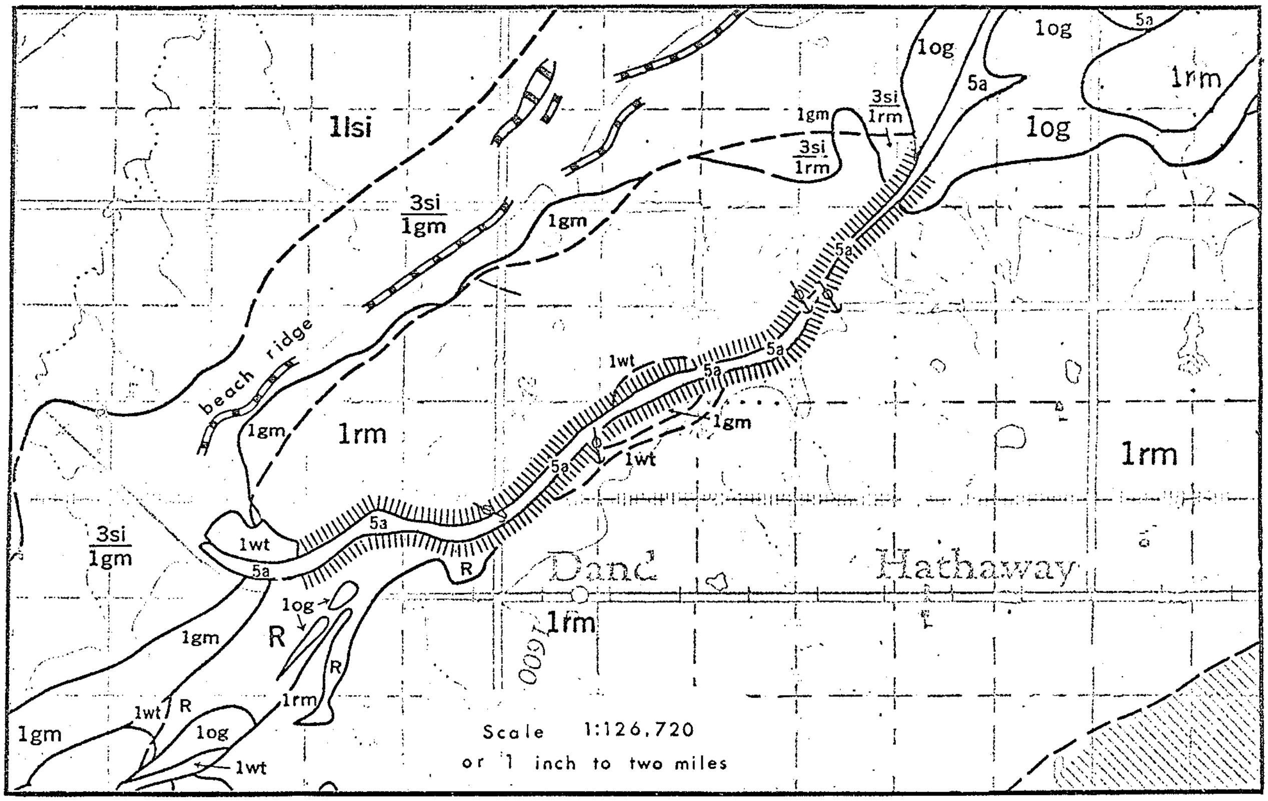


Fig. 4

Surficial Geology of the Dand Valley and Surrounding Area*

1wt	- water worked till
1gm	- ground moraine
1rm	- ridged moraine
1lsi	- silt
1og	- outwash containing pebble, gravel and sand
3si/1rm	- silt overlying ridged moraine
3si/1gm	- silt overlying ground moraine
5a	- alluvium
R	- area of shale outcrops

The portion of the valley considered in this study is indicated by the dark hachure lines.

* After J. A. Elson, Surficial Geology, Virden Sheet, Preliminary Series Map 39-1961.

Soils

The portion of the valley on which the profile measurements were taken is situated in an area which has two soil types, the Waskada and the Heaslip Complex.[17]

The Waskada covers the whole of the mapped area except in the northern tip where the valley extends into the Heaslip Complex. It is interesting to note that the boundaries of the outwash (log) and the Silt over ridged moraine (3Si/1rm) on Elson's map of surficial geology[18] are almost the same as those boundaries of the Heaslip Complex in this part of the valley.

Climate

According to the report on "The Climates of Canada for Agriculture" the Dand Valley is situated in an area which has the following characteristics;[19] i) the mean January temperature is approximately 2°F., ii) the mean July temperature is approximately 67°F., iii) the annual precipitation is about 19 inches, and iv) there is an overall yearly moisture deficiency.

2. FIELD TECHNIQUES

Method of Profile Measurement

The valley side profiles were measured with a clinometer by which the sightings and the reading of the slope angle are done simultaneously. A pole with the eye level height marked

---

[17] See Fig. 2, page 8.

[18] Elson, *op. cit.*

[19] ARDA, The Climates of Canada for Agriculture, Canada Land Inventory Report #3, Dept. of Forestry and Rural Development, Table #1, p.20-21, 1966.

on it was used for the sightings to ensure the accuracy of the measurements. In taking a slope reading the pole was placed at the lower limit of the slope unit and the sighting to the eye level mark on the pole was taken from the upper limit of the slope unit. This was the procedure followed in obtaining the angles for each of the slope units in each of the valley side profiles.

According to the manufacturers of the clinometer[20] the accuracy is such that the angles can be read directly to one degree and the angle can be estimated to ten minutes of one degree. In practice it was found that reliable estimates below one half a degree were difficult to make since even a fairly light wind was enough to cause the hand to move slightly which in turn would cause the indicator to move. For this reason the slope readings were taken only to the nearest half-degree.

Air photograph enlargements at a scale of 1:4,900 were used as a field base map for the plotting of the upper and lower limits of the profile units, and the recording of the angles of the slope units. Conventional symbols were used to record, i) if there was a break or a change of slope between the profile units, ii) the nature of the surface of each unit, i.e. whether it was irregular or fairly smooth, iii) whether the unit was a segment, a convex element or a concave element, and iv) the angle and the direction of the true slope of each unit.[21]

---

[20] Suunto Co., Helsinki, Finland.

[21] See the maps in the folder at the back for the location of each profile and the position of the units in the profiles.

For this study the top of the valley side or top of a profile was considered to be either where there was a zero slope reading or where there was a reverse slope reading. The base of each profile was considered to be where there was a zero slope on the valley floor. In some instances it was necessary to change the orientation of the slope units in order to have the profile extend from the top to the bottom of the valley side. This procedure is justified since the slope readings are taken orthogonal to the contours which means that the trace of the profile represents the most probable route or line of movement of material down the valley side.

The profiles were measured only on parts of the valley sides not directly under the influence of gullying. This procedure was adopted to ensure that none of the profiles had been modified by the process of gullying, thus simplifying the analysis and interpretation of the data.

An attempt was made to have a fairly uniform spacing of the profiles; approximately 250 feet between adjacent profiles if the area occupied by gullies is neglected. It was not possible to keep a strict spacing due to, i) the presence of scrub or brush which blocked the line of sight in some cases, and ii) the size and positions of the gullies. Note that in many instances a profile was measured on a nearly straight portion of the valley side which was bounded on both sides by gullies. In situations where there was a choice between spacing the profiles either too close together or too far apart it was the practise to adopt the closer spacing, (i.e. they were spaced closer than the 250 foot interval).

The spacing of the profiles was important since the statistical analysis of the data ideally requires a random sample. It is felt that the measurements obtained from this modified systematic (i.e. regular interval) method of sampling meets the statistical requirement of randomness.

There are small wave cut vertical cliffs (segments) at the base of most of the riparian profiles. Although they were usually only three to four feet high, these were measured and were taken into account in the calculation of the total height of the valley side at the point where the profile was measured.

Problems Encountered During the Field Work

The problems which were encountered during the field work were as follows: a) It was very difficult to keep the clinometer sufficiently motion-free in gusty winds to get a reliable slope reading and even in lighter winds it was felt that readings would give a false impression of accuracy if they were taken to more than a half-degree, b) The problem of the proper spacing of the profiles, c) The problem of the location of the boundaries of the slope units when these had a low angle of slope and were gently convex or gently concave.

The first two points have already been discussed under the methods of profile measurement, the third requires further elaboration.

In the Dand Valley the usual situation was that the unit containing the maximum slope angle was rectilinear while the units near the base of the profile or near the top of the profile were concave and convex respectively. This means that the problem of the location of the slope unit boundaries was also that of the correct location of the start and finish of each profile. It is recognized that the subjective nature of the placing of these boundaries might result in their being placed in a slightly different position by someone else measuring the same profile.[22] The changes in the profile parameters, such as the length of the mean valley side gradient or the length of the slope unit in question, would not be very great in most cases and probably would not significantly affect the results of the analysis of the data.[23]

---

[22] Cuchlaine A.M. King, (Techniques in Geomorphology, London; Edward Arnold, 1966, p.55) points out that, "Some features are very distinct and all surveyors would place them identically, but the more subtle changes could be mapped differently by different workers".

[23] For a discussion of the problem of locating profile boundaries, see A.F. Pitty, "Some problems in the location and delimitation of slope-profiles", Zeitschrift Fur Geomorphologie, NfBd 10, Haft 4, 1966, pp454-61.

CHAPTER III

ANALYSIS OF DATA

This chapter is divided into three sections. The first deals with the calculation of the various parameters which were used for the statistical analysis. The second part describes the theory on which the statistical tests are based and outlines the steps of the statistical analysis. The last section consists of a description of the reasons behind the selection of the profile groups for the analysis.

1. Preliminary Analysis

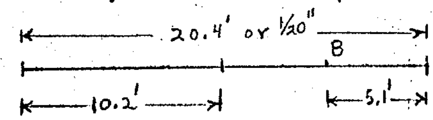
Calculation of the Profile Parameters

The basic data which was collected in the field consists of the angle of slope for each unit in the profile and the locations of the upper and the lower limits of each slope unit. This information was recorded on air photograph enlargements of the study area.

The first step in the calculation of the slope parameters was to measure the map horizontal distance (M.H.D.)[1] of each

---

[1] The map horizontal distance was measured in units of 1/20 of an inch and estimated to the nearest half (i.e. 1/40 of an inch). At the scale of the air photographs, 1:4,900, 1/20 of an inch is equivalent to 20.4 feet on the ground. Since the distances were estimated to the nearest 1/40 of an inch, this means that at the most a measurement would be out 5.1 feet, if the slope unit boundary was located at point B in the diagram. Generally the slope unit limits would be at some other point and the accuracy would therefore be within 5.1.



slope unit. These measurements were taken with a standard triangular engineering rule from the air photograph enlargements used as base maps in the field work. The M.H.D. values were then converted to distances in feet. This method was adopted since the author was unassisted in the field work and time was a critical factor.

With the M.H.D. and the angle of the slope for each unit it was possible to calculate the following information for each profile.[2]

a) the true length (distance on the ground) of each of the slope units.

b) the height of each slope unit.

c) the height of the valley side at the point where the profile was measured.

d) the angle of the average or mean valley side gradient between the top and the base of the profile. This will be referred to as the mean valley side gradient.

e) the length of the mean valley side gradient.

From the above, and from the M.H.D. values and the slope angles, the following profile parameters were selected for statistical treatment.[3]

a) the maximum slope angle in each profile, referred to as the maximum slope angle.

b) the length of the unit containing the maximum slope angle, referred to as the length of the maximum slope unit.

c) the height of the maximum slope unit.

d) the height (i.e. amplitude of relief) of the valley side.

[2, 3] These calculations were done by computer. See Appendix B, Section (i) for the details of the calculations, for a table of the computer output of slope parameters, and the fortran program.

e) the angle of the mean valley side gradient.

f) the length of the mean valley side gradient.

2. STATISTICAL ANALYSIS

Theory Behind the Analysis

As a basic premise, it was assumed that a hillslope is essentially an open system in which the forces removing material are adjusted to the forces supplying material.[4] The steepest part of a slope profile "will reflect the maximum angle which can be maintained, and is an indication of the opposed forces in the equilibrium relationship."[5]

The maximum angle can be considered to be the basic parameter and it will provide an indication of the processes which have operated to produce a particular slope. The processes are dependent on many physical conditions, such as climate, lithology, soil type, and vegetation.[6]

Strahler has stated that the frequency distribution of the maximum angle which is developed in an area with similar lithology, climate, soil type, vegetation, relief, and stage of development, willbe characterized by a normal distribution.[7]

---

[4]Allan D. Howard, "Geomorphological Systems - Equilibrium and Dynamic", Am. J. Sci., V.263, 1965, p. 303.

[5]Arthur N. Strahler, "Equilibrium Theory Of Erosional Slopes Approached by Frequency Distribution Analysis", Am. J. Sci., V. 248, 1950, p. 677.

[6]Richard J. Chorley, "Climate and Morphometry", J. Geol., 1957, p.628.

[7]Strahler, Op. Cit., p.675 & 685. See also, Strahler, "Davis' Concept of Slope Development Viewedin the Light of Recent Quantitative Investigations", Ann. Am. Assoc. Geog., V. 40, 1950, p. 212.

This concept provides a theoretical foundation for the analysis of the the slope data. By grouping the slope profiles on the basis of their relationship to various known physical conditions, or on the the basis of suspected variations in process, and then by testing to see if these groups have normal distributions, it should be possible to determine which variables have been important in the formation of the slopes in a given area. This is especially true if, as in the study area, it is possible to keep some of the variables constant.

It is hoped that if the passive variables, such as lithology, soils, etc., are constant but there are different processes operating, that changes in the processes would be reflected in the maximum angles which have been formed. Further, if the processes were constant, but the passive variables were to change, this change would also be reflected in the maximum angles.

For example, in an area with two different rock types and with all other factors constant, profiles located on each of the rock types would develop a set of maximum angles with a normal distribution of their frequency of occurrence, but they would each have a different mean maximum angle. Each mean value would be characteristic of the rock type on which it was developed and they would presumably be significantly different from each other.

The next step would be to test to see whether or not there was a significant difference between these mean values. If there are more than two profile groups, such as there are in this study, the best test for a difference between means is an analysis of variance.

If these hypotheses are correct then, in a given area which has several of the variables constant, by a careful selection of the profiles into groups it should be possible to determine which of the remaining variables are important in the slope formation.

The following combinations between the passive variables and processes are possible:

1) that the passive variables and the processes are both constant throughout the study area. This is definitely not the case as there are different surficial deposits, lake bordered and non-lake bordered slopes, and different orientations of the profiles.

2) that the passive variables are constant but processes change, e.g. riparian vs. non-riparian.

3) that processes are constant but the passive variables change.

4) that both the passive variables and the processes vary within the study area.

Each of the above possibilities could have a bearing on the development of the slope profiles. The selection of the profile groups was done with the aim of testing these various possibilities.

Statistical Tests and Their Use

The following is a summary of the steps of the statistical analysis of the data.

1) a chi-square test for the goodness of fit to the normal distribution.

2) determination of the mean values of the maximum angles in each of the profile groups.

3) an analysis of variance and an analysis of the least significant differences between the means of the maximum angle in each profile group.

4) a factor analysis for determining the degree of correlation between selected valley side profile parameters.

The chi-square test for the goodness of fit to the normal distribution was used to determine the profile groups that had normal distributions of their maximum angles. Once this was established, the mean was calculated for each of the profile groups with a normal frequency distribution. The analysis of variance and the least significant difference test were used to determine which profile groups had a significant difference between the mean values. Finally, the degree of correlation was determined for selected pairs of valley side profile parameters.

Since the degree of correlation is in part dependent on the type of distribution present in the two variables in question, all the selected parameters were analyzed to ascertain which of four different types of normal distribution (arbitrarily chosen) best described the frequency distribution of the data. The distribution which best fit the data was used for each parameter in the correlation analysis. This choice was made for each parameter in each of the profile groups found to be a probable statistical population.

The type of distributions tested for were: i) arithmetic normal, ii) logarithnic normal, iii) square root normal, and iv) reciprocal normal.

Each of the above statistical tests has been briefly described in Appendix B.

3. SELECTION OF THE PROFILE GROUPS FOR ANALYSIS OF MAXIMUM ANGLES

The grouping of the profile for statistical testing was done on the basis of the location of the profiles relative to various characteristics or variables. These variables include, process, microclimate, rock type, soil type, and surficial geology. Each of these will be considered in turn with a description and the reasons for the selection of the profile groups.

Process

It was noticed during the field work that the riparian slopes had an overall convex profile, while the non-riparian profiles were typically convex-concave. This observation suggested that possibly different processes may be operating to produce these characteristic forms. It provided a basis for the division of the profiles into two main groups - riparian and non-riparian. This division was considered to be important and where possible, every other profile grouping was also divided on this basis.

Microclimate

The role of microclimate in the development of slope profiles and in producing asymmetry in valley side is largely undetermined and controversial. Packer, in his study of the slopes in southern Ontario, concluded that orientation (the fundamental factor of microclimate) had no bearing on the angle of slope which was developed.[8] Melton suggests that no quantitative evidence has been offered to support or reject any one hypothesis.[9] He points out that there were only two quantitative studies of this question up to 1960 and that they produced opposite results.[10]

In the current study, the first division of the profiles was a general grouping according to their location on the north valley side (N.V.S.) or on the south valley side (S.V.S.).

The effect of orientation was then examined in more detail.[11] It was decided to group the profiles according to two factors in which slope orientation exerts an important influence, firstly with regard to insolation receipts, and secondly with regard to exposure to winds.

For the analysis of the profiles with respect to insolation receipts, it was decided to group them arbitrarily according to the following criteria, a) those profiles facing between 160 and 225 degrees azimuth[12] (this would only apply to the north

---

[8] R. W. Packer, "Stability Slopes in an Area of Glacial Deposition", Can. Geogr., VII, 1964, p.150.

[9] M. A. Melton, "Intravalley Variation in Slope Angles Related to Microclimate and Environment", Bull. Geol. Soc. Am., V.71, 1960, p. 134.

[10] Ibid., p. 134-135.

[11] See Appendix A, Section (ii) for a list of profile orientations.

[12] These orientation were chosen since the hottest part of the day is often in the early afternoon or mid-afternoon. The effect of the suns' rays would be the greatest during this period for the profiles at these orientations.

valley side), b) those N.V.S. profiles not facing between 160 and 225 degrees, c) those S.V.S. profiles facing between 340 to 0 to 45 degrees, and d) those S.V.S. profiles not facing between 340 to 0 to 40 degrees.

The second element of orientation, that of wind direction, was subdivided into prevailing winds and secondary winds. The effect of wind direction on slope development in the study area is difficult to assess accurately since the only weather records available for analysis are in towns which are about thirty miles from Dand.

A grouping was done on the basis of the regional prevailing wind, i.e. from the north west. It is possible that the slopes facing the wind would be subject to a greater drying effect in the summer. During the winter these slopes would be swept clean of snow which would leave less melt water available for the process of freeze-thaw in the spring, but there would also be greater frost penetration due to the lack of snow cover. The slopes not facing the prevailing winds may receive more snow accumulation due to their more sheltered position. This would result in less frost penetration since the snow would act as insulation, but there would also be more melt water available during the spring which might increase the effect of the freeze-thaw process. An arbitrary 50 degree range in orientation was chosen for grouping these profiles; this means that there is 25 degrees on each side of the orientation of the prevailing wind.

The prevailing wind probably causes wave erosion on the S.V.S. riparian profiles. A division of the above profile group into riparian and non-riparian may determine the effect of this wind direction on the development of the S.V.S. riparian slopes. It is also realized that there may be considerable funneling of winds (both prevailing and secondary) down the valley. But this is not of concern in this study, since the resulting wave action would be concentrated at the ends of the lakes rather than along the sides.

The following groups were selected on the basis of the prevailing wind direction; a) N.V.S. profiles facing between the azimuths of 110 and 160, b) N.V.S. profiles which are <u>not</u> facing between the azimuths of 110 and 160, c) S.V.S. profiles facing between azimuths 290 and 340, d) S.V.S. profiles which are <u>not</u> facing between the azimuths of 290 and 340, and e) the riparian and non-riparian divisions of the above groups.

The Souris weather records were examined to determine the secondary wind directions,[13] and two graphs were prepared which compared the maximum angles and the average maximum angle with the orientation of each profile[14] - one graph of the north

---

[13] See Appendix A, Section (iii) for a description of the analysis of the wind directions in the Souris area.

[14] The average maximum angle was calculated for each azimuth on which a maximum angle was plotted. This value was determined by averaging all the maximum angle located within 5 degrees azimuth on each side of the orientation in question. For example, on the north valley side there is a maximum angle of 11 degrees at azimuth 119. All the values of the maximum angles located between 114 and 124 were averaged and this value was plotted at azimuth 119.

This method is a modified version of that used by J.T.Hack and J.C.Goodlett, (<u>Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians</u>, U.S.Geol. Surv. Prof. Paper #347, 1960, p.36.)

valley side riparian profiles and one of the south valley side riparian profiles. Only the riparian profiles were graphed since a secondary wind would affect these profiles through increased wave action.

These graphs indicated that there is a distinct increase in the value of the average maximum angle of the north valley side profiles between the azimuths of 105 and 145.[15] These azimuths are nearly coincident with a south east secondary wind direction which is indicated in the results of the analysis of the Souris weather data. In contrast, the average maximum angle on the south valley side remained nearly uniform. There is a pronounced dip in the curve at azimuth 330, but as this could not be related to any physical feature and since there were only four profiles involved, it was disregarded.

The following profile groups were separated on the basis of the results of these studies.

a) N.V.S. riparian profiles which face between azimuths 105 and 145.

b) N.V.S. riparian profiles which do <u>not</u> face between azimuths 105 and 145.

c) all the S.V.S. riparian profiles . (Note that this already constitutes a group that was selected previously.)

d) all the S.V.S. riparian profiles <u>plus</u> those N.V.S. riparian profiles which face between azimuths 105 and 145. These profiles have similar average maximum angles, i.e. the average of the S.V.S. riparian profiles is 17.8 and the average of the N.V.S.

---

[15] Note that there are no N.V.S. riparian profiles having an orientation less than azimuth 105.

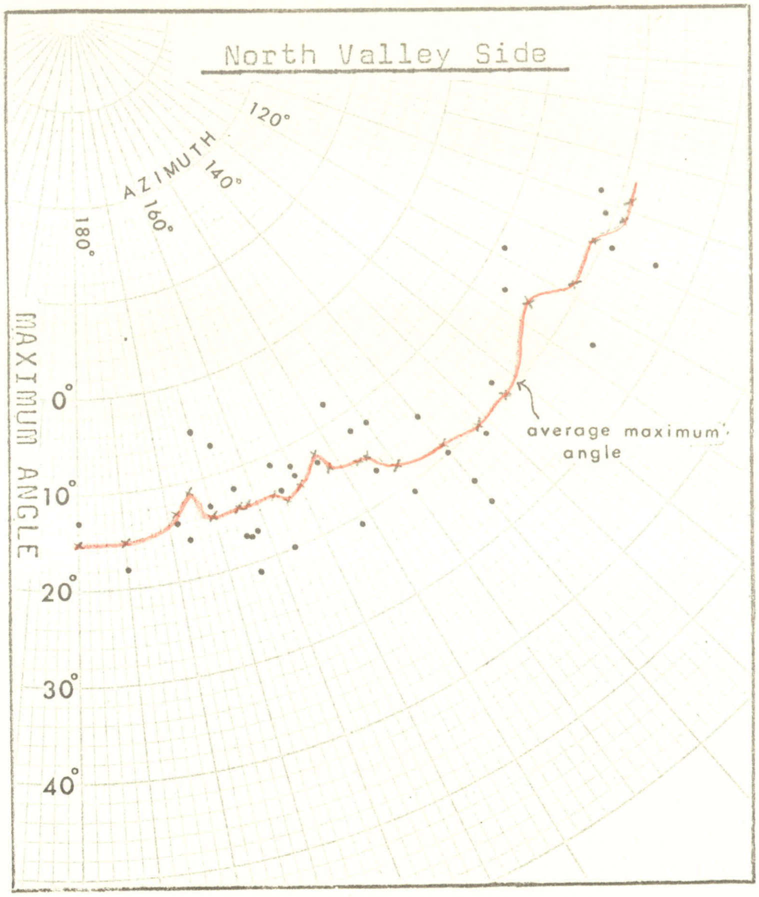


Fig. 5

Orientation vs. Maximum Angle (actual and average values).*

* For method of determining the average maximum angle values see page 27, footnote 14.

