SUPPOSED BEACH RIDGES IN THE LAKE AGASSIZ BASIN

A METHODOLOGICAL APPROACH TO THE

STUDY OF THEIR ORIGINS

A Thesis

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by

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ABSTRACT

A study of two areas of supposed Lake Agassiz beach ridges was undertaken to ascertain the origin of the features and to establish criteria by which similar features might be recognized in the field. One ridge is at Ste. Anne, in Southern Manitoba, the other three ridges are at Ponton, in Northern Manitoba.

This work was mainly achieved by a substantial study of the morphology and depositional elements of the ridges. The morphology was established by means of air-photograph analysis and accurate surveying. Firstly, the stratigraphy was described. For gravel size particles, sphericity, roundness and long-axis orientation values were determined. Secondly, textural analyses and the percent heavy mineral determinations were used to characterize the various deposits.

Throughout the work, an attempt is made to compare the various aspects of the supposed beach ridges with other features, in the literature, whose origin is known. The ridges could conceivably be beach-ridges, off-shore bars, berms, eskers, kames, drumlins, morainic features, or sand dunes. On the basis of morphology, statistical testing procedures, comparing these features with ones of known origin, indicated that because of the inequality of slopes, the Ste. Anne ridge and ridges 1 and 3 at Ponton may not be eskers or transverse dunes. Resemblances occur between these ridges and beaches, off-shore bars and berms. Ridge 2 at Ponton may be an esker.

The sediment description of the Ste. Anne deposits evidence a beach type of environment (with storm beach and foreshore constituents)

and the laminations, graded bedding and high angle stratification would substantiate this; but the latter features have also been described in the beds of known eskers. The Ponton sands are relatively homogeneous, which may be consistent with an aeolian environment. Modifications due to periglacial activity may also have occurred.

Sphericity values for the Ste. Anne ridge, using Folk and Ward's scale, range between 0.668 and 0.895. A plot of sphericity and distance suggests a shifting of grains from north to south, possibly due to long-shore drift. A marked increase in sphericity towards the center of the ridge is shown which suggests deposition in a fluvial environment. The pebbles are spherical (compact) and rod shaped. An average sphericity value for Ponton is 0.728.

Roundness values for Ste. Anne, according to the Krumbein Scale, are 0.354 to 0.571, and, by the Callieux Method 222 to 601. The roundness may suggest deposition in a beach environment. The long axis orientation showed only two significant directions, 80 - 100 degrees and 120 - 140 degrees (east of north), which may indicate beach deposits with their long axes parallel to the backwash direction. The high degree of scatter is also similar to that found in outwash deposits.

Textural analyses at Ste. Anne vary according to section position A - E across the ridge. The mean grain size suggests a shoreline environment, sorting is inconclusive, skewness indicates a shoreline or dune environment and kurtosis suggests a beach, dune or aeolian flat environment. The Ponton sediments may more closely approximate beach sands than dune or aeolian flat deposits. The sorting, which decreases from R3 to R1 is consistent with the decline in the level of Lake Agassiz from SW to NE. The heavy mineral content varies in Ste. Anne between 4.28

and 8.49 percent and at Ponton between 13.93 and 20.91. This indicates different source materials or a considerable amount of reworking, especially in the Ponton area.

The conclusions reached are that the Ste. Anne ridge consists of a modified till deposit which has been reworked by water in high and low energy environments. The Ponton ridges may have been deposited in a beach or aeolian environment, and have also been reworked, to a greater extent.

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Chapter 1

INTRODUCTION

The introductory chapter consists of the following sub-sections:

A. Introduction and aims.

B. A Survey of Previous Work on Lake Agassiz.

C. A Description of the Study Areas.

D. An Outline of the Analysis.

A. Introduction and Aims

The following research project is an attempt to add to the overall knowledge of the history and changing environment of the area that was once occupied by proglacial Lake Agassiz. Attention here is focussed on investigations of some ridge features which have been presumed to be beaches of the lake. The intention of the present work is to disregard this assumption and, following a detailed analysis of form and sediment content, to arrive at certain more specific conclusions concerning the origin of certain ridges.

Some of the supposed Lake Agassiz ridges need to be considered more closely for the following reason. Assuming some Pleistocene lake beaches were deposited on the periphery of Lake Agassiz, criteria are needed so that these forms might be recognized in the field and distinguished in a meaningful way from fluvio-glacial, aeolian and offshore features. A generalized lake beach morphology and stratigraphy should be elucidated so that beaches may be recognized and compared with others in the Agassiz Basin. Whether the conclusion is that the supposed Lake Agassiz beaches are beaches or not, the work leads ultimately to a more detailed knowledge of the dynamics of processes operative in the Pleistocene environment.

The chronology of the Lake Agassiz water-planes vis-à-vis the history of Lake Agassiz as a whole is omitted from the present work.

B. A Survey of Previous Work on Lake Agassiz

A necessary introduction to this thesis is a brief summary of the past literature on Lake Agassiz beach ridges. The reason for its inclusion is to emphasize the lack of detailed morphological and sedimentological description in the previous works. These, in general, include extensive areas and the descriptions of the beaches tend to be vague. There are no particular factors which would conclusively prove these features were Lake Agassiz ridges as distinct from similar features of entirely different origins.

The work of Warren Upham is, to some extent, exceptional, in so far as descriptions are included of generalized Lake Agassiz beach form and content. The Monograph of 1895 described how Upham surveyed an extensive area from the U.S. border to the Duck Mountains of Manitoba. He gave a graphic description of the "beaches", along with descriptions of other landforms. The features consist of "beach gravel and sand, and each forms a continuous smoothly rounded ridge" which rises 10 - 20 feet above the level of the surrounding terrain on the landward side and 3 - 10 feet on the lakeward side (p. 26). The width of these varies from 412½ to 495 feet. Upham asserted that variation in beach size was due to the unequal power of former waves and currents. He gave a generalized stratigraphy, varying from till or unstratified clay off the ridge to stratified sand and gravel, with some stones and boulders, underlying the ridge itself. A detailed sedimentological description is not given, but certain pebbles were measured and found to vary in size from between 2 - 3 inches and 6 inches in diameter. Upham's work is one of the more comprehensive treatises on the Agassiz Basin, because of its lucid, quantitative description which includes the heights, dimensions and deposits of the ridges. However, there are no particular characteristics which would distinguish these presumed Agassiz beach ridges from the eskers (osars) and kames which Upham also describes.

The accounts of morphology and sediments in later works are less specific. These include the writings of T. C. Chamberlain (1887), J. B. Tyrrell, who wrote papers in 1889, 1892 and 1893, and F. Leverett, writing in 1912, 1932 and 1936. Their papers tend to concentrate either on the mapping of the beaches, or tend to stress the geological history and interpretation of Lake Agassiz. The above authors exclude quantitative descriptions of the presumed beach ridges or their modes of formation.

More detail relating to the ridges (as opposed to other features in the basin) appeared in the work of W. A. Johnston (1946), who found that the Agassiz beaches were particularly conducive to a study of variations in isostatic uplift, because of their number (about 50) and their directional tilt. This is demonstrated in their length, which exceeds 300 miles (p. 2). Johnston's work consisted of a detailed recording of crest heights along most of the ridges. This included some crest heights which had not previously been recognized. The morphological description of the ridges is very brief in Johnston's work, since he was primarily concerned with hinge-line formation consequent upon isostatic readjustment than with the development of the beach ridges.

C. C. Nikiforoff (1947) demonstrated that the fragmentary nature of the beaches is such that their declination to the south is more apparent than real. He asserted that the beach fragments at similar heights represent stages of a falling lake level, thus negating the necessity of inferring isostatic readjustment.

Similarly, work completed on the geomorphology of Northern Manitoba has tended to exclude details of beach ridges. Certain ridges do occur, for instance, in the area where E. Antevs (1931) studied the depositional sequences of varved deposits and within the limits of the geo-botanical survey of J. C. Ritchie (1962). However, no analysis of these forms has yet been made.

Very little reference is made to the beach ridges of Manitoba in the general chapters of J. H. Ellis's publication of 1938, due to the comparative insignificance of the ridges as parent materials for soils. An exceptional section is that referring to the West-Lake region (pp. 58-60). Here a cross section is drawn showing a low hill of sand and gravel, overlying "boulder till or drift". Modified drift occurs landward of the ridge. Lake-ward there is "textured variation due to water sorting", but no details are given. In the well-defined beaches, the fines, silt and clay, have been removed by water sorting, leaving the gravel to be deposited as "more or less rounded, stratified beach ridges".

W. M. Laird (1964), working from North Dakota, described beach sediments lying unconformably over a planed till surface. These consist largely of gravel and sand. To the north of Grand Forks some of the multiple beaches appear to have the same general elevation within a given beach complex (e.g. the Blanchard Beaches), and so they may have been off-shore bars and do not necessarily represent still-stands of the lake level.

Earlier work by W. M. Laird (1944) shows a particle size analysis report of samples taken from beaches in North Dakota. Some beaches are extremely well-sorted and bimodal grain size distributions are common. But no decisive interpretation was drawn from the analysis.

A considerable amount of work on Lake Agassiz deposits has been compiled by J. A. Elson. In his "Soils of the Lake Agassiz Region" (1961) is found a table on lake deposits. Five different depositional types are discussed. These include beaches, near-shore (littoral) deposits, deltaic deposits, deep water deposits and lag concentrates (pp. 53-54). The beaches are described as consisting of "well-sorted sand and gravel" in the southeast and southwest of Manitoba and of "medium grained sand" which occurs on the inner part of the lake basin, especially on the west side. Associated with the former, in the south-west and the Whitemouth area are littoral deposits of silt and fine sand. Chemical and mineral analyses of "drift" deposits were performed and reported, as were the grain size distributions of tills and Lake Agassiz sediments in terms of silt, sand and gravel content. Elson described the beach ridges as being 2 to 20 feet high and 100 to 300 feet wide. The sand and gravel towards the center is 5 - 8 feet thick with lenticular cross sections (p. 71). There are no diagrams showing this. Elson also described many beaches with wave-cut terraces between them, possessing boulders several feet in diameter and made up of coarse gravel.

Later work by J. A. Elson (1962) finds only brief treatment given to the higher strandlines. This was surpassed in importance by the elucidation of the post-glacial history of Lake Agassiz.

In "Life, Land and Water" (1966), J. A. Elson has written the most comprehensive study to date on the Lake Agassiz region. In this work, the beaches are described as ridges usually 2 - 15 feet high, and locally as high as 30 feet where spits have extended across the embayments (p. 75). The width of these features ranges from approximately 150 to 500 feet, and some groups of ridges form complexes exceeding half a mile in width. Beach formation generally occurs when waves attack the parent material (till), which yields sand and gravel size particles.

J. A. Elson itemised some of the factors which influence the form of the Agassiz "strandlines" (p. 77). In outline these include:

1. slope of the coast
2. depth of the water
3. the fetch
4. the parent material
5. the duration of water level
6. the frequency of storms

Because of the unusual environmental conditions which persisted, and because of the proportions of the lake at any given time, other factors, such as the wave period (if any), periglacial modifications, the ice-push effect and the seiche effect, may be comsidered important in the formation of beach ridges. Preliminary roundness studies have been made by J. A. Elson on the Herman, Campbell and Burnside beaches, showing that there may be some relationship between the degree of roundness and the hypothetical fetch calculations.

Therefore, it is apparent that conclusions concerning lake levels and supposed beach ridge production have been drawn from an overall study of the entire Agassiz Basin. There is a comparative lack of detailed morphological and sedimentological work in specific areas. This deficit is, to some extent, being filled by present research. An important aspect is the necessity of determining whether these so-called beach ridges have, in fact, the lake shoreline origin which is ascribed to them by the previous authors. No one has been able to prove conclusively that these features are beach ridges. The intention in this thesis is to assume no specific environment of deposition. The aims are rather to validate the origin of certain ridges by acceptable morphological and sedimentological testing procedures, the results being checked and compared with comparable ones obtained by other authors.

C. A Description of the Study Areas

In order that the aims of this thesis might be fulfilled, the following areas of supposed Agassiz beach ridges were chosen for study, with the assistance of S. C. Zoltai.

The Ste. Anne ridge. The ridge occurs in an area 40 miles to the east of Winnipeg as shown on Map 1. It is 2½ miles in length, and at Latitude 49° 45' and Longitude 96° 40'. Fieldwork at this location took place during May and June, 1969. This area, which is designated the Ste. Anne ridge, was chosen for the following reasons:

I. Here are found reasonably exposed sections of a ridge, previously described by W. A. Johnston and noted in the interpretation of the southeastern part of Lake Agassiz.

2. Several depositional sequences are represented. These vary from boulder clay and lake clay off the ridge to stratified sand and gravel on the ridge itself.

3. The ridge is bounded immediately to the north by a similar area, containing ridges whose geomorphological history is currently being interpreted.

4. The morphology of the ridge is comparatively distinct in relation to others in the immediate area.

5. The accessibility along the ridge was permissible, since it was largely cleared of bush.

6. The area was also close to Winnipeg on the Trans-Canada Highway and was small enough to cover adequately with the financial assistance, and in the time available.

The Ponton ridges. Three ridges, totalling one mile in length, to the north of Lake Winnipeg and to the south of the Hudson Bay Railway at Ponton, were also chosen for study. The location of these ridges is at Latitude 54° 36' and Longitude 99° 05'. (See Map 1). Fieldwork in this area took place during June, 1969. The Ponton ridges were chosen for the following reasons:

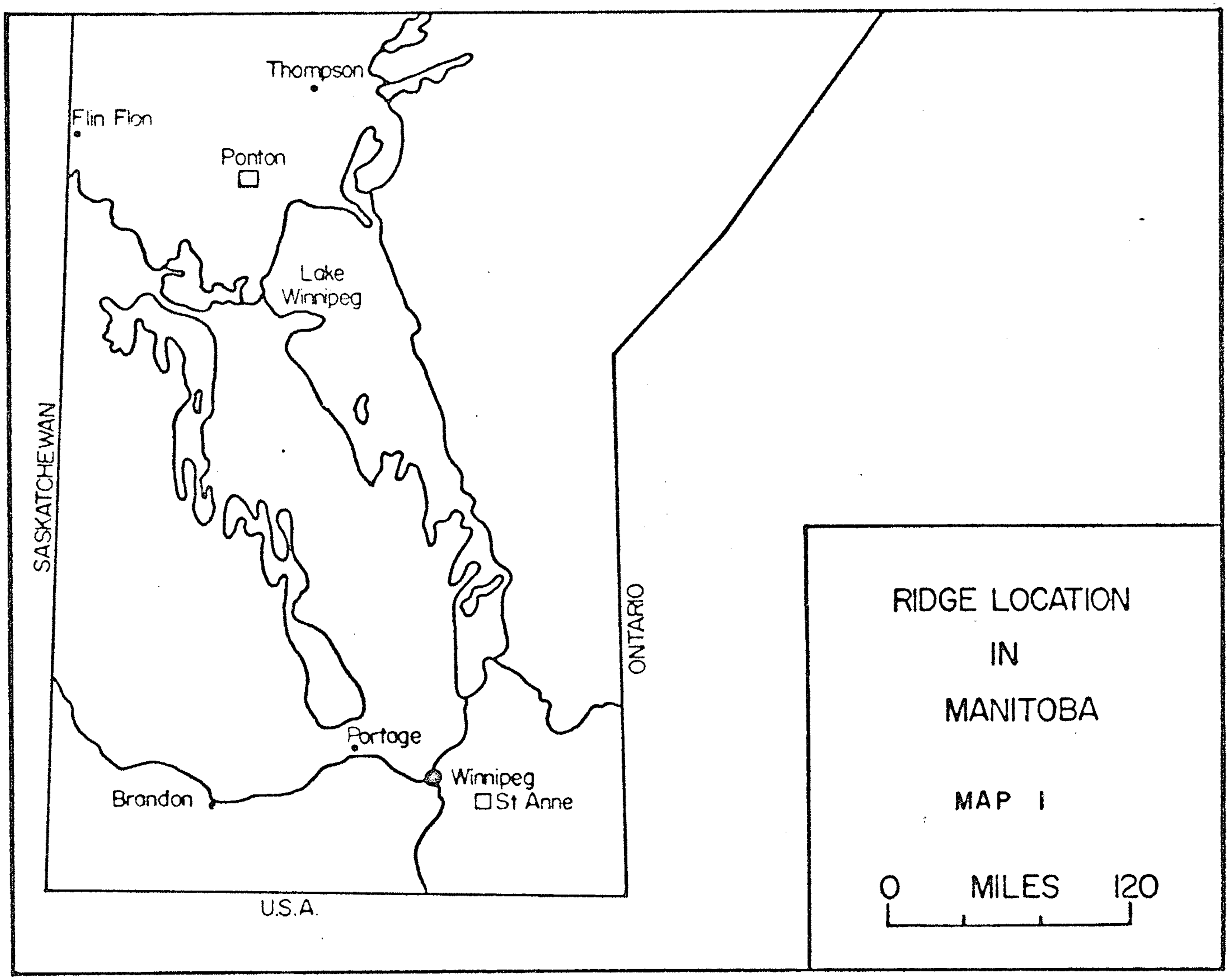
1. These are a series of ridges which, if, in fact, they are beaches, would represent the largely unknown later, or last, stages in the history of Lake Agassiz.

2. There is a lack of detailed geomorphological work done by field crews in Northern Manitoba. Interest particularly is focussed on the relatively unique conditions which occur in this particular sedimentological environment.

3. The area was reasonably accessible via the Thompson Highway and the newly formed Grand Rapids-Ponton road.

4. Despite the northern location, work in the area was financially feasible and could be adequately executed within a limiting time factor.

A further aspect of importance is an indication of how these ridges fit into the current histories of Lake Agassiz. The beaches to the east of Winnipeg are mentioned by W. A. Johnston (1946). The



RIDGE LOCATION
IN
MANITOBA

MAP 1

Burnside beach is indicated on Johnston's map (Johnston's Fig. 1), as occurring at 888 feet O.D. at the southern Ste. Anne location. The actual heights surveyed on this ridge are 897-8 feet. At this location, 48 miles north of the U. S. border, the ridge, according to Johnston's Fig. 2, corresponds to the Burnside beach. This occurs to the immediate south of isobase 6.

A similar diagram was modified by J. A. Elson (1966, p. 46). At the height at which the ridge occurs, and at the location given, the ridge at Ste. Anne becomes the Gladstone ridge. Therefore there is a discrepancy in identification. Elson (Fig. 6, p. 76) described the Gladstone ridge as being one step in the decline in lake level after the Lake Agassiz III maximum, dated as being formed approximately 8-9000 years, B.P. (Elson's Fig. 6). The northward retreat of ice at this stage opened easterly outlets such that the level of Lake Agassiz dropped in a series of steps to about the Grand Rapids waterplane (p. 93).

W. A. Johnston (1946, p. 4) referred to the Ponton ridges as being those 109 and 110 miles from The Pas on the Hudson Bay Railway. These are tentatively identified as "Grand Rapids" beaches because "they are the lowest Lake Agassiz beaches known anywhere in the Lake basin". On Johnston's diagram (Fig. 1) the heights indicated for this region range from 828 to 845 feet O.D. The ridges studied in the Ponton region vary in height from 821 to 843 feet O.D., 814 to 853 feet O.D., and 824 to 845 feet O.D. Therefore, it may be assumed that these are, in fact, the ridges which Johnston mentions. They are very irregular but tend to become lower at their extremities. Whether or not they continue south to the Grand Rapids region is debatable.

J. A. Elson (1966) does not include a water-plane at the particular heights and location where the Ponton ridges lie. The ridges are higher than the Pipun which is approximately 750-800 feet O.D. on the same latitude (Elson's Fig. 5, p. 46). The lower one of the two unnamed ridges between the Pipun and Grand Rapids "beaches" may correspond to the Ponton ridges in terms of location and height, but disappears to the south of the area in question. The ridges relate to the very last stages of Lake Agassiz and presumably can be accommodated between the Grand Rapids and Pipun water-planes. According to Elson, the last stages of Lake Agassiz took place with the disintegration of the ice-sheet on Hudson Bay which opened the northern outlets, such as the Sachigo, Echoing, Hayes and Bigstone River. The lake level fell in a series of steps until stabilizing as the present Lakes Manitoba, Winnipeg and Winnipegosis.

D. An Outline of the Analysis

The aims of the thesis will be fulfilled if it is possible to identify the features in terms of their morphology and sedimentological composition. This will be done in different sections of the thesis. Chapter 2 deals with the morphology of the ridges. Methods of morphological analysis are described, the quantitative measurement of the ridges is given. Once the relevant literature is reviewed, comparisons are made with a number of Pleistocene and modern landforms such as kames, eskers, ice-push ramparts, beach ridges (ancient and modern in each case). A similar procedure is followed in the sedimentological sections, Chapters 3 and 4. Chapter 3 deals with the stratigraphical and structural descriptions of the ridges, together with sphericity determinations and long axis orientation. Chapter 4 involves the particle size analysis of the samples obtained, followed by the percent heavy mineral content. Each section should provide evidence for the origin of the supposed beach ridges, and provide criteria by which they may be identified in future work.

Chapter 2

MORPHOLOGICAL ANALYSIS

The second chapter presents a detailed morphological analysis of the ridges at Ste. Anne and Ponton. The following aspects will now be covered:

A. A Review of the Relevant Current Literature on Morphological Studies.

B. A Quantitative and Qualitative Analysis of the Ridges At Ste. Anne and Ponton.

C. A Comparative Analytical Study of the Ridge Morphology at Ste. Anne and Ponton in Relation to Similar Ridges Described in Past Literature.

A. A Review of the Relevant Current Literature on Morphological Studies

Some past literature tends to suggest that the genesis of landforms may be determined by morphology. However, the evidence quoted in the present research indicates that this premise is untrue in the case of supposed Lake Agassiz beach ridges.

1. Some quantitative literature on slope studies. Very little has been written on the statistical analyses of slope components, despite the abundance of quantitative data. Certain writers have demonstrated that morphology is the result of particular controlling factors without focussing on the genesis of constructional landforms, as a whole. This type of slope study includes articles by A. Wood (1942, 1959), S. A. Schumm (1956), J. T. Hack (1960), A. Young (1960, 1963, 1964)

S. A. Schumm and R. J. Chorley (1966), and A. F. Pitty (1966). Work presented by K. J. Gregory and E. H. Brown (1966) exemplifies attempts to evaluate slope forming processes, in which the complexity of multivariate reality necessitates the formulation of a computer program.

2. <u>The literature on Pleistocene ridge-like forms</u>.

a. Drumlins. Detailed work on the dimensional, planimetric and spatial relations of drumlins has been written by R. W. Lemke (1958), R. J. Chorley (1959) and B. Reed, C. J. Galvin and J. P. Miller (1962). The paucity of the quantitative statistical literature on drumlins was particularly emphasized by the latter authors who state that "there is a lack of description of relatively simple symmetrical landforms which are characteristically associated with specific processes and commonly restricted in areal distribution".

b. Eskers. The analysed data on eskers is similarly restricted, although descriptions are numerous. Work which has tended to be quantitative includes that of W. V. Lewis (1949) and J. C. Stokes (1958). C. Embleton and C. A. M. King (1968, p. 380) illustrated a series of esker profiles from Reflection Lake, Baffin Island. These figures are used for comparison with the ridges of Ste. Anne and Ponton in the present study.

c. Kames and kame terraces. There is a paucity of quantitative data on the morphology of kames. Most articles are descriptive and emphasis is placed rather on the mode of formation than the detail of dimensions. These and other fluvio-glacial terraces usually have their heights accurately surveyed, but their overall morphology is generally disregarded, for instance, in the work of H. E. Tomlinson (1925) on the Warwickshire Avon. This and similar works are oriented towards establishing a chronology of formative events, based on water-plane heights. Morphology is ignored in favor of rather elusive height data. This has included the use of the height - range diagram, as shown in the work of A. Coleman (1954) and A. A. Miller (1955). Similar concepts were used in the detailed morphological analysis of glacio-fluvial terraces by R. P. Kirby (1969).

d. End moraines. End moraines have been extensively studied with regard to their mode of formation, but quantitative morphological data is rare. Exceptions include the work of J. T. Andrews and B. B. Smithson (1966) in Canada.

e. Beaches. The analysis of Pleistocene beaches solely on the basis of morphology has been neglected. Profiles have been drawn to demonstrate their history of formation (an example being shown in the work of F. E. Zeuner, 1961). Slope angle data on the raised beaches along the west coast of Scotland were not collected by S. B. McCann (1963), who obtained height data to indicate isostatic variations. Work on raised beaches carried out by J. B. Sissons, D. E. Smith and R. A. Cullingford (1966) similarly has tended to consist of map formation based on the accurate levelling of the features involved, together with a study of borehole records. The beaches have been analysed by a series of plots of distance against height and are regarded solely as indicators of isostatic and eustatic variations.

J. Chappell (1967) has examined the applicability of grain size analysis as a means of recognition of fossil strandlines in New Zealand. He considers morphology as an element which might lend itself to the diagnosis of origin. Morphology is not generally regarded to be completely diagnostic in the identification of glacio-fluvial or glacio-lacustrine features. Yet most of the identification of, and by inference, the origin of, supposed Lake Agassiz beaches has been predominantly morphological, with very few sedimentological studies.

3. The literature on aeolian ridge-like features. Other features which have been described in the literature as being "ridge-like" in form include the sand dunes of E. D. McKee (1966). Here various types of dunes are described, including the ridge-like transverse dune. S. L. Hastenrath's (1967) work consists of a quantitative account of barchans in the Arequipa region of Southern Peru. Among the analytical techniques used is a plot of crest height against the gradient angle of the windward slope of the barchan. This results in a high correlation coefficient. The method is adopted in Part B of Chapter 2 with the intention of formulating a clearer descriptive index of the hypothetical relationship of slope angle and height, as demonstrated by the ridges at Ste. Anne and Ponton.

4. Some literature on modern beach profiles. There is an extensive literature on beach ridge morphology, including that of off-shore bars and related features. As with other ridge-like features, most work has tended to include a description of morphology, and the mode of formation of the ridges is stressed. An important aspect is the profiling of such ridges. Despite the paucity of accurate height information associated with some of the data, the profiles themselves facilitate comparison, with respect to the ridges at Ste. Anne and Ponton.

A number of workers have profiled beaches at regular intervals to indicate seasonal erosional and depositional changes, and variations in sediment content at high and low water. Processes and the controls of development have been studied by W. C. Krumbein (1950). Aspects of grain size in relation to morphology are included in the work of W. N. Bascom (1951) and J. O. Norrman (1964). By contrast J. L. Davies (1957), N. P. Psuty (1967) and D. J. P. Swift (1968) have focussed their attention on variations in water level and associated sequential shoreline changes. Similar variations in profile formation can be seen from the diagrams of W. C. Krumbein (1963), D. Dolan and J. C. Ferm (1967), and A. O. Beall (1968). Recent morphological work involving the profiling of a bar-tombolo landform includes that of A. P. Carr (1969).

The comparison of these profiles with ones surveyed at Ste. Anne and Ponton can only be generally drawn. From the examples quoted above there is no typical beach ridge profile because of the variety of controlling factors involved. Most of the profiles, which have been drawn from the works mentioned above, are shown in Figs. 2-1 to 2-5. Some have no scale because this was omitted in the original draft, otherwise the scale, location and author are as indicated on the figure. The dimensions and the long and cross profile forms of modern beaches have to be determined so that comparisons with Pleistocene lake beaches can be made. Using morphology alone as the criterion for comparison, certain problems arise:

a. The Pleistocene lake beaches themselves must be extremely variable, changing in form with different environmental conditions.

b. The Pleistocene features are relict in nature and have been subjected to 5-7000 years of modifying processes by various agents, including man.

c. The literature relates beach profiles to present day energy conditions which may not be comparable to those of the Pleistocene.

d. Ocean beach ridges cannot readily be compared to lacustrine beach ridges because of inherent differences based on the relative scales of dynamics which vary in each case.

Therefore morphological comparisons of Pleistocene lake beaches and modern marine ones must be made cautiously with respect to these important considerations.

With reference to Section A, it can be concluded that particular values or statistical (analytical) formulae are rare in the past works. Yet, by comparing the relevant morphology of the cited literature with that of the ridges at Ste. Anne and Ponton, certain similarities may be found to assist in providing an indication as to the origin of the supposed Lake Agassiz beach ridges. In particular, it may be possible to determine whether the Ste. Anne or Ponton ridges were deposited in a fluvio-glacial, glacial, aeolian or littoral environment, and to ascertain which particular feature(s) of those reviewed above do they most likely resemble.

B. A Quantitative and Qualitative Analysis of the Ridges at Ste. Anne and Ponton

1. A general description of the area. For purposes of simplification the Ste. Anne ridge will be discussed first, followed by the Ponton ridge.

The Ste. Anne ridge, as indicated by Map 2, is one of a series of ridges trending north - south where the Manitoba Lowlands approach the Pre-Cambrian Shield in Southern Manitoba. Generally these ridges become progressively lower towards the west, demonstrating a drop in the level of Lake Agassiz, concurrent with the development of a prograding shoreline sequence. Photographs showing the form of the ridge between Sections 6 and 7 are shown as Plates 1 and 2. Plate 1 shows a higher degree to the east of the area. Plate 2 shows the western boundary of the Ste. Anne ridge and a gradual drop towards the former Lake Agassiz. These features have been described by J. A. Elson (1966) as being Lake Agassiz beaches and appear to range in altitude from the Campbell in the east to the Gladstone or Ojata in the west. Research by R. A. McPherson (unpublished Ph.D. thesis, 1970) has shown that the Ste. Anne area is basically an end moraine, extending from the Milner ridge and through the Agassiz Forest Reserve (as shown on the inset map of Map 3). Most of the moraine is apparent in the present day landscape. The linear ridges are superimposed upon it.

The basic form of the Ste. Anne ridge, as determined by preliminary aerial photograph investigations (shown on Map 2), tends to be linear, trending from north to south and having some degree of sinuosity. A sample area was studied, measuring $2\frac{1}{2}$ miles long, but varying in width (Map 3). This ridge was chosen for the reasons outlined in Chapter 1. It becomes indistinct, both on the ground and on the aerial photographs, when traced northwards, and its southern limits have been destroyed by man.

More information on the ridge was obtained by accurate surveying. The overall form was mapped by plane-tabling, and heights measured across and along the ridge, using an N3 level. The heights were levelled to an accuracy of 0.1 foot and taken from a pre-existing bench mark to the south of the ridge, where it is crossed by the Trans-Canada Highway. Eighteen sample cross-sections were selected along the length of the ridge, and numbered 2-19. The center point of each was chosen so that a

Plate 1

Between Sections 6 and 7 looking east

Plate 2

Between Sections 6 and 7 looking west

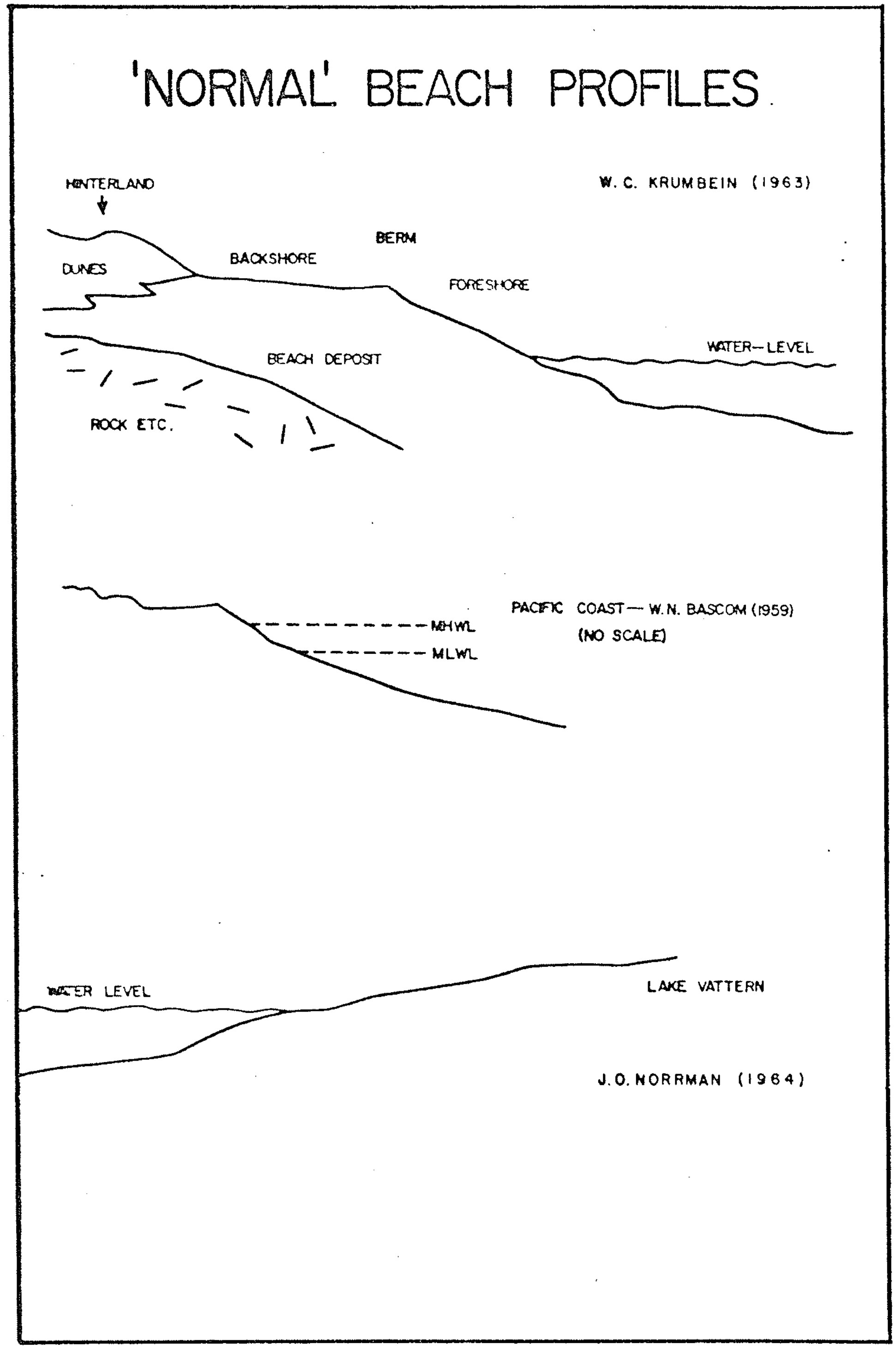
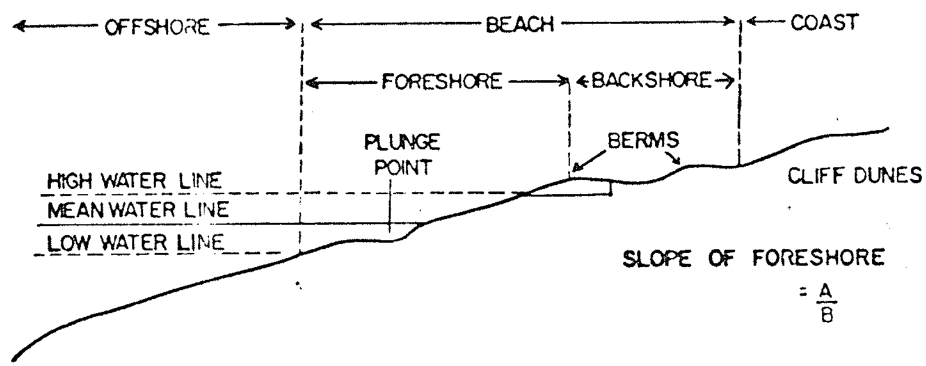

'NORMAL' BEACH PROFILES.
HINTERLAND
W. C. KRUMBEIN (1963)
BERM
BACKSHORE
DUNES
FORESHORE
WATER–LEVEL
BEACH DEPOSIT
ROCK ETC.
PACIFIC COAST— W.N. BASCOM (1959)
(NO SCALE)
MHWL
MLWL
WATER LEVEL
LAKE VATTERN
J.O. NORRMAN (1964)

Fig. 2-1

Fig. 2-2



DIAGRAMMATIC SKETCH OF SHORELINE FEATURES

ADAPTED FROM THE BEACH EROSION BOARD (1933)

AFTER W.C. KRUMBEIN (1950)

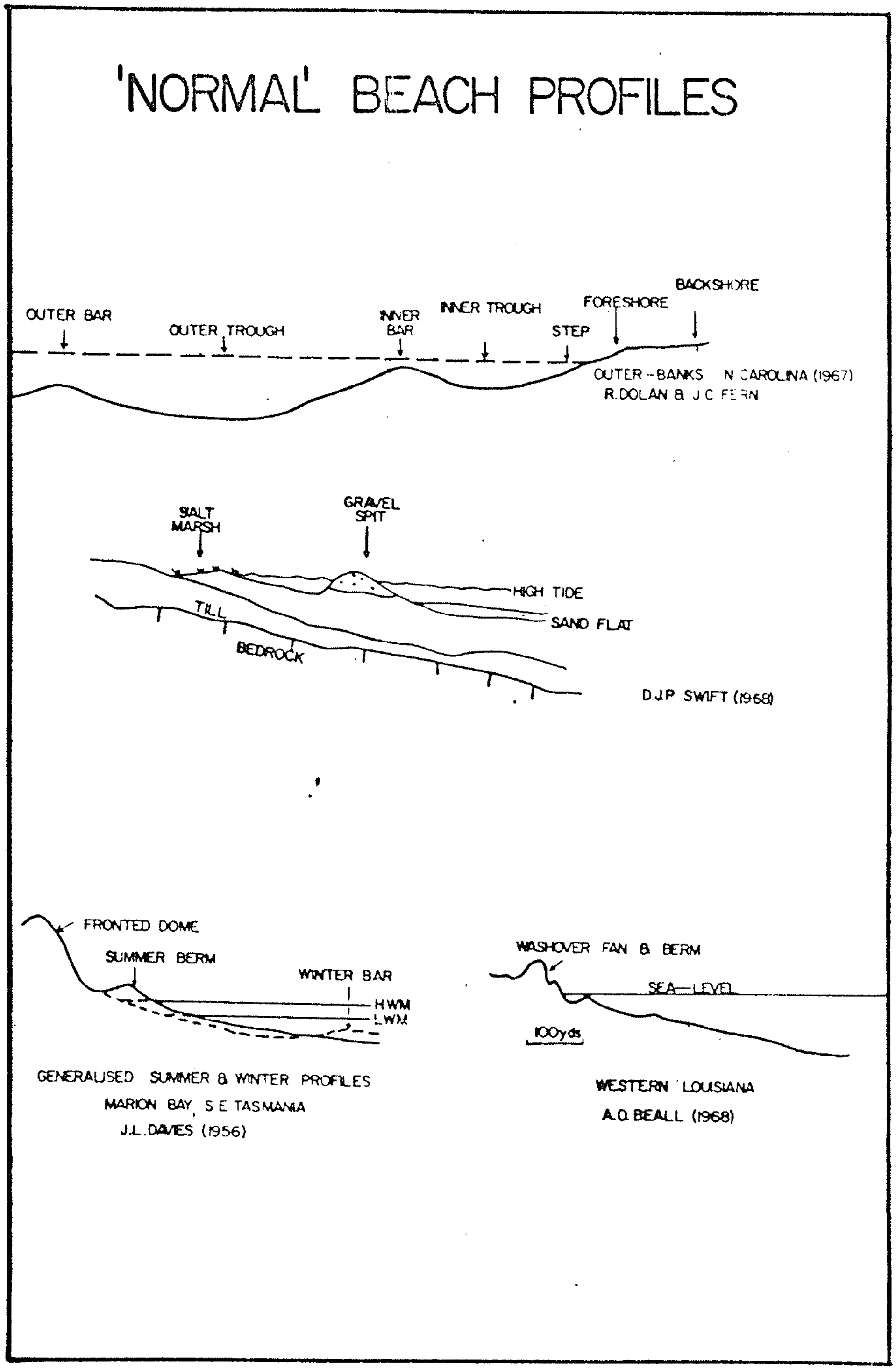

'NORMAL' BEACH PROFILES
OUTER BAR
OUTER TROUGH
INNER BAR
INNER TROUGH
STEP
FORESHORE
BACKSHORE
OUTER-BANKS N CAROLINA (1967)
R.DOLAN & J C FERN
SALT MARSH
GRAVEL SPIT
HIGH TIDE
SAND FLAT
TILL
BEDROCK
D.J.P SWIFT (1968)
FRONTED DOME
SUMMER BERM
WINTER BAR
HWM
LWM
GENERALISED SUMMER & WINTER PROFILES
MARION BAY, S E TASMANIA
J.L.DAVIES (1956)
WASHOVER FAN & BERM
SEA-LEVEL
100yds
WESTERN LOUISIANA
A.O.BEALL (1968)

Fig. 2-3

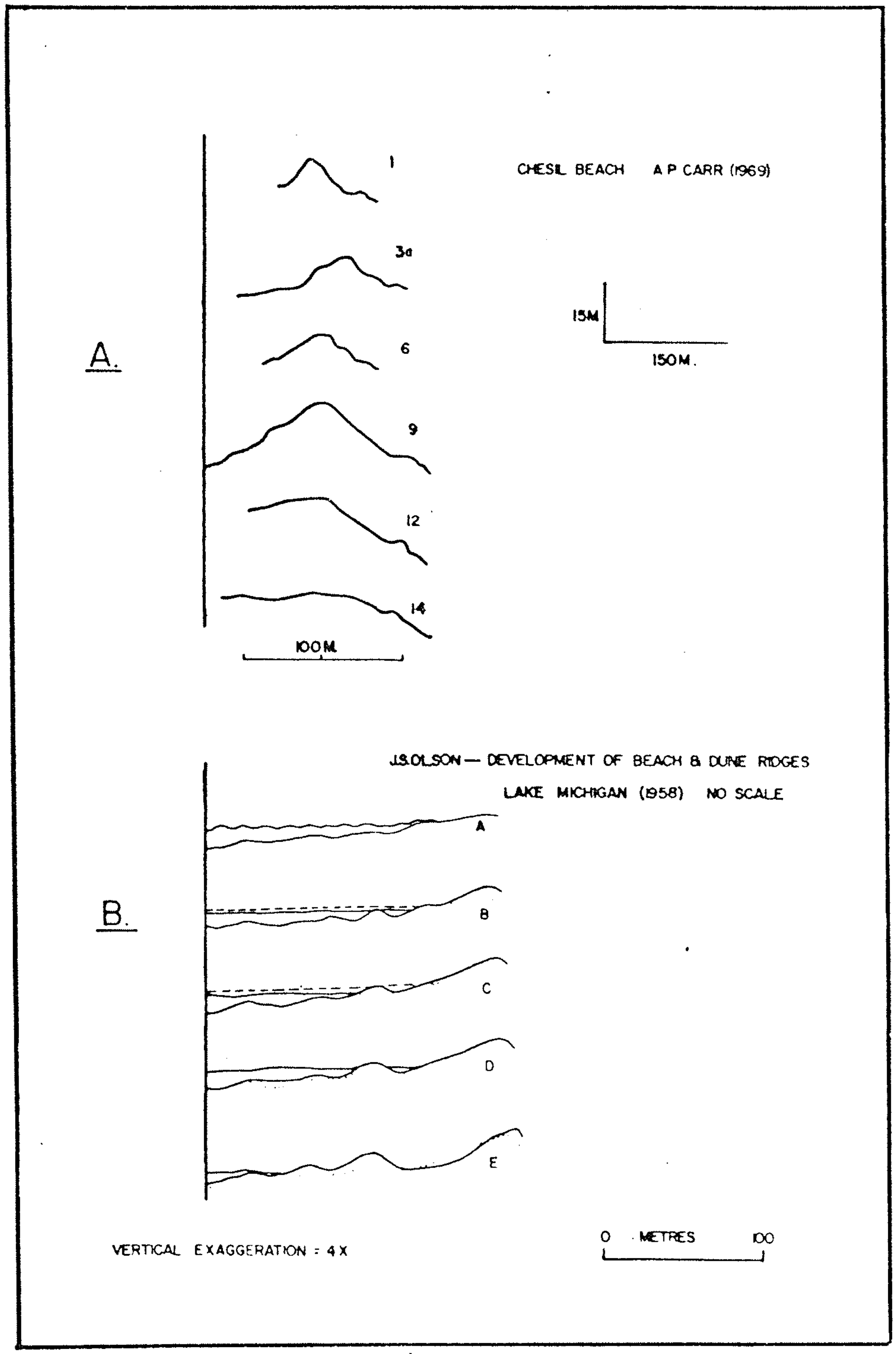

A.
CHESIL BEACH A P CARR (1969)
1
3a
6
9
12
14
15M
150M.
100M.
B.
J.S.OLSON — DEVELOPMENT OF BEACH & DUNE RIDGES
LAKE MICHIGAN (1958) NO SCALE
A
B
C
D
E
VERTICAL EXAGGERATION = 4 X
0 METRES 100