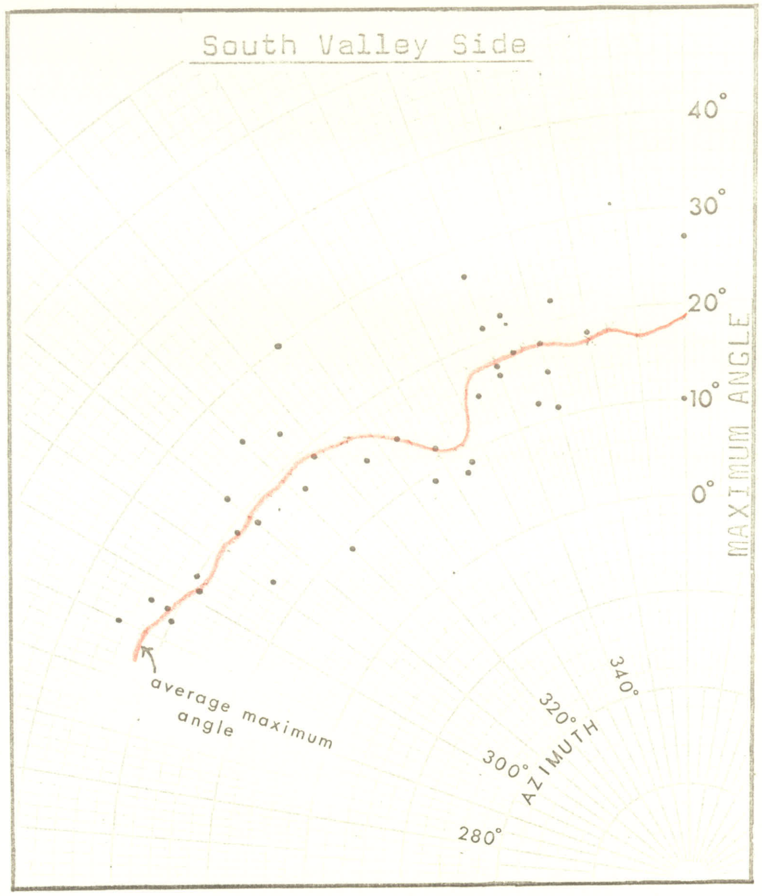


Fig. 6

Orientation vs. Maximum Angle (actual and average values).*

* For method of determining the average maximum angle values see page 27, footnote 14.

riparian profiles facing between azimuth 105 and 145 is 19.4. (The average of the N.V.S. riparian profiles <u>not</u> facing between azimuths 105 and 145 is 14.2).

The non-riparian profiles were also grouped on the basis of those azimuths that were found to be important for the riparian profiles. A graphic interpretation was not attempted since any differences which might be present would probably be too small to be adequately portrayed by this technique.

The following list of profile groups is presented as a summary of the microclimatic conditions which were considered in selecting groups to be tested for normal distributions.

<u>I. General Location</u>

i) North Valley Side

1) all profiles

2) all non-riparian profiles

3) all riparian profiles

ii) South Valley Side

1) all profiles

2) all non-riparian profiles

3) all riparian profiles

<u>II. Orientation With Respect to Insolation</u>

i) North Valley Side

1) all profiles which face between azimuths 160 and 225

2) all profile which do <u>not</u> face between azimuths 160 and 225

3) the riparian profiles which face between azimuths 160 and 225

4) the non-riparian profiles which face between azimuths 160 and 225

5) the riparian profiles which do <u>not</u> face between azimuths 160 and 225 .

6) the non-riparian profiles which do <u>not</u> face between azimuths 160 and 225

ii) South Valley Side

1) all profiles which face between azimuths 340-0-45

2) all profiles which do <u>not</u> face between azimuths 340-0-45

and the riparian and non-riparian divisions of these groups, similar to part i).

III. Orientation With Respect to Wind Direction

i) North Valley Side

1) all profiles which face between azimuths 110 and 160

2) all profiles which do <u>not</u> face between azimutha 110 and 160

and the riparian and non-riparian divisions of these groups.

3) the N.V.S. riparian profiles which face between azimuths 105 and 145

4) the N.V.S. riparian profile which do <u>not</u> face between azimuths 105 and 145

and the non-riparian counterparts of the above two groups.

ii) South Valley Side

1) all the riparian profiles

2) all profiles which face between azimuths 290 and 340

3) all the profiles which do <u>not</u> face between azimuths 290 and 340

and the riparian and non-riparian divisions of the above two groups.

iii) the N.V.S. profiles which face between azimuths 105 and 145 <u>plus</u> all the S.V.S. riparian profiles

Rock Type

The Dand area is underlain by only one rock type, the Odanah Shale (See chapter 2 for a description of the geology of the study area). It is only necessary to examine one profile grouping - that of all the profiles measured in the study area. If these do not have a normal distribution of the maximum angles then it can be concluded that there are other controls over the development of the maximum angle in a profile.

Soil Type

Soil type was also used as a basis for the grouping of profiles. The study area is largely located in one soil type - that of the Waskada (See Figure 2) and all profiles which are situated thereon were tested for normal distribution.

A small portion of the northeast end of the study area contains soils belonging to the Heaslip Complex. Unfortunately, there were too few profiles on these soils to permit testing. However, these profiles were omitted from all other profile groups since profiles on different soils could be expected to develop a different set of maximum angles which might adversely affect the results if they were included.

As with the other major groups, the profiles on the Waskada soil types were also divided into those on the north valley side and those on the south valley side, as well as the riparian and non-riparian subdivisions of each of these.

Surficial Geology

Elsons' map of the surficial geology in the area provided a basis for testing to see if the type of surficial deposit has played a role in slope formation in the Dand Valley.[16] Profiles were grouped according to their position on the various deposits. Those deposits which were considered are: ground moraine, ridge moraine, and an area described by Elson as shale outcrop covered by a thin layer of till. There were too few profiles on any of the other deposits to warrant further subdivisions. Also, the additional complication of grouping on the basis of microclimate as well as surficial geology was not attempted.

The following are the profile groups selected for normal distribution analysis on the basis of surficial deposits.

1) all profiles on ridge moraine for i)all the study area, ii) the north valley side, iii) the south valley side, and iv) the riparian and non-riparian subdivisions of these groups.

2) all profiles located on ground moraine. These are all found on the south valley side and they are all riparian except one.

3) all profiles located on the are of shale covered with till. These are all on the south valley side and are all non-riparian.

4) all non-riparian profiles less those profiles located on the area of shale covered with till.

Discussion

It is obvious on examining the various profile groups, which were selected for normal distribution analysis, that many appear two or more times. This is due primarily to having selected the study area where there was uniformity about several physical variables. There is no point in listing all the groups for which this duplication occurs, but it is necessary to mention those groups for which this similarity is not readily apparent.

For example, the group 'all non-riparian profiles less those on the area of shale covered with till' contains essentially the same profiles as the group 'all non-riparian profiles located on ridge moraine in the study area', the exception is profile #65 in the latter group which is located on ground moraine. These two groups are considered as being the same for the purpose of the statistical analysis.

Also, the groups 'all north valley side non-riparian profiles located on ridge moraine' and 'all the north valley side non-riparian profiles' contain the same profiles.

By coincidence the following profile groups were discovered to contain essentially the same profiles, although they were selected for completely different reasons:

1) the groups 'all S.V.S. profiles which face between azimuths 290 and 340' and 'all S.V.S. profiles which do <u>not</u> face between azimuths 340-0-45' contain the same profiles with one exception - profile #23 which has an azimuth of 287 degrees. These two groups were considered to be the same for statistical purposes.

This means that the following groups also contain the same profiles:

a) the ' S.V.S profiles <u>not</u> facing between azimuths 290 and 340' and 'the S.V.S. profiles which face between azimuths 340-0-45'

b) all the riparian and non-riparian subdivisions of these groups.

2) the groups 'all N.V.S. profiles which face between azimuths 110 and 160' and 'all N.V.S. profiles whcih do not face between azimuths 160 and 225' contain essentially the same profiles. The exceptions are profiles #16, with an azimuth of 90 degrees, and #26, with an azimuth of 109 degrees. These two groups were considered to be identical for the statistical analysis, as are their riparian and non-riparian subgroups.

Note that profiles which contained a maximum angle of greater than 35 degrees, were omitted from all of the profile groups. These were removed for the reason that, since these angles are much higher than any of the other values, if they were included it would result in a distorted value of the mean and also possibly distort the frequency distribution of the maximum angles.

A complete list of the profile groups which were analyzed for a normal frequency distribution is found in figure 7, chapter IV. The results of this analysis and a list of the profiles in each group are also found in this table.

Chapter IV

Results and Discussion

1. The Analysis of the Maximum Angles in the Profiles for Normal Distributions

Each of the profile groups selected in the previous chapter was tested to see if the frequency of occurrence of the maximum angles in each of the groups had a normal distribution. The results of this analysis is presented in Figure 7.[1]

These results indicate that all of the profile groups that were selected do not have a normal distribution of the frequency of occurrence of their maximum angles (henceforth referred to as normal distribution of the maximum angles). This would suggest that there may be more than one statistical population of the maximum angles in the study area.

I do not propose to discuss in detail each one of the profile groups, but to describe enough of them to illustrate the value of this analysis.

Since all the profiles (group #2)[2] do not have a normal distribution but all the non-riparian (group #3) and all the riparian profiles (group #4) do have a normal distribution of their maximum angles, it can be expected that any subdivisions of these two later groups will also be normally distributed and that any groups which are composed of profiles from both riparian

---

[1] A description of the chi-square test for the goodness of fit to the normal distribution is given in Appendix B, section ii.

[2] These refer to the profile group numbers listed in Figure 7.

Fig. 7 Profile Groups Selected for Testing for Normal Distributions of the Frequency of the Occurrence of the Maximum Angle in Each Profile

No.	Profile group Title	Profiles in Group	Total	Chi-square Value	Significant at P.0
1	All the measured profiles	North Valley Side (N.V.S.) 1 to 109* South Valley Side (S.V.S.) 1 to 113	222	70.24	No
2	All profiles except those located on the Heaslip Complex soil type	N.V.S. 7 to 109 S.V.S. 9 to 113	208	48.45	No
3	All the non-riparian profiles except those located on the Heaslip Soil Complex	N.V.S. 7 to 22, 28 to 30, 39 to 41, 68 to 109. S.V.S. 9 to 25, 32 to 34, 42, 43, 65, 73 to 113.	128	7.79	Yes
4	All the riparian profiles except those with a value greater than 30 degrees (except those with an extreme value).	N.V.S. 23 to 27, 31 to 38, 42 to 67, less extreme values of profile nos. 61 and 63. S.V.S. 26 to 31, 35 to 41, 44 to 64, 66 to 72, less the extreme values of profile nos. 38, 39, 54, and 68.	74	1.29	Yes

*These refer to the profile numbers as shown on the maps (Fig. 32) in the pocket at the back of the thesis.

No.	Profile Group Title	Profiles in Group	Total	Chi-square value	Significant at P.05
5	*All the north valley side (N.V.S) profiles less the riparian extreme values.	N.V.S. 7 to 109 less nos. 61 and 63.	101	12.51	No
6	All the south valley side (S.V.S.) profiles less the riparian extreme values.	S.V.S 9 to 113 less nos. 38, 39, 54, and 68.	101	15.83	No
7	All the N.V.S. non-riparian profiles	N.V.S. 7 to 22, 28 to 30, 39 to 41, 68 to 109.	64	7.16	Yes
8	All the S.V.S. non-riparian profiles	S.V.S. 9 to 25, 32 to 34, 42, 43, 65, 73 to 113.	64	1.92	Yes
9	All the N.V.S. riparian profiles less the extreme values	N.V.S. 23 to 27, 31 to 38, 42 to 50, 58 to 60, 62, 64 to 67.	37	8.51	Yes
10	All the S.V.S. riparian profiles less the extreme values	S.V.S. 26 to 31, 35 to 37, 40, 41, 44 to 64, 66, 67, 69 to 72.	37	3.46	Yes
11	all the N.V.S. profiles having an orientation between azimuths 160 and 225	N.V.S. 29, 32, 34 to 39, 43, 45, 46, 54, 55, 60, 75 to 94, 96, 105 to 109.	39	4.75	Yes

*The profiles located on the Heaslip Complex are omitted from this group and all subsequent groups.

No.	Profile Group Title	Profiles in Group	Total	Chi-square value	Significant at P.05
12	All the N.V.S. profiles having an orientation not between azimuths 160 and 225 (less extremes)	N.V.S. 7 to 28, 30, 31, 33, 40 to 42, 44, 47 to 53, 56 to 59, 62, 64 to 74, 79, 95, 97 to 104.	62	9.55	Yes
13	All the N.V.S. non-riparian profiles having an orientation between azimuths 160 and 225	N.V.S. 29, 39, 75 to 78, 80 to 94, 96, 105 to 109.	27	4.46	Yes
14	All the N.V.S. non-riparian profiles having an orientation not between azimuths 160 and 225	N.V.S. 7 to 22, 28, 30, 40, 41, 68 to 74, 79, 95, 97 to 104.	37	6.41	Yes
15	All the N.V.S. riparian profiles not having an orientation between azimuths 160 and 225 (less extremes)	N.V.S. 23 to 27, 31, 33, 42, 44, 47 to 53, 56 to 59, 62, 64 to 67.	25	2.78	Yes
16	All the N.V.S. riparain profiles having an orientation between azimuths 160 and 225	This group contains too few profiles to test.			
17	All the S.V.S. profiles having an orientation between azimuths 290 and 340 (less extremes)	S.V.S. 9 to 22, 24 to 33, 35, 36, 44, 47, 48, 50 to 53, 55, 57, 58, 60, 62 to 67, 69 to 84, 98 to 108, 112.	71	13.01	No
18	All the S.V.S. profiles not having an orientation between azimuths 290 and 340 (less extremes)	S.V.S. 23, 34, 37, 40 to 43, 45, 46, 49, 56, 59, 61, 85 to 97, 109 to 111, 113	30	3.18	Yes

No.	Profile Group Title	Profiles in Group	Total	Chi-square value	Significant at P.05
19	All the S.V.S. non-riparian profiles having an orientation between azimuths 290 and 340	S.V.S. 9 to 22, 24, 25, 32, 33, 65, 73 to 84, 98 to 108, 112.	43	2.86	Yes
20	All the S.V.S. non-riparian profiles not having an orientation between azimuths 290 and 340	S.V.S. 23, 34, 42, 85 to 97, 109 to 111, 113.	21	4.86	Yes
21	All S.V.S. riparian profiles having an orientation between azimuths 290 and 340 (less extreme values)	S.V.S. 26 to 31, 35, 36, 44, 47, 48, 50 to 53, 55, 57, 58, 60, 62 to 64, 66, 67, 69, 70 to 72	28	2.73	Yes
22	All S.V.S. riparian profiles not having an orientation between azimuths 290 and 340 (less extreme values)	This group contains too few profiles to test.			
23	All N.V.S. riparian profiles having an orientation between azimuths 105 and 145 (less extreme values)	N.V.S. 23 to 27, 47, 50, 51, 53, 58, 59, 64 to 67.	15	2.01	Yes
24	All N.V.S. riparian profiles not having an orientation between azimuths 105 and 145	N.V.S. 31 to 38, 42 to 46, 48, 49, 52, 54 to 57, 60, 62.	22	4.06	Yes

No.	Profile Group Title	Profiles in Group	Total	Chi-square value	Significant at P.05
25	All N.V.S. riparian profiles having an orientation between azimuths 105 and 145, plus all the S.V.S. riparian profiles (less extremes)	N.V.S. 23 to 27, 47, 50, 51, 53, 58, 59, 64 to 67. S.V.S. 26 to 31, 35 to 37, 40, 41, 44 to 53, 55 to 64, 66, 67, 69.	52	1.97	Yes
26	All N.V.S. non-riparian profiles having an orientation between azimuths 105 and 145	N.V.S. 7, 9 to 22, 28, 68 to 74, 98 to 104.	30	3.46	Yes
27	All N.V.S. non-riparian profiles not having an orientation between azimuths 105 and 145	N.V.S. 8, 29, 30, 39 to 41, 75 to 97, 105 to 109.	34	4.06	Yes
28	All profiles which are located on Elsons' ridge moraine (lrm) surficial deposit	N.V.S. 7 to 50, 58 to 60, 62, 64 to 109. S.V.S. 9 to 37, 40 to 53.	137	17.49	No
29	S.V.S. profiles located on ridge moraine	S.V.S. 9to 37, 40 to 53.	43	6.49	Yes
30	N.V.S. profiles located on ridge moraine	N.V.S. 7 to 50, 58 to 60, 62, 64 to 109.	94	15.37	No
31	S.V.S. non-riparian profiles located on ridge moraine	S.V.S. 9 to 25, 32 to 34, 42, and 43.	22	3.10	Yes
32	S.V.S. riparian profiles located on ridge moraine (less extremes)	S.V.S. 26 to 31, 35 to 37, 40, 41, 44 to 53.	21	2.72	Yes
33	N.V.S. nonriparian profiles located on ridge moraine	This group is the same as all the N.V.S. non-riparian profiles (less those on Heaslip Complex).			

No.	Profile Group Title	Profiles in Group	Total	Chi-square value	Significant at P.05
34	N.V.S. riparian profiles located on ridge moraine	N.V.S. 23 to 27, 31 to 38, 42 to 50, 58 to 60, 64 to 67.	30	4.83	Yes
35	All profiles located on ground moraine. These are all on the S.V.S. and are all riparian except for one profile (#65)	S.V.S.52 to 72.	19	2.85	Yes
36	Those profiles located on the area of shale bedrock covered by a thin layer of till - the R area on Elsons' map of surficial deposits. These are all non-riparian and are all on the S.V.S.	S.V.S. 80 to 113.	38	0.44	Yes
37	All the non-riparian profiles less those profiles on shale covered by till.	S.V.S. 9 to 25, 32 to 34, 42, 43, 65, 73 to 79. N.V.S. 7 to 22, 28 to 30, 39 to 41, 68 to 109.	94	9.84	Yes
38	All riparian profiles located on ridge moraine	S.V.S. 26 to 31, 35 to 37, 40, 41, 44 to 53. N.V.S. 23 to 27, 31 to 38, 42 to 50, 58 to 60, 62, 64 to 67.	51	5.68	Yes

and non-riparian locales will not be normally distributed. This was indeed the case and almost all of the deviations from this generality are readily explainable on a closer examination of these profile groups.

For example, consider the following groups:

i) All the north valley side profiles which are located on Elsons' 1rm surficial deposit type (less the extreme values on the riparian profiles). (Group #30).

ii) All the south valley side riparian profiles on the 1rm surficial deposit. (Group #32).

iii) All the south valley side on the 1gm surficial deposit. (Group #35).

iv) All the south valley side profiles not facing between azimuth 290 and 340. (Group #22).

v) All the south valley side profiles which are facing between azimuth 290 and 340. (Group #21).

The first group, since it contains both riparian and non-riparian profiles, could be expected not to have a normal distribution and this is indicated by the X^2 value.

The second group, since it is located entirely on a riparian location, could be expected to have a normal distribution and this is the case.

The third group, although it contains both riparian and non-riparian profiles, has a normal distribution, but it has only one non-riparian profile in the group.

Both of the last two groups could be expected not to have a normal distribution, since they both contain profiles from riparian and non-riparian locations. But one group has a normal distribution and the other group does not. This is an exception which can be explained only by chance, i.e. the frequencies of occurrence of the maximum angles in the two groups coincide in such a way as to give a normal distribution.

The results of this analysis seem to indicate that a) there is a possible difference between the profiles on the riparian locations as compared to those profiles on the non-riparian locations, b) that the surficial deposits have at best only a minor influence on the formation of the maximum angles, and c) that orientation may not influence the formation of the maximum angles.

For example, if there was nothing special about the profiles located on the riparian situations as opposed to the profiles located on non-riparian positions, then groups containing profiles from both these locations should exhibit a normal distribution, providing of course that there are not any other influencing factors. This is not the case as was shown by group #5.

If the surficial deposits were a dominant control in the formation of the slopes, then all subdivisions based on this criterion should have normal distributions. But this also is not the case. The same arguments can be stated for the profile groups based according to orientations.

The analysis of variance of the mean values of the maximum angles in each profile group should substantiate these above mentioned conclusions.

2. Analysis of Variance

The analysis of variance was carried out on the mean values of the maximum angles of the various profile groups which had a normal distribution. This analysis indicated that all these groups were not from a single statistical population. The results of this test are as follows:

Source of variation	Degree of freedom	Sum of Squares	Mean Square
between groups	27	7894.76	292.39
within groups	1160	24,596.98	21.20

$$\text{value of } F = \frac{\text{mean square of the between group variation}}{\text{mean square of the within group variation}}$$

$$= 13.79$$

Fig. 8

Analysis of Variance of the Maximum Angles

where; a) the between group degrees of the freedom is equal to the number of groups tested minus one.

b) the within group degrees of freedom is equal to the total number of replicates less the number of groups which were tested.

c) the sum of squares is the square of the difference of each term from the mean added together.

d) the value of the mean square is the sum of squares divided by the degrees of freedom.

At the .05 level of probability the value of F indicates that there are significant differences between the means of some of the groups.[3]

3. <u>Least Significant Difference Analysis</u>

The next stage in the analysis of the data was to determine which of the profile groups could be considered as representing statistical populations, and which are only sub groups of the same populations or contain profiles from two or more different populations. This was accomplished by an analysis of the least significant differences (L.S.D.) as calculated by computer for all possible different pairs of group mean values (maximum angles) for the groups with a normal frequency distribution (Figure 9).[4] Figure 10 shows the results of the L.S.D. analysis.[5] The computer was programmed to print 0.0 when there was no significant difference between the pair of means in question, and to print the actual value of the difference when this difference was significant.

It would involve an extremely lengthy and burdensome discussion if each of the pairs of means (a total of 392) were to be described as to why they have or do not have a significant difference. Instead, only the major trends or sub-divisions

---

[3] A table of F values is in Croxton and Cowden <u>Applied General</u> Statistics, New York: Prentice-Hall Inc., 1939, p. 878-879. Using n = 27 (the number of profile groups minus one) and n_2 = infinity (the within groups source of variation), the value of F at P.05 is between 1.000 and 1.517. The F value calculated for the profile groups is greater than the value in the table, therefore it indicates that significant differences exist between some of the profile groups.

[4] As an aid in the interpretation of the L.S.D. table, the profile groups were arranged in order of increasing values of their means.

[5] A description of this test is presented in section (IV) of Appendix B.

Figure 9.

Key for the L.S.D. Analysis

Group No.	Title of Profile Group	Mean
1.	All the north valley side (N.V.S.) non-riparian profiles facing between azimuths 160 and 225*	10.32
2.	N.V.S. non-riparian profiles not facing between azimuths 105 and 145	10.68
3.	South valley side (S.V.S.) non-riparian profiles not facing between azimuths 290 and 340.	10.69
4.	S.V.S. profiles on the area of shale covered by a thin layer of till	11.18
5.	S.V.S. non-riparian profiles	11.19
6.	S.V.S. non-riparian profiles located on ridge moraine	11.25
7.	S.V.S. non-riparian profiles facing between azimuths 290 and 340	11.43
8.	All the non-riparian profiles (both S.V.S. and N.V.S.)	11.51
9.	All the non-riparian profiles except those located on the area of shale covered by a thin layer of till	11.69
10.	All N.V.S. profiles between azimuths 160 and 225	11.78
11.	N.V.S. non-riparian profiles	11.84
12.	All S.V.S. profiles not facing between azimuths 290 and 340	12.65
13.	N.V.S. non-riparian profiles not facing between azimuths 160 and 225	12.66

* The profiles on the Heaslip Soil Complex, and the profiles with extreme values of the maximum angles have been omitted from all of these profile groups.