Fig. 2-4

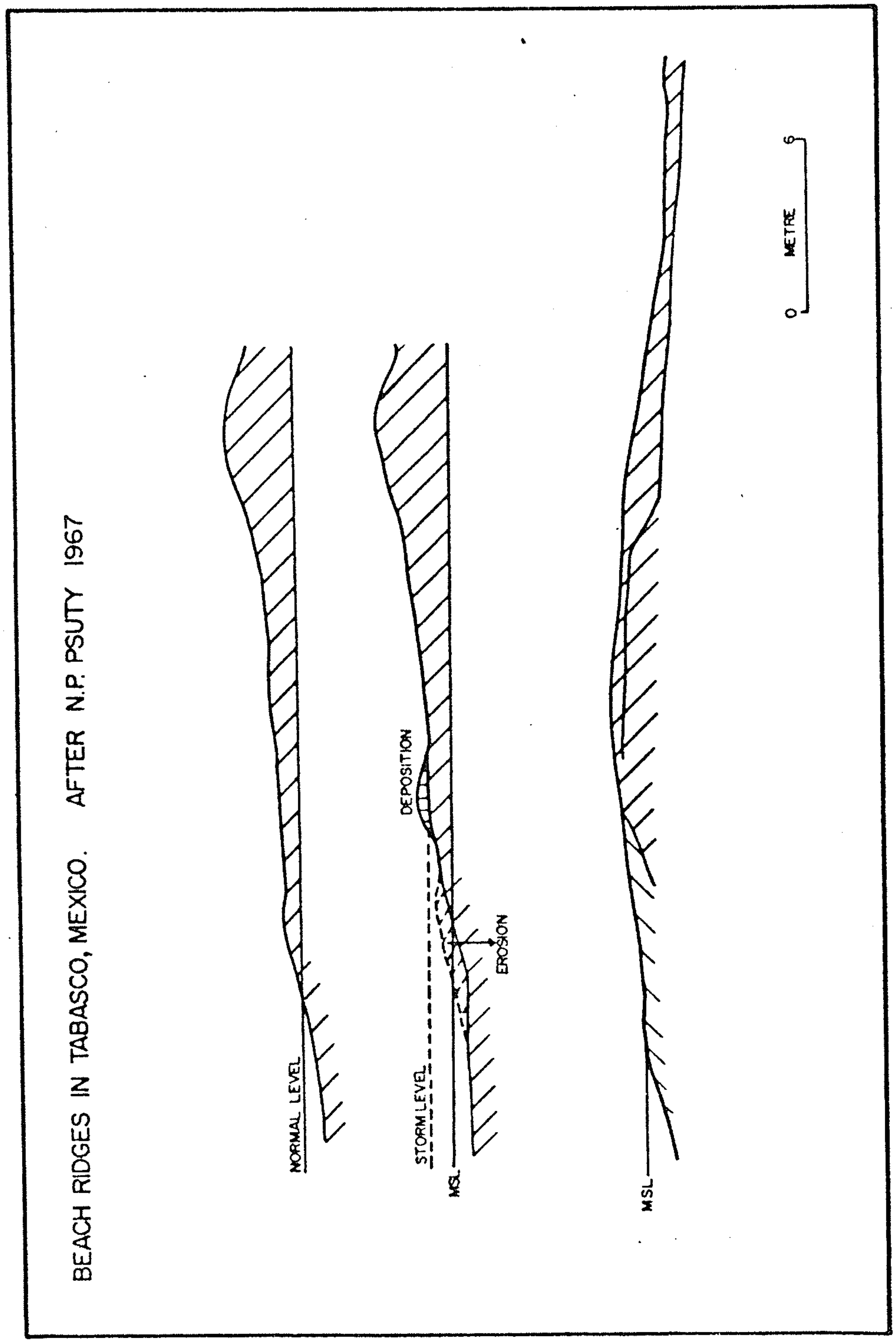

BEACH RIDGES IN TABASCO, MEXICO. AFTER N.P. PSUTY 1967
NORMAL LEVEL
DEPOSITION
STORM LEVEL
MSL
EROSION
MSL
0
METRE
6

Fig. 2-5

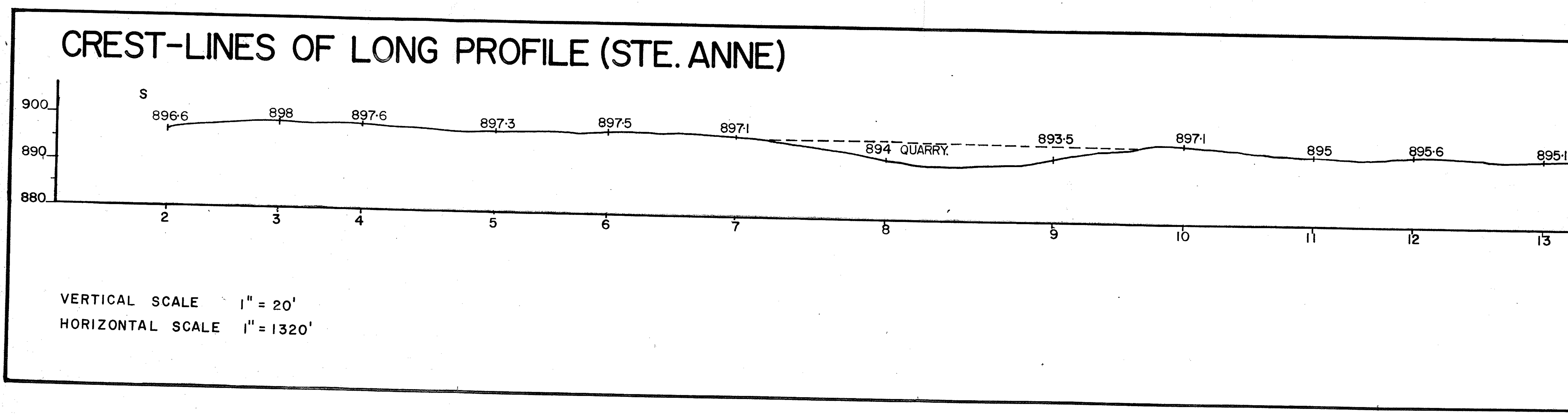
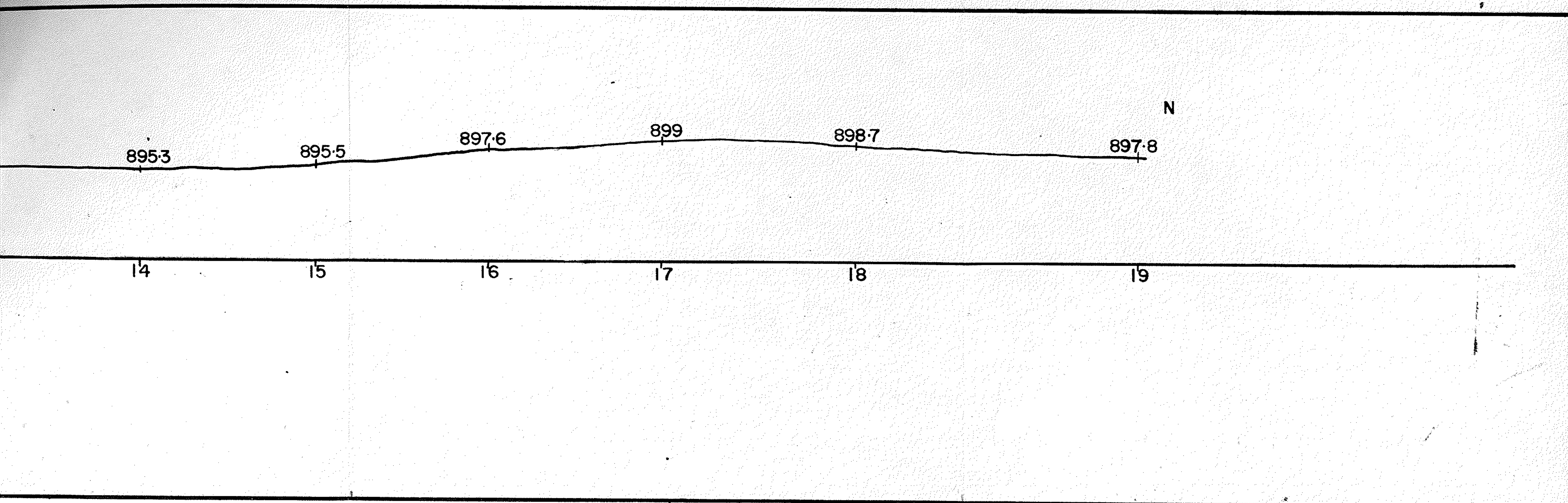

CREST-LINES OF LONG PROFILE (STE. ANNE)
S
900
890
880
896·6
898
897·6
897·3
897·5
897·1
894 QUARRY.
893·5
897·1
895
895·6
895·1
2
3
4
5
6
7
8
9
10
11
12
13
VERTICAL SCALE 1" = 20'
HORIZONTAL SCALE 1" = 1320'

Fig. 2-6



N
895·3
895·5
897·6
899
898·7
897·8
14
15
16
17
18
19

long profile could be drawn. From each center point certain cross profile positions were also chosen. The interval for these varies with local circumstances, but averages 700 ft. This form of systematic serial sampling was used so that all types of morphology, changing throughout the length of the ridge, would be equally regarded. The spatial distribution of the cross-profiles is shown on Map 3. Other reasons for choosing this particular number and spacing include:

a. The length was relatively accessible by means of a road and track through the bush.

b. The size of the area was reasonable in terms of the extent of the financial resources and the time available.

c. There is a comparative lack of dense vegetation over half the length of the surveyed section. This facilitated distinguishing the A, B, C, D, E points.

2. <u>A numerical study of height data (Ste. Anne)</u>. On each cross profile the five points marked A, B, C, D, E and, in once case, F (on Map 3) were chosen such that:

a. They would give an accurate picture of the outline of the ridge.

b. The variations in height along the ridge could be determined.

c. The variations in height across the ridge could be determined.

d. The planimetric position of the crest could be determined.

The variation in height (with distance) along the ridge can be seen in the long profile which has been drawn of the complete ridge (Fig. 2-6), and the data shown on Table 1. Despite local variations the ridge maintains essentially the same height throughout. The average height of the southern half is 897 ft. O.D. and the average of the northern half, 898 ft. Although there is a localised rise, the sample is too small to allow generalized conclusions to be drawn on the longitudinal gradient. The long profile data is hypothetical because it is interpolated between the surveyed points 2-19. Some compensation has been made for quarrying. However, the maximum variation in crest height is between Section 17 (899') and Section 9 (893.5'), thus giving an overall variation of 5.5 ft.

The height differences of A, B, C, D, E, (F) west - east across the ridge are shown in Figs. 2-7 and 2-8 and given in the accompanying Table 1. The average height of A (the lowest western extremity) is 889.61', of B, 893.17', of C (the crest in many cases) 895.82', of D, 895.27' and of E (the lowest eastern extremity) 892.71'. The average elevation above the surrounding ground level is 6.21' on the west (lakeward side) and 3.11 on the east side. This varies considerably from the dimensions given by W. Upham (1895, Ch. 1). In Upham's description the landward side of the ridge in relation to the surrounding terrain is twice as high as the lakeward size.

The ridge has a smoothly rounded convex form, which often appears to be steeper towards the west and gentle in slope towards the eastern, landward extremity. This marked difference tends to decrease at Sections 7, 8 and 9, but the convexity is pronounced again in Sections 10, 11 and 12, where the ridge becomes a narrower, semi-cylindrical feature. The convexities flatten again through Sections 14 and 15, but become more pronounced, though less rounded than at 10, 11

Table 1

Long Profile, Cross Profile and Width Data (Ste. Anne)

Section Number	Long Profile Data (ft.)	Cross Profile Data (ft.) (Ste. Anne)						Width Data (ft.)
		A	B	C	D	E	F	
2	896.6	890.14	889.98	896.56	895.56	890.80		384.4
3	898	890.70	896.73	897.15	897.98	894.57		440.2
4	897.5	887.83	893.18	890.32	897.48	893.18		415.4
5	897.3	884.88	888.17	897.37	897.22	892.95		489.8
6	897.5	886.69	889.67	896.38	897.49	893.32		446.4
7	897.1	890.26	894.41	897.11	894.98	892.14		409.2
8	894	889.76	891.53	893.00	891.46	893.97	892.02	514.6
9	893.5	889.04	890.45	891.30	893.53	891.24		235.4
10	897.1	889.03	895.07	897.14	894.95	891.45		192.2
11	895	890.44	893.84	894.91	894.61	892.25		124.0
12	895.6	892.62	894.46	895.58	894.99	894.87		155.0
13	895.1	892.81	893.57	893.93	895.14	892.63		62.2
14	895.3	889.81	895.03	895.33	894.90	893.34		161.2
15	895.5	888.52	892.18	895.51	893.41	890.31		608.2
16	897.6	888.99	892.42	897.59	893.13	892.31		427.8
17	899	891.19	897.27	899.05	895.55	893.35		378.2
18	898.7	890.10	893.36	898.69	896.41	890.45		415.4
19	898.8	890.24	895.70	897.78	895.60	895.82		334.8

and 12, at 17 and 18. There is a tendency for the ridge to decrease again at 19.

3. A numerical study of width data. The width of the various sections is also given on Table 1, and illustrated in Figs. 2-7 and 2-8. The widest point is at Section 15 (608.2') and the narrowest at Section 13 (62.2'),demonstrating the considerable variation. The original width variation here may have been caused by differences in sedimentation--current processes and deposition. Present day contributory factors include the large swamp to the eastern edge of Section 13, which has encroached on the ridge itself by a process analogous to spring sapping. At Section 15, the relative clarity of morphological expression has resulted from a road traversing the ridge at this point. A subjective assessment of ridge limits was necessary because additional materials--exaggerating the ridge's width--may have been brought in for road building. The average width of the ridge is 344.13', one hundred feet narrower than the average width of ridges described in W. Upham's (1895) work.

4. A comparative study of slopes using the Wilcoxon Matched Pairs Signed Ranks Test. The slope angles for the 18 sections are given on Table 2. The angles are denoted by α being the points between A and B, β between B and C, γ between C and D, and δ between D and E. A non-parametric test was used to compare the angles of the east and west facing slopes. The two steepest comparable angles α and δ had to be compared separately from β and γ because the area B, C, D represents the rounded crest portion of the ridge, with little or no angle of elevation.

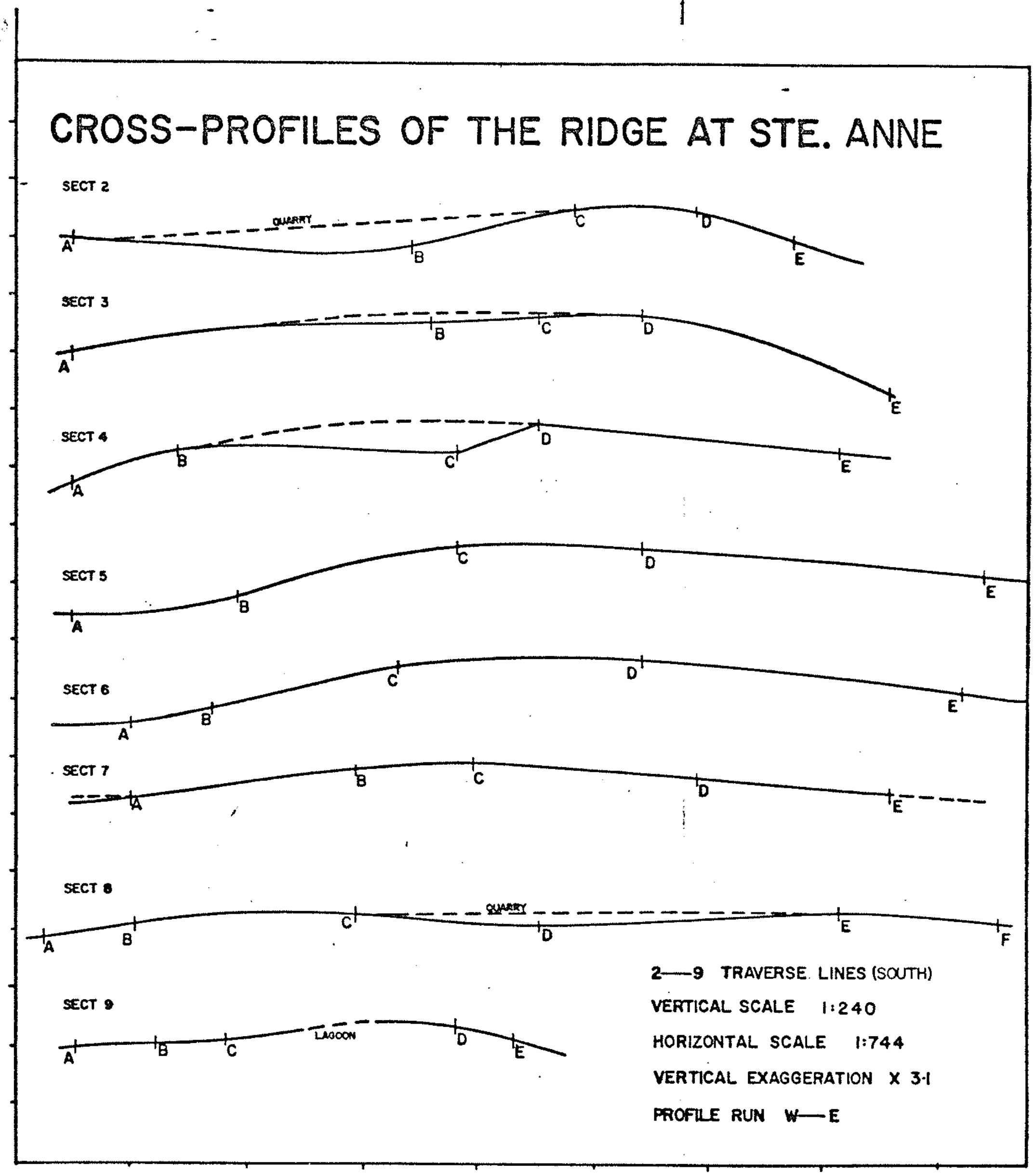

CROSS-PROFILES OF THE RIDGE AT STE. ANNE
SECT 2
QUARRY
SECT 3
SECT 4
SECT 5
SECT 6
SECT 7
SECT 8
QUARRY
SECT 9
LAGOON
2—9 TRAVERSE LINES (SOUTH)
VERTICAL SCALE 1:240
HORIZONTAL SCALE 1:744
VERTICAL EXAGGERATION X 3·1
PROFILE RUN W—E

Fig. 2-7

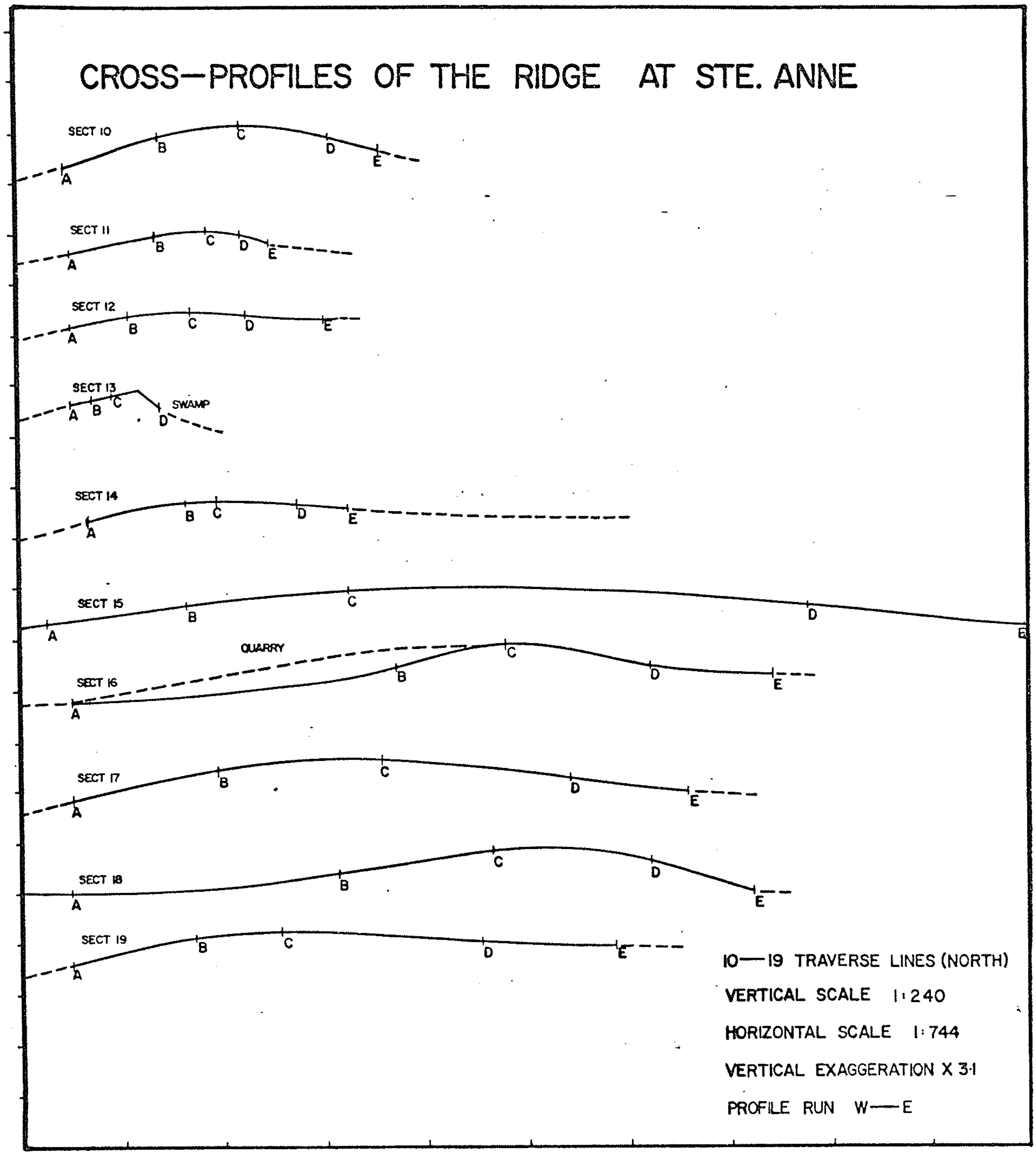

CROSS-PROFILES OF THE RIDGE AT STE. ANNE
SECT 10
SECT 11
SECT 12
SECT 13
SWAMP
SECT 14
SECT 15
QUARRY
SECT 16
SECT 17
SECT 18
SECT 19
10—19 TRAVERSE LINES (NORTH)
VERTICAL SCALE 1:240
HORIZONTAL SCALE 1:744
VERTICAL EXAGGERATION X 3·1
PROFILE RUN W—E

Fig. 2-8

The Wilcoxon Matched Pairs Signed Ranks Test was used for the following reasons:

a. The study employs two related samples (i.e. the steepest gradients on the same cross profile).

b. The study yields different angles of elevation which may be ranked in order of magnitude.

c. The data is non-normal and has a positive skewness.

Considering the comparison of the α and δ slopes (referred to as the steeper slopes) and the β and γ (upper slopes) on the east and west sides of the ridge, the data can be found in Table 2.

The Null Hypothesis:

Ho: The steeper or upper slopes on the west of the Ste. Anne ridge do not differ from the comparable slopes to the east of the ridge.

Hi: Either the steeper or upper slopes on one side of the ridge have a greater gradient than the corresponding slopes on the other side of the ridge.

Significance level = .05

N = number of pairs (18) minus any pairs whose difference is zero

$$\therefore N = 16$$
$$T = 37$$

The critical value from Tables (p. 254 S. Seigel, 1956) = 30

$\therefore$ reject the Null Hypothesis.

The conclusion is that at the .05 level, the slopes are unequal. The α slope is significantly steeper than the δ slope, and the β slope significantly steeper than the γ slope.

Table 2

The Wilcoxon Matched Pairs Signed Ranks Test (Ste. Anne)

Section Number	α	β	γ	δ	Diff.		Rank	
2	7	(1)	6	(1)	+1	(0)	+4	(0)
3	6	(0.5)	2	(1)	+4	(-0.5)	+15	(-1)
4	5	(5)	1	(1)	+4	(+4)	+15	(+14.5)
5	4	(4)	1.5	(1)	+2.5	(+3)	+8.5	(+13)
6	2	(4)	1.5	(0)	+0.5	(+4)	+1.5	(+14.5)
7	4	(3)	2	(1)	+2	(+2)	+6.5	(+9.5)
8	2	(2.75)	5	(5)	-3	(-2.25)	-11.5	(-11)
9	3	(2)	4	(1)	-1	(+1)	-4	(+4.5)
10	7	(3)	7	(4)	0	(-1)	0	(-4.5)
11	5	(4)	7	(3)	-2	(+1)	-6.5	(+4.5)
12	2	(3)	1	(1)	+1	(+2)	+4	(+9.5)
13	3	(5.5)	0	(16)	+3	(-9.5)	+11.5	(-16)
14	5	(0)	2	(1)	+3	(-1)	+11.5	(-4.5)
15	2	(3)	1.5	(2)	+0.5	(+1)	+1.5	(+4.5)
16	4.5	(3.5)	2	(2)	+2.5	(+1.5)	+8.5	(+8)
17	4	(4)	4	(1.5)	0	(+2.5)	0	(+12)
18	2	(3)	6	(2)	-4	(+1)	-15	(+4.5)
19	4	(1)	1	(1)	+3	(0)	+11.5	(0)

Steeper slope angles: The sum of the (least) negative values = 37 (T)
Number in sample = 16 (N)

Upper slope angles: (in parenthesis) The sum of the (least) negative values = 37 (T)
Number in sample = 16 (N)

The heights A, B, C, D and E are indicated on Table 1 and the relevant data shown on Table 3. The graph of the plots is given in Fig. 2-9. The calculations are indicated in Table 4. The results are as follows:

Regression: $(B - A) = 1.01 + 41.7\ (\mathrm{Sin}\,\alpha)$: $r = +.682$

Regression: $(D - E) = 2.36 + 12.27\ (\mathrm{Sin}\,\delta)$: $r = +.307$

The coefficients of correlation are not high, but in the regression curve, at least 47% of the variable (B-A) is accounted for by differences in the variable α or, almost along half the ridge, the variation in slope angle on the west side of the ridge but not on the east, is associated with increased crest height. The formulae are given as an index for later comparison. The curve does not resemble the one found in S. L. Hastenrath's work.

6. A slope orientation study. From the slope angle data presented in Table 2 further determinations were made to check the relative steepness of the slopes in relation to their orientation. From Maps 2 and 3 it can be seen that the ridge is sinuous in form, having an open "S" shape. Consequently, various segments of the ridge are oriented in different directions. The orientation taken here consists of three major directions. The northwest - southeast oriented profiles (from 300-120 degrees east of north) occur in Sections 2, 3, 4, 8, 9, 10, 16, 17, 18 and 19. The east - west oriented profiles (from 270-90 degrees) occur at 5, 6, 7 and 15. The northeast - southwest oriented profiles (from 230-60 degrees) occur at 11, 12, 13 and 14. In the NW-SE oriented portion of the ridge, the mean angle of elevation for the relevant NW facing slope is 4.45 degrees and that for the SE facing slope is 3.8 degrees.

Table 3

Calculations of Regression Analysis (Ste. Anne)

		Sin α (x)	(B-A) (y)	(Sinα)(B-A) (xy)	$(\text{Sin}\alpha)^2$ (x^2)	$(\text{B-A})^2$ (y^2)
2	7			QUARRYING		
3	6	.105	6.03	.633	.011	36.36
4	5	.087	5.35	.465	.008	28.62
5	4	.070	3.29	.230	.005	10.82
6	2	.035	2.98	.104	.001	8.88
7	4	.070	4.15	.291	.005	17.22
8	2	.035	1.77	.062	.001	3.13
9	3	.052	1.41	.073	.003	1.99
10	7	.122	6.04	.737	.015	36.48
11	5	.087	3.40	.296	.008	11.56
12	2	.035	1.84	.064	.001	3.39
13	3	.052	0.76	.040	.003	0.58
14	5	.087	5.22	.464	.008	27.25
15	2	.035	3.66	.128	.001	13.40
16	4.5	.087	3.43	.268	.006	11.76
17	4	.070	6.08	.426	.005	36.97
18	2	.035	3.26	.114	.001	10.63
19	4	.070	5.46	.383	.005	29.81

$\Sigma x = 1.125$ $\qquad \bar{x} = 0.066$

$\Sigma y = 64.13$ $\qquad \bar{y} = 3.772$

$\Sigma xy = 4.767$

$\Sigma x^2 = 0.087$

$\Sigma y^2 = 288.85$

Slope: $y = 1.022 + 41.673x$

Table 3 (continued)

Calculations of Regression Analysis (Ste. Anne)

		Sin δ (x)	(D-E) (y)	(Sinδ)(D-E) (xy)	(Sinδ)^2 (x^2)	(D-E)^2 (y^2)
2	6	.105	4.86	.510	.011	23.62
3	2	.035	3.41	.119	.001	11.63
4	1	.017	4.30	.073	.000	18.49
5	1.5	.026	4.27	.111	.001	18.23
6	1.5	.026	4.17	.108	.001	17.39
7	2	.035	2.84	.099	.001	8.07
8	5			QUARRYING		
9	4	.070	2.29	.160	.005	5.24
10	7	.122	3.50	.427	.015	12.25
11	7	.122	2.36	.288	.015	5.57
12	1	.017	0.12	.002	.000	.01
13	0	.0	-	-	-	6.30
14	2	.035	1.56	.055	.001	2.43
15	1.5	.026	3.10	.081	.001	9.61
16	2	.035	0.82	.029	.001	0.67
17	4	.070	2.20	.154	.005	4.84
18	6	.105	5.96	.626	.011	35.52
19	1			QUARRYING		

$\Sigma x = 0.846$ $\bar{x} = 0.056$
$\Sigma y = 45.76$ $\bar{y} = 3.05$
$\Sigma xy = 2.842$
$\Sigma x^2 = 0.069$
$\Sigma y^2 = 173.57$

Slope: $y = 2.36 + 12.268x$

Table 3 (continued)

Calculations of Regression Analysis (Ste. Anne)

Using $$b = \frac{\Sigma xy(n) - (\Sigma x)(\Sigma y)}{n(\Sigma x^2) - (\Sigma x)^2}$$

$$b = \frac{(17)(4.767) - (1.125)(64.13)}{(17)(0.087) - (1.125)^2}$$

$$a = \bar{y} - b\bar{x}$$

$$a = 3.772 - (41.673)(0.066)$$

$$a \doteq 1.022$$

Slope $$y = 1.022 + 41.673x$$

Using $$r = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

$$r = \frac{(17)(4.767) - (1.125)(64.13)}{\sqrt{[(17)(0.087) - (1.125)^2]\,[(17)(288.85) - (64.13)^2]}}$$

$$r = \frac{81.039 - 72.146}{\sqrt{(0.213)(797.793)}} = \frac{8.893}{13.036}$$

$$r = 0.682$$

Table 3 (continued)

Calculations of Regression Analysis (Ste. Anne)

Using $b = \dfrac{\Sigma x(n) - (\Sigma x)(\Sigma y)}{n(\Sigma x^2) - (\Sigma x)^2}$

$b = \dfrac{(15)(2.842) - (0.846)(45.76)}{(15)(0.069) - (0.846)^2}$

$a = \bar{y} - b\bar{x}$

$a = 3.05 - (12.268)(0.056)$

$a = 2.36$

Slope $y = 2.36 + 12.268x$

Using $r = \dfrac{n\Sigma y - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$

$r = \dfrac{(15)(2.842) - (0.846)(45.76)}{\sqrt{[(15)(0.069) - (0.846)^2][(15)(173.57) - (45.76)^2]}}$

$r = \dfrac{42.63 - 38.713}{\sqrt{.319 - 509.572}} = \dfrac{3.917}{12.750}$

$r = 0.307$

RELATIONSHIP BETWEEN HEIGHT AND SLOPE ANGLE AT STE. ANNE.

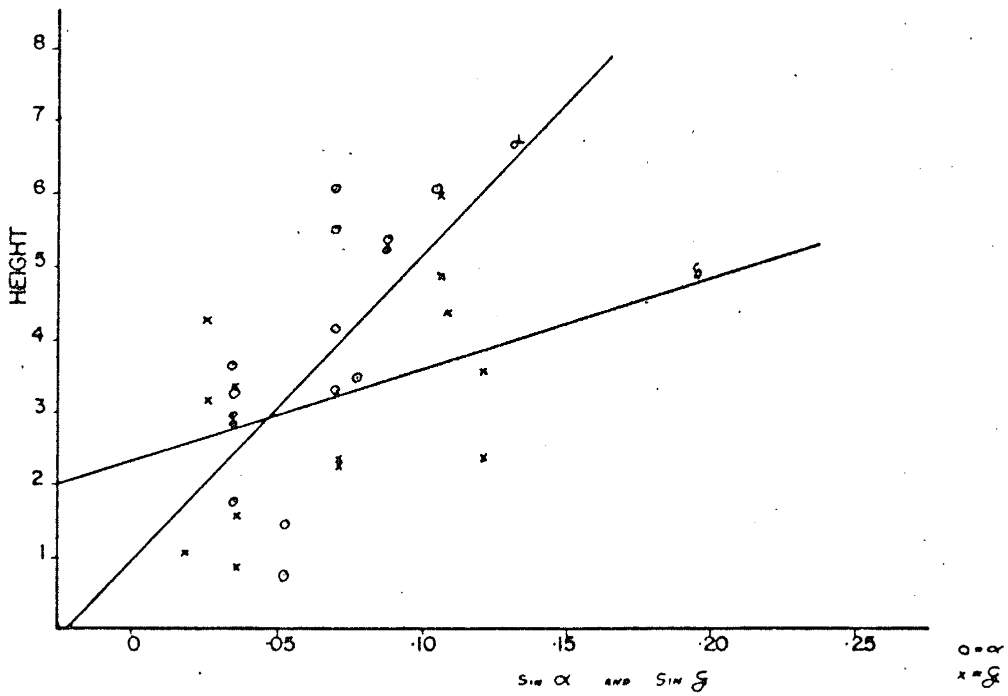


Fig. 2-9

In the N - S oriented portion of the ridge the mean angle of elevation for the west facing slopes is 3 degrees, and for the east facing slope is 1.625 degrees. In the NE - SW oriented profiles the mean angle of elevation for the SW facing slope is 3.75 degrees and for the NE facing slope is 2.5 degrees.

This emphasizes the fact that the slopes on the westward side of the ridge are steeper, as indicated by the Wilcoxon Test. There is a higher degree of equality in the opposing steeper slopes. If one assumes that the ridge is a storm beach, then it is possible that the greatest directional energy emanated from the northwest, with a secondary force from the northeast. The west-east oriented segments may have been in a relatively sheltered position.

1. <u>A general description of the area</u>. At Ponton there is an irregular series of three parallel ridges (Map 4), which may relate to the latter stage of Lake Agassiz, since the final basin of sedimentation is found in the Grass River area (J. A. Elson, 1967). These three ridges are relatively unique "beach" features in the area that is depicted by the Weskusko Lake topographic sheet. Other features include wave-washed eskers and moraines. Because the exact relationship of the ridges with other features is obscured by the dense vegetal cover (conifers and muskeg), which reduces accessibility and visibility in the area, an aerial photograph analysis does not show the features clearly.

The Ponton ridges trend from northwest to southeast and are relatively short. Each ridge is approximately half a mile in length. These are designated R1, R2, R3 on Map 4, reading from northeast to southwest. Each tends to be linear. R2 and R3 are slightly sinuous. R1 and R2 extend northwards beyond the railway tracks.

Table 4

Slope Angle vs Orientation Data (Ste. Anne)

NW - SE		E - W		NE - SW	
W	E	W	E	W	E
7	6	4	1.5	5	7
6	2	2	1.5	2	1
5	1	4	2	3	0
2	5	2	1.5	5	2
3	4				
7	7				
4.5	2				
4	4				
2	6				
4	1				
44.5	38	12	6.5	15	10

$\bar{\bar{X}}$ NW - SE (W) = 4.45
$\bar{\bar{X}}$ NW - SE (E) = 3.8

$\bar{\bar{X}}$ E - W (W) = 3
$\bar{\bar{X}}$ E - W (E) = 1.625

$\bar{\bar{X}}$ NE - SW (W) = 3.75
$\bar{\bar{X}}$ NE - SW (E) = 2.5

NW-SE, E-W, NE-SW = profile orientations

The ridges vary considerably in morphological composition with distance. An overall map was drawn up after the area had been surveyed by the compass and chain method. A clearing which had been cut for a line of Hydro pylons was used as a base line, because it could be traced on the aerial photographs which were employed as a base map for the area. Also, the initial surveyed heights of this line were provided by Manitoba Hydro. Sample traverses were selected, perpendicular to this line, and incorporating the observed length of the three ridges to the south of the railway tracks. These are designated, from northwest to southeast, -400, 000, 200, 400, 600, 700, 900, 1100, 1300, 1500. An interval of 200 ft. was generally used, but this was extended to 400 in the north (-400) because of morphological similarity at the -200 point. There are only 100 ft. between 600 and 700 because of the relative morphological complexity towards the center of the three ridges.

On the ground, surveying took place to obtain height and slope measurements. A steel tape and clinometer were used, with an Abney level serving as a check. Limited accessibility precluded the use of heavier, more accurate equipment. A variable number of points were chosen for measurements leading to the morphological profile. These are lettered throughout the lengths of the profiles, commencing with A on Ridge 3 and proceeding through the alphabet to P or beyond until the Hydro line is reached (Map4).

The density of traverse lines (-400 to 1500) was selected because it was necessary to use the same systematic serial sampling as had been used at Ste. Anne. This was to include all the major changes in morphology which occur along the ridges in the most systematic manner. The frequency of the points A - P were chosen for the following reasons:

a. The frequency includes most of the varieties of morphological form exhibited by the ridges.

b. There is a lack of vegetation on the ridges compared with the surrounding muskeg. This facilitates the distinction of the points lettered A - P.

c. The number of points which were included complied with the financial resources and time available.

2. <u>A numerical study of height data</u>. The variation in height along the ridge can be seen in the long profiles, shown in Fig. 2-10 and Table 5. This variation is quite marked, particularly in R2. R1 varies from 827' in the northwest, reaches 843' towards the center, and decreases to 839' in the southeast. There is an overall increase towards the south of 12 feet in 1900 feet. The maximum height difference throughout is 16 ft. R2 varies from 828' in the northwest, drops in 400 ft. to 814', reaches 853' at the center, and drops again to 834' in the southeast. The difference from north to center is 39 ft., and from center to south, 14 ft. The R3 varies from 838' and 823' in the northwest to 844' towards its southeastern extremity, and finally drops to 837'. The overall height variation along the ridge is 21 ft.

The variations in height across the morphological traverses are also shown on Table 5 and on Fig. 2-11. The three columns of readings here refer to the heights on either side and on the center of the ridge. The average figures for R1 are 828(SW), 834(C), 829(NE). For R2 they are 827(SW), 838(C), 827(NW), and for R3 833(SW), 835(C), 828(NE).

The average elevations of the three ridges above the surrounding ground level are:

This steepness of slope indicates that the lower western slope of the ridge, facing the former lake, is significantly steeper than its counterpart on the landward side. Again this does not correspond to Lake Agassiz beach ridges, quoted in Ch. 1, or the present day beach profiles, seen in Figs. 2-1 to 2-5.

5. A regression analysis--the plot of height versus slope angle. Attempts here are also made to effect some type of correlation between the angle of slope and the height of the crest. This follows the method used by S. L. Hastenrath (1967). In this study the angle of the windward side of a barchan increases with increasing height, while the angle of the leeward side is maintained. In the present study the test was used for the following reasons:

a. To provide an index to account for the variations between slope angles and crest height of supposed Agassiz beach ridges.

b. If the Ste. Anne data results in similar equations to the ones resulting from S. L. Hastenrath's work, then it may indicate that the Ste. Anne ridge was a wind-formed feature.

The plots were made on the steeper slope angles marked α and δ. The sine of the angle was used because:

$$\text{Sine } x = \frac{\text{Height of feature}}{\text{Slope length of feature}}$$

The other slope angles (β and γ) were ignored because of the relative insignificance of the slopes in relation to height around the crest area, and that 4 faces at Ste. Anne could not be compared to Hastenrath's windward and leeward slopes.

Sin α is plotted against height (B - A)

Sin δ is plotted against height (D - E)

Plate 3

S.W. slope of R2 from 900 looking S.E.

Plate 4

N.E. slope of R2 from 900 looking S.E.

R1	6 ft. (SW) - 5 ft. (NE)
R2	11 ft. (SW) - 11 ft. (NE)
R3	2 ft. (SW) - 7 ft. (NE)

Comparatively speaking, there is no apparent uniformity of morphology of the ridges, or similarity in terms of local relief.

3. A numerical study of width data. The widths of the ridges, as determined at the various cross-profiles, are given in Table 5. The average width of Ridge R1 is 92 ft., of R2 is 89 ft. and of R3 is 59 ft. There is a considerable variation in difference over the 660 yds. covered. R1 varies from 17 to 199 ft. wide, giving a variable difference of 182 feet. R2 varies from 20 to 133 ft., the variation being 113 feet. R3 varies from 25 to 100 ft., the variation being 75 feet. The width between ridges also varies (see Table 5). These figures, in the case of R1, refer to the distance between R1 and the Hydro line. In the case of R3, they refer to the distance between R2 and R1, and, under R3, they refer to the distance between R3 and R2.

R2 is seen to be the most variable ridge in terms of height, and R1 the most variable in terms of width. Because of these morphological differences, a different origin may be signified.

The profiles themselves vary throughout their length. Inspection of Fig. 2-11 shows:

a. the variations in the cross profiles from -400 to 1500

b. the differences with each cross-profile.

The Figure also shows a marked inequality of the opposite slopes of R1 and R3, when compared to R2 whose slopes are equal. This pattern is relatively consistent throughout the length of the ridge, as observed by inspecting the slope angles of Table 5. In the case of compounded slopes, the steepest, or longer facet is here taken.

4. <u>A comparative study of slopes using the Wilcoxon Matched Pairs Signed Ranks Test</u>. In order to compare the variation between the southwest and northeast facing slopes on each ridge, the Wilcoxon Matched Pairs Signed Ranks Test was used. The data is shown on Table 5a.

a. For each ridge, respectively, the following hypothesis was tested:

The Null Hypothesis:

Ho: That the NE facing slopes on the Ponton Ridge 1 do not differ significantly in inclination from the SW facing slopes.

Hi: The NE facing slopes are steeper than the SW facing slopes.

b. Significance level = .05

N = the number of pairs, minus any pairs whose difference is zero.

c. R1 There are no least values.

T = 0
N = 9 ∴ reject the Null Hypothesis

R2 T = 11.0
N = 8 ∴ accept the Null Hypothesis

R3 T = 1.5
N = 9 ∴ reject the Null Hypothesis

The results show that, along R1, all the steeper slopes face SW. R2 exhibits a marked similarity between the NE and SW facing slopes. R3 has most of its steeper slopes (to the .01 level) facing NE.

5. <u>The plots</u>. On the regression analysis, plotting height against slope for the three Ponton ridges were very scattered and had

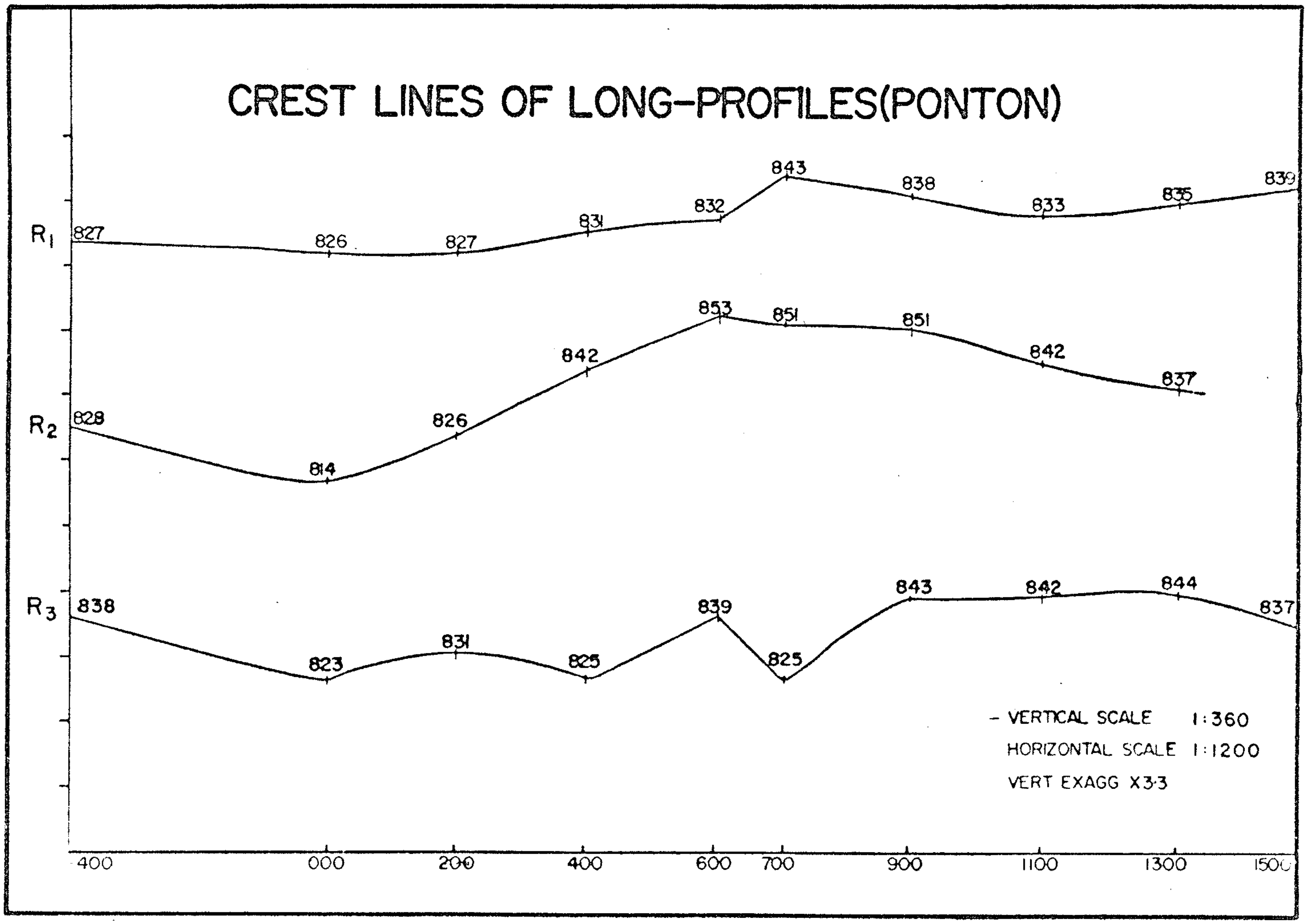

CREST LINES OF LONG-PROFILES(PONTON)
R1
827
826
827
831
832
843
838
833
835
839
R2
828
814
826
842
853
851
851
842
837
R3
838
823
831
825
839
825
843
842
844
837
VERTICAL SCALE 1:360
HORIZONTAL SCALE 1:1200
VERT EXAGG X3·3
400
000
200
400
600
700
900
1100
1300
1500

Fig. 2-10

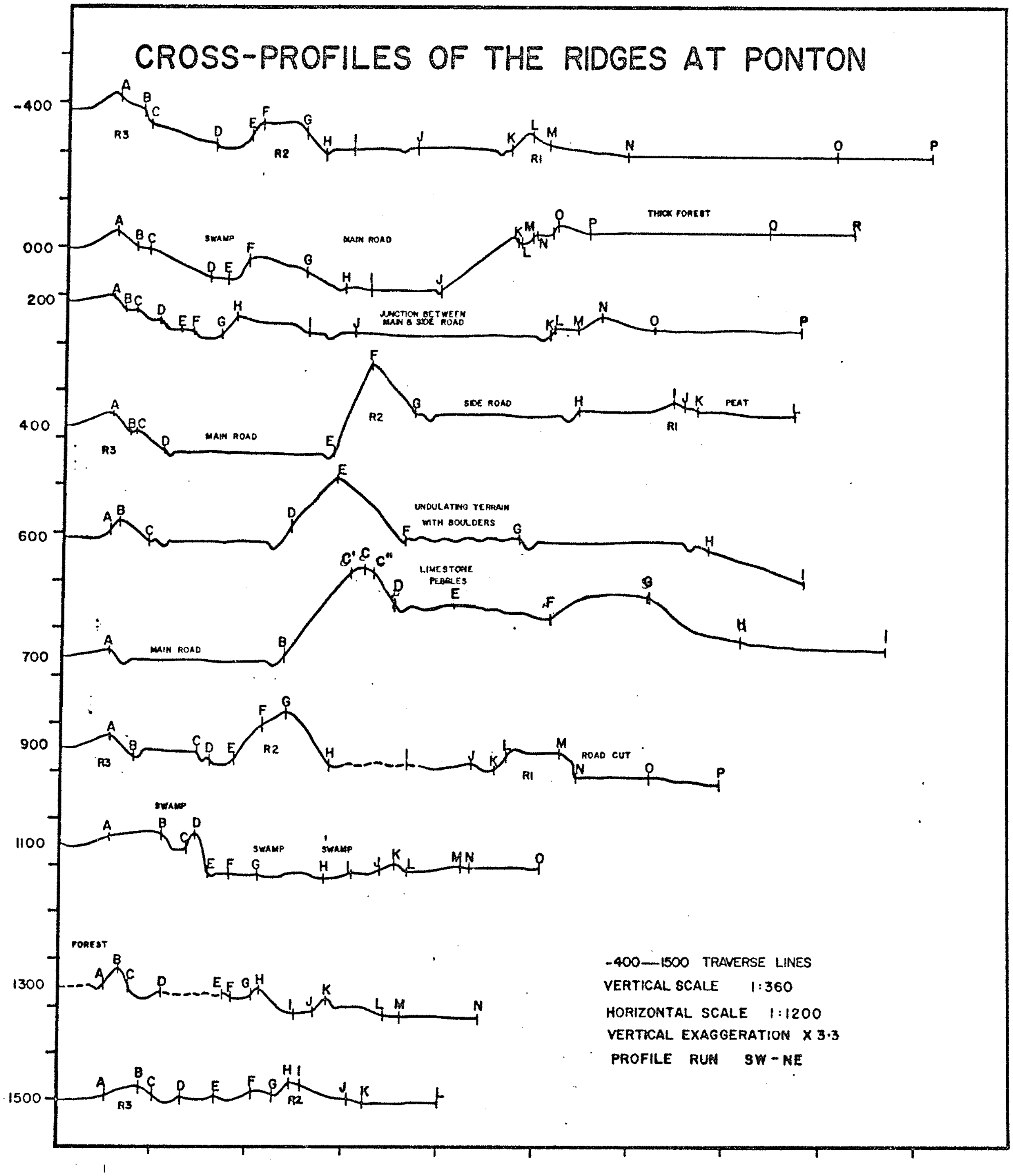

CROSS-PROFILES OF THE RIDGES AT PONTON
-400
000
200
400
600
700
900
1100
1300
1500
R3
R2
R1
SWAMP
MAIN ROAD
THICK FOREST
JUNCTION BETWEEN MAIN & SIDE ROAD
SIDE ROAD
PEAT
UNDULATING TERRAIN WITH BOULDERS
LIMESTONE PEBBLES
ROAD CUT
FOREST
-400—1500 TRAVERSE LINES
VERTICAL SCALE 1:360
HORIZONTAL SCALE 1:1200
VERTICAL EXAGGERATION X 3·3
PROFILE RUN SW-NE

Fig. 2-11

Table 5

Height and Width Data (Ponton)

	Section Number	Heights (absolute)			Traverse #S	Width of ridge	Width between ridges
		SW	C	NE			
Ridge 1	-400	822	827	824	K - M	42	(399)
	000	806	832	824	K - R	199	(287)
	200	821	827	823	K - O	114	(254)
	400	828	830	828	H - K	129	(216)
	600						
	700	837	843	830	F - I	197	(97)
	900	838	839	833	K - N	85	(79)
	1100	829	833	830	J - L	17	(140)
	1300	832	836	832	J - K	13	(156)
	1500	835	839	834	K - I	30	(141)
Ridge 2	-400	822	828	820	E - H	77	(196)
	000	810	814	806	F - I	108	(100)
	200	820	826	821	S - I	91	(250)
	400	814	842	827	E - S	71	(172)
	600	839	853	834	D - F	117	(320)
	700	825	851	839	B - D	133	(180)
	900	836	851	835	E - H	98	(142)
	1100	841	843	829	C - D	20	(178)
	1300	837	839	832			
	1500						
Ridge 3	-400	831	838	832	A - D	100	(39)
	000	820	823	810	A - D	89	(18)
	200	830	831	820	A - F	91	(30)
	400	822	825	814	A - D	59	(179)
	600	837	839	833	A - C	42	(152)
	700		825				
	900	841	843	837	A - B	24	(90)
	1100	841	842	841	A - B	52	(26)
	1300	840	844	838	A - C	25	(36)
	1500	835	837	833	A - C	51	(142)

Table 5a

Wilcoxon Matched Pairs Signed Ranks Test (Ponton)

		Slope Angles SW	NE	di	Rank
Ridge 1	-400	12	2	+10	
	000	18	2	+16	
	200	11	4	+7	
	400	17	7	+10	
	600				
	700	11	9	+2	
	900	13	1	+12	
	1100	16	8	+8	
	1300	18	4	+14	
	1500	10	5	+5	
Ridge 2	-400	21	20	+1	+2
	000	21	6	+15	+7
	200	22	4	+18	+8
	400	20	19	+1	+2
	600	17	15	+2	+4
	700	20	25	-5	-5.5
	900	15	20	-5	-5.5
	1100	7	6	+1	+2
	1300				
	1500				
Ridge 3	-400	10	13	-3	-3.5
	000	6	7	-1	-1.5
	200	3	14	-11	-7.5
	400	3	14	-11	-7.5
	600	8	12	-4	-5
	700				
	900	10	13	-3	-3.5
	1100	3	2	+1	+1.5
	1300	16	27	-11	-7.5
	1500	4	15	-11	-7.5

extremely low correlation coefficients. Therefore there is no resemblance to the dune plots of S. L. Hastenrath (1967).