Group No.	Title of Profile Group	Mean
14.	N.V.S. non-riparian profiles having an orientation between azimuths 105 and 145	13.15
15.	S.V.S. located on ridge moraine	13.48
16.	N.V.S. riparian profiles not facing between azimuths 105 and 145.	14.18
17.	N.V.S. profiles not facing between azimuths 160 and 225	14.50
18.	S.V.S. riparian profiles located on ridge moraine	15.81
19.	Riparian profiles on 1 rm	16.22
20.	N.V.S. riparian profiles	16.24
21.	N.V.S. riparian profiles located on ridge moraine	16.50
22.	All riparian profiles (N.V.S. and S.V.S)	17.03
23.	N.V.S. riparian profiles not facing between azimuths 160 and 225	17.22
24.	S.V.S. riparian profiles	17.86
25.	The S.V.S. riparian profiles facing between azimuths 290 and 340	18.07
26.	N.V.S. riparian profiles facing between azimuths 105 and 145 plus all the S.V.S. riparian profiles	18.27
27.	N.V.S. riparian profiles facing between azimuths 105 and 145	19.27
28.	All profiles on ground moraine	14.53

Profile Groups	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
XB	10.3	10.7	10.7	11.2	11.2	11.2	11.4	11.5	11.7	11.8	11.8	12.6	12.7	13.1	13.5	14.2	14.5	15.8	16.2	16.2	16.5	17.0	17.2	17.9	18.1	18.3	19.3	19.5
1	0.0																											
2	0.0	0.0																										
3	0.0	0.0	0.0																									
4	0.0	0.0	0.0	0.0																								
5	0.0	0.0	0.0	0.0	0.0																							
6	0.0	0.0	0.0	0.0	0.0	0.0																						
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0																					
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0																				
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0																			
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0																		
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0																	
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0																
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0															
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0														
15	0.49	0.28	0.0	0.0	0.12	0.0	0.0	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
16	0.73	0.49	0.14	0.05	0.27	0.0	0.0	0.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0												
17	1.68	1.47	1.03	1.05	1.35	0.52	0.89	1.29	1.01	0.47	0.78	0.0	0.0	0.0	0.0	0.0	0.0											
18	2.32	2.08	1.73	1.44	1.35	1.21	1.45	1.71	1.47	1.05	1.20	0.03	0.15	0.0	0.0	0.0	0.0	0.0										
19	3.31	3.11	2.68	2.68	2.97	2.17	2.61	2.89	2.62	2.10	2.22	1.04	1.13	0.54	0.46	0.0	0.0	0.0	0.0									
20	3.17	2.95	2.55	2.52	2.78	2.03	2.34	2.68	2.42	1.94	2.13	0.89	1.02	0.39	0.29	0.0	0.0	0.0	0.0	0.0								
21	3.29	3.07	2.68	2.63	2.83	2.16	2.45	2.76	2.50	2.05	2.23	1.01	1.14	0.61	0.40	0.0	0.0	0.0	0.0	0.0	0.0							
22	4.27	4.07	3.62	3.46	3.66	3.11	3.49	3.91	3.63	3.07	3.31	2.00	2.16	1.50	1.44	0.18	0.64	0.0	0.0	0.0	0.0	0.0						
23	3.97	3.44	3.28	3.21	3.44	2.76	3.02	3.31	3.06	2.62	2.79	1.59	1.71	1.09	0.97	0.0	0.11	0.0	0.0	0.0	0.0	0.0	0.0					
24	4.79	4.57	4.17	4.14	4.40	3.65	3.96	4.30	4.04	3.56	3.75	2.51	2.64	2.01	1.91	0.72	1.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
25	4.81	4.58	4.21	4.15	4.39	3.69	3.97	4.27	4.01	3.57	3.74	2.53	2.66	2.03	1.92	0.76	1.07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
26	5.37	5.16	4.74	4.74	5.03	4.22	4.57	4.95	4.69	4.16	4.38	3.10	3.24	2.60	2.52	1.29	1.70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
27	5.43	5.18	4.86	4.74	4.93	4.24	4.54	4.76	4.52	4.19	4.28	3.14	3.24	2.66	2.49	1.41	1.61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
28	5.94	5.70	5.36	5.26	5.47	4.84	5.07	5.32	5.07	4.67	4.82	3.66	3.77	3.16	3.32	1.91	2.19	0.24	0.35	0.19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Fig. 10.

Least Significant Difference Between Profile Group Means

The means are listed in the row marked XB. See Fig. 9 for the key to the profile groups (numbers 1 to 28).

indicated by the analysis are disclosed, along with the exception to these trends. Both of these situations are illustrated by a selected number of examples.

On examining the L.S.D. values it was quickly realized that there was a general division between the riparian and the non-riparian profiles. For example, there is no significant difference between the means of the N.V.S. riparian prifiles (#20)[6] and N.V.S. non-riparian profiles (#20) and similarly for the S.V.S. non-riparian (#5) and the S.V.S. riparian (#24) profile groups. This relationship is true for nearly all the various sub-groups of the riparian and non-riparian profiles. The following exceptions occur: i) N.V.S. riparian profiles not facing between azimuth 105 and 145 (#16), and (#14) N.V.S. non-riparian profiles having an orientation between azimuth 105 and 145, ii) (#16) and (#13) all N.V.S. non-riparian not facing between azimuths 160 and 225, and iii) (#16) and (#11) all N.V.S. non-riparian profiles. These exceptions will be discussed later.

The second feature shown by this analysis is that, without exception, there are no significant differences within all the non-riparian sub-groups. This means that the micro-climatic conditions of orientation with respect to wind direction or with respect to insolation, there is no significant difference between the means of the N.V.S. non-riparian profiles facing between azimuths 160 and 225 (#10) and the N.V.S. non-riparian profiles not facing between azimuths 160 and 225 (#13). Similarly

---

[6] The numbers in the brackets refer to the corresponding profile group number in the table of L.S.D. values, Figure 8.

no significant differences exist between the profile groups selected on the basis of wind direction.

For the riparian profiles, there are too few profiles for an examination of orientation with respect to insolation. It can be reasonably assumed that this has no significant effect on the riparian profiles, since non-riparian profiles in similar orientations were unaffected.

However, the other aspects of micro-climate, i.e. wind direction, do have a possible influence on the riparian profiles. Again there is the problem of an insufficient number of profiles in one of the groups. This applied only to the examination of the prevailing winds on the S.V.S. profiles. This evidence is: a) there is no significant difference between those profiles directly under the influence of the prevailing winds (S.V.S. riparian profiles facing between azimuths 290 and 340 - #25) and all the S.V.S. riparian profiles (#24). The profiles directly under the influence of the prevailing wind direction can not be compared with those profiles which are not under the influence of that wind because there are too few profiles in that group for statistical tests; b) the graph of the maximum angles versus their orientation indicates that a similar average maximum angle is produced irregardless of orientation.

Orientation with respect to secondary winds may be important in the development of maximum angles in the North Valley Side. Profile groups (#16) N.V.S. riparian <u>not</u> facing between 105 and 145, and (#26) N.V.S. riparian facing between azimuths

105 and 145 show a significant difference in their mean values.

Such a difference could arise from there being a decrease in the efficacy of a process which will tend to produce lower slope angles, i.e. that the balance between the rate of removal and the supply of material (the steady state condition) will occur at a lower maximum slope angle.

This would also explain why there is no significant difference between this group (#16) and some (but not all) of the non-riparian profile groups.

It would seem that the combination of processes which operate on the riparian slopes not facing between azimuths 105 and 175 produce a mean maximum angle which is only slightly greater than the mean produced on the riparian profiles.

The fact that the riparian profiles not facing between azimuths 105 and 145 (#16) and (#32) S.V.S. riparian profiles on ridge moraine show a significant difference seems to be fortuitous, since this particular grouping of S.V.S. profiles contains several low maximum angles (these are at azimuth 330, see Figure 6) which cannot be related to a particular cause. Since these angles represent nearly one sixth of the sample size of 21, it is likely that if they were omitted this difference would not exist.

Finally, there is only one remaining exception to the above mentioned significant profile grouping. There are those which contain a combination of the signficant groups, such as the riparian profiles affected by wave action and the non-riparian profile. Examples of these groups are: a) all S.V.S.

profiles not facing between azimuths 290 and 340, and b) all S.V.S. profiles located on ridge moraine.

It is completely fortuitous whether or not groups of this type show a significant difference between any of the other groups.

For example, (#15) all S.V.S. profiles on ridge moraine and (#28) all profiles (S.V.S.) in ground moraine show a significant difference between their mean values. But this is a chance occurrence due to the fact that the 21 profiles on ground moraine are nearly all riparian while half of the 43 of non-riparian profiles has lowered the mean value of that group to a point where it shows a significant difference on the L.S.D. analysis.

From the foregoing discussion on the L.S.D. values it can be concluded that profile groups may belong to three separate statistical populations of maximum slope angle. These are listed in Figure 11 with their means and standard deviations.

	Profile Group	No. of Profiles	Mean	Standard Deviation
1.	All the non-riparian profiles less those profiles on the Heaslip Soil Complex.	128	11.51	3.89
2.	The north valley side riparian profiles facing between azimuth 105 and 145 plus all the south valley side riparian profiles	52	18.27	5.37
3.	The north valley side riparian profiles which are not facing between azimuth 105 and 145.	22	14.18	4.23

Figure 11.

Profile Groups Found to be Significant from the L.S.D. Analysis

This analysis also indicated that lithology is not a dominant control in slope formation in the Dand Valley since these profile groups have been developed on the same rock type.

One of the assumptions at the beginning of the analysis was that the relief in the valley was nearly constant, since this appeared to be the case according to the contours on a 1:50,000 N.T.S. map. An analysis of variance of the mean valley side heights of the above three profile groups was conducted to determine if relief was in fact the same in the different groups. The results of this test supported the original assumption. The analysis gave a value of 1.09 for F which at the P.05 level of significance indicates that there is no significant difference between the relief of the various groups.

4. Correlation Analysis

The final step in the statistical analysis was the determination of the degree of correlation which exists between the profile parameters selected in Chapter III. (These parameters are listed again in Figure 13).

Before the correlation test could be performed it was necessary to determine the type of normal frequency distribution which each parameter exhibited.[7] For this study, four types of distributions were arbitrarily selected:- a) an arithmetic

---

[7] This step is necessary since the correlation coefficient is in part dependent on the type of distribution present in the data.

normal distribution, i.e. no data transformation, b) a logarithmic normal distribution, c) a square root normal distribution, d) a reciprocal normal distribution.[8] The chi-square values for each distribution are presented in Figure 12.

Note that the M.H.D. of the maximum slope unit was not included in the analysis for types of normal distributions. This parameter, plus the maximum angle, formed the basis from which the remaining parameters pertaining to the maximum slope unit were calculated. However, it was included in the calculation of correlation coefficients and the rotated factor matrix for checking purposes. In these tests this group was considered to have an arithmetic normal distribution.

Once the types of distributions were determined it was possible to calculate the correlation coefficient r for each pair of parameters by the factor analysis method.[9] As well as correlation coefficients this program calculated the standard deviations and means of the parameters,[10] and provided a principle factor matrix and a rotated factor matrix.

The principle factor loading matrix and the rotated

---

[8] These operations were performed by computer. The test for the various types of normal distributions is the same as that which was used in determining the distribution of the maximum angle.

[9] A brief description of the factor analysis test, a copy of the factor analysis program (supplied by the Computer Centre, University of Manitoba), and the fortran steps in the program are provided in Section (IV) of Appendix B.

[10] These values could not be used since they were calculated after the data transformations were performed for the different types of normal distributions. The means and standard deviations were calculated separately and are presented in Fig. 11a.

Fig. 12

Results of the Analysis of the Types of Normal Frequency Distributions of the Parameters of Selected Profile Groups.

Profile Group	Parameter	Chi-square Values of the Distribution Types			
		Arithmetic	Log	Square Root	Reciprocal
1. North valley side riparian profiles not facing between azimuths 105 and 145.	Height of the max. unit	3.02	3.25	4.58	6.78
	Length of the max. unit	10.22	5.41	3.99	11.94*
	Maximum angle	4.06	8.11	4.21	12.92*
	Valley relief	5.60	2.46	4.80	2.30
	Length of the mean slope	5.28	1.66	3.27	5.43
	Mean valley side gradient	4.42	6.82	4.86	7.18
2. All south valley side riparian profiles <u>plus</u> the north valley side riparian profiles facing between azimuth 105 and 145.	Height of the max. unit	24.58*	6.72	4.55	30.76*
	Length of the max. unit	21.11*	9.76	14.62*	21.96*
	Maximum angle	1.97	7.39	1.92	15.12*
	Valley relief	7.21	25.45*	12.78*	112.06*
	Length of the mean slope	3.89	4.36	2.45	23.29*
	Mean valley side gradient	8.86	5.11	5.52	6.33

*All the chi-square values are significant at the $P_{.05}$ level except those which are marked with an asterisk.

Fig. 12 con't.

Profile Group	Parameter	Chi-square values of the Distribution Types			
		Arithmetic	Log	Square Root	Reciprocal
3. All non-riparian profiles those on the Heaslip soil complex.	Height of the max. unit	7.24	12.64*	5.27	49.25
	Length of the max. unit	13.20*	18.65*	13.87*	107.40*
	Maximum angle	7.79	12.24*	6.03	8.31
	Valley releif	4.98	8.33	6.21	43.65*
	Length of the mean slope	1.45	4.13	1.70	47.68*
	Mean valley side gradient	11.35*	2.82	4.61	23.22*
4. All the profiles measured in the Dand Valley.	Height of the max. unit	32.94*	28.46*	7.51	138.09*
	Length of the max. unit	52.04*	46.84*	8.80	204.18*
	Maximum angle	63.24*	3.44	28.44*	28.85*
	Valley relief	12.48*	36.43*	17.32*	155.70*
	Length of the mean slope	11.72*	11.89*	5.45	127.66*
	Mean valley side gradient	99.93*	5.18	32.27*	29.41*

Profile Group	Parameters						
	1	2	3	4	5	6	7
1. All non-riparian profiles less those on the Heaslip soil complex.							
Mean –	29.6	167.5	11.5	164.5	54.3	564.9	0.1086
Standard Deviation –	14.6	103.6	3.9	103.1	15.6	219.6	0.0417
2. South valley side riparian profiles <u>plus</u> the north valley side riparian profiles between azimuths 105 and 145.							
Mean –	20.5	73.3	18.2	70.0	49.7	287.5	0.2038
Standard Deviation –	12.8	58.8	5.4	57.9	15.5	166.6	0.0939
3. North valley side riparian profiles which do <u>not</u> face between azimuths 105 nad 145.							
Mean –	22.8	110.1	14.2	107.3	48.4	317.8	0.1612
Standard Deviation –	10.8	83.8	4.2	83.6	11.2	109.4	0.0647
4. All the measured profiles in the Dand Valley.							
Mean –	26.7	137.7	14.2	134.4	52.6	461.7	0.1449
Standard Deviation –	14.0	103.3	7.3	103.2	15.0	235.6	0.0942

Fig. 12a.

Means and Standard Deviations of the Parameters of Selected Profile Groups

Note that the standard deviation is an indication of the amount of dispersion of the data about the mean. That is about 68% of the data falls within ± 1 standard deviation of the mean, and about 95% of the data falls within ± 2 standard deviations of the mean.

Fig. 13.

Key for the Parameters in the Analysis of the Correlation Coefficients and Rotated Factor Matrix

Variable	Profile parameter
1	The height of the maximum slope unit
2	The length of the maximum slope unit
3	The maximum angle
4	The map horizontal distance of the maximum slope unit
5	The valley height, i.e. relief
6	The length of the mean valley side gradient
7	The angle of the mean valley side gradient

SIMPLE CORRELATION COEFFICIENTS

VARIABLE*	1	2	3	4	5	6	7
1	1.0000000						
2	0.7484005	1.0000000					
3	-0.0706487	-0.5963288	1.0000000				
4	0.7354637	0.9998009	-0.6077271	1.0000000			
5	0.5211766	0.2336785	0.2674444	0.2218183	1.0000000		
6	0.1325985	0.3445132	-0.4343913	0.3475525	0.4190681	1.0000000	
7	0.2030079	-0.1814229	0.6406589	-0.1914446	0.1961742	-0.7644899	1.0000000

ROTATED FACTOR MATRIX

	1	2	3
VAR* 1	0.81289	0.18933	0.44800
VAR 2	0.97159	-0.19330	0.05103
VAR 3	-0.53378	0.62424	0.47149
VAR 4	0.96916	-0.20279	0.03759
VAR 5	0.18489	-0.03114	0.95384
VAR 6	0.15101	-0.89434	0.39934
VAR 7	-0.01254	0.95031	0.19991

*See fig. 13 for the key to these parameters.

Fig. 14

Correlation Coefficients and Rotated Factor Matrix of all the Non-riparian Profiles.

SIMPLE CORRELATION COEFFICIENTS

VARIABLE*	1	2	3	4	5	6	7
1	1.0000000						
2	0.9004605	1.0000000					
3	0.0564036	-0.3525805	1.0000000				
4	0.7852450	0.9197329	-0.4790203	1.0000000			
5	0.3197725	0.1688898	0.2179357	0.1810280	1.0000000		
6	0.0108445	0.1008485	-0.3159326	0.2336430	0.6419556	1.0000000	
7	0.3062172	0.0217416	0.6895872	-0.1312516	0.0373942	-0.7119826	1.0000010

ROTATED FACTOR MATRIX

	1	2	3
VAR* 1	0.93129	0.26905	0.15634
VAR 2	0.98337	-0.10463	0.02647
VAR 3	-0.27232	0.89212	0.18534
VAR 4	0.93239	-0.27393	0.07542
VAR 5	0.17014	0.18054	0.93877
VAR 6	0.01952	-0.55561	0.81932
VAR 7	0.13746	0.93563	-0.21627

*See fig. 13 for the key to these parameters.

Fig. 15

Correlation Coefficients and Rotated Factor Matrix of the North Valley Side Riparian Profiles Facing Between Azimuths 105 and 145 plus all the South Valley Side Riparian Profiles.

SIMPLE CORRELATION COEFFICIENTS

VARIABLE*	1	2	3	4	5	6	7
1	1.0000000						
2	0.7990740	1.0000000					
3	-0.2451720	-0.7293881	1.0000000				
4	0.7120639	0.9763883	-0.7230757	1.0000000			
5	-0.0041298	0.3275566	-0.5937649	0.3065137	1.0000000		
6	-0.0270323	0.2645170	-0.4718019	0.2776620	0.0219448	1.0000000	
7	0.0541699	-0.3901594	0.7501639	-0.3881949	-0.6040047	-0.7676217	1.0000000

ROTATED FACTOR MATRIX

	1	2	3
VAR* 1	0.93037	-0.13249	-0.12285
VAR 2	0.93926	0.21160	0.26231
VAR 3	-0.48441	-0.50585	-0.62155
VAR 4	0.90460	0.23583	0.25685
VAR 5	0.07512	0.03174	0.97433
VAR 6	0.07529	0.98534	-0.04483
VAR 7	-0.08320	-0.79491	-0.56812

*See fig. 13 for the key to these parameters.

Fig. 16

Correlation Coefficients and Rotated Factor Matrix of the North Valley Side Riparian Profiles not Facing Between the Azimuths of 105 and 145.

SIMPLE CORRELATION COEFFICIENTS

VARIABLE*	1	2	3	4	5	6	7
1	1.0000000						
2	0.8002576	1.0000000					
3	-0.2037457	-0.7125698	1.0000000				
4	0.7431383	0.9704805	-0.6917597	1.0000000			
5	0.4326353	0.1698296	0.1866702	0.1798551	1.0000000		
6	0.2372331	0.4921613	-0.5721958	0.4882324	0.4415341	1.0000000	
7	0.0004715	-0.4268567	0.7646212	-0.4148597	0.0837004	-0.8268000	1.0000000

ROTATED FACTOR MATRIX

	F_1	F_2	F_3
VAR* 1	-0.33942	0.89775	-0.10523
VAR 2	-0.02111	0.93081	0.35623
VAR 3	-0.32855	-0.48151	-0.75875
VAR 4	-0.02565	0.90742	0.35727
VAR 5	-0.96805	0.15773	0.00583
VAR 6	-0.44383	0.18486	0.86534
VAR 7	-0.07876	-0.09431	-0.97076

*See fig. 13 for the key to these parameters.

Fig. 17

Correlaion Coefficients and Rotated Factor Matrix of all the Profiles Measured in the Dand Valley.

factor matrix contain the same information, but it is in a more meaningful form in the latter matrix, i.e. the computer was programmed to adjust the principle factor matrix, by a simple rotation about an axis, in order to facilitate the interpretation of the results (Figures 14 to 17).[11] Only the rotated factor matrix is included in the results. These tests were conducted on the three profile groups selected from the L.S.D. analysis as representing individual statistical populations (or at least samples from such a population). In order to compare the results from these groups with the results from a 'heterogeneous' sample, all the profiles measured in the Dand Valley were similarly tested.

A) The correlation coefficient matrix

In the correlation coefficient matrix any value of r which is 0.5 or greater was considered as indicating a positive correlation. These values have been underlined in each of the tables. Values under 0.5 were considered as having zero correlation.

Note that a high positive correlation between two parameters indicates that when the value of one parameter increases, the value of the other parameter also decreases.

Conversely, a high negative correlation indicates that when the value of one parameter decreases, the other parameter will increase, or vice versa.

---

[11] See Appendix B, Section (iv) for a brief description of factor analysis.

The level of significance of r was calculated (at the 5% level) for each profile group. This indicates the probability of another sample, of the same size and from the same area, having a correlation coefficient similar to that obtained. For example, in the profile group 'north valley side riparian prifiles not facing between azimuths 105 and 145' the critical r value is 0.42.[12] For another sample from the same area there would be about 95 chances in 100 of having similar values for each correlation coefficient which is greater than 0.42. There is little chance of obtaining similar values for those correlation coefficients below 0.42 and as a result these can be considered as having zero correlation.

The critical r values for the other profile groups are:

a) all the non-riparian profiles - an r of 0.20.

b) all the south valley side riparian profiles plus the north valley side riparian profiles between azimuths 105 and 145 - an r of 0.40.

c) for all the measured profiles - an r less than 0.10.

These values indicate that for the larger samples, there is a greater probability of obtaining similar correlation coefficients. Note that all of the critical r values are less than 0.5

The results of the correlation analysis will be discussed under the following headings; a) similarities between

---

[12] This test is described in Appendix B, Section (IV).

the three main profile groups, b) correlations which are unique to particular groups, and c) a comparison between the three main groups and all the measured profiles.

i) Similarities between the three main profile groups. The following pairs of parameters show a positive correlation in each of these profile groups.

a) the height of the maximum unit and the length of the maximum unit (Var. 1 and 2).

b) the height of the maximum unit and the M.H.D. of the maximum unit (Var. 1 and 4).

c) the length of the maximum unit and the M.H.D. of the maximum unit (Var. 2 and 4).

d) the maximum angle and the angle of the mean valley side gradients (Var. 3 and 7).

Consider a, b, and c, it is noticed that with an increase in the length of the maximum slope unit, there is a corresponding increase in the height of the unit. This situation would occur when the M.H.D. is constant.

In comparing Var. 2 and 4, we find that when the length of the slope of the maximum unit is increased - the M.H.D. is also increased. This would occur when the height was constant.

These seemingly conflicting results suggest that when there is an increase in any one of these parameters, there is also a corresponding increase in the other two parameters, as in Figure 18.

This is supported by the fact that the correlation (between Var. 1 and 4) indicates that when the height of the maximum unit increases so does the M.H.D.

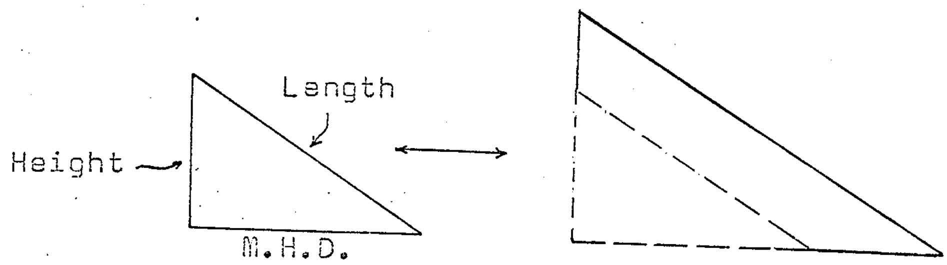


Fig. 18.

Illustrating the type of correlation which exists between the M.H.D., the height, and the length of the maximum unit.

This would also explain why there is no correlation between the maximum angle and these parameters since increases or decreases in the maximum angle would depend on the relative changes of the other parameters. From these obvious geometrical relationships it would not be expected to have the maximum angle dependent on the height. This is supported by the correlation coefficients which indicate that there is either no correlation or at best a tendency (partial negative correlation, i.e. a negative r value below 0.5) for the maximum angle to decrease with an increase in the height of the maximum unit.

Finally, the last positive correlation which is common to all three profile groups is between the maximum angle and the angle of mean gradient. This indicates that, with an increase in the maximum angle, there is an increase in the angle of the mean gradient. Since the relief of the valley has been deomonstrated to be uniform (p. 55) the situation is similar to that illustrated in Figure 19.

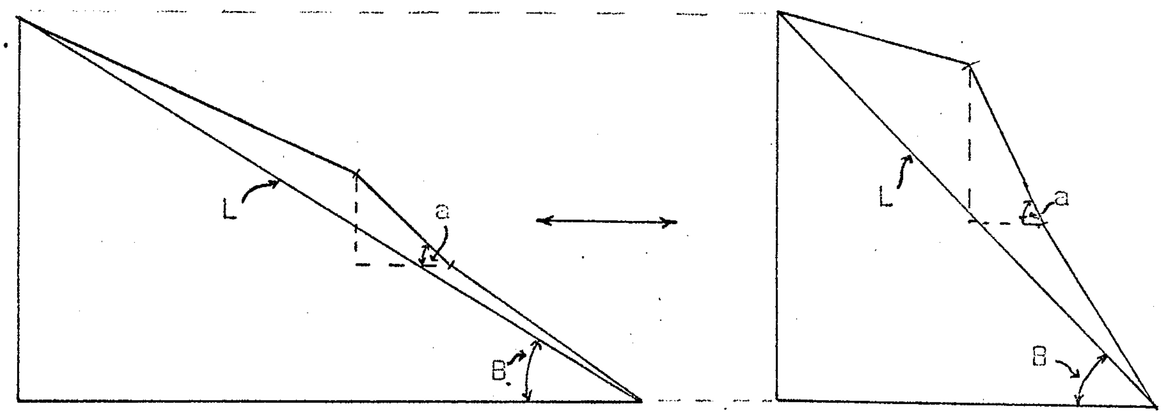


Fig. 19.

The relationship between the maximum angle and the mean valley side gradient, where

a - the maximum angle

B - the angle of the mean gradient

L - the length of the mean gradient.

This also accounts for the negative correlation between the mean gradient length and the angle of the mean gradient. Since the valley relief is constant, the length of the mean gradient will decrease as the angle of the mean gradient increases. An examination of Figure 19 indicates that there should also be a negative correlation between the angle of the mean gradient and the total M.H.D. of the profile.

ii) Correlations unique to particular profile groups.

a) There is a positive correlation between the relief and the length of the mean gradient in only one profile group, that of the 'S.V.S. riparian profiles plus the N.V.S. riparian profiles facing between azimuths 105 and 145'.

This seems to indicate that there are fluctuations in the relief of those profiles, even though the average relief is similar to the other profile groups. Reference to the standard deviation of this parameter (Figure 12a) supports this view. The correlation coefficient demonstrates that when increases in the relief occur, they are accompanied by increases in the length of the mean gradient. Also, as there is no correlation between the angle of the mean valley side gradient and the relief, the increases in the relief occur independently of changes in the length of the mean gradient (Figure 20).

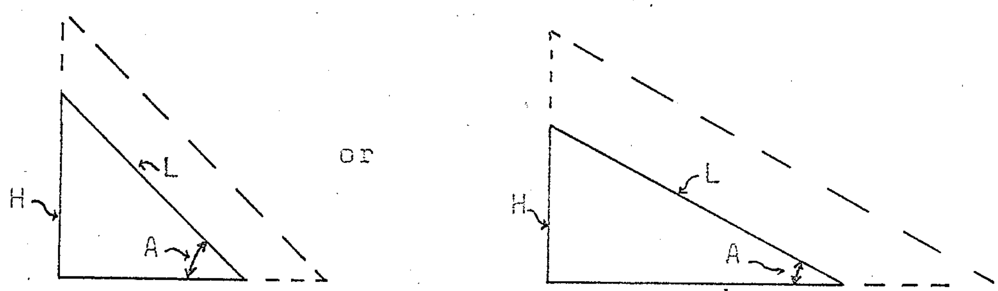


Fig. 20.

Demonstrating the relationship between the angle of the mean valley side gradient (A) and the length of the mean valley side gradient (L), assuming that the relief (H) is constant. The effect of an increase in (H) is indicated by the dashed lines.

b) Only in the non-riparian profile group is there a correlation (positive) between the height of the maximum unit and the relief of the valley. This correlation indicates that when the height of the maximum unit increases - the relief also increases and vice versa (Figure 21), and that fluctuations about the average relief must occur.

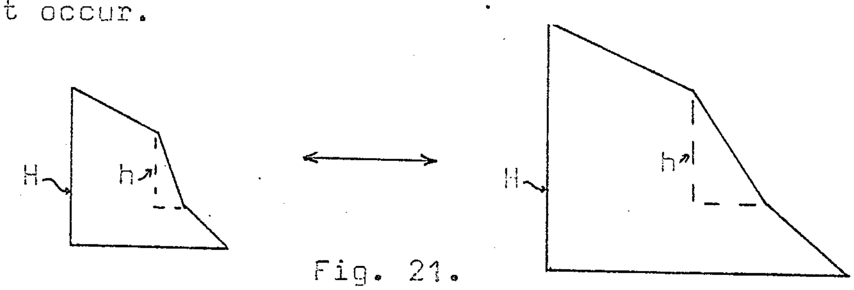


Fig. 21.

The relationship between relief (H) and the height of the maximum unit (h).

c) The N.V.S. riparian profiles not facing between azimuths 105 and 145 is the only group to have a negative correlation between relief and the maximum angle. This means that as the relief increases, the value of the maximum angle decreases (Figure 22).

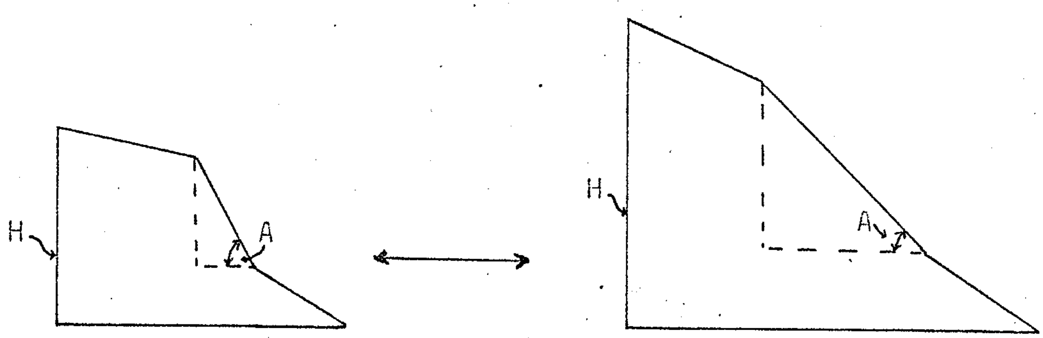


Fig. 22.

Illustrating the relationship between the relief (H) and the maximum angle (A).

This profile group is also the only one to exhibit a negative correlation between the length of the mean gradient and the angle of the mean gradient. Thus, as the angle of the mean gradient increases, the length of the mean gradient decreases. This would occur if the relief was constant. Reference to the standard deviation in Figure 12a indicates that this is the case.

d) The final unique correlation is one which is found in two profile groups. 'all the non-riparian profiles' and 'the N.V.S. riparian profiles not facing between 105 and 145'. In these groups there is a negative correlation between the maximum angle and the length of the maximum unit. That is, an increase in the maximum angle results in a decrease in the length of maximum unit. Such a correlation would occur if the height of the maximum unit was constant. Since there is a large standard deviation (Figure 12a) of the heights of the maximum unit, this does not appear to explain the correlation.

The correlation coefficients indicate that there is an increase in the length of the maximum unit with increases in the height and M.H.D. of the maximum unit. Therefore, in order to have a decrease in the maximum angle as well, the situation could be as it is illustrated below.

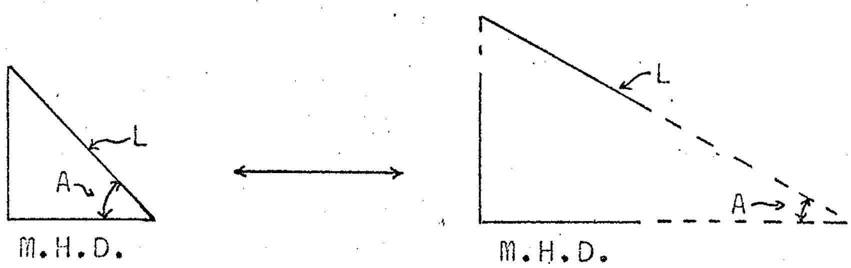


Fig. 23.

The possible relationship between the maximum angle (A), the length of the maximum unit (L) and the map horizontal distance (M.H.D.). The dashed lines indicate the possible increases in the lengths of these parameters.

B) The Rotated Factor Matrix.

A preliminary analysis produced a factor matrix in which four factors had been removed from each of the profile groups. An examination of the amount of variability which each of these accounted for, showed that factor 1 accounted for about 40%, factor 2 about 30%, factor 3 about 20%, and factor 4 only 2-3%. Since the fourth factor accounted for only a small amount of the total variance, it was decided to re-test the data and extract only three factors.[1] The interpretation of the results was also simplified by having only the three factors.

The high factor loading values have been underlined in the matrix for each of the profile groups (Figure 14 to 17).

The parameters opposite these high values in a factor column can be grouped together and are independent of similar groups in adjacent columns (see Appendix B, Section iv, for a more complete discussion of the rotated factor matrix).

The following pattern of parameters is considered as being basic to all the profile groups. Differences between the profile groups is reflected in addition to the basic pattern.

a) the first group of parameters consists of the height of the maximum unit, (var. 1) the length of the maximum unit (var 2.), and the M.H.D. of the maximum unit (var. 4). This group will be referred to as the length of the maximum unit, since it is the parameter with the highest factor loading value in each case.

b) the second group consists of the maximum angle (var. 3) the length of the mean gradient (var. 6), and the angle of the mean gradient (var. 7). Since these are related

---

[1] In the original test, factors accounting for less than 0.03% of the variability were not retained. In order to reduce the number of factors it was necessary to arbitrarily increase this constant to 0.05.

The amount of variability accounted for by each of the new factors is 55% in the first factor, 24% in the second, and 16% in the third.

to the general steepness of the profile, it will be referred to as the general steepness group

c) the last group consists of one parameter, that of the valley relief.

Each of the profile groups will be discussed in turn and the parameter groups which are peculiar to each will be dealt with separately.

a) All the non-riparian profiles

The pattern which was outlined above is present in this group with only minor modifications. Parameter number 3, that of the maximum angle, has values which indicates that it is a mixed variable. This means that it can be correlated with the other parameter groups, i.e. it is a function of the general steepness, the length of the maximum unit, and the valley relief.

Also, there is a negative value for the length of the mean gradient. This indicates that as the maximum angle, or the angle of the mean gradient, increases then the length of the mean gradient decreases. These relationships are also indicated by the correlation coefficients of these parameter pairs.

b) The north valley side riparian profiles facing between azimuths 105 and 145 plus all the south valley side riparian profiles.

In addition to the basic parameter pattern, the length of the mean gradient is related to the valley relief. As this is also indicated by the correlation coefficients, it can be considered to be a characteristic feature of this particular profile group. This correlation is such that as the relief increases so will the length of the mean gradient. Since the angle of the mean gradient is not part of the same factor group as the relief or the length of the mean gradient, it suggests that there is a possible homogeneity of the angles of the mean gradient. This is illustrated in figure 19, i.e. if the mean gradient angle is constant an increase in relief will result in an increase in the length of the mean gradient.

It will be noticed that the maximum angle is a pure variable, i.e. it is not correlated with any other group (there are no high factor loading values in the other factor groups). Thus, for this group it is a characteristic value or parameter.

Also, as with the non-riparian profiles, there is a negative factor loading value for the length of the mean gradient.

These three features can be considered as being the identifying characteristics which distinguish it from the other profile groups.

c) The north valley side riparian profiles not facing between azimuths 105 nad 145.

The maximum angle is a mixed variable in this group as it was in the non-riparian profile group. But unlike the other two profile groups, the angle of the mean valley side gradient is in the factor group containing the relief which also has the high maximum angle value. This means that in this group there is an inter-relationship between these three variables, although it is only a partial relationship. Note that the angle of the mean valley side gradient is also a mixed variable.

The angle of the mean gradient has a negative factor loading value in both the general slope and the valley relief factor groups. This indicates that i) as the mean gradient angle decreases the relief will increase, or vice versa, and ii) as the length of the mean gradient increases the angle of the mean gradient decreases. This must mean that for these profiles, there is also an increase in the M.H.D. of the profile which accompanies the increase in relief.

There is also a negative value for the maximum angle in the valley relief factor group. This is associated with the above considerations, i.e. as the relief increases the maximum angle decreases. These relationships have already been described (see figures 22 and 23) and the factor loading values support the conclusions drawn from the correlation coefficients.

d) All the profiles measured in the Dand Valley.

The basic factor groups are found in all the profiles. This adds support to the idea that these factor groups reflect a fundamental attribute of the slopes in the Dand Valley. It is possible that the pattern is common to every valley or slope which has been developed under the same conditions as the Dand Valley, or possibly it is common to every landscape.

In summary, the discussion of the correlation matrix and the rotated factor matrix indicates that certain relationships between the parameters hold true regardless of the location of the profiles. Most of these are expected since they are governed by geometry but some are unexpected such as the correlation between the maximum angle and the angle of the mean valley side gradient. This relationship seems to negate the theory of parallel slope retreat since it indicates that as the valley sides are eroded down and the valley is infilled the maximum angle will decrease in value.

The fact that there is a basic pattern common to all the profile groups, and that each profile group has characteristic differences supperimposed on the basic pattern, suggests that there are different processes or other variables operating within the valley.

The differences in the r values and the factor loading values can be considered to be indicative of the conditions in the Dand Valley. Whether or not these features are characteristic of other landscape types or occur only in the Dand Valley is a question which requires further investigations to answer.

The results in the rotated factor matrix indicate that, in two of the profile groups, the maximum angle is not a pure variable. This suggests that some other variable or combination of variables might provide a better basis than the maximum angle for determining those slopes which have developed in response to particular conditions (of soil, microclimate, etc.). The results from this study indicate that the following parameters and normal distribution types may better represent slope development in a given area:-

a) the length of the maximum unit, with a log normal frequency distribution.

b) the valley relief, with an arithmetic normal frequency distribution.

c) the mean gradient angle, with an arithmetic normal frequency distribution.

and d) the maximum angle, with either an arithmetic or a square root normal frequency distribution.

Chapter V

CONCLUSIONS

1. The analysis of variance indicated that there were significant differences between profile groups with a normal distribution of the maximum angles which were selected on the basis of their relationship to various physical conditions in the Dand Valley.

There is a basic difference between the riparian and non-riparian profiles. Within the riparian profiles, it is concluded that those profiles which are affected by winds (i.e. wave action) are significantly different from those profiles which are not under the direct influence of waves. Also, these differences in the maximum angle reflect differences in the process (or set of processes) or the intensity of the processes in each of these locations. As such, these two riparian profile groups and the non-riparian group can be considered to be from separate statistical populations. These are a) all the non-riparian profiles, b) the south valley side riparian profile <u>plus</u> the north valley side riparian profile facing between azimuths 105 and 145, and c) the north valley side riparian profiles which do <u>not</u> face between azimuths 105 and 145.

It is probable that local conditions influence the effect of the wind directions (prevailing and secondary) and that the particular profile orientations which are important in the Dand Valley will not apply elsewhere.

The exact importance of the effect of the secondary wind is not known. Since it is from a direction which is almost opposite to the prevailing wind, and that the valley sides under the influence of these winds have a greater maximum angle (average) than that portion of the valley which is not affected by these winds, it seems likely that

a) these winds increase the rate of removal of material from the base of the valley side by increased wave action. This may account for the steeper angles found in these positions. The values of the means of the maximum angles suggest that the secondary wind may be more effective than the prevailing wind since they have produced steeper maximum angles.

b) it would follow that the profiles which are not effected by these winds have a lower mean maximum angle due to a lower rate of removal of material from the base of these profiles.

The hypothesis that wave action is the mechanism which may cause these steeper maximum angles is supported by the fact that neither the prevailing wind nor the secondary wind have any apparent effect on the slope formation of the non-riparian profiles.

2. The analysis also indicated that surficial geology and orientation with respect to insolation received have not produced significant differences in the maximum angles which were developed in the Dand Valley.

3. There is no significant difference in the relief within the study area. Thus, changes in the maximum angle can not be related to this variable.

4. The analysis of the types of normal distributions present in the selected valley side parameters of each profile group indicates that:-

a) the maximum angle has a log normal distribution in the profile group containing all the profiles measured in the Dand Valley. This may be characteristic of any heterogeneous sample.

b) the data of most of the parameters has more than one type of normal distribution in any one group of profiles, indicating that the type of distribution is not important (it may also indicate that the sample sizes are not large enough for this type of analysis.) However, parameters from different groups are not always characterized by the same type of distribution which is related to the operation of different processes or variables, or that certain distributions are more useful in describing different parameters. No definite conclusions can be made on these theories on the basis of the results of this study.

5. The correlation analysis indicated that there is a basic set of relationships which are common to all of the profile groups. These are:-

a) a positive correlation between the height of the maximum unit and the length of the maximum unit.

b) a positive correlation between the height of the maximum unit and the M.H.D. of the maximum unit.

c) a positive correlation between the length of the maximum unit and the M.H.D. of the maximum unit.

d) a positive correlation between the maximum angle and the angle of the mean valley side gradient.

e) a negative correlation between the mean gradient length and the angle of the mean gradient.

It is concluded that these are a common feature to the slopes developed under the particular conditions found in the

Dand Valley, and possible that they are common to all slopes, or at least to slopes which have developed under similar conditions of climate and lithology.

Each profile group has correlations between parameters which are unique to that group. It is concluded that these correlations are characteristic of the conditions under which the group in question has developed. As such, if similar relationships are found in other areas, it can be suspected that they are the result of conditions corresponding to those in the Dand Valley.

6. It is concluded that there are three basic parameters from which the basic characteristics of all the profiles can be derived. These are:-

a) the length of the maximum unit

b) the valley relief

c) the mean gradient angle.

It is possible that these may be basic to all landscape, or at least to those areas which have similar climate and lithology to the Dand area.

The differences within the study area can be completely described by a consideration of two additional parameters (in addition to the basic parameters) - the maximum angle and the length of the mean gradient.

7. This study has indicated that a combination of parameters may provide the best means of evaluation of those slopes which have formed in response to various conditions. These parameters are the maximum angle and the length of the mean valley side gradient. In analyzing profile groups which have been selected on the

basis of their relation to various physical variables it may provide a more sensitive test for selecting the important groups if both of these parameters were examined for normal frequency distributions.

8. The fact that the length of the mean valley side gradient increases when there is a decrease in the maximum angle has several geomorphological implications.

If the increase in the length of the mean valley side gradient has resulted from colluvial deposition at the base of the slopes, then this correlation suggests that parallel slope retreat is not occurring and that the maximum angle decreases with time.

The correlation could also indicate that there has been a change in the relative rate of supply and removal of material, if the steady state condition is assumed to be true. These results suggest that there may have been a decrease in the rate of removal of material or an increase in the rate of supply, since both of these conditions would likely produce lower maximum angles. Changes such as these may be a reflection of changes in climatic conditions, possibly from a more humid climate to a drier climate.

APPENDIX A

i) A Summary of the Pleistocene History of South West Manitoba[1]

The south west portion of Manitoba and the northern part of North Dakota were covered by ice originating from the Keewatin ice centre which was located to the west of Hudson Bay.

On deglaciation, many lakes formed at the edge of the ice sheet which was blocking the normal drainage. One of the first lakes to form entirely in Manitoba was in the Whitewater Lake Basin near Boissevain. This small lake discharged eastward into what is now the Pembina River.

Glacial Lake Souris was in existence in North Dakota at this time - discharging through the Sheyenne River to the south. A slight withdrawal of the ice caused the lake to expand into Manitoba and also opened a lower, western outlet of the lake in the Whitewater Lake Basin.

> [2]retreat of the ice margin north westward to Dand removed the source of this small lake (in the Whitewater Lake Basin)[3] and uncovered an outlet (The Dand Spillway).... through which Lake Souris discharged north east into Carroll glacial lake .... formed between the retreating Moose Mountain Lobe and the ice flowing westward up the Assiniboine Valley. (See Fig.24).

---

[1] This is largely a summary of J.A. Elson, "Pleistocene History of South Western Manitoba", p.62-73. In Guidebook, Ninth Annual Field Conference of the Mid-Western Friends of the Pleistocene, North Dakota Geol. Surv. Series, No. 10, 1958.

[2] John A. Elson, "Souris Basin Glacial Lakes, South Western Manitoba, Canada", (abstr.), Geol. Soc. Am. Bull. 68, p. 1722, 1957.

[3] Brackets are the authors.

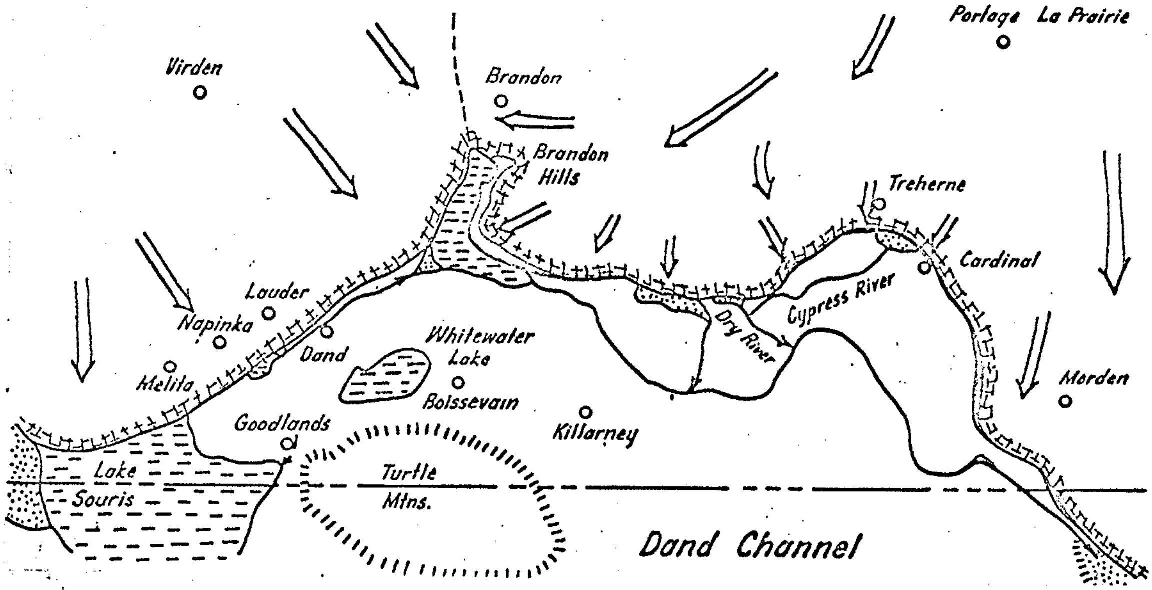


Fig.

*Position of the Dand Channel in relation to Lake Souris during an early stage of deglaciation.

ice front.......................

direction of ice movement.....

drainage channel..............

delta.........................

lake..........................

Glacier retreats caused the Dand Channel to be abandoned and the Glacial Lake Souris to merge with Glacial Lake Carroll. This lake discharged through the Pembina Valley. One of the final stages of deglaciation of this area occurred when Glacial Lake Souris was isolated from the ice front to form Glacial Lake Hind.

*J.A.Elson, 1958, op. cit., fig. 4.

ii) Profile Orientation

The orientation of each profile unit containing the maximum angle was measured after the profiles had been plotted on a map. The azimuth recorded is the direction which the slope faces,ie. as if measured with your back to the valley side. The following table lists each profile number and the corresponding azimuth of that profile.

South Valley Side

Profile No.	Azimuth	Profile No.	Azimuth	Profile No.	Azimuth
1	300	18	312	35	340
2	293	19	306	36	342
3	305	20	300	37	347
4	305	21	300	38	341
5	301	22	307	39	342
6	300	23	282	40	350
7	305	24	302	41	345
8	304	25	290	42	350
9	318	26	316	43	360
10	316	27	302	44	333
11	318	28	301	45	343
12	325	29	308	46	345
13	323	30	310	47	330
14	320	31	298	48	332
15	315	32	322	49	360
16	313	33	322	50	337
17	321	34	347	51	327

Profile No.	Azimuth	Profile No.	Azimuth	Profile No.	Azimuth
52	315	78	320	104	320
53	318	79	313	105	330
54	315	80	340	106	322
55	340	81	293	107	325
56	360	82	320	108	338
57	323	83	324	109	344
58	340	84	330	110	346
59	342	85	346	111	354
60	340	86	350	112	335
61	345	87	360	113	360
62	310	88	10		
63	323	89	17		
64	328	90	25		
65	308	91	40		
66	306	92	15		
67	297	93	17		
68	313	94	5		
69	315	95	360		
70	298	96	353		
71	295	97	342		
72	319	98	340		
73	310	99	325		
74	313	100	336		
75	312	101	320		
76	317	102	315		
77	328	103	318		

North Valley Side

Profile No.	Azimuth	Profile No.	Azimuth	Profile No.	Azimuth
1	124	25	111	49	147
2	126	26	109	50	145
3	114	27	114	51	140
4	136	28	138	52	152
5	130	29	160	53	140
6	111	30	150	54	162
7	131	31	157	55	165
8	148	32	180	56	157
9	135	33	158	57	147
10	135	34	162	58	140
11	130	35	162	59	140
12	140	36	161	60	168
13	130	37	169	61	180
14	127	38	175	62	151
15	125	39	180	63	143
16	90	40	155	64	136
17	119	41	155	65	114
18	118	42	155	66	123
19	123	43	162	67	132
20	120	44	148	68	132
21	121	45	165	69	140
22	125	46	163	70	138
23	123	47	145	71	138
24	118	48	155	72	120

Profile No.	Azimuth	Profile No.	Azimuth	Profile No.	Azimuth
73	125	86	204	99	122
74	146	87	186	100	132
75	165	88	180	101	140
76	167	89	175	102	145
77	167	90	178	103	145
78	168	91	183	104	143
79	155	92	175	105	173
80	182	93	170	106	180
81	180	94	160	107	180
82	180	95	158	108	189
83	185	96	160	109	205
84	188	97	158		
85	194	98	145		

iii) Wind Frequency Analysis

Souris, Melita, and Boissevain are the only weather stations which are located in the vicinity of the study area. Wind data is unavailable for the town of Boissevain. Melita is located to the west of Turtle Mountain which probably has a considerable effect on the winds in the surrounding district, and for this reason the data from this station was not considered. The town of Souris is north of the study area , but since it is located on a similar position with respect to Turtle Mountain as the study area, it was felt that an analysis of the frequencies of winds at Souris might provide some indication of the wind conditions in the study area.