6. A slope orientation study. As an extension of the slope angle data which is found in Table 5A, determinations were made to check the relative steepness of slopes in relation to their orientation. The ridges at Ponton are very slightly sinuous in form, trending from northwest to southeast. The relative steepness of each slope is shown in Section 4. The average slope angles on each side of the ridge are again taken as this may reflect differences in weathering and/or erosional and depositional agents, active on either face. The average angle for the SW facing slope of R1 is 4.67 degrees; the NE slope is 14.0 degrees. On R2 the average angle for the SW facing slope is 14.38 degrees and for the NE slope 17.88 degrees. For R3 the average SW facing angle is 5.1 degrees and the NE angle, 13 degrees. Because of the linearity of the ridges, the orientation of the cross-profiles is not here considered.

In general, there is no apparent uniformity throughout the three ridges other than the fact that R1 and R3 face inwards towards the center, (R2), and are steeper on the inward facing slopes, while the center ridge (R2) has equal slopes.

C. A Comparative Analytical Study of the Ridge Morphology at Ste. Anne and Ponton in Relation to Similar Ridges Described in Past Literature

A comparison of the data which has been presented in the previous section with some similar ridge-like forms described elsewhere will now be attempted.

1. A comparison with drumlins, eskers and kames. In the review of the literature of Pleistocene ridge-like forms in Section A2, drumlins, eskers and kames were included. The drumlin form, according to R. J. Chorley (1959) and B. Reed, C. J. Galvin and J. P. Miller (1962) is inherently ellipsoidal and therefore does not resemble the elongated narrow morphology of either the Ste. Anne or Ponton ridges. Linear drumlins are found in the work of R. W. Lemke (1958). Hence drumlins may not be recognized solely on the basis of morphology and, in terms of the past literature, the ridges at Ste. Anne and Ponton may be identified as drumlinoidal forms, or parallel drumlinoid flutings.

Because of their long and narrow form the ridges may be considered to resemble eskers. Eskers may be sinuous or straight, narrow ridges. According to C. Embleton and C. A. M. King (1968) the slopes are steep, although gentle 5-10 degree modified slopes may occur, often approximating the angle of the rest of the material (p. 369). The diagrammatic form of an esker at Reflection Lake, Baffin Island, is shown in Fig. 2-12, and detailed slope angles are given in Table 6. Not all the slope profiles are here reproduced because of irregularities on the diagram. The Wilcoxon Matched Pairs Signed Ranks Test is also shown in Table 6. On the esker shown, there was found to be no significant difference between the east and west facing slopes. The same test was used on the Ste. Anne slope profile data in Section B4(a). Here the west facing slope was found to be significantly steeper than the east facing slope at the .05 level. When applied to the ridges at Ponton (Section B4 (b)), the test showed that the southwest facing slope of R1 is significantly steeper as is the northeast facing slope of R3. This is again at the .05 level. The central ridge, R2, demonstrates no significant difference between northeast and southwest facing slopes.

Although this test is inconclusive in so far as only one example has been taken, the following hypothetical conclusions might be drawn:

a. The ridges at Ste. Anne and R1, R3 of Ponton do not resemble eskers morphologically because of their inequality of slopes.

b. Because of the strong similarity of slope gradients on both flanks of R2, it more resembles an esker than does either R1 or R3.

There is not sufficient comparable data on kames to test the resemblance of the Ste. Anne and Ponton ridges with these features. However, this origin should not be discounted completely since a superficial likeness (linearity and sinuosity) may be seen.

2. <u>A comparison with morainic forms</u>. The moraines studied by J. T. Andrews and B. B. Smithson (1966) are asymmetrical in cross-section, with a steep distal slope averaging 34 degrees and a gentler proximal slope averaging between 18 and 24 degrees. They vary from 1-20 meters above the adjacent swales. The moraines are spaced at intervals of about 50 m. Their form varies from being simple, linear, hooked or S-shaped. This detail, and the diagram given (2-12) leads to the following tentative conclusions:

a. The inequality of opposite slopes is similarly a feature of the Ste. Anne ridge, as it is of ridges 1 and 3 at Ponton.

b. The average slope angles of the moraines are considerably higher than those measured at Ste. Anne and Ponton. The closest approximation of slope angles is R2, which also has equal opposite slopes.

Table 6

Wilcoxon Test on Esker Profiles (Reflection Lake, Baffin Island p. 380) after C. Embleton and C. A. M. King (1968)

#	L	R	di	Rank
1	44	36	-8	-11
2	54	36	-18	-16
3	49	48	-1	-1.5
4	50	42	-8	-11
5	55	50	-5	-8.75
6	50	55	-5	-8.75
8	50	55	-5	-8.75
9	43	20	-23	-17
11	50	40	-10	-13.5
13	50	40	-10	-13.5
14	50	48	-2	-3.
16	40	55	-15	-15
17	45	50	-5	-8.75
21	45	41	-4	-4
22	43	42	-1	-1.5
23	42	47	-5	-8.75
24	28	20	-8	-11

L = left side of ridge
R = right side of ridge

The Null Hypothesis:

Ho: The slopes on the left (L) of the diagram are equal to those on the right (R)

Hi: There is inequality of slopes between L and R.

Significance level:

Let = .05
N = the number of pairs
T = the sum of the least values

T = 50
N = 17

∴ accept the Null Hypothesis

c. The height above adjacent swales is considerably higher in moraines.

d. There are overall similarities in form. The simple linear form resembles that of the ridges at Ponton. The S-shaped form is not dissimilar from the ridge at Ste. Anne.

Therefore, as a result of morphological interpretation from an aerial photograph survey, the ridges at Ste. Anne and Ponton might conceivably be identified as moraines. More detailed observations could indicate that they were unlikely to be morainic.

3. A comparison with aeolian features. The similarity of the ridges to aeolian features is now considered. The transverse dunes described by E. D. McKee (1965) are long, parallel ridges which tend to be straight crested for as long as 800 feet. The Fig. 7 of E. D. McKee (p. 22-24) reveals their inequality of opposite slopes. Their maximum height is 40 ft. and width is 400 ft.

The height and width of the transverse dune is considerably larger than the ridges found at Ste. Anne and Ponton. The inequality of opposite slopes resembles the ridge at Ste. Anne and R1 and R3 at Ponton. R3, in parts, has a similar height with a narrower width, but its opposite slopes are equal. R2 is also very unevenly crested, with a considerable variation in height with distance. Therefore, on morphological grounds, the ridges do not resemble transverse dunes similar to the ones described by McKee.

Further aeolian features (barchans) have been described by S. L. Hastenrath (1967). The dunes themselves have no morphological resemblance to the supposed beach ridges. In order to demonstrate the

Table 7

Wilcoxon Test on Beach Profiles (Chesil Beach, South England) after A. P. Carr (1969)

#	E	W	di	Rank
1	55	49	+6	+2
2	50	30	+20	+12.5
3	30	45	-15	-8.5
4	42	23	+19	+11
5	44	22	+22	+14
6	41	34	+7	+3.5
7	45	36	+9	+6
8	39	24	+15	+8.5
9	40	32	+8	+5
10	35	28	+7	+3.5
11	31	28	+3	+1
12				
13	31	20	+11	+7
14	25	8	+17	+10
15	30	10	+20	+12.5

The Null Hypothesis:

Ho: The slopes on the east side (E) of the diagram (2-2A) are equal to those shown on the west side (W).

Hi: There is inequality of slopes between E and W.

Significance level:

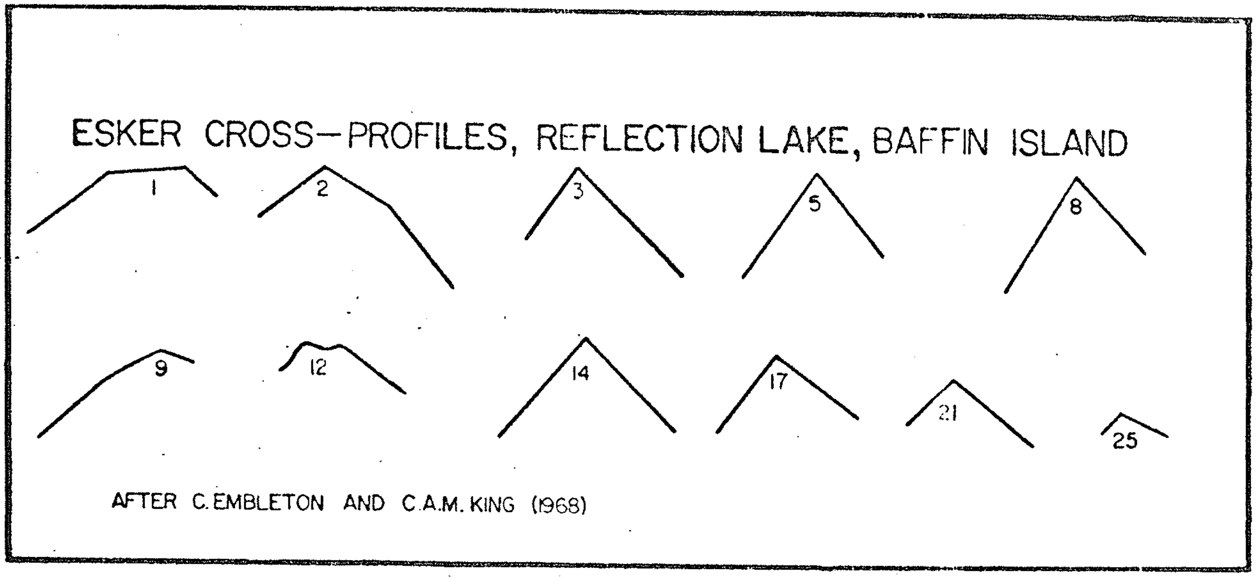
Let $\alpha = .05$
N = the number of pairs
T = the sum of the least values

T = 8.5
N = 14

∴ reject the Null Hypothesis

relationship between crest height and slope angle (Hastenrath, Fig. 9, p. 309), a plot of crest height H as a function of Sin α is used. The figure showed that the angle of the windward slope increased with increasing height. At Ste. Anne by comparison, in Section B5(a), the angle of slope is seen to increase with increasing height only 47% of the time. No positive correlation could be found in the Ponton area. Therefore it is unlikely, on morphological grounds alone, that these features were formed in an aeolian environment.

4. <u>A comparison with present shoreline forms</u>. The supposed beach ridges may also resemble, in terms of their long and cross profiles, shoreline forms existing in the present environment. Certain of these beach ridges are shown in Figs. 2-1 to 2-5. There is a notable tendency for the profiles to dip down towards the water level, forming a consistent slope from the land to the sea or lake. This is the case in the generalized profiles drawn by W. C. Krumbein (1963), W. N. Bascom (1951) and J. O. Norrman's work from Lake Vattern (Fig. 2-1). Profiles drawn by other authors show major and minor undulations. These include the beach profiles and berms drawn by W. C. Krumbein (1950) (Fig. 2-2), the generalized winter and summer profile of J. L Davies (1956), the inner and outer bar on the profile of R. Dolan and J. C. Ferm (1967), the washover fan and berm of A. O Beall's profile (1968), and finally the gravel-spit formation shown in D. J. P. Swift's work (1968) (all shown in Fig. 2-3). The formation of sub-aqueous features with inequality of slopes is demonstrated by the sequence of profiles, A - E, taken from J. S. Olson's work (1958) on the sequential development of beach and dune ridges on Lake Michigan (Fig. 2-4). Only by visual comparison can


ESKER CROSS-PROFILES, REFLECTION LAKE, BAFFIN ISLAND
1
2
3
5
8
9
12
14
17
21
25
AFTER C. EMBLETON AND C.A.M. KING (1968)

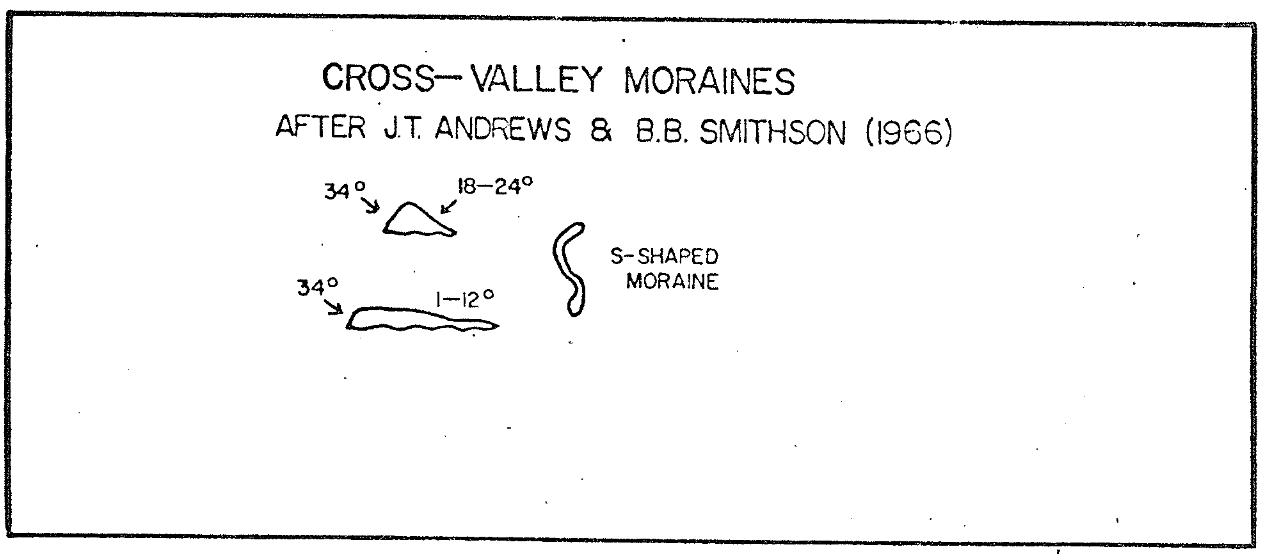

CROSS-VALLEY MORAINES
AFTER J.T. ANDREWS & B.B. SMITHSON (1966)
34°
18–24°
34°
1–12°
S-SHAPED
MORAINE

Fig. 2-12

these latter profiles be said to resemble the supposed Lake Agassiz beach ridges, and their genesis, therefore, coincident with supposed Lake Agassiz ridges.

A more detailed analysis was taken from slope studies, the work of A. P. Carr (1969) on the spit-tombolo formation known as Chesil Beach, South England. A series of profiles are shown in Fig. 2-4. The Wilcoxon Matched Pairs Signed Ranks Test showed that, at the .01 level of significance, the lagoonward facing slopes were steeper than the seaward facing ones, Table 7. This would seem to demonstrate that the steepest slope is on the landward side and therefore, reasonably sheltered from the effects of the open ocean. This spit is essentially a storm-constructed feature, the larger pebbles being those washed over during periods of storms and high waves.

The ridge at Ste. Anne shows a similar inequality of opposite slopes, although in this case, the steeper slope occurs lakewards towards the former Lake Agassiz. In Ponton one steeper slope, R1, faces landwards (towards the SW). In the case of R3 the steeper slope faces lakewards (towards the NE). Therefore the level of Lake Agassiz may have fluctuated considerably at this time before J. A. Elson's (1966) Pipun phase. The inequality of opposite slopes may indicate a washover berm or spit origin for these ridges.

Lastly, comparison may be between the supposed beach ridges and those described by N. P. Psuty (1967) in Tabasco, Mexico. Admittedly visual, there is some resemblance between the third profile there drawn (Fig. 2-5) and the ridge at Ste. Anne's cross-profiles. The steeper slope is here seaward and the gentler slope, landward.

5. <u>Tentative conclusions regarding the origin of the supposed</u>

beach ridges. Only tentative conclusions can be drawn at this juncture, because the methods of comparing the Ste. Anne and Ponton ridges with similar forms of known origin is inherently limited. When the aspect of morphology alone is considered, a number of different origins may be seen to be equally applicable to the ridges under study.

a. Visual similarities indicate that the Ste. Anne and Ponton ridges may be kames or drumlinoid figures.

b. The results of the Wilcoxon Test, comparing the ridges with eskers at Baffin Island (Table 6), suggests that they are not eskers.

c. Dimensions and visual similarities suggest a resemblance of the ridges to the moraine forms of J. T. Andrews and B. B. Smithson (1966), shown in Fig. 2-12.

d. Dimensions and visual similarities, in the case of the work of S. L. Hastenrath (1967) and E. D. McKee respectively, suggest that the ridges were not formed in an aeolian environment.

e. Comparison to the various cross-profiles (Figs. 2-1, 2-5) suggests that the ridges may have been formed as a beach. The Wilcoxon Test for Chesil Beach (Table 7) indicates that, because of inequalities of slope, the ridge may be a spit-tombolo feature, with a subsequent storm ridge formation. The lagoonward slopes are steeper than the seaward slopes. In the case of Ste. Anne, if the ridge is a bar, the active (lakeward) side would be, by analogy, the eastern side as this has the gentler slope, the lagoonward side being the steeper west facing slope. This is contrary to the idea of a Lake Agassiz to the west of Ste. Anne. At. Ponton, R1 has a steep SW facing slope; the gentler NE facing one, if analogous to Chesil Beach, represents the lakeward side of the bar. The SW side of R3 would be the lakeward side of this bar.

Therefore, on the basis of morphological evidence, the supposed beach ridges at Ste. Anne and Ponton may owe their genesis to processes similar to those forming kames, drumlinoid features, morainic forms, beach ridges or spit-tombolo formations or storm beaches. It is impossible to determine the true origin of the features on the basis of morphology alone.

Chapter 3

MACROSCOPIC ELEMENTS OF SEDIMENTARY ANALYSIS

Because of the apparent lack of sensitivity of morphological analysis in determining the origin of the ridges at Ste. Anne and Ponton, depositional elements of the latter are now considered to see if any of the tentative conclusions found in Chapter 2 may be validated, or if any new conclusions can be made.

Chapter 3 is divided into the following sections:

A. A Description of the Stratigraphy.

B. An Evaluation of Sphericity Data.

C. An Evaluation of Roundness Data.

D. An Evaluation of Orientation Data.

Section A. A Description of the Stratigraphy

The description of the sedimentary sequences involves a number of different aspects of the entire sedimentology of the present work. The sampling points have been discussed in Chapter 2, with reference to the morphology. The rationale behind the selection of both the horizontal and vertical sampling patterns is now discussed. The samples taken from pits dug at these points in the horizontal sampling grid are relevant not only to the description of the sedimentary sequence which was found in the various pits, but also as a data basis for the sphericity, roundness and orientation studies (Chapter 3) and for the textural analysis and heavy mineral content (Chapter 4).

The description consists of the following sub-sections:

1. The horizontal sampling net
2. The stratigraphy.
3. Tentative conclusions.

1. <u>The horizontal sampling net</u>. Because of the unknown origin of the ridges, the application of a horizontal sampling net presented problems. Variations in sediment types across the ridges (E - W at Ste. Anne and NE - SW at Ponton) had to be included, as well as variations along them. This type of sampling in the literature is mainly found in connection with shoreline sampling patterns. W. N. Bascom (1951), in his work on the Pacific Coast of the U.S.A., chose to consider some 500 profiles, which mainly extended in straight line traverses from the dune line to minus 30 ft. below sea level. One of the most comprehensive works on beach sampling methods was written by W. C. Krumbein and H. A. Slack (1956). The principal objective of the sampling methods described by these authors was to ascertain depositional changes across and along the beach. One method of fulfilling this is by determining the various beach zones and designing the sampling net to coincide with these. The beach zones which the authors described consist of the following:

a. the nearshore bottom
b. the foreshore
c. the backshore
d. the dune belt.

It is possible that, if the Ste. Anne or Ponton ridges were beach ridges, some or all of these environments of deposition would be represented.

Krumbein and Slack have described varieties of spacing based on a practical compromise between cost and a desired degree of reliability. This could only be done on a quantitative basis after the variation of deposits in each beach zone was known. Eight sampling plans were tried:

a. simple random samples

b. random in cells

c. systematic in cells

d. clusters of four

e. three level design

f. stratified random

g. three strata (combined samples)

h. purposive selection.

Particle size data were collected in each and the "relative efficiency" of each was formulated. The use of particular sampling grids varies according to the purpose for which the sample is being taken. In the case of Ste. Anne and Ponton, the principal objective was to ascertain the variability of deposits along and across the ridge. Therefore some form of random sampling is desirable. Stratified random sampling, which has a high "relative efficiency", could not be accomplished because of the lack of prior knowledge of the depositional environments of so-called Pleistocene beach ridges.

A similar procedure has been described by E. W. Biederman (1962) to find a meaningful distinction between shoreline environments in New Jersey, U.S.A. Randomness was introduced by dividing the environment zones into equidimensional blocks, then choosing certain blocks for sampling by using Random Number Tables.

Other studies on the sampling of variable beach deposits include the work of R. N. Ginsburg (1956) in South Florida carbonate sediments. This study was to relate variations in grain size and constituent composition to differences in environment. Two sampling methods were used:

a. The traverse method by which the samples were taken along three traverses oriented perpendicularly to the trend.

b. Grab samples were taken in a more random manner, where traverses were less appropriate.

A grid system of sampling has been used by C. C. Mason and R. L. Folk (1958) on Mustang Island, Texas. The basic pattern consists of four traverses (perpendicular to the shoreline) spaced at intervals of four miles. Stratified samples were taken within the grid, relating to the depositional environments found on the shoreline. Two traverses were also taken parallel to the shoreline, spaced 0.8 miles apart, thus making up the grid pattern. This sampling pattern is a systematized stratified system and accurately parallels topographic variation along and across the ridge.