Fig. 25 is the result of the investigation of the weather data from Souris.[1] The total frequency of occurrence of winds from eight compass directions were calculated from these records. The period of observation was from 1912 to 1963, but the records are not complete. There are only a total of 5,410 wind observations or about 135 observations per year.

The table indicates that most of the time the winds in the Souris area are from a westerly direction, with the prevailing wind from the north west. There are secondary winds from the the south east and from the north east.

---

[1]These weather records were made available to the author by R.M.Sanderson, the editor of the Souris newspaper, The Plainsdealer.

Fig. 25.
Wind Frequencies at Souris

Wind Direction	Frequency	%Frequency
N	235	4.3
NE	571	10.6
E	425	7.9
SE	813	15.0
S	298	5.5
SW	898	16.5
W	888	16.6
NW	1202	22.2
Calm	74	1.3
Total	5,404	99.9

Since Souris is to the north of the Dand Channel and the weather data is incomplete, it is realized that this analysis can at best provide only an indication of the actual wind conditions in the study area.

APPENDIX B

i) Preliminary Calculations

The measured slope angles and the corresponding map horizontal distances of each slope profile unit were the basic data from which the following morphological parameters were calculated by computer.[1]

1) the height (h) of the slope unit containing the maximum slope angle.

2) the height (H) of the valley side where the profile was measured.

3) the true slope length (l) of the slope unit containing the maximum angle.

4) the length (L) of the hypothetical mean valley side gradient.

5) the angle (B) of the mean valley side gradient.

As well as the above information, the computor was programed to print out the value of the maximum angle in each profile,the map horizontal distance (x) of the slope unit containing the maximum slope angle, and the total map horizontal distance (X) of the entire profile. This additional information was printed in order that all the data would be available in convenient form for subsequent analysis. The computor output is found at the table at the end of this section, as is the fortran program used in the calculation of these parameters.

The following formula were used in calculating the parameters.

$$X = x_1 + x_2 + \ldots\ldots x_n$$

$$H = h_1 + h_2 + \ldots\ldots h_n$$

[1]See Fig. 26 for an illustration of the position of each of these parameters in a profile.

$h = \tan b$, note that x and b are the measured parameters.

$$l = \frac{x}{\cos b} = x \sec b$$

$$\tan B = \frac{H}{X}$$

$$L = \frac{X}{\cos B} = X \sec B$$

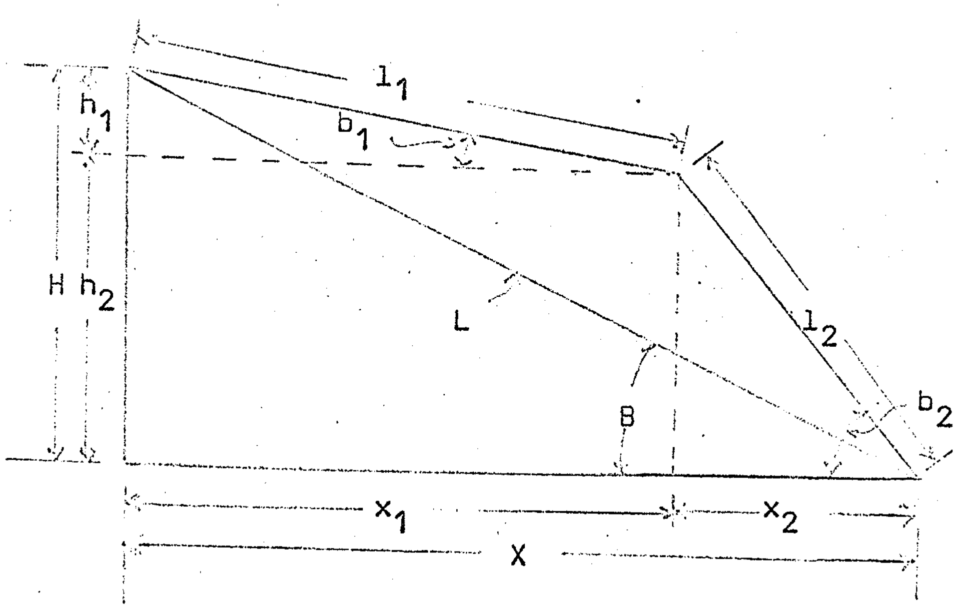


Fig. 26.

A Hypothetical Valley Side Profile Illustrating the Position of the Various Morphological Parameters

b - is the angle of a slope unit.

The remaining symbols have been defined in the text.

The subscript numbers refer to the position of the slope unit in the profile, for example, b_1 - refers to the angle of the slope unit at the top of the profile.

DISK OPERATING SYSTEM/360 FORTRAN   360N-FO-451 20

```
      DIMENSION X(7),A(7)
  100 FORMAT (I3,7(F6.1,F5.1))
  201 FORMAT (1H ,I3,2X,4F15.1,    2F15.1,F15.4,F15.1/)
  202 FORMAT (     I3,2X,4F10.1,    2F10.1,F10.4)
      F(S,T)=SQRT(S*S+T*T)
      G(U,V)=U*SIN(V)/COS(V)
      C= 3.14159/180
    1 READ (1,100) N,(X(I),A(I),I=1,7)
      IF (N) 20,20,2
    2 XSUM=0
      HSUM=0
      AMAX=0
      DO 10 I=1,7
      IF (X(I)) 11,11,7
    7 IF (AMAX-A(I))8,9,9
    8 AMAX=A(I)
      XMAX=X(I)
    9 HSUM=HSUM + G(X(I),C*A(I))
   10 XSUM=XSUM + X(I)
   11  TANA= HSUM/XSUM
      HMAX= G(XMAX,C*AMAX)
      YMAX= F(XMAX,HMAX)
      YSUM= F(XSUM,HSUM)
      WRITE (3,201)N,HMAX,YMAX,AMAX,XMAX,HSUM,YSUM,TANA,XSUM
      WRITE (2,202) N,HMAX,YMAX,AMAX,XMAX,HSUM,YSUM,TANA
      GO TO 1
   20 CALL EXIT
      END
```

Fig. 27.

PROGRAM FOR THE PRELIMINARY ANALYSIS OF DATA

Fig. 28.

Computor Output of Slope Profile Parameters

A. South Valley Side

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D.* Of Profile
1	24.4	101.0	14.0	98.0	48.5	278.7	0.1769	274.4
2	36.3	199.3	10.5	196.0	39.1	219.1	0.1813	215.6
3	41.9	219.6	11.0	215.6	50.5	492.6	0.1030	490.0
4	34.6	199.0	10.0	196.0	44.2	433.5	0.1024	431.2
5	41.5	433.2	5.5	431.2	55.0	883.7	0.0624	882.0
6	17.3	99.5	10.0	98.0	69.7	806.6	0.0868	803.6
7	49.4	473.0	6.0	470.4	62.3	766.9	0.0815	764.4
8	30.9	295.6	6.0	294.0	47.3	726.7	0.0653	725.2
9	18.6	119.1	9.0	117.6	60.8	747.3	0.0816	744.8
10	47.2	492.3	5.5	490.0	51.5	590.2	0.0875	588.0
11	24.8	158.0	9.0	156.8	53.6	668.6	0.0804	666.4
12	51.4	453.7	6.5	450.8	59.6	844.9	0.0707	842.8

*Refer to the key at the end of the table for clarification of the slope parameter abbreviations. See Appendix B, section i) for a diagram which illustrates the position of the parameters in a slope profile..

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
13	31.7	140.8	13.0	137.2	48.8	336.8	0.1465	333.2
14	34.6	199.0	10.0	196.0	58.7	629.9	0.0936	627.2
15	22.6	100.6	13.0	98.0	63.0	494.0	0.1286	490.0
16	37.4	179.9	12.0	176.0	63.1	513.1	0.1240	509.2
17	22.9	119.8	11.0	117.6	77.1	534.8	0.1458	529.2
18	27.5	197.9	8.0	196.0	44.2	472.5	0.0939	470.4
19	14.3	41.7	20.0	39.2	77.7	476.8	0.1651	470.4
20	55.8	280.0	11.5	274.4	66.3	436.3	0.1537	431.2
21	19.1	61.8	18.0	58.8	69.5	436.8	0.1613	431.2
22	49.8	221.3	13.0	215.6	76.6	534.7	0.1447	529.2
23	27.9	178.6	9.0	176.4	45.4	707.1	0.0643	705.6
24	47.2	259.1	10.5	254.8	67.8	572.4	0.1193	568.4
25	49.8	221.3	13.0	215.6	65.5	494.4	0.1337	490.0
26	12.0	41.0	17.0	39.2	55.4	532.1	0.1047	529.2
27	21.4	62.6	20.0	58.8	68.1	417.2	0.1656	411.6
28	13.5	41.5	19.0	39.2	60.1	338.6	0.1803	333.2
29	6.7	20.7	19.0	19.6	66.4	378.3	0.1784	372.4
30	19.1	61.8	18.0	58.8	66.2	378.2	0.1778	372.4

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
31	7.5	21.0	21.0	19.6	49.0	298.1	0.1667	294.0
32	6.7	20.7	19.0	19.6	38.1	354.9	0.1081	352.8
33	24.4	101.0	14.0	98.0	62.7	630.3	0.1000	627.2
34	23.0	139.1	9.5	137.2	28.1	236.9	0.1195	235.2
35	7.5	21.0	21.0	19.6	54.6	415.2	0.1326	411.6
36	12.7	41.2	18.0	39.2	55.7	241.7	0.2370	235.2
37	47.5	126.8	22.0	117.6	60.8	186.6	0.3445	176.4
38	16.4	25.6	40.0	19.6	70.0	302.2	0.2381	294.0
39	14.2	24.2	36.0	19.6	54.8	129.7	0.4657	117.6
40	6.4	20.6	18.0	19.6	52.0	453.8	0.1153	450.8
41	34.3	179.7	11.0	176.4	39.9	530.7	0.0755	529.2
42	21.7	177.7	7.0	176.4	52.5	785.8	0.0669	784.0
43	10.3	98.5	6.0	98.0	20.1	353.4	0.0569	352.8
44	18.6	119.1	9.0	117.6	46.0	492.2	0.0940	490.0
45	4.2	20.0	12.0	19.6	41.2	530.8	0.0779	529.2
46	5.3	20.3	15.0	19.6	49.5	551.0	0.0903	548.8
47	16.7	80.2	12.0	78.4	25.5	139.5	0.1855	137.2
48	27.5	197.9	8.0	196.0	57.1	512.8	0.1120	509.6

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
49	6.9	39.8	10.0	39.2	7.1	59.2	0.1205	58.8
50	13.0	50.2	15.0	48.5	17.1	89.4	0.1953	87.7
51	10.5	40.6	15.0	39.2	10.7	59.8	0.1815	58.8
52	12.4	79.4	9.0	78.4	12.4	79.4	0.1584	78.4
53	8.3	21.3	23.0	19.6	12.9	50.2	0.2659	48.5
54	41.3	50.4	55.0	28.9	45.8	66.7	0.9443	48.5
55	11.2	40.8	16.0	39.2	24.1	158.6	0.1539	156.8
56	30.0	66.0	27.0	58.8	32.7	103.3	0.3337	98.0
57	11.3	22.6	30.0	19.6	55.3	147.9	0.4030	137.2
58	34.2	75.3	27.0	67.1	44.6	152.2	0.3064	145.5
59	31.7	84.6	22.0	78.4	39.7	124.1	0.3372	117.6
60	41.9	143.5	17.0	137.2	52.3	202.9	0.2669	196.0
61	38.2	123.7	18.0	117.6	43.3	239.2	0.1843	235.2
62	31.7	84.6	22.0	78.4	62.5	251.4	0.2565	243.5
63	11.2	40.8	16.0	39.2	64.7	262.9	0.2538	254.8
64	40.4	258.0	9.0	254.8	40.4	258.0	0.1584	254.8
65	34.6	199.0	10.0	196.0	68.5	630.9	0.1092	627.2
66	36.2	160.9	13.0	156.8	50.3	317.6	0.1604	313.6

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
67	42.8	125.1	20.0	117.6	62.4	205.7	0.3181	196.0
68	36.6	53.6	43.0	39.2	77.5	229.1	0.3596	215.6
69	27.4	64.9	25.0	58.8	44.4	163.0	0.2834	156.8
70	25.0	63.9	23.0	58.8	45.3	201.2	0.2312	196.0
71	13.5	31.9	25.0	28.9	58.7	194.7	0.3160	185.7
72	6.7	20.7	19.0	19.6	40.6	171.0	0.2443	166.1
73	40.6	162.0	14.5	156.8	46.7	239.8	0.1986	235.2
74	29.3	198.2	8.5	196.0	44.4	414.0	0.1078	411.6
75	18.2	99.7	10.5	98.0	44.7	765.4	0.0585	764.1
76	15.2	60.7	14.5	58.8	55.2	746.8	0.0742	744.8
77	20.8	100.2	12.0	98.0	64.9	903.9	0.0720	901.6
78	39.1	161.6	14.0	156.8	49.2	492.5	0.1004	490.0
79	13.8	79.6	10.0	78.4	33.3	628.1	0.0532	627.2
80	45.7	239.6	11.0	235.2	50.7	531.6	0.0958	529.2
81	12.5	60.1	12.0	58.8	41.6	256.8	0.1642	253.4
82	41.7	200.4	12.0	196.0	41.7	200.4	0.2126	196.0
83	34.8	160.6	12.5	156.8	34.8	160.6	0.2217	156.8
84	41.7	200.4	12.0	196.0	54.2	356.9	0.1536	352.8

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
85	40.7	181.0	13.0	176.4	61.6	708.3	0.0873	705.6
86	37.6	161.3	13.5	156.8	49.3	648.7	0.0762	646.8
87	41.9	143.5	17.0	137.2	50.2	202.3	0.2562	196.0
88	26.2	159.0	9.5	156.8	26.2	159.0	0.1673	156.8
89	24.4	101.0	14.0	98.0	29.2	237.0	0.1243	235.2
90	35.5	141.7	14.5	137.2	50.2	414.7	0.1220	411.6
91	26.8	110.6	14.0	107.3	78.2	641.3	0.1229	636.5
92	12.5	60.1	12.0	58.8	57.8	590.8	0.0983	588.0
93	20.6	158.2	7.5	156.8	32.6	647.6	0.0504	646.8
94	16.7	80.2	12.0	78.4	33.1	393.4	0.0845	392.0
95	22.4	128.9	10.0	126.9	27.2	265.5	0.1029	264.1
96	27.6	159.2	10.0	156.8	43.2	570.0	0.0761	568.4
97	22.9	119.8	11.0	117.6	41.4	667.7	0.0621	666.4
98	18.6	119.1	9.0	117.6	43.5	687.4	0.0634	686.0
99	40.0	219.3	10.5	215.6	41.2	355.2	0.1167	352.8
100	19.7	62.0	18.5	58.8	38.6	290.6	0.1342	288.0
101	19.3	158.0	7.0	156.8	43.9	707.0	0.0622	705.6
102	26.5	217.2	7.0	215.6	47.5	570.4	0.0836	568.4

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
103	36.3	199.3	10.5	196.0	56.5	551.7	0.1030	548.8
104	31.1	179.1	10.0	176.4	58.7	805.7	0.0731	803.6
105	39.9	200.0	11.5	196.0	50.1	492.6	0.1023	490.0
106	45.8	220.4	12.0	215.6	54.1	512.5	0.1061	509.6
107	15.5	99.2	9.0	98.0	51.2	746.6	0.0687	744.8
108	32.2	218.0	8.5	215.6	55.5	1040.3	0.0534	1038.8
109	31.3	276.2	6.5	274.4	42.0	804.7	0.0523	803.6
110	34.6	199.0	10.0	196.0	59.2	1118.8	0.0530	1117.2
111	32.8	198.7	9.5	196.0	54.2	727.2	0.0747	725.2
112	11.7	79.3	8.5	78.4	28.9	354.0	0.0818	352.8
113	24.8	158.8	9.0	156.8	51.1	453.7	0.1133	450.8

B. North Valley Side

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
1	13.6	60.3	13.0	56.8	38.8	277.1	0.1415	264.2
2	18.8	80.6	13.5	78.4	38.4	238.3	0.1634	235.2
3	31.0	198.4	9.0	196.0	46.5	453.2	0.1031	450.8
4	37.6	161.3	13.5	156.8	57.1	396.1	0.1456	392.0
5	28.2	120.9	13.5	117.6	64.1	591.5	0.1090	588.0
6	15.0	42.0	21.0	39.2	56.8	280.2	0.2071	274.4
7	22.6	100.6	13.0	98.0	47.7	317.2	0.1521	313.6
8	20.8	100.2	12.0	98.0	47.3	317.1	0.1508	313.6
9	12.0	41.0	17.0	39.2	58.2	357.6	0.1650	352.8
10	6.7	20.7	19.0	19.6	54.4	357.0	0.1542	352.8
11	43.3	143.9	17.5	137.2	62.1	377.5	0.1669	372.4
12	43.5	200.8	12.5	196.0	65.7	630.6	0.1048	627.2
13	7.5	21.0	21.0	19.6	65.3	378.1	0.1754	372.4
14	6.6	20.7	18.5	19.6	44.6	472.5	0.0949	470.4
15	35.9	180.0	11.5	176.4	55.8	454.2	0.1237	450.8
16	16.0	80.0	11.5	78.4	52.0	453.8	0.1153	450.8
17	38.2	123.7	18.0	117.6	61.8	377.5	0.1660	372.4
18	12.7	41.2	18.0	39.2	51.5	337.2	0.1546	333.2

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
19	13.5	41.5	19.0	39.2	50.4	356.4	0.1430	352.8
20	7.9	21.1	22.0	19.6	61.5	415.2	0.1498	410.6
21	42.0	162.3	15.0	156.8	64.0	397.2	0.1633	392.0
22	8.1	21.2	22.5	19.6	70.4	709.1	0.0998	705.6
23	40.7	181.0	13.0	176.4	73.7	885.1	0.0835	882.0
24	49.5	259.6	11.0	254.8	65.7	397.5	0.1677	392.0
25	13.5	41.5	19.0	39.2	64.6	397.3	0.1647	392.0
26	19.1	61.8	18.0	58.8	68.2	436.6	0.1582	431.2
27	38.2	87.2	26.0	78.4	74.6	218.4	0.3635	205.3
28	25.5	82.4	18.0	78.4	72.6	360.2	0.2058	352.8
29	26.2	159.0	9.5	156.8	26.2	159.0	0.1673	156.8
30	52.5	202.9	15.0	196.0	61.6	455.0	0.1366	450.8
31	30.4	121.5	14.5	117.6	51.6	307.7	0.1703	303.3
32	18.1	80.5	13.0	78.4	40.8	258.1	0.1602	254.8
33	28.5	83.4	20.0	78.4	45.3	211.2	0.2195	206.3
34	30.1	84.0	21.0	78.4	52.4	241.0	0.2227	235.2
35	24.0	82.0	17.0	78.4	70.7	311.4	0.2331	303.3
36	47.9	164.0	17.0	156.8	50.0	183.3	0.2834	176.4

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
37	14.7	60.6	14.0	58.8	58.8	338.4	0.1766	333.2
38	9.4	30.4	18.0	28.9	52.9	482.6	0.1103	479.7
39	40.7	181.0	13.0	176.4	51.0	279.1	0.1860	274.4
40	19.0	99.0	11.0	98.0	67.7	708.8	0.0960	705.6
41	15.2	79.9	11.0	78.4	26.2	197.7	0.1338	196.0
42	14.7	70.6	12.0	69.1	27.1	305.5	0.0890	304.3
43	19.9	100.0	11.5	98.0	40.5	394.1	0.1033	392.0
44	30.3	217.7	8.0	215.6	31.7	295.7	0.1077	294.0
45	37.7	393.8	5.5	392.0	37.7	393.8	0.0963	392.0
46	24.1	197.5	7.0	196.0	28.9	471.3	0.0613	470.4
47	12.5	60.1	12.0	58.8	36.2	315.7	0.1156	313.6
48	18.1	80.5	13.0	78.4	44.5	549.6	0.0812	547.8
49	33.3	160.3	12.0	156.8	43.3	511.4	0.0849	509.6
50	7.5	21.0	21.0	19.6	43.6	433.4	0.1012	431.2
51	25.2	73.5	20.0	69.1	54.1	347.7	0.1574	343.5
52	40.7	181.0	13.0	176.4	50.0	298.2	0.1700	294.0
53	10.5	40.6	15.0	39.2	37.7	170.3	0.2272	166.1
54	12.0	41.0	17.0	39.2	43.7	181.7	0.2475	176.4

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
55	18.1	80.5	13.0	78.4	46.6	268.2	0.1766	264.1
56	15.2	79.9	11.0	78.4	37.3	296.4	0.1268	294.0
57	14.8	50.7	17.0	48.5	28.2	168.5	0.1696	166.1
58	28.7	65.4	26.0	58.8	40.4	96.5	0.4601	87.7
59	21.6	53.1	24.0	48.5	39.2	104.6	0.4046	97.0
60	11.6	40.9	16.5	39.2	46.2	201.4	0.2357	196.0
61	15.3	24.9	38.0	19.6	44.8	423.3	0.1064	420.9
62	7.5	21.0	21.0	19.6	73.3	322.1	0.2338	313.6
63	28.0	34.2	55.0	19.6	68.5	262.9	0.2700	253.8
64	7.5	21.0	21.0	19.6	43.1	200.7	0.2201	196.0
65	22.6	63.0	21.0	58.8	48.8	356.2	0.1383	352.8
66	17.5	42.9	24.0	39.2	46.8	336.5	0.1404	333.2
67	9.4	30.4	18.0	28.9	46.6	365.1	0.1288	362.1
68	16.7	80.2	12.0	78.4	40.4	277.4	0.1472	274.4
69	26.5	217.2	7.0	215.6	46.9	550.8	0.0854	548.8
70	66.1	689.2	5.5	686.0	79.7	1080.9	0.0740	1078.0
71	11.4	59.9	11.0	58.8	60.5	708.2	0.0857	705.6
72	16.5	157.7	6.0	156.8	39.9	628.5	0.0637	627.2

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
73	17.3	99.5	10.0	98.0	45.3	648.4	0.0700	646.8
74	29.4	188.0	9.0	185.7	56.8	932.2	0.0611	930.5
75	99.8	255.5	23.0	235.2	152.9	846.4	0.1837	832.5
76	33.5	257.0	7.5	254.8	58.7	1001.3	0.0587	999.6
77	27.5	159.2	10.0	156.8	62.9	903.8	0.0698	901.6
78	38.1	199.7	11.0	196.0	67.2	689.3	0.0980	686.0
79	54.2	260.5	12.0	254.8	79.8	846.6	0.0947	842.8
80	36.8	142.0	15.0	137.2	47.7	346.8	0.1388	343.5
81	36.1	218.6	9.5	215.6	50.0	473.0	0.1062	470.4
82	46.4	355.8	7.5	352.8	67.0	650.3	0.1036	646.8
83	23.0	139.1	9.5	137.2	74.2	573.2	0.1305	568.4
84	45.3	201.2	13.0	196.0	65.7	600.9	0.1100	597.3
85	52.1	240.9	12.5	235.2	78.9	671.1	0.1184	666.4
86	53.3	279.5	11.0	274.4	66.7	552.8	0.1216	548.8
87	17.3	99.5	10.0	98.0	56.4	532.2	0.1066	529.2
88	41.5	433.2	5.5	431.2	57.1	981.7	0.0583	980.0
89	33.3	160.3	12.0	156.8	65.1	796.0	0.0820	793.3

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
90	22.6	100.6	13.0	98.0	46.8	883.2	0.0530	882.0
91	40.0	219.3	10.5	215.6	54.2	766.3	0.0709	764.4
92	45.7	375.2	7.0	372.4	45.7	375.2	0.1228	372.4
93	61.9	474.5	7.5	470.4	66.8	602.0	0.1117	598.3
94	12.4	118.2	6.0	117.6	53.8	844.5	0.0638	842.8
95	8.5	69.6	7.0	69.1	59.1	1040.5	0.0569	1038.8
96	36.0	413.2	5.0	411.6	54.5	766.3	0.0713	764.4
97	26.8	156.2	6.0	254.8	53.8	805.4	0.0670	803.6
98	13.8	79.6	10.0	78.4	56.0	1020.7	0.0549	1019.2
99	13.4	70.4	11.0	69.1	39.8	492.6	0.0811	491.0
100	20.7	119.4	10.0	117.6	25.9	392.9	0.0660	392.0
101	29.0	256.4	6.5	254.8	40.7	589.4	0.0692	588.0
102	30.9	295.6	6.0	294.0	52.8	746.7	0.0709	744.8
103	38.1	257.6	8.5	254.8	72.0	845.9	0.0854	842.8
104	24.8	178.1	8.0	176.4	58.2	844.8	0.0690	842.8
105	19.7	119.2	9.5	117.6	59.8	649.6	0.0924	646.8
106	36.2	160.9	13.0	156.8	57.9	483.5	0.1205	480.0

Profile No.	Ht. of Max. Unit	True Length of Max. Unit	Maximum Angle	M.H.D. of Max. Unit	Valley Height	Length of Mean Slope	Mean Gradient (Tangent)	Total M.H.D. of Profile
107	39.1	161.6	14.0	156.8	62.1	493.9	0.1267	490.0
108	19.5	80.8	14.0	78.4	54.1	482.7	0.1128	479.7
109	38.0	218.9	10.0	215.6	60.3	474.3	0.1282	470.4

ii) The Chi-Square Test

The chi-square test was used for the determination of normal distributions in the frequency of occurrence of the maximum angle in the various profile groups described in chapter three,[1] and in determining the type of distributions of the various morphometric parameters used in the correlation analysis.[2]

This test compares the observed frequency of occurrence with the theoretical frequency of occurrence which would be expected if the sample was from a population having a normal distribution.

The formula for the chi-square test is

$$X^2 = \frac{(f - fc)^2}{fc}$$

where f is the observed frequency of occurrence and fc is the theoretical frequency of occurrence.[3]

The theoretical frequencies were determined from a table of normal curve areas of the Z distribution.[4] By using this method the theoretical frequencies of occurrence can be easily calculated for any sample size. The formula for converting an observed value to a Z score or Z value is:

---

1 See pages 22 and 23.

2 The types of normal distributions which were examined were the arithmetic normal, the logarithmic normal, the square root normal, and the reciprocal normal. See page 23.

3 Frederick E. Croxton and Dudlay D. Cowden, Applied General Statistics, New York, Prentice-Hall, Inc., 1939, p. 286.

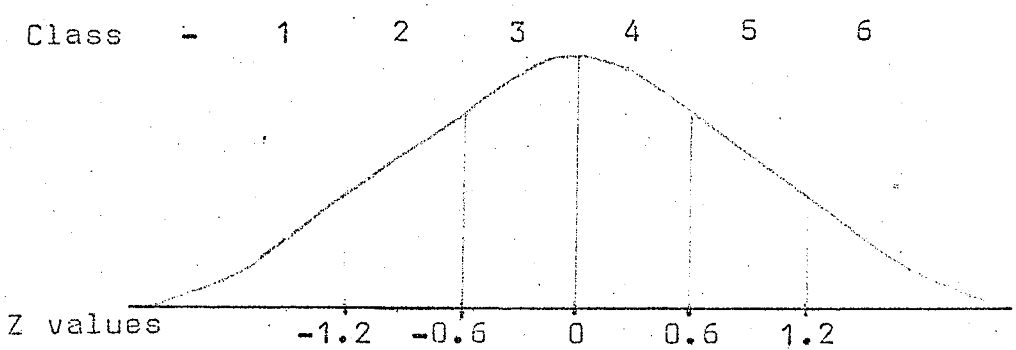
4 For this table see George H. Weinberg and John A. Schumaker, Statistics: An Intuitive Approach, Wadsworth Publishing C., 1962, p. 321.

$$Z \text{ values} = \frac{\text{mean} - \text{observed value}}{\text{standard deviation}}$$ [5]

This table gives the percentage of area which will be in each class of a normal distribution curve. By multiplying this percentage by the sample size, the theoretical frequencies can be arrived at for each class into which the normal distribution has been subdivided. A class interval of 0.6 and six classes were arbitrarily chosen for all the tests for normal distributions.

The following example presents the sequential details of this method of determining the theoretical frequencies.

a) Choose the class interval and the number of classes. For this example the class interval is 0.6, and the number of classes is six. See diagram.



In general, these values should be chosen so that no theoretical frequency is less than five for any sample size.

b) Read from the table of normal curve areas the value for Z = 0.6 which is 0.2257 or 22.57%. This is the percent area of the curve between 0 and 0.6, and means that each of classes 3 and 4 will have 22.57% of the sample size for the theoretical frequencies.

---

[5] Wienberg and Schumaker, op. cit., p. 44.

c) Read from the table the value opposit Z = 1.2 which is 38.49%. This is the area between 0 and 1.2. Therefore, the area between 0.6 and 1.2 will be 38.49 minus 22.57 or 15.92%. This is the percent area in classes two and five.

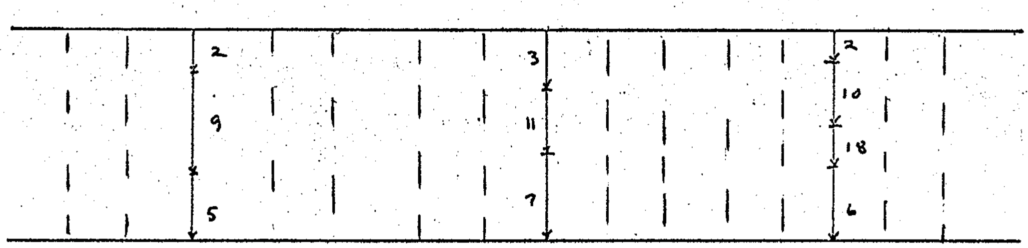
d) Since the percent area of each side of the distribution must be equal to 50.00%, the percent area in classes one and six will be equal to 50.00 minus 38.49 or 11.51%.[6]

It is realized that some of the profile groups have a small number of profiles, and that it is difficult to determine accurately the type of distribution for small sample sizes. But the analysis was attempted for the following reasons:

a) it was impossible to increase the sample size at this point in the study.

b) there is the possibility that an increase in the sample size would not appreciably alter the relative frequencies of occurrence of the maximum slope angles which were already obtained. That is if the number of profiles were increased by four times there is a good possibility that the frequency of occurrence of the maximum angles would also be increased by a factor of four.

For example, consider profiles in the following positions with the slope values shown.



[6] Note that the values of the class interval and the number of classes determines the percent area of theoretical frequency of each class.

By taking four or more times as many profile measurements (indicated by the dashed lines) the slope units of the adjacent units would be the same or very similar to those already measured. The overall effect of the increased sample size would probably be nearly the same as if the original sample values for the frequency of occurrence of the maximum angle were just multiplied by a factor of four.[7]

This is a generalization, but it is hoped that it will justify, sufficiently, the use of small sample size in the normal distribution analysis, and to allow a reasonably accurate interpretation of the results of this analysis.

The level of significance used for rejecting or accepting the X^2 value as indicating a normal distribution is P.05.[8] The number of degrees of freedom for the computer chi-square values in n - 1, where n is the number of classes.[9]

---

[7] This would be especially true after the profiles were grouped into classes for the normal distribution test.

[8] R. A. Fischer, Statistical Methods For Research Workers, Edinburgh: Oliver and Boyd, 1950, p. 80.

[9] Personal Communication, Professor Chebib, Computer Centre, University of Manitoba, 1967.

```
C
C HEADER CARD MUST PRECEED EACH DATA SET
C IF NOT LAST DATA SET THEN BLANK CARD AT END OF DATA
C IF LAST DATA SET THEN -VE NO. IN COL 1-3AT END OF DATA
C
      DOUBLE PRECISION B(6),H(5)
      DIMENSION A(15),FE(15),N(6,15),S(6),SS(6),CHI(6),T(6),X(6,250),
     1   EE(15)
      IVAR =6
      IT=4
      READ (1,102) (B(I),I=1,IVAR)
  102 FORMAT (10A8)
      READ (1,100) K,A(1),D,(EE(I),I=1,K)
  100 FORMAT (I2,   2F5.0,(8F8.0))
      DO 1 I=2,K
    1 A(I)=A(I-1)+D
      A(K)=10
   22 READ (1,102) (H(I),I=1,5)
      DO 2 J=1,250
      READ (1,101) NFIN,(X(I,J),I=1,IVAR)
  101 FORMAT (I3,2X,3F10.0,10X,3F10.0)
      IF (NFIN) 3,3,2
    2 CONTINUE
    3 NCD=J-1
      WRITE (3,202) (H(I),I=1,5),NCD
  202 FORMAT ('1TEST FOR NORMALITY ',5A8,' NO OF PROFILES ',I3//
     1  ' CLASS NO.   UPPER CLASS BD.   EXP FREQ. ',6X,'LINEAR',5X,
     2  'LOG',7X,'SQRT',6X,'RECIP')
      DO 4 I=1,K
    4 FE(I)=NCD*EE(I)
      DO 20 M=1,IVAR
      DO 5 J=1,IT
      S(J)=0
      SS(J)=0
    5 CHI(J)=0
      DO 42 J=1,IT
      DO 42 I=1,K
   42 N(J,I)=0
      DO 6 J=1,NCD
      CALL TRANS(X(M,J),T)
      DO 6 I=1,IT
      S(I)=S(I)+T(I)
    6 SS(I)=SS(I)+T(I)*T(I)
      DO 10 I=1,IT
      SS(I)=SQRT((SS(I)-S(I)*S(I)/NCD)/(NCD-1))
   10 S(I)=S(I)/NCD
      DO 8 J=1,NCD
      CALL TRANS(X(M,J),T)
      DO 8 L=1,IT
      Z=(T(L)-S(L))/SS(L)
      DO 7 I=1,K
      IF (Z-A(I)) 8,8,7
    7 CONTINUE
      I=K
    8 N(L,I)=N(L,I)+1
      DO 9 I=1,IT
      DO 9 J=1,K
    9 CHI(I)=CHI(I)+(N(I,J)-FE(J))*(N(I,J)-FE(J))/FE(J)
```



```
      IF (M-4) 13,12,13
   12 WRITE (3,202) (H(I),I=1,5),NCD
   13 DO 11 I=1,K
   11 WRITE (3,200) I,A(I),FE(I),(N(J,I),J=1,IT)
  200 FORMAT ('0',I5,F14.1,F18.2,3X,8I10)
      WRITE (3,201) B(M),(CHI(I),I=1,IT)
  201 FORMAT ('0',A8,32X, 4F10.2,'   CHI-SQ. GOODNESS OF FIT')
   20 WRITE (3,203)
  203 FORMAT(' ')
      IF (NFIN) 21,22,21
   21 CALL EXIT
      END
```

Fig. 29. Program for the Chi-square Analysis for Normal Frequency Distributions

iii) Analysis of Variance

The analysis of variance is a statistical test which is used to determine whether or not significant differences exist between two or more sample means.

A computor program - the factorial analysis of variance - was used to compare the means of the profile groups which were found to have normal distributions of the frequency of occurrence of the maximum angles. This program indicated that there were significant differences between the means of these groups but it did not provide the information needed to determine which groups had a significant difference between them.[1]

In order to determine those pairs of means which have (or do not have) a significant difference, a second program was written which calculated the least significant difference (L.S.D.) for each possible different pair of means.[2,3]

---

[1]This program was written by Professor Chebib of the Department of Computor Science, University of Manitoba. It is made available to reseach students who are working under a faculty member. A copy of the program description is at the end of this section, but the fortran steps in the program are not available.

[2]See figure 30 for the fortran steps to this program.

[3]The least significant difference is equal to

$$T \times \frac{E.M.S.}{r_1} + \frac{E.M.S.}{r_2}$$

where:- r-is the number of replicates, i.e. the sample size, of the groups which are being compared.
E.M.S.-is the error mean square and is equal to 21.20 in this case.
T-is a constant which was taken to be 2.0 in this test (at the P.05 level). See the table of T values in Croxton and Cowden, Applied General Statistics, New York: Prentice Hall, 1939, p.875.

The L.S.D. is subtracted from the absolute difference between the means of the pair of profile groups in question. If the absolute value of the difference between the two means is greater than the L.S.D. value for that pair of profile groups it indicated that the difference between their means is significant.

The computer was programed to print 0.0 if there was no difference between the means being compared, or the actual value of the difference where the latter was significant.

As an aid in the interpretation, the means of the profile groups were arranged in order of increasing value (Figure 8). A table of the results of the L.S.D. analysis is presented in Chapter IV (Figure 10).

The University of Manitoba

puter Centre

April, 1967

FACTORIAL ANALYSIS OF VARIANCE PROGRAM

by: F. Chebib

This program is designed to analyze multifactorial experiments with equal or unequal subclass numbers. It was written for the IBM/360 using FORTRAN IV. It consists of a main program and 7 subroutines. It requires a core storage of approximately 110,000 cores and three external storage devices.

The dimensions are set up so that the program can handle experiments up to 10 factors. Its Limitations are as follows:

(1) Maximum number of factors 10.

(2) Maximum number of levels for factors

1,2,3	=	999
4,5	=	99
6,7,8,9,10	=	9

(3) Maximum number of observations per cell 999.

(4) Maximum number of cells 16000.

(5) When secondary epsilons are required, they will be calculated only when the product of the number of levels of the two factors involved does not exceed 4000.

OUTPUT consists of:

(1) A list of input data, for purpose of checking.

(2) A list of means, standard deviations and standard errors based on both pooled and unpooled data for each level of each possible combination of the factors.

(3) A complete analysis of variance for all main effects and interactions.

(4) Values of the F variance ration for all main effects and interactions, based on the within cells mean square as the error term.

(5) The coefficient of variability.

(6) Values of epsilon and epsilon squared for each of the main effects (Primary Epsilon).

(7) Values of epsilon and epsilon squared for each factor within each level of all other factors (optional) - Secondary Epsilons.

DATA SET UP for each experiment is as follows:

A. FIRST HEADER CARD

Col. 1 - 40 Title of experiment (alphanumeric).

Col. 41 - 42 Number of factors.

Col. 43 - 50 It is preferable to include in this field a value (with decimal) which is close to the mean of the data to reduce rounding errors during computations.

Col. 51 Secondary epsilon option:
Leave blank unless the secondary epsilon values are to be omitted. In this case, insert any value from 1 to 9 in this column.

Col. 52 Transformation option according to the following code:

0 or blank: no transformation

1 : $\sqrt{x}$

2 : $\sqrt{x + .5}$

3 : $\sqrt{x} + \sqrt{x + 1}$

4 : $\text{Log}_{10}(x)$

5 : $\text{Log}_{10}(x + 1)$

6 : $1/x$

7 : $1/(x + 1)$

8 : Arc sin $\sqrt{x}$

9 : Arc sin $\sqrt{x \pm 1/2N}$

Col. 53 - 80 Leave blank.

B. SECOND HEADER CARD

Col. 1 - 3 Name of factor 1 (alphanumeric).

Col. 4 - 6 Number of levels of factor 1.

Col. 7 - 60 Repeat the above two entries for the remaining factors.

C. DATA CARDS

Each cell will have a cell identification card and one or more data cards. The format for the cell identification card is:

Col. 1 - 3 Level of factor 1

Col. 4 - 6 Level of factor 2

Col. 7 - 9 Level of factor 3

Col. 10 - 11 Level of factor 4

Col.	12 - 13	Level of factor 5
Col.	14	Level of factor 6
Col.	15	Level of factor 7
Col.	16	Level of factor 8
Col.	17	Level of factor 9
Col.	18	Level of factor 10
Col.	19 - 22	Number of observations in the cell.

The format for the data cards is:

Col.	1 - 4	Observation 1
Col.	5 - 80	The above entry is repeated for each remaining observation. If a cell has more than 20 observations, add an additional data card(s) as needed.

D. The program handles MULTIPLE JOBS so any number of experiments may be stacked and analyzed with one run of the program.

```
      DIMENSION XB(28), R(28), DIF(28)
      EMS=30.2290
      READ(1,50)  (XB(I), R(I), I=1,28)
      WRITE (3,51)
      WRITE (3,52)  (I, XB(I), R(I), I=1,28)
      WRITE (3,53)  (I, I=1,25)
      WRITE(3,55) (XB(I),I=1,25)
      DO 12 I=1,28
      J=1
    1 D=ABS(XB(I)-XB(J))
      SD=2.*SQRT(EMS/R(I) + EMS/R(J))
      D=D-SD
      IF(D) 2,10,10
   10 DIF(J)=D
      GO TO 11
    2 DIF(J)=0
   11 J=J+1
      IF(J-25) 3,3,4
    3 IF(J-I) 1,1,4
    4 J=J-1
      WRITE (3,54) I,(DIF(K), K=1,J)
   12 CONTINUE
      WRITE(3,55) (XB(I),I=26,28)
      WRITE (3,53) (I,I=26,28)
      DO 5 I=1,25
    5 WRITE (3,54)
      DO 9  I=26,28
      DO 8  J=26,28
      D=ABS(XB(I)-XB(J))
      SD=2.* SQRT(EMS/R(I) +EMS/R(J))
      D=D-SD
      IF (D) 6,7,7
    6 DIF(J)=0.
      GO TO 8
    7 DIF(J)=D
    8 CONTINUE
    9 WRITE (3,54) I, (DIF(K), K=26, I)
   49 CALL EXIT
   50 FORMAT(2F10.0)
   51 FORMAT ('0 INPUT DATA'/'0 TREATMENT' 6X'MEAN' 3X'NO REPLICATES'/)
   52 FORMAT (1H , I10, F10.2, F10.0)
   53 FORMAT ('1 COMPARISON OF TREATMENT MEANS VIA L.S.D.'/ '0' 3X25I5)
   54 FORMAT (1H , I3, 2X, 25F5.2)
   55 FORMAT('0XB '25F5.1/)
      END
```

Fig. 30.

Program for the L.S.D. Analysis

iv) Correlation

The data gathered during this study is well suited for correlation analysis since as Fisher states "the principal utility of the correlation coefficient lies in its application to subjects of which little is known, and upon which the data is relatively scanty."[1]

The degree of correlation between the various parameters was determined by the factor analysis method by computer.[2] Miller and Kahn give the following description of the factor analysis technique:[3]

> In its most restricted sense we may consider factor analysis to be a consideration of the degree of association between pairs of variables. Usually a number of variables is involved and the degree of association is taken between all possible pairs. This association is usually measured by the correlation coefficient, r.....

A second part of the factor analysis is the extraction of variables or 'factors' (factor loadings from the data). There are usually several factors for each of the variables, with each of the factors being completely independent (the factors are in the vertical columns in figures 14 and 17). The interpretation of the results of this analysis is discussed in Chapter 4.

---

[1] R.A. Fisher, Statistical Methods For Research Workers, Oliver and Boyd: Edinburgh and London, 1950, p. 195.

[2] This program was written by Professor F. Chebib of the Computer Center, University of Manitoba. A copy of the program description is provided at the end of this section along with the fortran steps in the program.

[3] R. L. Miller and L. S. Kahn, Statistical Analysis in the Geological Sciences, John Wiley and Sons: New York, 1962, p. 292.

a) Correlation Coefficients

The statistical significance of the correlation coefficients was calculated for each of the profile groups. Statistical significance indicates the probability of obtaining similar 'r' values if another sample of the same size was taken from the same area. A value of the correlation coefficients was determined below which there is no likelihood of obtaining similar 'r' values in another sample.

For example, in the group 'north valley side riparian profiles not facing between azimuth 105 and 145', there is little likelihood of obtaining similar values in subsequent samples for those correlation coefficients which are less than about 0.42. For practical purposes, these values indicate zero correlation since they have no statistical significance.

The significance test used is a students 't' test, the formula for which is[4].

$$t = r \frac{\sqrt{N - 2}}{\sqrt{1 - r^2}}$$

where N = the sample size

r = the correlation coefficient

and the degrees of freedom

n, is N - 2.

Reference to a table of t values gives "the number of times in 100 a sample drawn from a population with zero correlation would result in a correlation coefficient as high

---

[4] Frederick E. Croxton, and Dudley J. Cowden, Applied General Statistics, New York: Prentice-Hall, 1939, p. 681.

as that actually obtained. If this chance is low the correlation is assumed to be significant".[5]

For the purpose of this study, any r value which gives more than 5 chances in 100 ($p = .05$) of the sample having been taken from a population with zero correlation was rejected.

b) Principle factor matrix and the rotated factor matrix

The values in the principle factor matrix represent the degree of correlation which exists between the data and hypothetical parameters. The purpose of this is to reduce the data so that variation within the data can be explained by a few common factors. Each factor accounts for one or more variables in the original data.

The principle factor matrix can be considered geometrically. Each pair of factors (vertical rows, F_1, F_2 and F_3, Figure 14) can be referred to a set of horizontal and horizontal axes as follows:

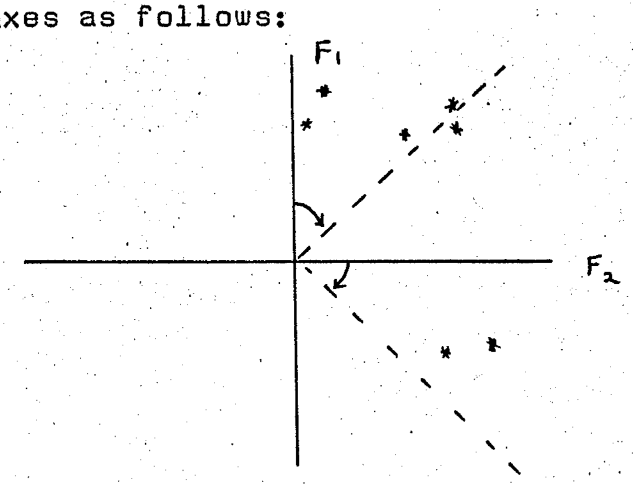


Fig. 31.
An Illustration of the Rotation of the Factor Axes

The results in the principle factor matrix are difficult to interpret, but if the main axes are rotated so that one of them coincides with a cluster of points, then the tabulated results become more meaningful. This is what is meant by a rotated factor matrix.

Since each factor can be represented by a different axis, they are independent of each other. For practical purposes, the 'factors', which are removed from the data, can be considered to be the parameter corresponding to the 'highest' factor loading value in a factor loading column.

Note that the factor loading values are only relative values and do not represent actual units, such as percentages.

The results in a rotated factor matrix are useful if there is only one 'high' factor loading value opposit each parameter, and if the pattern formed by these high values is repeated in other groups.

The University of Manitoba

Computer Centre

FACTOR ANALYSIS PROGRAM

By: F. Chebib

This program is designed to calculate means, standard deviations, the intercorrelations for any set of data and to perform a principle factor analysis and varimax rotation. It consists of one main program and 6 subroutines, 5 of which are from the scientific subroutine package of which 2 (CØRRE and TRACE) have been modified. The program requires a core storage of approximately 100 thousand cores.

The dimensions are set up so that the program can handle a maximum of 90 variables.

OUTPUT consists of:

(1) A list of the input data, for purpose of checking (optional).
(2) The mean and the standard deviation for each variable.
(3) An m x m matrix containing all possible intercorrelations between the m variables.
(4) The principle factor loadings matrix and the percent variability explained by each factor.
(5) The rotated factor matrix and the commonality for each variable.

DATA SET UP, for each set of data is as follows:

A - HEADER CARD:

Col. 1 - 40	Title of experiment (alphanumeric).
Col. 41 - 45	Number of samples (N).
Col. 46 - 47	Number of variables (m).
Col. 48 - 55	Constant (such as 0.03). The factors which account for less than this constant will not be retained.
Col. 56 - 58	Input data option; any value in this field will prohibit the output of the list of input data (see (1) above).

B - DATA CARDS

Each card will normally accommodate one sample and will contain m values. The usual format is 4 columns to a value (decimals may be included). If the number of variables is greater than 20, add an additional data card for each 20 additional variables up to a maximum of 5 cards to each sample.

This format may be changed to suit individual user (Format 50 of subroutine DATA).

C - The program handles MULTIPLE JØBS so any number of sets of data may be stacked and analyzed with one run of the program. Insert a blank card after the last set.