Relatively recent work by J. R. Hails (1967) considers the sampling of Pleistocene and Holocene sediments on a barrier coast of New South Wales, Australia. Sections were taken perpendicular to the beach, extending from the low water mark, across a barrier or deltaic plain, to a degraded Pleistocene beach. A regular grid sampling pattern, perpendicular to the coastline, is used by A. P. Carr (1969). Along Chesil Beach, England, 23 sections were chosen at approximately half mile intervals. Samples were taken at beach crest, high water mark, and low water mark, and where variability in pebbles occurred.

On the basis of the literature described above, two varieties of sampling patterns are appropriate to the sampling of sediments at

Ste. Anne and Ponton:

a. the method of grid and traverse

b. stratified random sample.

An outline grid was formulated for both the Ste. Anne and Ponton ridges. At Ste. Anne, 18 cross-sectioned traverses were sampled at intervals of 660 yds. (approximately). Five samples, labelled A - E, were taken along each profile, as shown on Map 3. These were selected on the basis of morphological variation, which may reflect stratigraphic change. The variations across the ridge coincide with

a. the lake level in the west

b. environmental changes between the crest and the lake level

c. the crest

d. environmental changes between the crest and the eastern boundary

e. the eastern boundary.

In total 90 pits were dug in the Ste. Anne ridge. These varied in depth from 2-9 feet. The depth limitation was the water table, beyond which the sediments became mixed. At Ponton 10 cross-sectional traverses, averaging 200 ft. apart, were used as a sampling grid. All three Ponton ridges were sampled in the same manner. A variable number of samples was taken across each profile to coincide with supposed facies changes from the NE to SW of the ridges. Occasionally the ridges are complicated with terrace-like forms on one or both flanks. Additional samples were taken on the terraces, on a stratified basis. Samples were taken between the three ridges, since it was thought that by doing so useful supplemental evidence concerning the depositional environments may be derived.

At Ponton, 130 pits were dug, varying from 1-6 feet in depth. The depth limitation was frozen ground in the lower lying areas. All the pits were hand dug, using shovels.

2. The sediment description. From the various pits in the localities descriptions were made of the sediments, structures and depositional changes.

Once a pit was dug the procedure was as follows. The section (depth) was measured by means of a steel tape, calibrated to 0.1 ft. A description of the section was made, indicating the constituent materials and structures. Because of the orientation of the quarries on the Ste. Anne ridge, some pits were dug parallel to the long axis of the ridge, hence cross profile depositional structures were not easily determinable. Structures were noted in pits dug parallel to the transverse axis of the ridge. All significant structural and depositional changes were noted. Whereas there is considerable variety in the depositional structures in the pits dug at Ste. Anne, there is more apparent homogeneity in the Ponton pits.

The sediment descriptions from the various pits are to be found in Appendix 1 (Ste. Anne) and Appendix 2 (Ponton). The descriptive nomenclature and sediment size grades follows that outlined by R. L. Folk, (1968) p. 25, and on Table 13.

For the descriptions of the depositional sequences the ridge at Ste. Anne will be discussed first, followed by the ones at Ponton.

As is apparent from Appendix 1, the section descriptions vary considerably throughout the length of the ridge. The diagrams (figs. 3-1 to 3-6) demonstrate this variety both along and across the ridge.

Illustrations of 4 sections are shown as Plates 5, 6, 7 and 8. A number of surface horizons have been disturbed by quarrying.

Significant and recurrent aspects of the sections include certain tendencies:

a. Coarse material tends to occur towards the crest of the ridge and fine material occurs at the eastern and western limits. This is shown in Figs. 3-2 to 3-6 and Plates 5 and 6.

b. A characteristic generalized section of the ridge from ground level downwards may consist of the following: very coarse sediments, granules and pebbles occur near the surface, as is shown in Figs. 3-2 (2C), 3-3 (4C), 3-4 (10C), 3-5 (16B) and 3-6 (19C). The fact that there are 45 out of a total of 55 sections with coarse pebble or granule horizons in the top two feet of the section is highly significant. These beds tend to be unsorted in nature and contain a particle size range from sand to cobbles. Of the 45 sections in which this bed was represented, 39 were unsorted. It is possible that these beds may be classified in one particular category as regards their environment of deposition. Perhaps they were laid down by the same agency or agencies.

Below the surface strata horizons of medium to coarse sand size sediments may be distinguished. These are shown on Figs. 3-2, 3-4, 3-5 and 3-6. These beds may also comprise a significant depositional unit since examples may be found in 48 of a possible 55 sections. The beds, or individual laminae, are relatively well sorted. Either graded bedding or laminations are exhibited in 40 of the 48 beds described. These may also represent a different environment of deposition at a particular time in the depositional sequence.

Below the sands, and in certain sections only, silty-clay

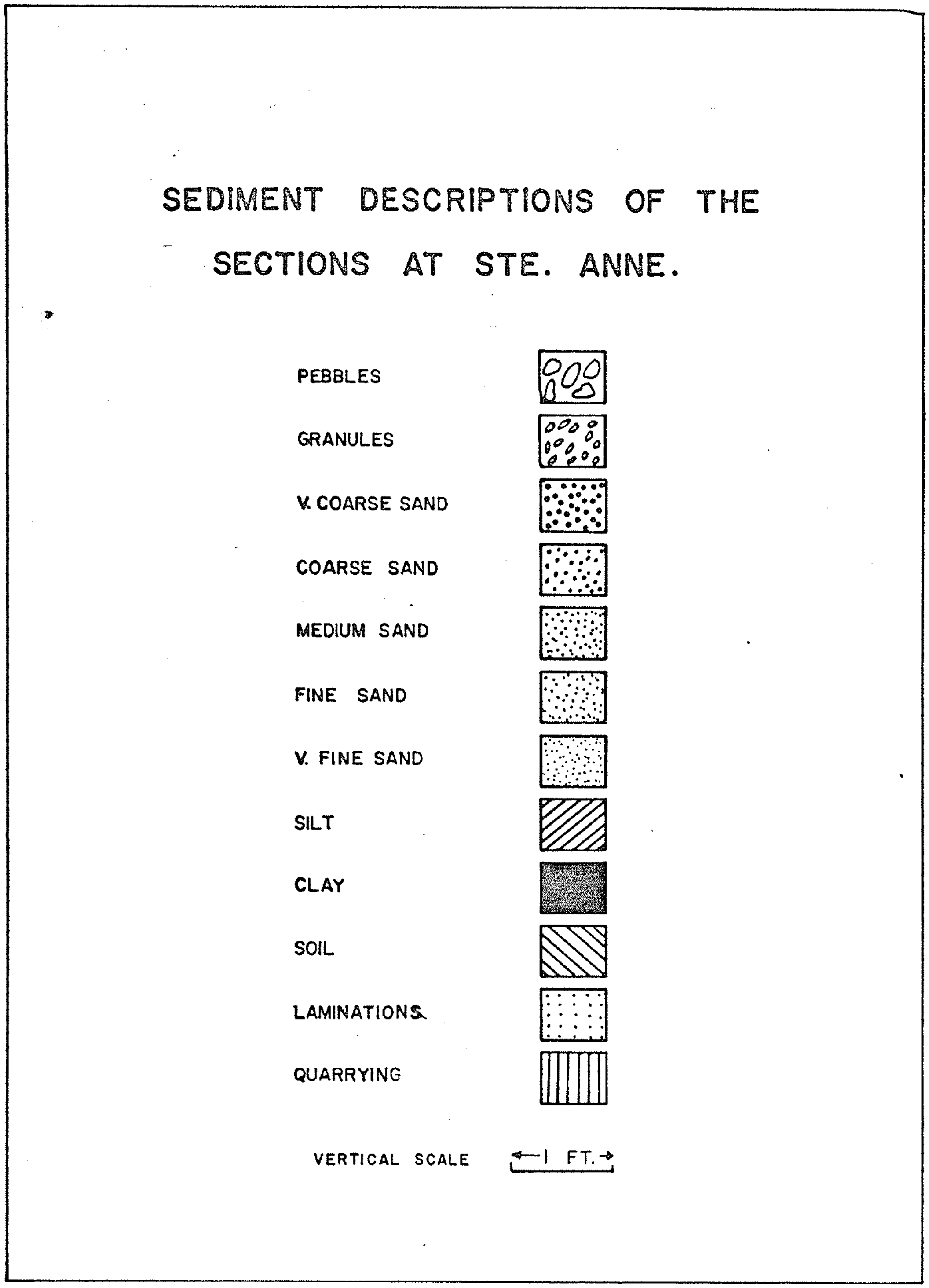

SEDIMENT DESCRIPTIONS OF THE SECTIONS AT STE. ANNE.
PEBBLES
GRANULES
V. COARSE SAND
COARSE SAND
MEDIUM SAND
FINE SAND
V. FINE SAND
SILT
CLAY
SOIL
LAMINATIONS
QUARRYING
VERTICAL SCALE
1 FT.