* * * * * * *

Fig. 32. Program for the Factor Analysis

```
DISK OPERATING SYSTEM/360 FORTRAN    360N-FO-451 21
C         FACTOR ANALYSIS AND VARIMAX ROTATION
          COMMON IO,TITLE(10),V(8000),VV(8029),SD(127),B(127)
C         COMMCN IO,R(4095),SD(90),B(90),XB(90),V(8100 ),D(90),TV(90)
          DIMENSION R(8128),XB(127),D(127),TV(127)
C         REWIND 8
        1 READ (1,50) TITLE,N,M,CON,IO
          IF(N) 49,49,2
        2 IF(IO) 4,3,4
        3 WRITE(3,61) TITLE,N,M,(I,I=1,M)
          WRITE(3,52)
        4 CALL CORRE (N,M,0,0.,XB,SD,V,R,D,B,TV)
          WRITE (3,51) TITLE,N,M
          DO 5 I = 1,M
        5 WRITE(3,52)I,XB(I),SD(I)
          WRITE(3,53)(I,I=1,M)
          L= 0
          DO 7 I = 1,M
          DO 6 J = 1,I
          L = L + 1
        6 B(J)=R(L)
        7 WRITE (3,54) I,(B(J),J=1,I)
          CALL EIGEN (R,V,M,0)
          CALL TRACE (M,R,CON,K,D)
          WRITE (3,55)K,(D(J),J=1,K)
          CALL LOAD (M,K,R,V)
          WRITE (3,56)(I,I=1,K)
          DO 9 I = 1,M
          DO 8 J = 1,K
          L = M * (J-1) + I
        8 D(J) = V(L)
        9 WRITE (3,57) I,(D(J),J=1,K)
          CALL VARMX (M,K,V,NC,TV,B,SD,D)
          WRITE(3,58) (I,I=1,K)
          WRITE(3,59)
          DO 11 I = 1,M
          DO 10 J = 1,K
          L =  M * (J-1) + I
       10 D(J) = V(L)
          WRITE(3,57) I,(D(J),J=1,K)
       11 WRITE(3,60) SD(I)
          GO TO 1
       49 CALL EXIT
       50 FORMAT(10A4,I5,I2,F8.0,I2)
       51 FORMAT ('1FACTOR ANALYSIS PROGRAM BY F.CHEBIB'/1H010A4/'ONUMBER OF
         1 SAMPLES ='I6/
         2      ' NUMBER OF VARIABLES ='I4/'OMEANS AND STANDARD DEVIATIONS'/
         3 'OVARIABLE'16X,'MEAN'15X'STANDARD DEVIATION'/1H )
       52 FORMAT(1H  , I5, 2(5X,F20.5))
       53 FORMAT('1SIMPLE CORRELATION COEFFICIENTS'/'OVARIABLE'I8,9I12/(1H 4
         1X10I12))
       54 FORMAT(1HOI4,4X10F12.7/(9X10F12.7))
       55 FORMAT('1NUMBER OF FACTORS RETAINED ='I3/'OCUMULATIVE PERCENT OF V
         1ARIABILITY ACCOUNTED FOR BY FACTORS'/1H05X2P10F11.3/(6X2P10F11.3))
       56 FORMAT('OPRINCIPLE FACTOR MATRIX'/1H03X10I11/(1H 3X10I11))
       57 FORMAT('OVAR'I3,10F11.5,/(1H ,6X,10F11.5))
       58 FORMAT(1H1'ROTATED FACTOR MATRIX'/1H03X10I11/(1H 3X10I11))
       59 FORMAT(1H+,120X'COMMUNALITY')
       60 FORMAT(1H+,118XF11.5)

14/09/67             FORTMAIN
       61 FORMAT('1OPTION: INPUT DATA'/1H010A4/'ON ='I6/'OM ='I6//(1H I11,
         19I13))
          END
```

References*

A.R.D.A. The Climates of Canada for Agriculture. Canada Land Inventory Report #3, Department of Forestry and Rural Development, Ottawa, 1966, 24 p.

Baulig, H, "W. M. Davis: Master of Method", Ann. Assoc. Am. Geogr., 1950, 40, p. 188-195.

Burton, Ian. "The Quantitative Revolution and Theoretical Geography", Canadian Geographer, VII, 4, 1963, p. 151-162.

Chorley, R. J., "Illustrating the Laws of Morphometry", Geol. Mag., 1957, p. 140-149.

Chorley, R. J., "Climate and Morphometry", J. Geol., 1957, V. 65, p. 628-638.

Chorley, R. J., "Aspects of the Morphometry of a 'Poly Cyclic' Drainage Basin", Geogr. J., 1958, V. 124, p. 370-374.

Croxton, Frederick E. and Dudley J. Cowden, Applied General Statistics, New York: Prentice-Hall, Inc., 1939, 944 p.

Curtis, L. F., J. C. Doornkamp and K. J. Gregory, "The Subdivision of Slopes into Slope Categories", Brit. Univ. Geomorph. Res. Group, Rept. 1962, No. 5, p. 4-9.

Davies, J. F., B. B. Bannatyne, G. S. Barry and H. R. McCabe, Geology and Mineral Resources of Manitoba, Province of Manitoba, Dept. of Mines and Tech. Res., Winnipeg, 1962, 190 p.

Elson, J. A., "Pleistocene History of S. W. Manitoba", in Guide Book Ninth Annual Field Conference of the Mid-Western Friends of the Pleistocene, North Dakota Geol. Surv. Misc. Series No. 10, 1955, p. 62-73.

Elson, J. A., Surficial Geology of Virden Area, Preliminary Series Map 39 - 1961, Dept. of Mines and Tech. Surveys, Geological Survey of Canada.

Elson, John A., "Souris Basin Glacial Lakes - Southwestern Manitoba, Canada", (Abatr.), Geol. Soc. Am. Bull., 1957, 68, p. 1722.

Fisher, R. A., Statistical Methods For Research Workers, Oliver and Boyd, Edinburgh: Tweeddale Court, London: 98 Great Russel Street, W.C., 1950, 354 p.

Freeze, R. A., Ground Water Probability Map Virden Sheet (east half), Dept. of Mines and Tech. Surveys, Geological Survey of Canada, 1962.

*Some of these have not been referred to in the thesis but they have been included since they are pertinent to the study.

Glock, W. S., "Available Relief as a Factor of Control in the Profile of a Landform", J. Geol., 1932, 40, p. 74-83.

Gregory, K. J. and E. H. Brown, "Data Processing and the Study of Landform", Annals of Geomorphology, 1966, 3, p. 237-263.

Hack, J. J. and Goodlett, Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians, U. S. Geol. Survey Prof. Paper #347, 1960, 66 p.

Horton, R. E., Erosional Development of Streams and Drainage Basins, Bull. Geol. Soc.-Am., 1945, 56, p. 275-370.

Howard, A. D., "Geomorphological Systems - Equilibrium and Dynamic", Am. J. Science, 1965, V263, No. 4, p. 302-312.

King, Cuchlaine, A. M., Techniques in Geomorphology, Edward Arnold (Publishers) Ltd., London, 1966, 342 pp.

Kirk, S. R., "Cretaceous Stratigraphy of the Manitoba Escarpment", G.S.C. Sum. Rept., Part B., 1929, p. 112-135.

Lawley, D. N. and A. E. Maxwell, Factor Analysis as a Statistical Method., London: Butterworths, 1963, 117p.

Melton, Mark A., "Intravalley Variation in Slope Angles Related to Micro-climate and Erosional Environment", Bull. Geol. Soc. Am., 1960, 71, p. 133-44.

Miller, R. L., and Kahn, L. S., Statistical Analysis in the Geological Sciences, New York: John Wiley and Sons, 1962, 483 p.

Packer, R. W., "Stability Slopes in an Area of Glacial Deposition", Can. Geogr., 1964, 8 (3), p. 147-154.

Pitty, A. F., "Some Problems in the Location and Delimination of Slope-Profiles", Zeitochrift fur Geomorphologie, N.S. Bd. 10, Haft. 4., p. 457-561.

Reconnaissance Soil Survey of South Western Manitoba (Map), Manitoba Soil Survey, Manitoba Dept. of Agriculture and Conservation.

Reichman, W. J., Use and Abuse of Statistics, Methuen and Co. Ltd., 1961, 335 p.

Savigear, R. A., "A Technique of Morphological Mapping", Ann. Assoc. Am. Geog., 1965, 55, p. 514-537.

Scheideggar, A. E., "Mathematical Models of Slope Development", Bull. Geol. Soc. Am., 1961, V. 72, p. 37-49.

Schumm, S. A., "Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey", Bull. Geol. Soc. Am., 1956, 67, p. 597-646.

Smith, K. G., "Erosional Processes and Landforms in Badland National Monument, S.D.", Geol. Soc. Am. Bull., 1958, V.69, p. 975-1008.

Strahler, A. N., "Equilibrium Theory of Erosional Slopes Approached by Frequency Distribution Analysis", Am. J Sci., 1950, V.248, p. 673-696 and p. 800-814.

Strahler, A. N., "Davis' Concepts of Slope Development Viewed in the Light of Recent Quantitative Investigations", Ann. Assoc. Am. Geog., 1950, 40, p. 209-213.

Strahler, A. N., "Quantitative Analysis of Watershed Geometry", Trans. Amer. Geophys. Union, 1954, 38, p. 913-920.

Strahler, A. N., "Statistical Analysis in Geomorphic Research", J. Geol., 1954, V. 62, 1, p. 1-25.

Strahler, A. N., "Quantitative Slope Analysis", Geol. Soc. Am. Bull., 1956, V. 67, p. 571-596.

Strahler, A. N., "Dimensional Analysis Applied to Fluvially Eroded Landforms", Bull. Geol. Soc. Am., 1958, V. 69, p. 279-300.

Tanner, V. F., "Geomorphic Analysis, Departure from The Gausian", Am. J. Sci., 1959, V. 257, p. 458-460.

Walker, E. H., "Differential Erosion on Slopes of Northern and Southern Exposures in Western Wyoming" (abstr.), Geol. Soc. Am. Bull., 1948, V. 59, p. 1360.

Waters, R. S. "Morphological Mapping. Geography", 1958, 43, p. 10-17.

Weinberg, G. H. and J. A. Schumaker, Statistics: An Intuitive Approach. Wadsworth Publishing Company, Inc., 1962, 338 p.

Webster's New Collegiate Dictionary, Thomas Allen Limited, Toronto, Ontario, 1960.

Young, A., "Slope Angles Characteristics and Limiting", Geol. Soc. Am. Bull., 1959, V.70, 12, pt. 2, p. 1816-17.

Young, A., "Some Field Obs. of Slope Form and Regolith, and Their Relationship to Slope Development", Trans. and Papers, Inst. of Br. Geogr., 1963, 32, p. 1-29.

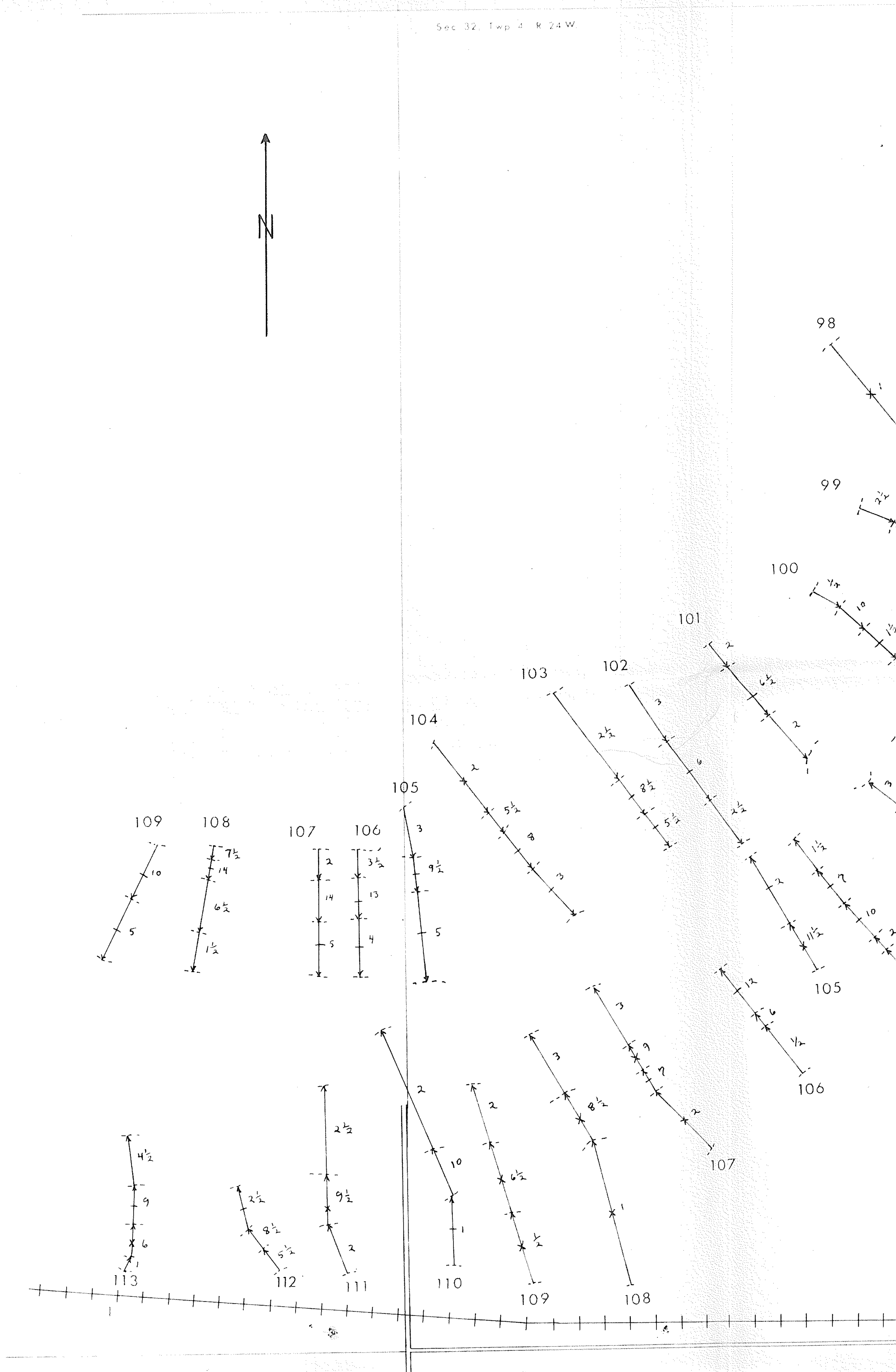
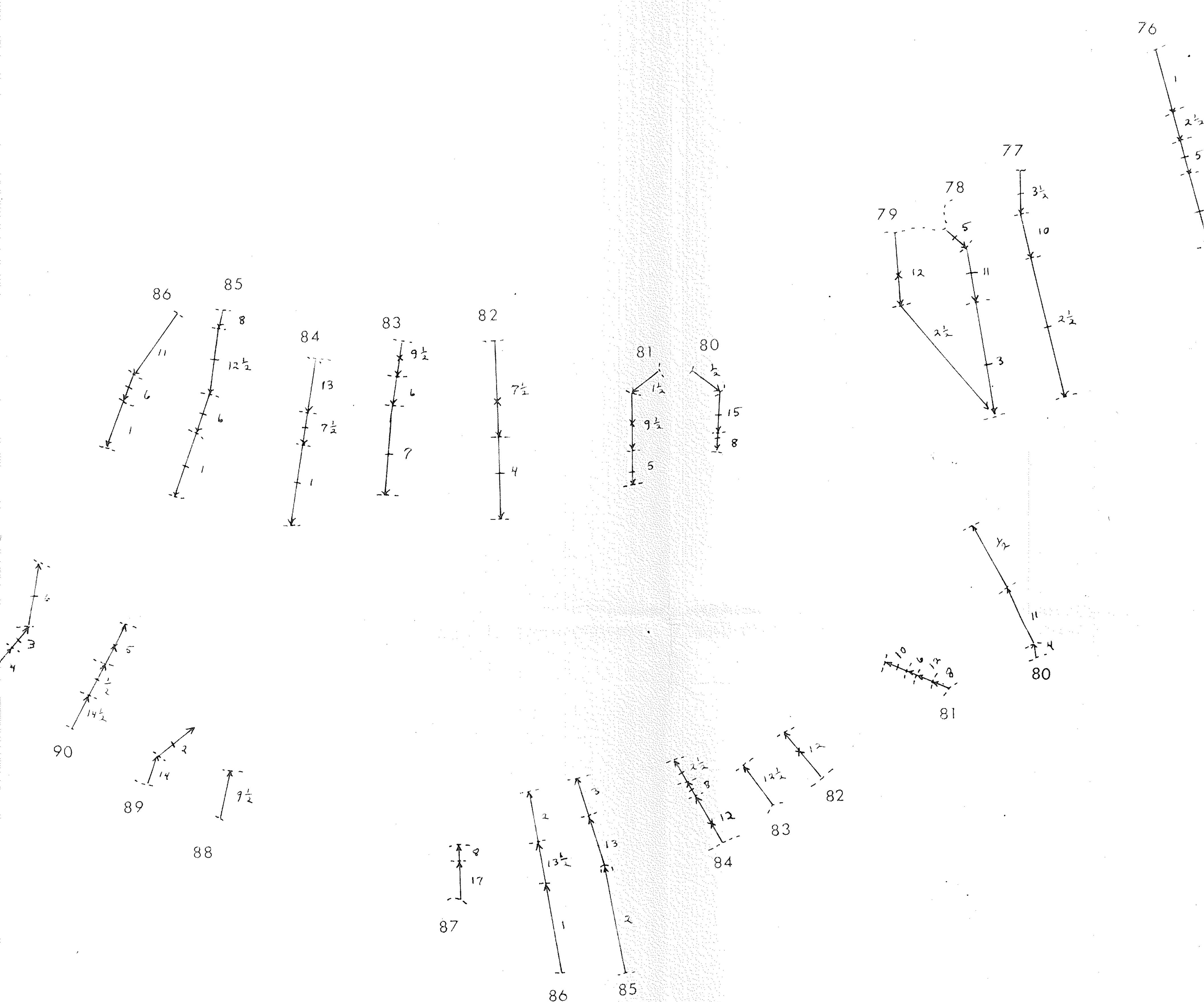
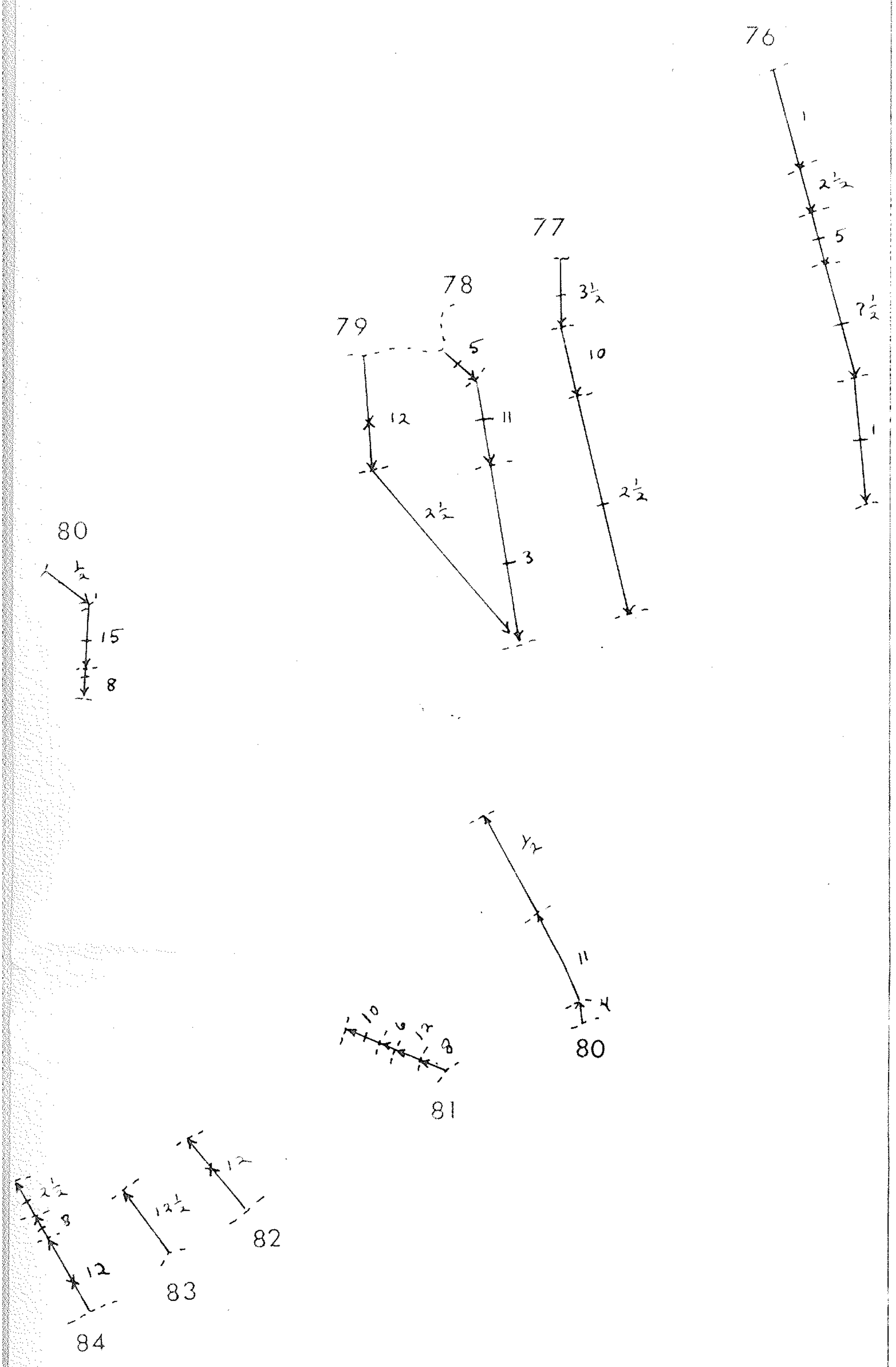

Sec 32, Twp 4, R 24 W
N
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113

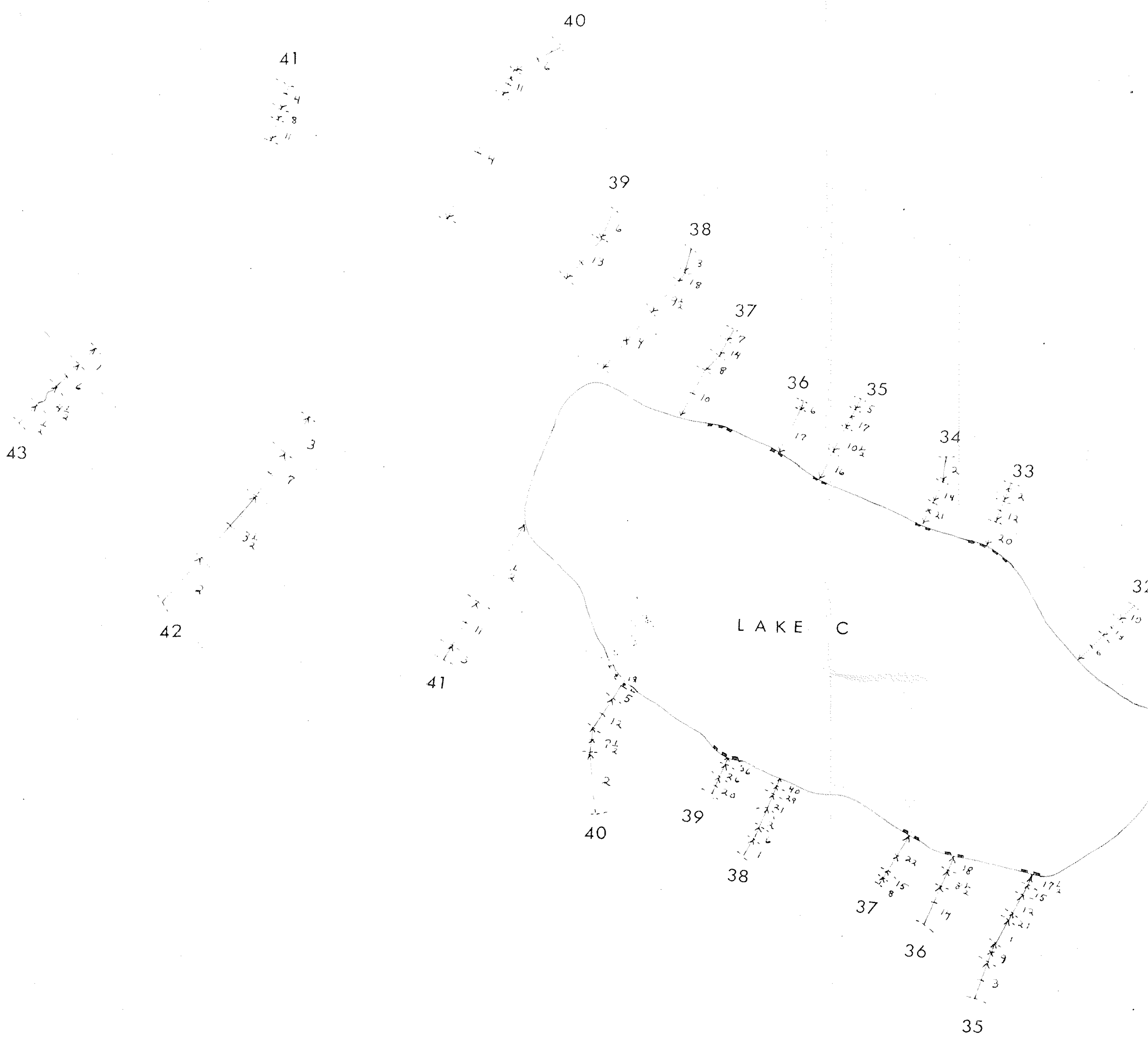
Fig.33 cont.

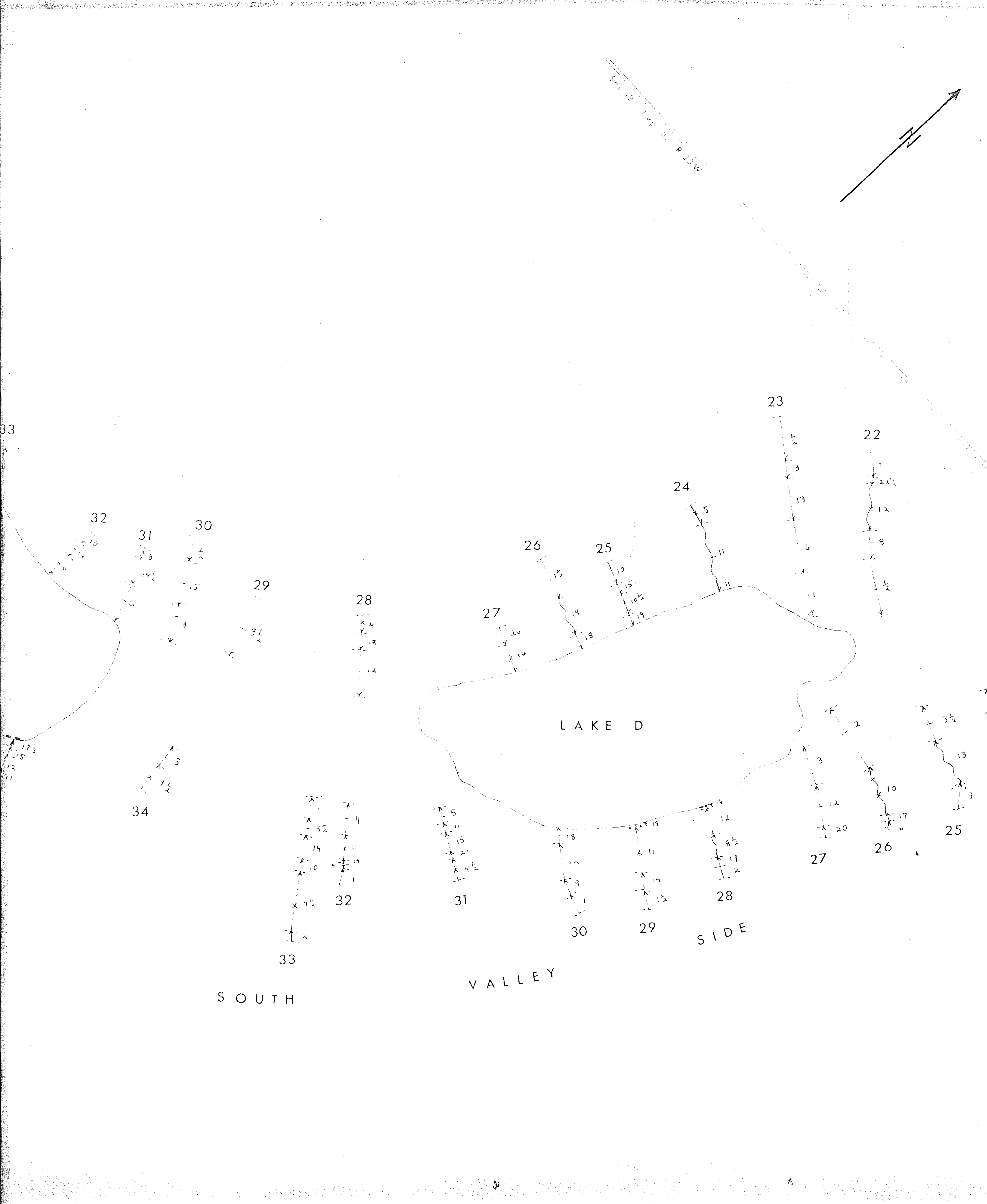


CANADIAN NATIONAL RAILWA

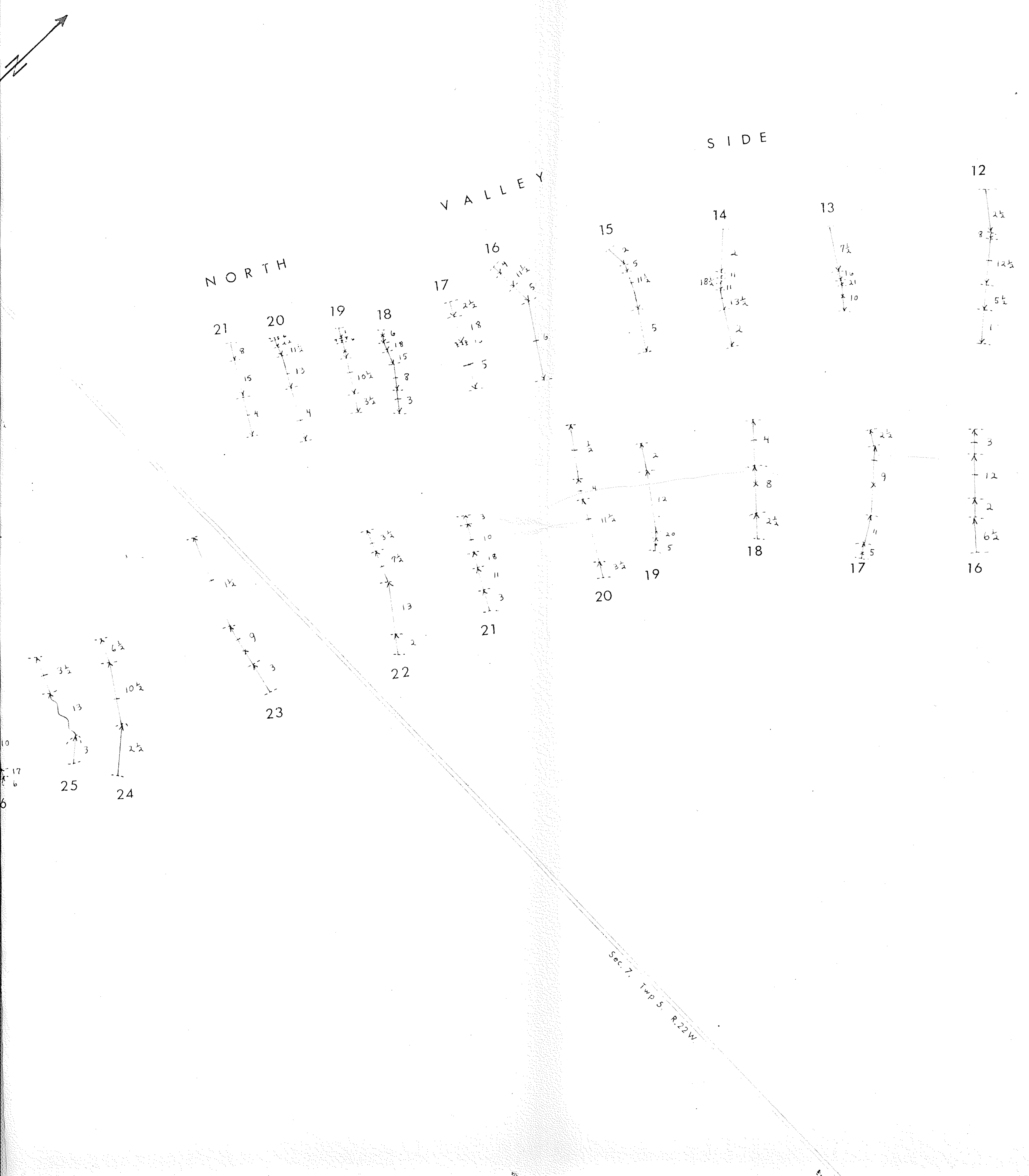


76
77
78
79
80
80
81
82
83
84


40
41
39
38
37
36
35
34
33
43
42
41
LAKE C
40
39
38
37
36
35



Sec 12 Twp 5 R 23W
LAKE D
SOUTH VALLEY SIDE


NORTH VALLEY SIDE
12
13
14
15
16
17
18
19
20
21
16
17
18
19
20
21
22
23
24
25
Sec. 7, Twp 5, R.22W

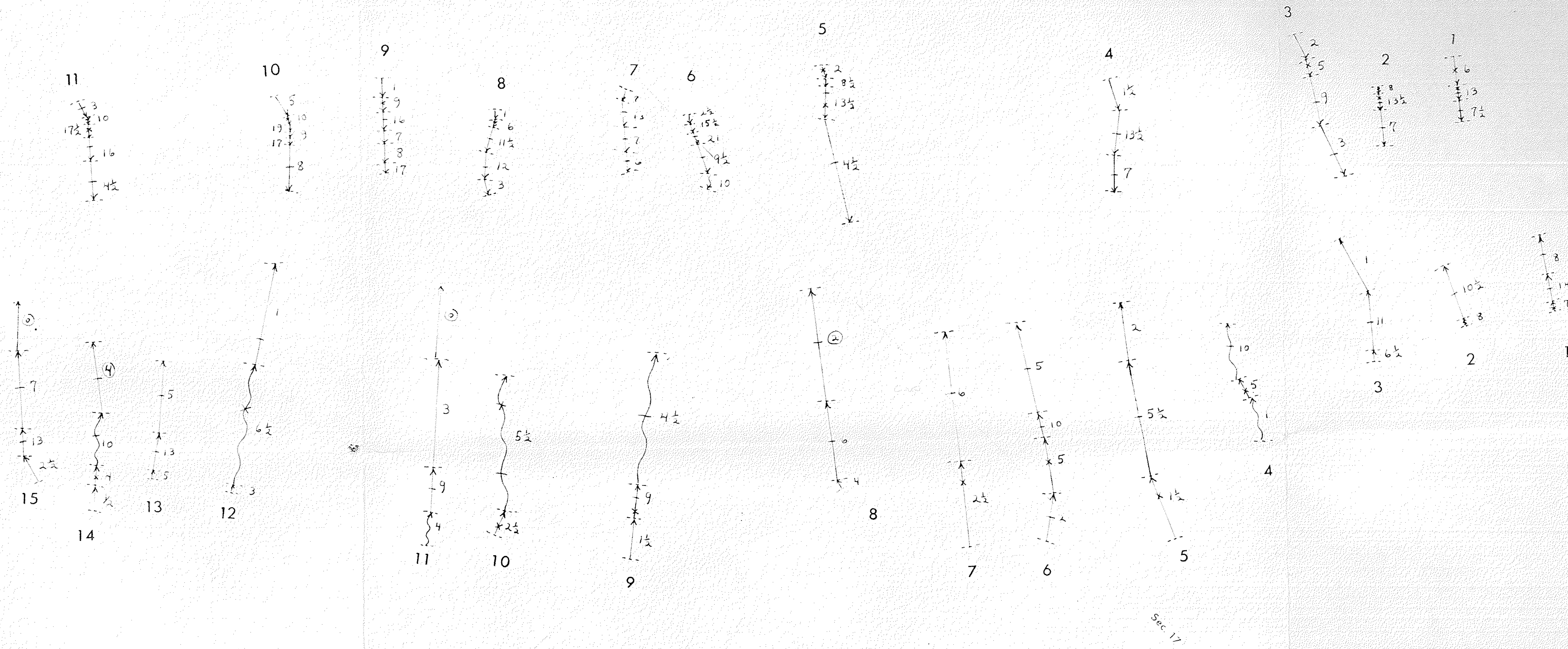


Fig. 33

Position of the Measured Profiles in the Dand Valley

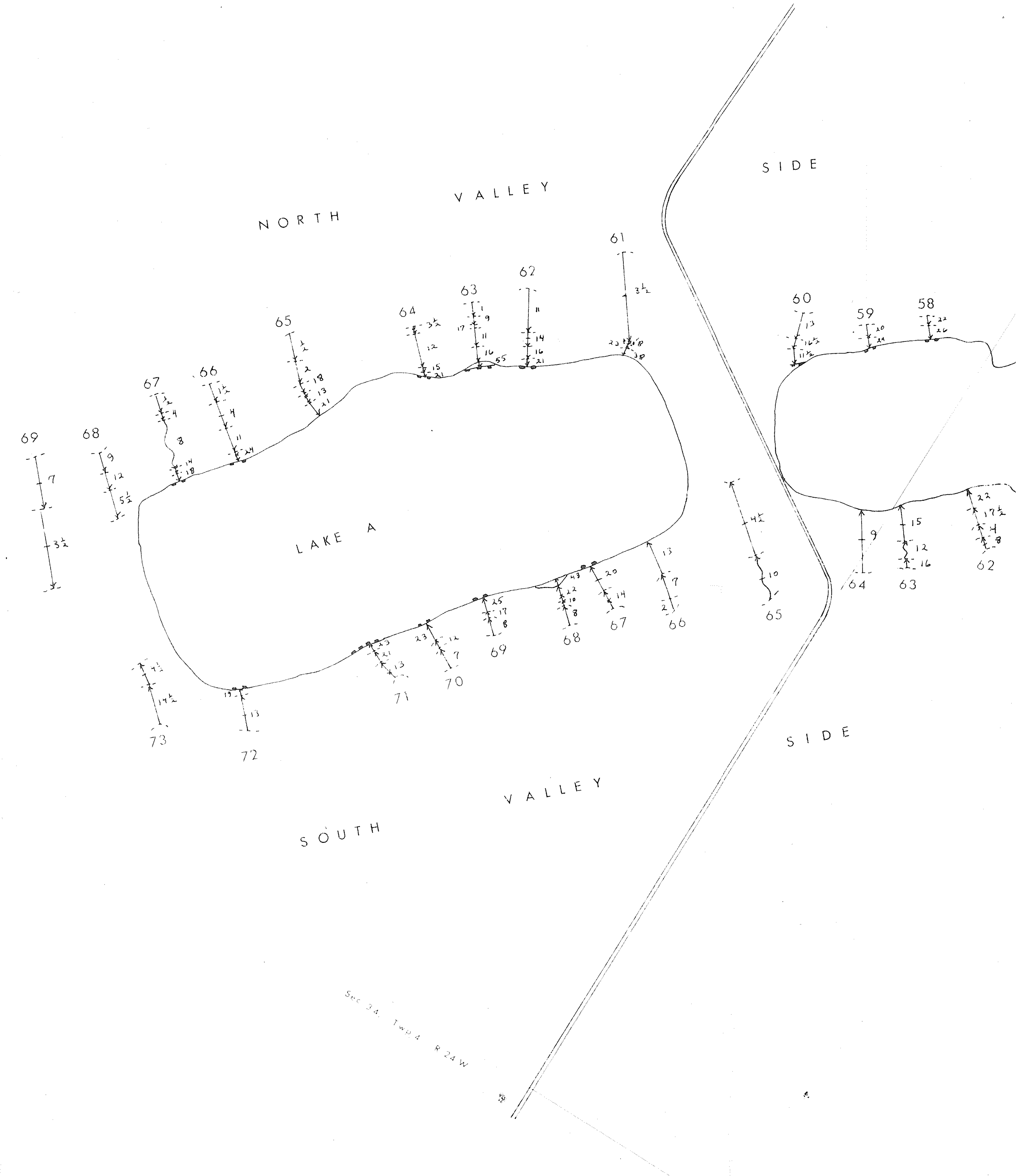
DIRECTION AND ANGLE OF SLOPE......
ANGLE ESTIMATED......
CLIFF..
BREAK OF PROFILE SLOPE ....
CHANGE OF PROFILE SLOPE..............

MORPHOLOGICAL UNITS*
a) SEGMENT........................
b) CONVEX ELEMENT..............
c) CONCAVE ELEMENT..............
d) UNIT WITH IRREGULAR SURFACE...
e) MICRO UNIT..........................

*for the definition of these terms see page 3

Scale 1:4 900

69
7
3½
70
2
5½
71
2
5
11
5
6
2
72
3
6
4
½
73
1½
7½
10
2½
1
74
4½
3
9
2
75
1
5
1½
12½
3
½
½
4
12
9½
½
77
½
4
14
78
3½
10
1
2½
½
79
½
10
1½
76
1
10½
½
7½
3
1
75
4
8½
4
74


NORTH VALLEY
SIDE
LAKE A
SOUTH VALLEY
SIDE
Sec 34, Twp 4, R 24 W
69
68
67
66
65
64
63
62
61
60
59
58
73
72
71
70
69
68
67
66
65
64
63
62

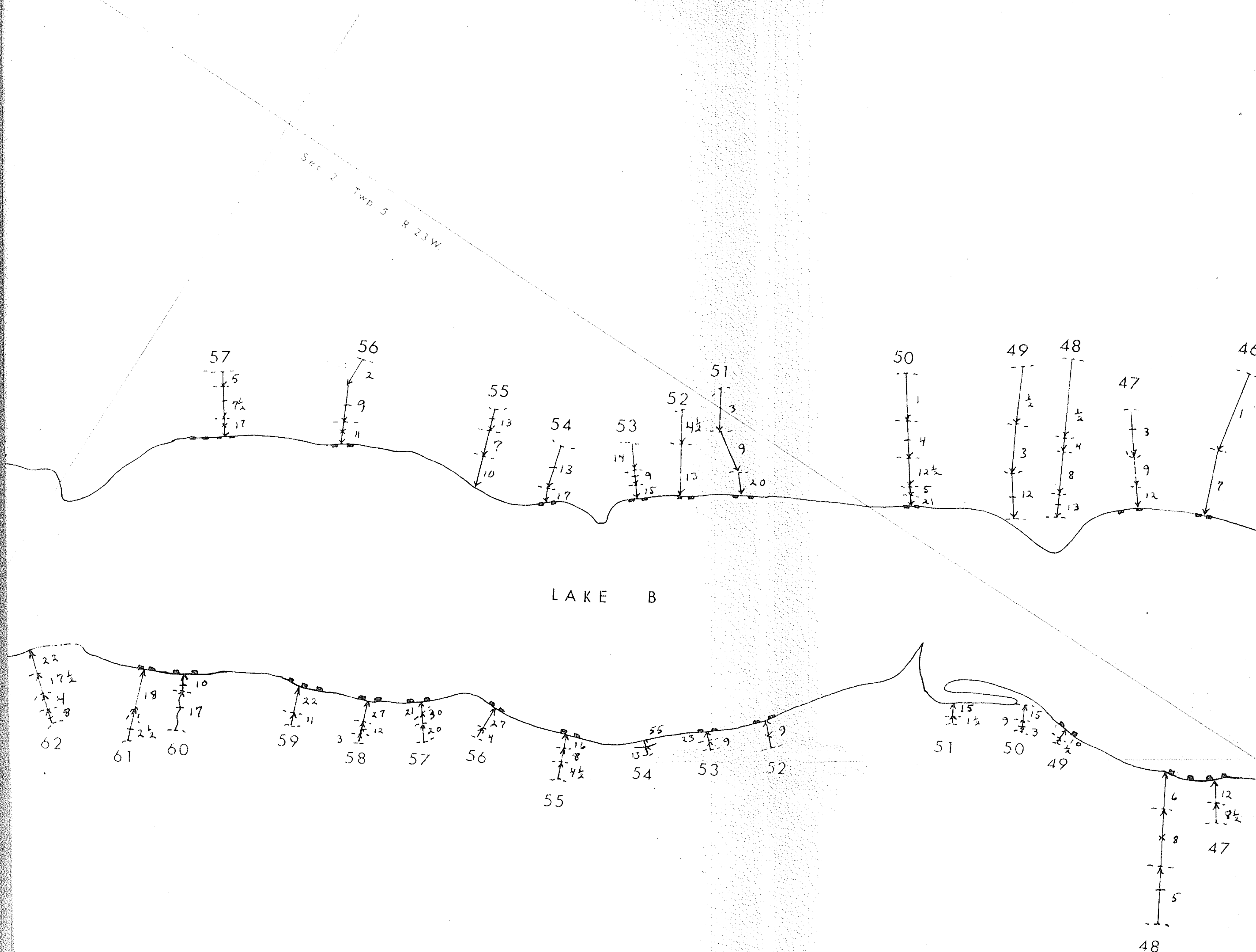
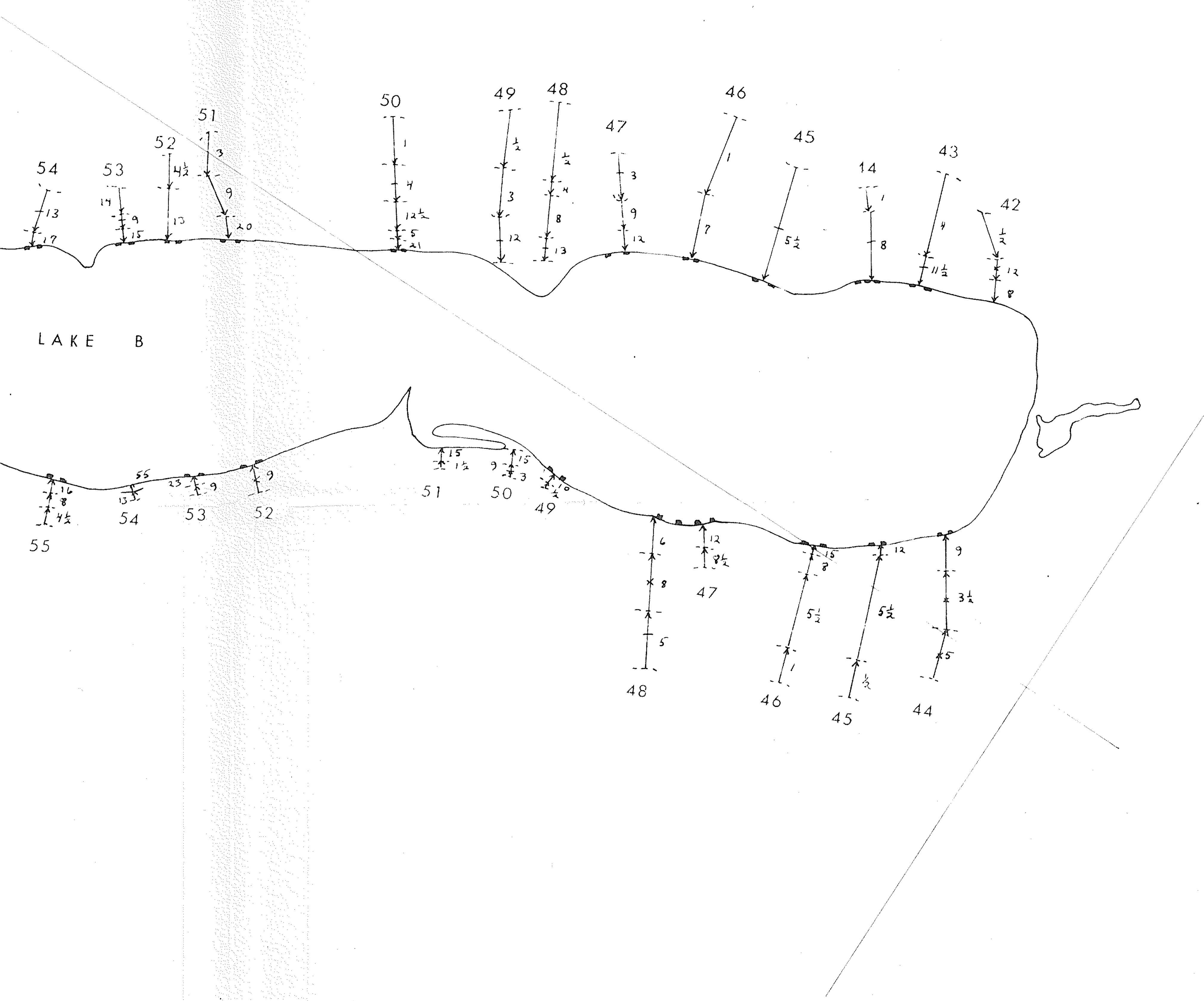


Fig. 33 cont.


LAKE B
54
53
52
51
50
49
48
47
46
45
14
43
42
55
54
53
52
51
50
49
48
47
46
45
44