Fig. 3-1

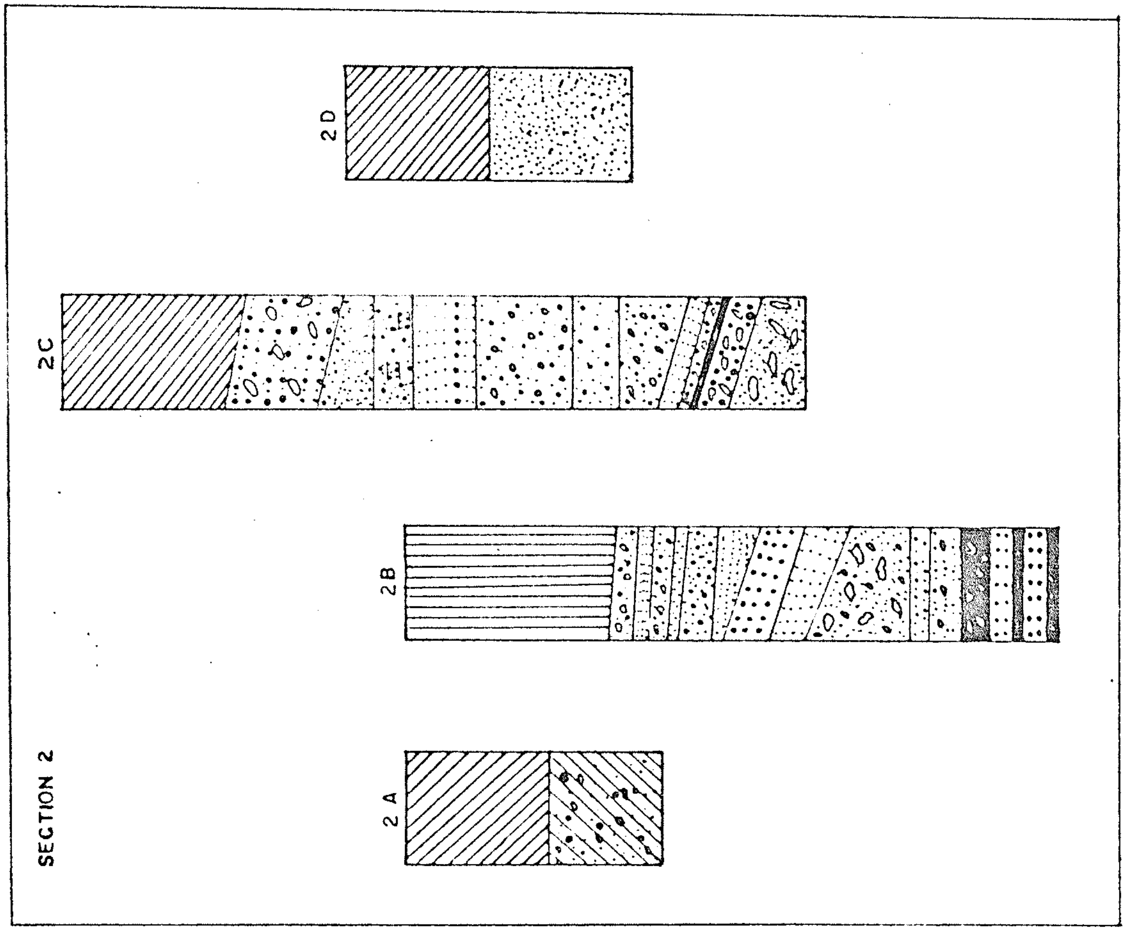


Fig. 3-2

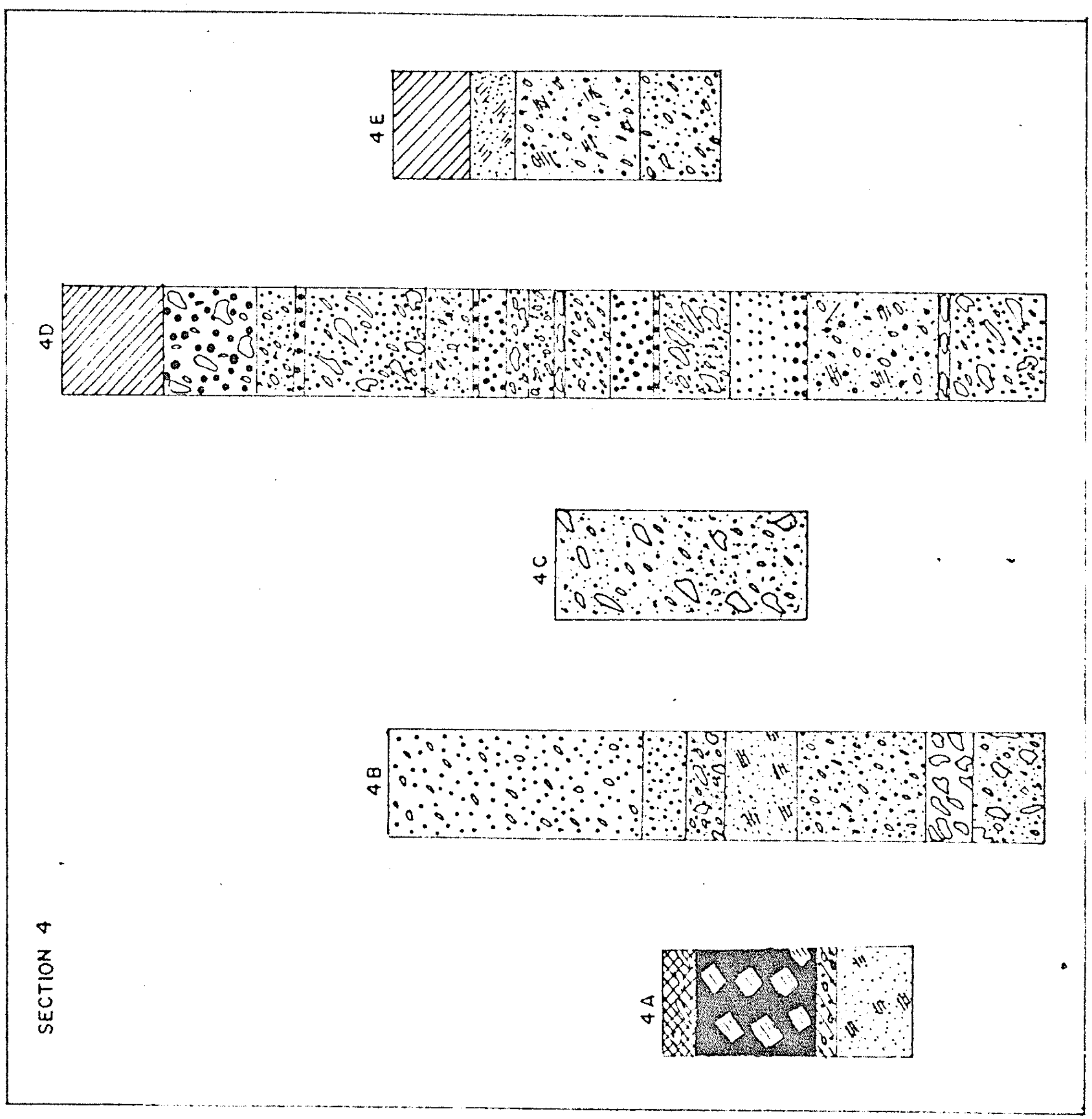


Fig. 3-3

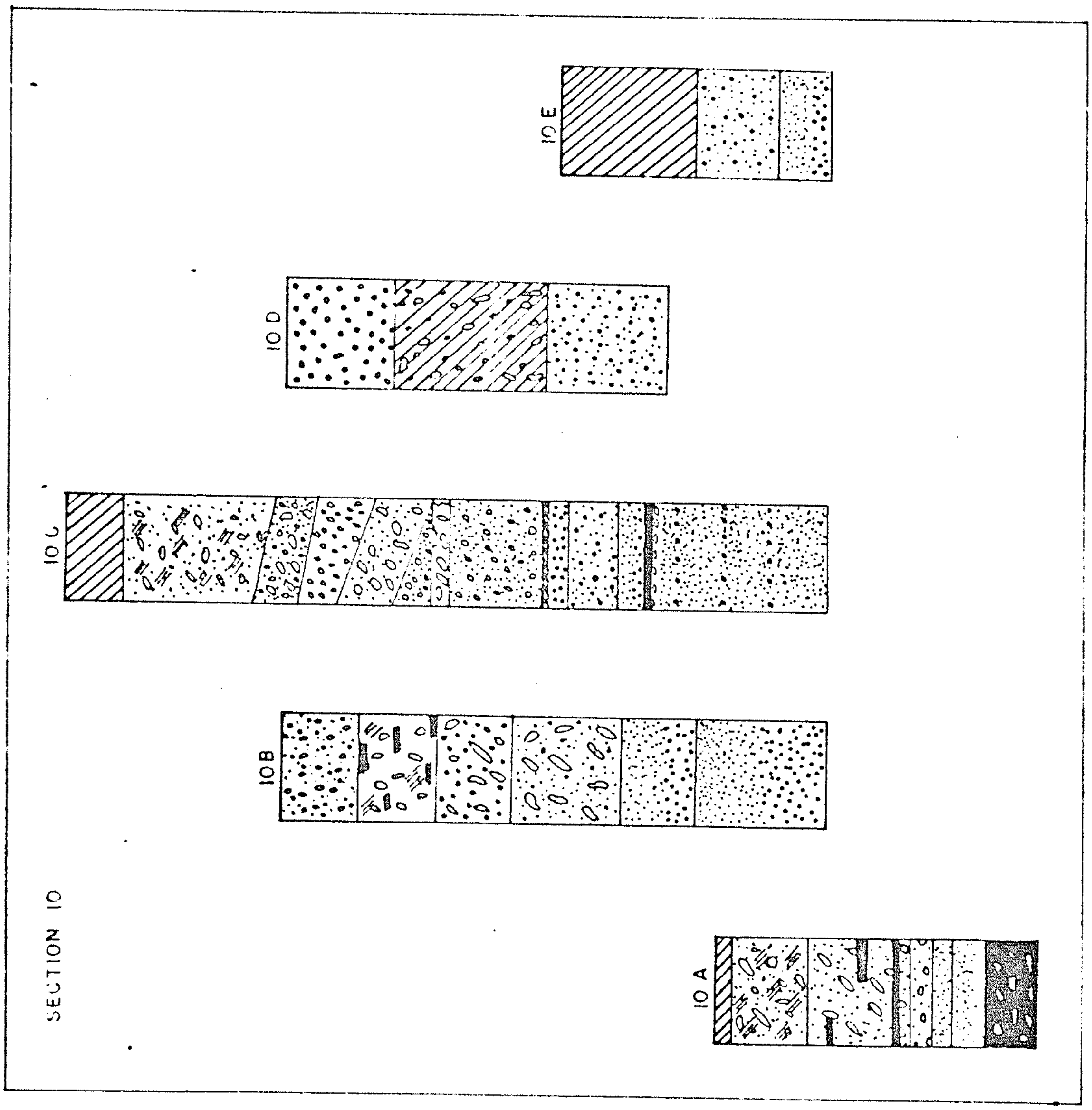


Fig. 3-4

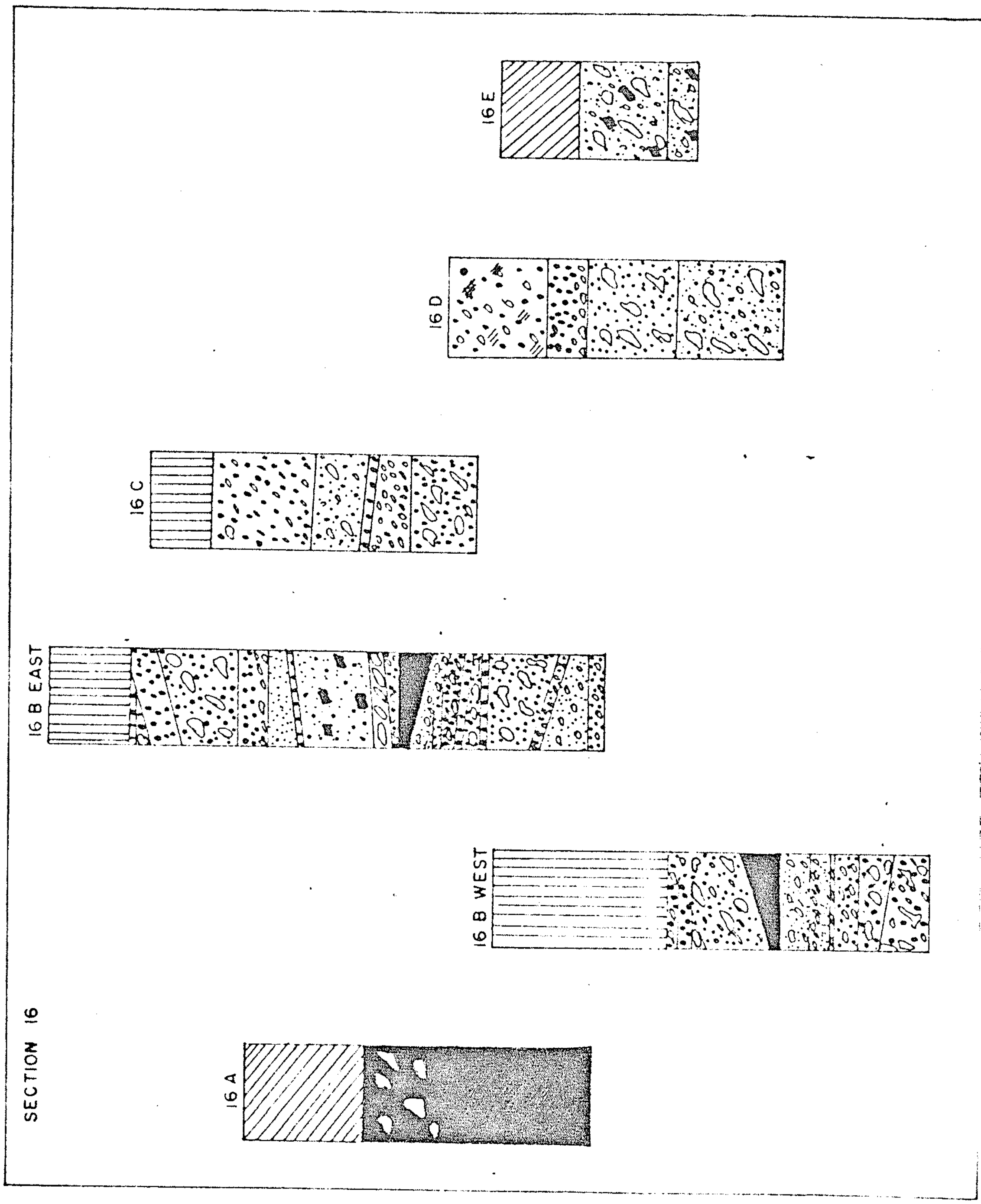


Fig. 3-5

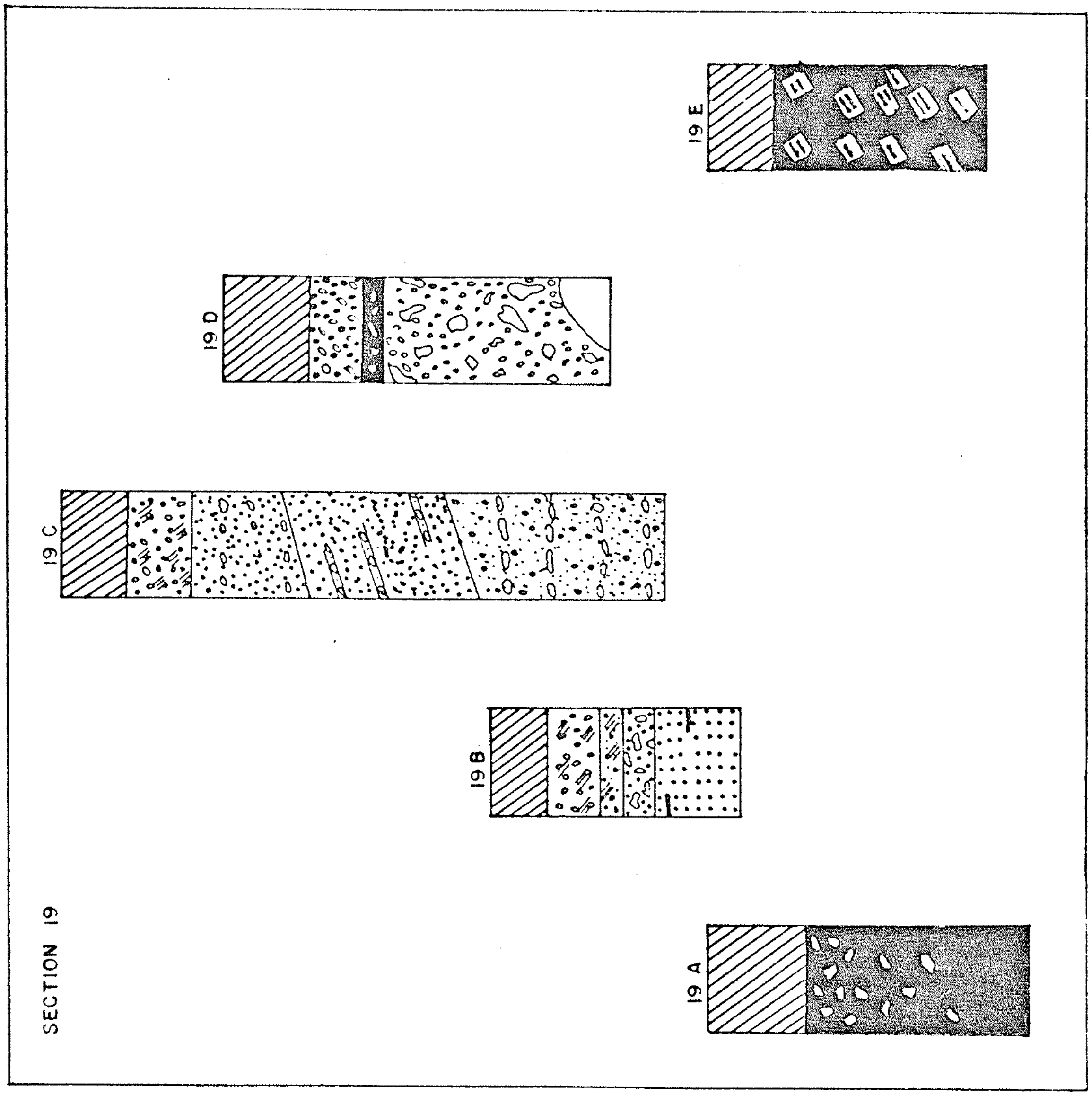
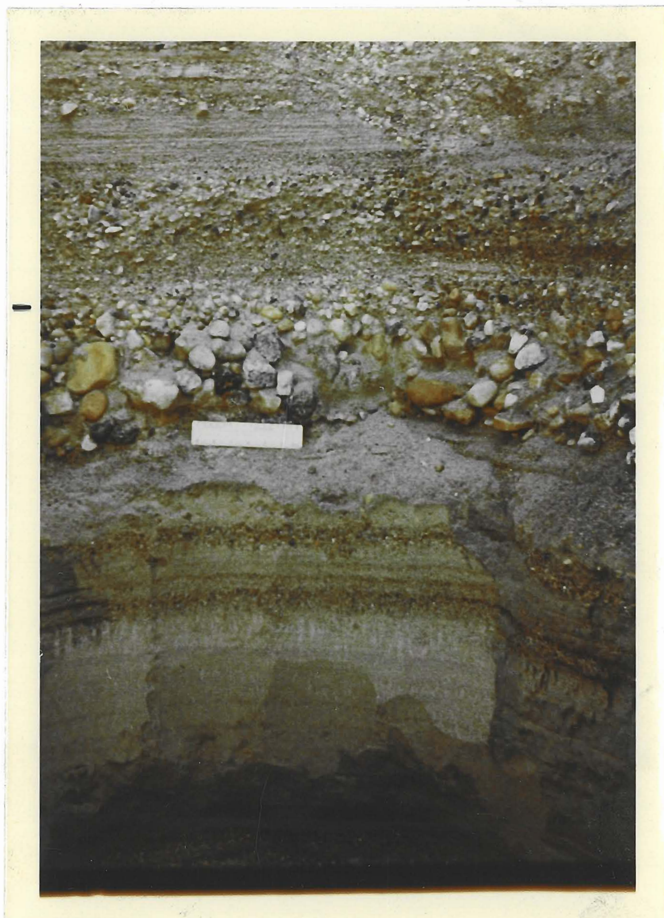


Fig. 3-6

Plate 5



Section 2C

Plate 6

Section 4D

sediments are observed. These are shown on Figs. 3-2 and 3-3. These deposits only occur in 15 out of a possible 55 sections. At the base of some sections very coarse sediments, including quantities of pebbles, are occasionally found. Examples are seen in Figs. 3-2 (2B), 3-4 (10C), 3-5 (10B) and 3-6 (19D). These deposits are only found at the base of 25 out of a possible 55 sections.

c. The majority of the beds display grading, sorting and laminations (especially in the B, C, D sections). Evidence of this may be seen in all the Figures 3-2 to 3-6. The very unsorted beds tend to occur at the top and base of each section.

d. A number of the coarser beds towards the top of the section are inclined in an east - west plane. This high angle (in some cases) stratification is therefore seen to dip both landward and lakeward. Examples are shown in the B, C, and D sections of Figures 3-2 to 3-6.

e. Silt and clay horizons predominate in the A and E sections, or on the periphery of the ridge. Different combinations of silt and clay occur in 25 of the 36 possible locations. To the south of the ridge, silt, silty-clay or clay with pebbles are found in the A sections. Towards the center of the ridge, clean grey and white clays, silty-clays and boulder-clays are found in the A section, with variable sand, silty-clays and pebbles in the E section. Towards the north of the ridge, silty sand with clay and pebbles occur at the A points, with silty-sands, silty-clays, clays and silts found at E.

Generally speaking, boulder-clays (clays and pebbles) are more prevalent on the west side (lakeward) than on the east side (landward) of the ridge. The relatively homogeneous silt or clay beds found on the west side are presumably reworked boulder-clay, deposited by some agency, possibly water sorting. Their texture and color is similar to that found in a lacustrine environment.

Following the above descriptions (a to e) certain tentative deductions may be drawn. Further evidence concerning environments of deposition awaits the textural analysis of the sedimentation unit samples (Chapter 4).

It is possible that some indication as to the origin of the ridge may be deduced by comparing the stratigraphy with that found in features of known origins. Morainic deposits and drumlins generally consist of boulder-clay deposits and these are found on the periphery of the ridge. Therefore, although the ridge itself, based on the stratigraphy, is not a moraine, it appears to be (as R. A. McPherson, 1970, suggested) some ridge-like form superimposed on a moraine.

The ridge may be an esker or fluvial deposit. A fluvioglacial deposit is by definition stratified, due to the differential flow of meltwater streams. Such deposits contain abundant sand and gravel. The eskers described by C. Embleton and C. A. M. King (1968) are bedded and dip at 10-20 degrees or more. Normally the beds dip outward from the axis of the esker, their gradients occasionally paralleling the lateral slopes. Additional sedimentary features (G. Hoppe, 1961) include the occasional presence of silt in the esker or on its surface heaps of boulders may be found. Variability of deposits is also a marked feature. For instance, there are depositional changes from fine sand to coarse gravel within an esker. Embleton and King (p. 375) maintain that "there appears to be relatively little connection between their internal structure and their external form". Certain structural variations have been described by F. M. Synge (1950) with respect to eskers in Antrim. In outline these features include apparently horizontally bedded sand and gravel, arch-bedding, unsorted washed gravels, with erratics and delicate deltaic bedding, with bands of lacustrine clay. Bedding is graded or reverse graded.

Assuming an esker to be a water-laid deposit, there should be depositional correspondence between present day fluvial sediments and some of those found at Ste. Anne. According to L. B. Leopold, H. G. Wolman and J. P. Miller (1964) there is a decrease in the velocity of flow towards the bed and banks of a stream. The maximum velocity occurs near the stream's center line. There is a lack of information appertaining to the character of materials comprising the river bed and banks for a given discharge. According to the authors last quoted, the Einstein bed load function demonstrates the dependence of sediment transport rate on sheer stress and particle size. With a decreasing rate of transport (discharge) there is a decrease in sediment concentration.

Assuming the ridge to be a fluvioglacial deposit, the coarse material towards the center of the ridge may have been the lag deposit of a glacial stream, when the coarser size grades could not be carried by the velocity of flow.

Therefore the Ste. Anne ridge may be an esker because of:

a. bedded sands and gravels

b. dipping or arch-bedded deposits

c. the occasional presence of silt

d. the occasional presence of boulders

e. internal variation of deposits

f. deltaic bedding, with bands of clay, and the graded or reverse graded deposits

g. the transition from coarse to fine deposits in keeping with present day observations of streams.

It is possible that the ridge may be an aeolian deposit, since it is long and sinuous. In his work in the White Sands National Monument E. D. McKee (1966) examined vertical trench sections cut through 4 different types of dune. The transverse dune is made up of medium sand, with good sorting, and has steeply (20-30 degrees) dipping laminae in its lower part. The upper part consists of thin, gently dipping to horizontal beds, with moderately dipping cross-strata. Wavy or contorted laminae also occur. Despite certain similarities (for instance, the sand content at Ste. Anne) it cannot be described as a dune because

a. There is a lack of current bedding at Ste. Anne.

b. Sand size particles only make up about half the sections.

c. The laminae, and certain other beds, show a greater tendency towards horizontality.

d. A major constituent is medium to coarse size sand.

A third possibility is that the ridge could be a shore-like form. The forms of shorelines have been indicated in earlier diagrams. W. C. Krumbein (1950) has defined certain beach areas where different sedimentation processes occur. The foreshore extends from the low water line to the crest of the berm (Fig. 2-2). The crest of the berm is the limit of normal uprush of waves. The backshore extends from the crest of the berm to the landward limit of the beach. The slope of the foreshore ranges from flat to steep, according to prevalent energy characteristics. The backshore consists of sand which has been shifted about by blowing winds. The foreshore represents a zone of active hydraulic force (W. C. Krumbein, 1963) between the berm and the plunge point where waves break, and is subjected to a succession of highly turbulent waves which wash the foreshore before their water returns downslope as backwash. The effect of this motion is to sort out and arrange the foreshore material selectively according to its particle size, shape and density. Because of the dependence of the beach properties on the process elements, a beach as such is difficult to define in nature. So much depends on the height, period and steepness of waves and currents in terms of direction and velocity (W. C. Krumbein, 1961).

In his work on the sediments of Trout Lake, Wisconsin, V. G. McKelvey (1940) similarily recognized different zones of beach deposits. Eight textural zones, parallel to the shoreline, were recognized:

a. washed cliff, consisting of pebbles

b. backshore of medium to fine sand with occasional pebbles and cobbles derived from ice ramparts

c. swash-line, containing pebble concentrations, sticks, twigs and shells; pebbles rolled up on the beach by heavy waves, finer material removed by backwash.

d. foreshore of well sorted, coarse - medium sand

e. plunge-line of very coarse sand

f. cobble-line of well washed cobbles, covered partially by medium sand (first breaking point for waves)

g. a well rippled medium to fine sand zone which forms a veneer over cobbles.

h. a zone of dirty sand and plant covered cobbles, apparently free from wave action.

A feature which is characteristic of deposition under differential flow rates is the graded bedding found in the sections. This may be ascribed to the

a. varying backwash and swash action on the foreshore

b. varying aeolian activity in the backshore.

If this deposit was to occur beyond or below the reach of wave action, it could be formed as a result of turbidity currents (P. H. Kuenen and H. W. Menard, 1952).

Beach laminations have been described by K. O. Emery and R. E. Stephenson (1950). They found laminae in beach samples from Bikini Atoll, Mono Lake and a beach near Newport, California. Laminae were present in fine and coarse sand, the coarser sand having thicker laminae. All the sands were well sorted.

A further important aspect of beach formation is the high angle stratification which was observed by J. M. Hoyt (1962) in the Sapelo Islands, Georgia. Here the foreshore sand bars were reported to have a steep landward slope. Deposition on this slope resulted in the landward movement of the bar, such that the slopes were as high as 30° on the seaward side.

The beach ridge at Ste. Anne contains certain features which accompany modern marine shoreline developments:

a. There is a distinct decrease in sediment size lakeward, which corresponds to a decrease seaward in modern shorelines.

b. At Ste. Anne certain stratigraphic units may be recognized. They may be assigned tentatively to shoreline units.

i. The coarse unsorted dipping material at top may be a washover, berm deposit.

ii. The medium and fine sands may be a backshore or foreshore deposit.

iii. The relatively fine silt and clay may be lacustrine incursions.

iv. Coarse, unsorted material at depth may be parent materials.

c. Laminations, sorting and grading are characteristic features of modern day ridges and of Ste. Anne ridge.

d. At Ste. Anne there are a number of examples of high and low angle stratification, which are shown in the Figs. 3-2 to 3-6. A number of these dip lakeward and therefore may be relict foreshore deposits. Others (the majority) dip landwards. The latter resemble the structures found in Hoyt's foreshore sand bars and Psuty's beach ridges in Tabasco.

The last alternative is the realization that the beach ridge resembles a spit or bar. In this case, certain characteristics of the shoreline sedimentation zones would also be recognized, plus additional peculiar features.

Aspects of the geomorphology of beach ridges have been described by N. P. Psuty (1967). The Tabascan beach ridges occur on part of a deltaic plain. Here, because of active distributory discharge, there is local progradation and a series of beach ridges have built up. By some means there must be sufficient sediment to produce the progradation and to result in its accumulation in the form of a ridge. Psuty describes the norte winds as the agency involved. After a norte season of storm waves a berm was analyzed and seen to display near-surface stratification, which is either horizontal or dips slightly inland. The sediments are also stratified below the berm crest. According to Psuty the steepest dip represents the storm foreshore. When the storm abates the dip is seen to occur at slightly lower inclinations. Some of the beach laminae at Tabasco sloped seawards at less than 10°. Some groupings were horizontal or landward dipping at a lower inclination. Below the berm stratifications the laminations have slopes of less than 5°. There is a 3 fold division of laminae, reminiscent of deltaic sedimentation. This type of stratification is shown on Fig. 2-5.

On present day beaches, examined by Psuty, the landward dipping foreset laminae were seen to develop by water washing over a ridge. This type of deposit, characteristic of a marine bar or spit, is the same as that of a foreshore zone. On the bayward side of an offshore bar or spit it resembles a backshore beach. This consists of short, steeply inclined foreset laminae, dipping bayward interstatified with layers of long gently inclined topset laminae, which also dip bayward.

An analysis of graded coarser materials towards the surface of a spit-tombolo formation is found in the work done by A. P. Carr on Chesil Beach, England. Here coarse material on, or immediately behind, the beach crest is thought to be "stranded" during longshore transport under severe storm conditions. No evidence of stratification is given.

Therefore, in addition to the features mentioned above, the ridge at Ste. Anne may be a former

a. beach ridge on a prograding coast

b. spit or offshore bar, with high angle stratification, both landward and lakeward, with coarse washover (berm) deposits at its crest.

Despite the apparent simplicity of the deposits, the stratigraphies of the Ponton area are of considerable geomorphic complexity. A description of the stratigraphy is found in Appendix 2. Therefore an explanation of the features described above in terms of present day environments of deposition is extremely problematical. Certain tentative points can be made, but no definite conclusions, concerning:

a. the depositional environment(s) of the clays

b. the depositional environment(s) of the sands and gravels

c. the problems of modification in a periglacial environment

d. alternative specialized environments of deposition.

Environments of deposition for the clay deposits may have occurred at two stages. The original source material following the presumed glacial retreat is boulder-clay. This has been extensively reworked throughout the entire Grass River basin of sedimentation (J. A. Elson, 1966, p. 59). This basin has been quoted by Elson as being the last area of lake formation, immediately prior to the drainage of Lake Agassiz via the Nelson River. Therefore it is possible that the clays at Ponton are lake bottom deposits.

The sediments of the Ponton ridges are illustrated by Figs. 3-7 to 3-11 and Plates 7 and 8. Although the individual sections show a degree of homogeneity, variation can be seen across the traverses (A - M) and between the different traverses (-400 to 1500). A number of generalizations can be made from the sections.

a. The ridges are made up of medium to fine sand with a well marked grey (podsolized) horizon. This is shown in Figs. 3-8 (A), (FG), (LM), 3-19 (M), 3-11 (H). Silty sand occurs off the main ridges in 3-9 (C), (K) and 3-10 (K).

b. The inter-ridge areas are made up of clay with occasional

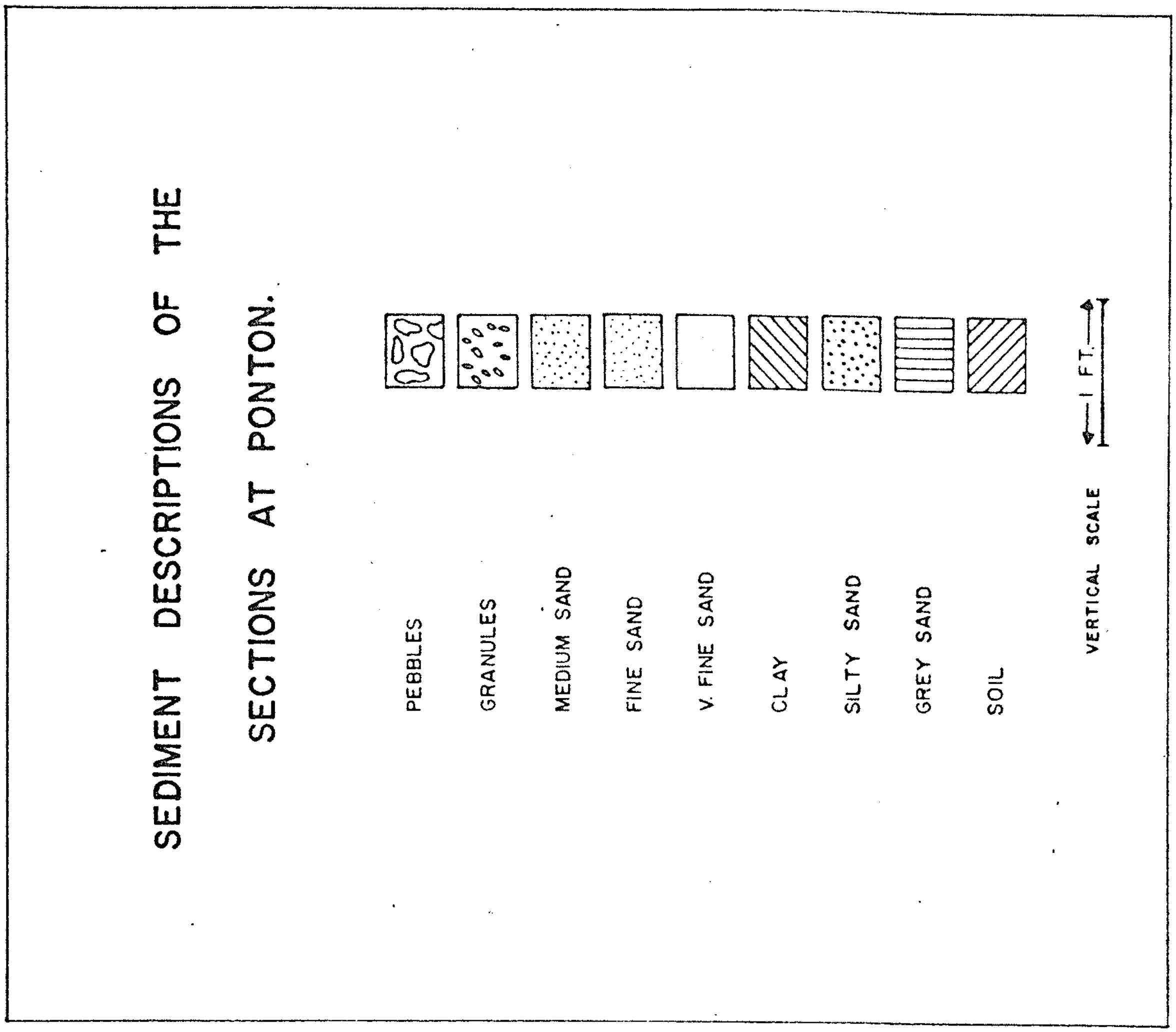

SEDIMENT DESCRIPTIONS OF THE
SECTIONS AT PONTON.
PEBBLES
GRANULES
MEDIUM SAND
FINE SAND
V. FINE SAND
CLAY
SILTY SAND
GREY SAND
SOIL
VERTICAL SCALE
1 FT.

Fig. 3-7

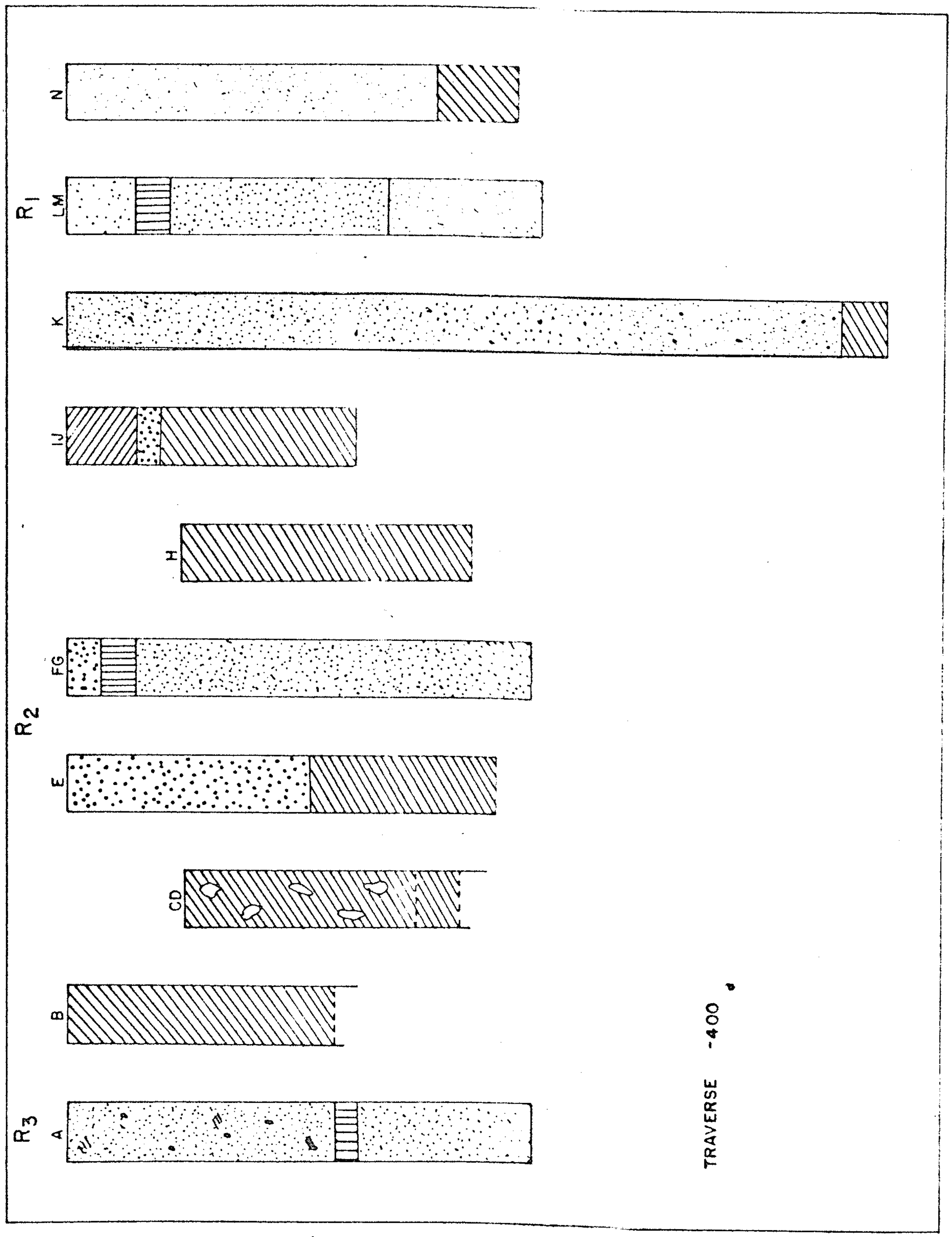


Fig. 3-8

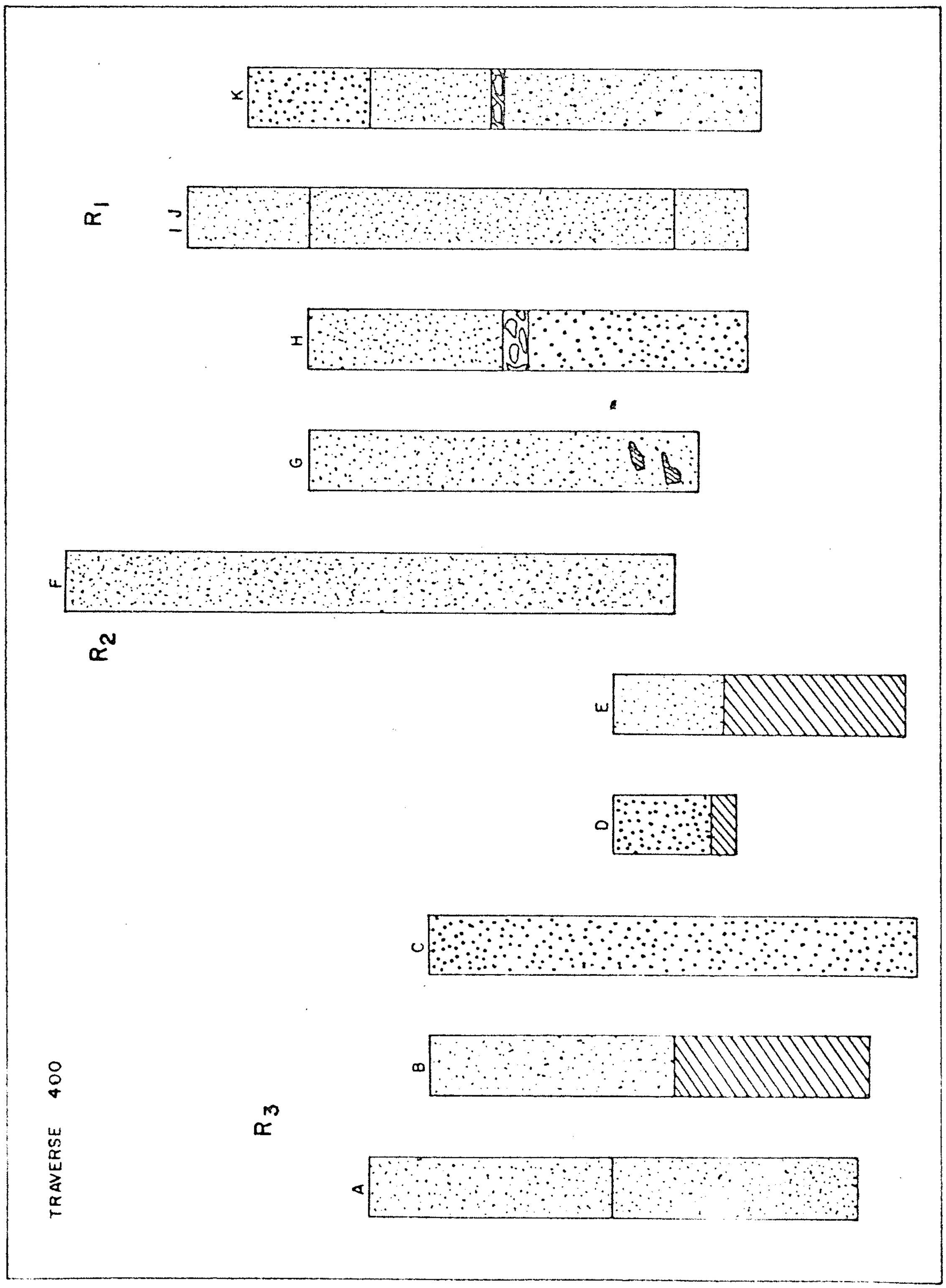


Fig. 3-9

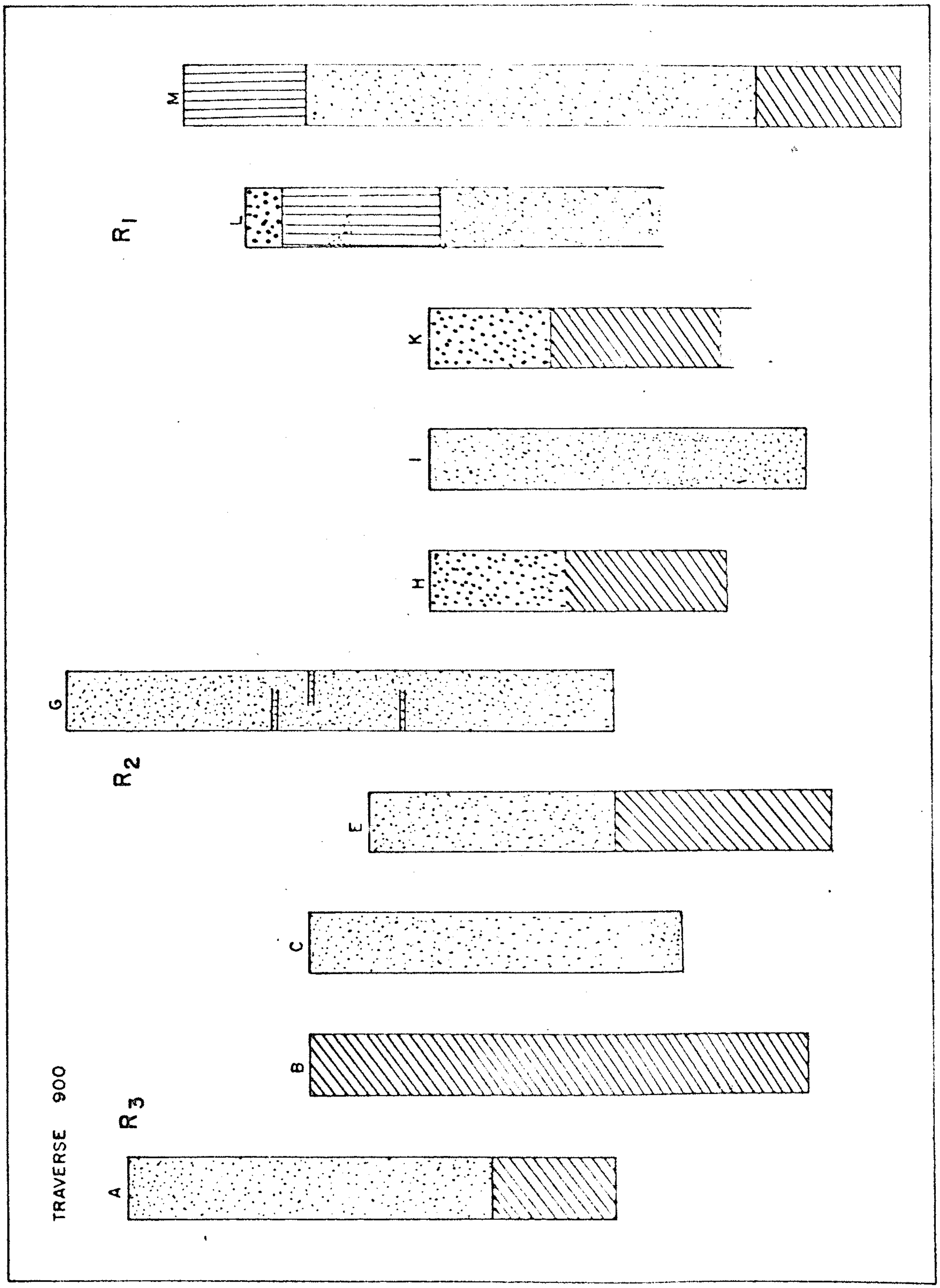


Fig. 3-10

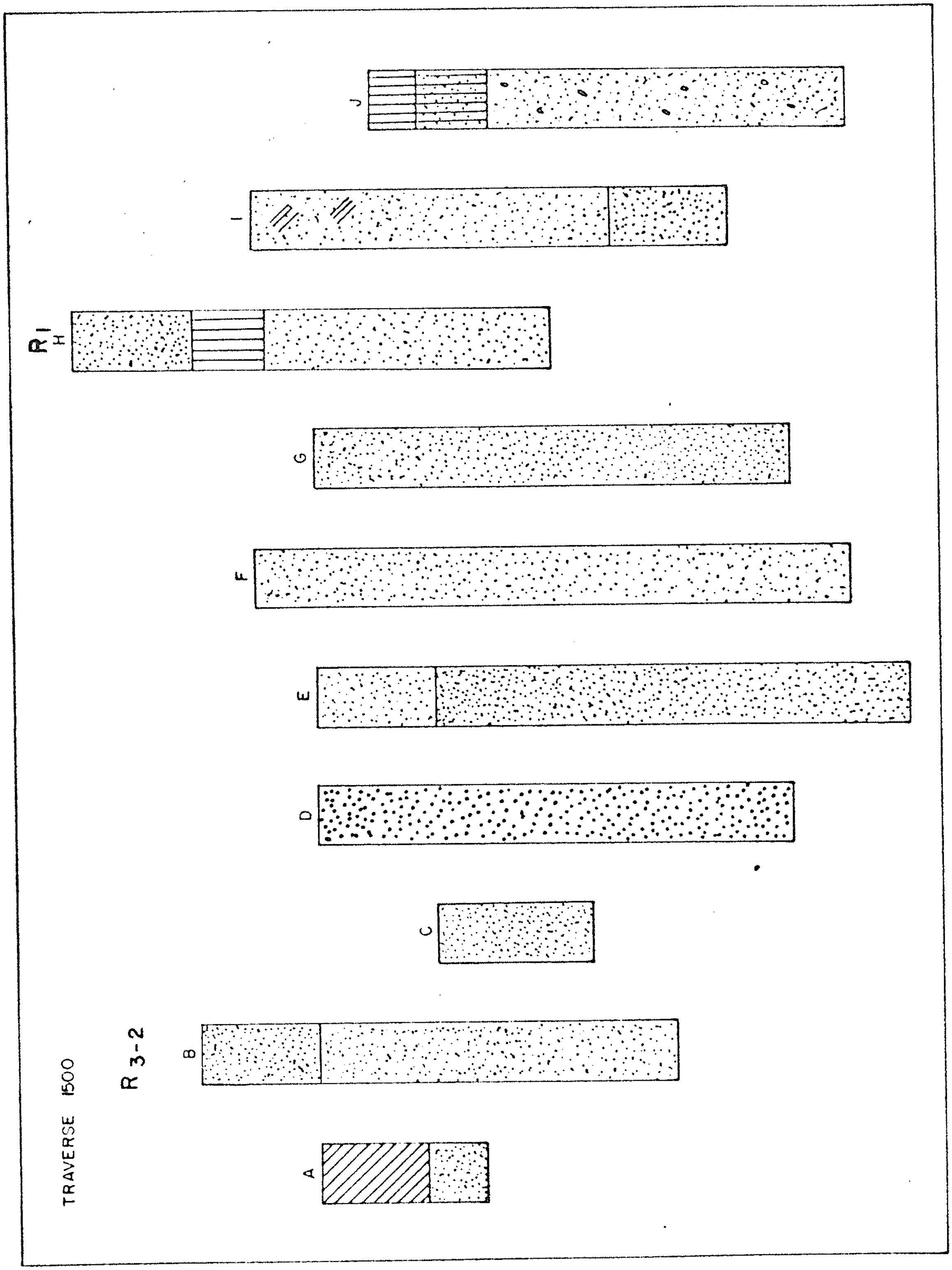


Fig. 3-11

Plate 7

Section 700C' (R2)

Plate 8

Section 900M

Plate 9

Boulders on Minor Terrace

N. E. Ridge 2

pebbles. They are illustrated in Fig. 3-8 (B), (H) and (CD). Minor sand undulations which also occur between the main ridges are exemplified in Fig. 3-10.

c. The sands overlie clay at depth, shown in Fig. 3-8 (K), (N).

d. Some current bedding occurs (especially in R2), but this is rarely distinct.

Deposition of sands and gravels could have occurred in a number of environments similar to the ones described for the Ste. Anne region. These include the possibilities that the Ponton ridges may be an esker of fluvial deposit, a dune, a beach deposit (with ice push features) or a spit or bar formation. There also may be evidence of modification in a periglacial environment.

a. For the reasons described in the background literature in the section on Ste. Anne it is possible that the ridges are not fluvioglacial features. An esker possesses bedded sand (and possibly gravel), and these features are not seen at Ponton. Furthermore, there is no evidence of inclined or arched beds, nor is there variability in the deposits. However, there are features which resemble sediments deposited in a fluvial environment. This is the coarser-medium sand deposited towards the center of the ridge and the finer silty sand on the periphery.

b. The Ponton ridges may have been deposited as sand dunes. Following the work of W. A. Thompson (1937), a diagnostic feature of dunes is their laminations. On the U.S. coast, between San Francisco and San Diego, gently inclined laminae consist of coarse grain sizes and dip into the wind. Steeply inclined laminae of fine grain sizes dip with the wind. Laminations of this type are quite rare in the three ridges at Ponton. With reference to other works quoted above (for example, E. D. McKee, 1966) certain similarities do exist between the Ponton ridges and dunes. These are their homogeneity, which is exhibited in all sections and ridges, their current bedding and grading which is particularly seen in R2, and moderately good sorting which is seen in all the ridges.

c. Some examples of the extensive literature on shoreline sediments have been quoted above. At Ponton there is a lack of bedding or depositional change with depth or distance lakeward or landward, such as that described by V. E. McKelvey (1940).

i. There is no evidence of differential flow rates.

ii. There is a lack of distinct laminations.

iii. There are few dipping beds--indicative of foreshore deposits.

iv. However, moderately good sorting is a characteristic feature of the sand.

d. A particular aspect of beach deposition in a polar environment may be applicable to the area in question. J. D. Hume and M. Shalk (1964) have described the effects of ice push on arctic beaches. This phenomenon occurs where the beach is frozen for nine months of the year. The ice finally breaks up and chunks of it are forced onto the beach by wind. The ice gouges beach material and pushes it up the shore. At the furthest position of the ice edge a line of mounds (20-30 ft. high) of sand and gravel was deposited. This deposit is protected by beach progradation.

R. L. Nichols (1961) describes other beach deposits found in the

McMurdo Sound, Antartica. A particular form of pitted beach occurs when debris falls from glaciers onto ice floes which are washed up onto beaches. Sediment then covers the ice, which hardly melts. This gives rise to an extremely irregular surface, due to differential collapse.

Certain aspects of the Ponton ridges may resemble ice push or pitted (glacial) beach deposits:

i. Terrace-like mounds, made up of sand and clay, occur peripherally to R1 and R3.

ii. Assuming the original source sediment consisted of homogeneous sand, the ridges could have been deposited as a result of ice push. Their variability of form might be explained in this way. The three parallel ridges may have resulted along one shoreline, with an oscillating lake level, causing progressive rafted beaches to have been developed.

iii. The fact that boulders (medium sized, igneous rock) occur, perched on the terraces, could provide more evidence for ice push features. The boulders themselves may be ice rafted. (Plate 9).

e. Certain sedimentological changes may have taken place as a result of the Ponton area occurring in a periglacial environment. A possible explanation for the ridges is that they may have been formed as a result of altiplanation, and may therefore be solifluction terraces. This is unlikely because the bedding is not convoluted, although the possibility still remains. The Ponton area is one of sporadic permafrost, according to R. F. Black (1940). In this environment the sediment will have been exposed to alternate freezing and thawing. A. E. Corte (1962, 1963) subjected a saturated sandy gravel to freeze-thaw. The results showed a vertical sorting of mixed material, with fine particles moving downwards and coarse particles upwards. The differentiation of coarse sands and silts in the Ponton region could be the result of the freezing of a sandy sediment from the base upwards.

One of the peculiar features of the Ponton region is the fact that large boulders have become perched on the edge of the terrace forms. Flat slab-like limestone and dolomite rocks also occur on the surface in the inter-ridge area between R1 and R2. These anomalies may have arisen due to the ridges being subjected to periglacial processes in the broad sense. According to A. Holmes (1964) in cool, temperate climates there is a tendency for stones to work their way up to the surface. During freezing the undersurface of a stone is chilled more quickly than the surrounding sediment. Ice, therefore, collects underneath the stone. This expansion, in turn, opens up an increasing number of porespaces (capillaries) in the soil. This enables more water to collect, and the ice thickens. As this occurs, the stone is pushed upwards. The whole effect is to give stones a perched appearance. Boulders may or may not be able to rise up through clay in the same manner. The thin slabs of limestone-dolomite are equally not well explained by this process, but alternative explanations are not available, since the slabs are underlain by frozen silty sand and the bedrock is many feet below the surface.

The following are the deductions made in the previous section. Resemblances are based solely on verbal descriptions of other sites. However, a description of the stratigraphy at Ste. Anne indicates that the ridge was constructed either as an esker or a beach (possibly a berm or offshore bar), but not as a dune.

The Ponton ridges do not fulfill the bedding requirements for an esker or a "normal" beach deposit. There is evidence that the ridges may have been formed in an aeolian environment. Other features peculiar to the Ponton ridges suggest an ice push effect or freeze-thaw (leading to sorting). Furthermore, there is some evidence of subsequent peri-glacial modification.

Section B. An Evaluation of Sphericity Data

The second section of Chapter 3 deals with the evaluation of sphericity data from Ste. Anne and Ponton and consists of the following sub-sections:

1. A Review of the Methods of Sphericity Determination.

2. Considerations of the Variations of Sphericity, Longitudinally and Transverse to, Each Ridge.

3. Evaluation of the Ste. Anne Data from Sphericity Form Triangles.

4. Some Measure of the Subjectivity of the Sphericity Form Triangle.

5. Comparison with the Pre-existing Literature and Formulation of Tentative Conclusions Regarding the Origin(s) of the Ridges.

1. A Review of the Methods of Sphericity Determination. The purpose of this section is to ascertain whether or not the origin of the Ste. Anne and Ponton ridges can be determined by sphericity studies. Some indication of their origin may be seen by the shape of the particles in the pebble-granule class (R. L. Folk, 1968). The motion of such particles , both in and out of a liquid medium, gives some indication as to

their environment of deposition. A sphere rolls more easily than solids of other shapes because it has the smallest surface area in relation to volume than any other solid. Certain problems arise when considering the relative settling velocities of pebbles of different shapes because the variation in shape affects the settling velocity. C. K. Wentworth's (1919, 1922a, 1922b) quantitative study of shapes was expressed in terms of roundness and flatness ratios. Later H. Wadell (1935) derived a sphericity formula which has, in common with the work of C. K. Wentworth, an inclination to ignore the settling velocities of the different shapes. For instance, one is unable to determine whether or not the pebbles are disc-shaped or rod-shaped, which are useful factors in environmental differentiation.

The limitations of the earlier methods are shown by the following formula of Wadell (1935).

$$\sqrt[3]{\frac{vp}{vcs}}$$

where vp = the actual volume of the particle when measured by immersion in water

vcs = the volume of the circumscribing sphere (or the smallest sphere which will just enclose the particle).

The measurement of relatively large sedimentary particles has been discussed by W. C. Krumbein (1941). This determination involves the measurement of the long, intermediate and short diameters, which are three perpendicularly intercepting planes. The actual sphericity is then read off on a chart "by means of two ratios between pairs of the diameters" (p. 65). The intercept method, based on the triaxial ellipsoid, is less time consuming than the Wadell method and comparably accurate to within a few percent.

A further method of expressing particle sphericity has been described by B. C. Aschenbrenner (1956). This method is not strictly comparable to the pebble size fractions in question because sand size particles were used. Aschenbrenner advocates the return to Wadell's concept of true sphericity, although he measured shape tridimensionally since it is defined by three mutually perpendicular parameters. Measurement by this method, after sieving, is done photogrammetrically, the error being approximately 6.4% smaller than the sphericity as measured by Krumbein's (1941) method. The sphericity (ψ) is converted into a shape factor (F) by the use of a chart.

This type of work has been expanded by P. A. Catacosinos (1965) who formulated additional tables to determine the sphericity and shape of rock particles. These tables are derived from W. C. Krumbein's intercept method and the T. Zingg (1935) classification of shape. The tables have been produced to eliminate the manual plot and to increase the speed of determining the required values.

In 1958 E. D. Sneed and R. L. Folk developed a new method of sphericity determination. This involved the formulation of the "maximum projection sphericity". Sphericity was found to be related to the size of the pebbles, and so form determinations were made to indicate changes in particle morphology. Because shape is also involved, this method is thought to be more useful when applied to the pebbles and granules found in the Ste. Anne and Ponton ridges. Sneed and Folk developed a sphericity triangle, which is further exemplified in R. L. Folk (1968). Here the sphericity value, which is a more behavioristic measure in terms of particle transportation, is reiterated and described by the formula,

$$\sqrt[3]{\frac{S}{LI}} = \text{maximum projection sphericity}$$

where S, I and L equal the short, intermediate and long axes, respectively. The maximum projection area (transportation potential) is the plane of the long and intermediate axes. Particles tend to settle with this plane perpendicular to the direction of motion. To apply this method, the long, intermediate and short axes are measured, using vernier calipers. These values are then substituted in the formulae

$\frac{S}{L}$ and $\frac{L-I}{L-S}$ and plotted on the sphericity form triangle (e.g. Figs. 3-15 to 3-20). Where the two values intercept, the third value--the maximum projection sphericity—can readily be determined.

A more recent method of determining the maximum projection sphericity has been described by K. Burke and S. J. Freeth (1969). They advocated placing pebbles on a grid, which is then projected on an over-head projector. The fragment is moved around the platform such that the intercepts (long, intermediate and short) can be measured. This method is claimed to be quicker than the caliper method of Krumbein (1941) and E. D. Sneed and R. L. Folk (1958). This is considered by the author not to be a considerable advantage, especially if accuracy is sacrificed.

2. <u>Considerations of the Variations of Sphericity, Longitudinally and Transverse to each Ridge</u>. In order to ascertain the sphericity of the granule-pebble content of the Ste. Anne ridge, 390 pebbles were taken from 44 sedimentation units (G. H. Otto, 1938) from depths of 2 and 4 feet. The samples were taken from a variety of sedimentation units along and across the ridge, but were mainly limited to the C,B,D pits because of

the paucity of appropriately sized pebbles in the A and E sections. The particles measured were overwhelmingly (98%) limestone and dolomite, the remainder, granitic and metamorphic. The granites tended to have low sphericities because of the disaggregation of the minerals as a result of weathering.

The long, intermediate and short axes were measured with vernier calipers and substituted directly in the formula

$$\sqrt[3]{\frac{S}{LI}} \qquad \text{(Folk, 1968)}$$

because of the necessity of eye-balling in the second and third decimal values when using the triangle method. The results of the formula were determined for each pebble. The mean, median, range, variance and standard deviation were then calculated for the pebbles in each section sample. The calculations were made to quantify the changes in sphericity which may occur with distance. Shape is considered later in the chapter. The computed data are shown on Table 8.

a. <u>Variations N - S along the ridge</u>. In Table 8 the first column indicates the sections from which the pebbles were sampled. Where pebbles occurred at depth two or more samples were taken. The random nature of the selection is here shown. The highest mean sphericity occurs at Section 13C and the lowest at 11B, being 0.895 and 0.644 respectively. Since all other sphericity measurements occur between the two, there is a high overall sphericity value for the pebbles in the entire ridge. The highest median value also occurs in Section 13C with a sphericity of 0.944, and the lowest in 11B with 0.568. The highest and lowest sphericity values occur in close proximity along the ridge which emphasizes the variability of the values. The range between the highest and lowest values is small and the standard deviation is also quite low, which would tend to indicate uniformity in the data. A plot (Fig. 3-12) has been drawn up showing the relationship of sphericity with distance along the ridge, as indicated by the section numbers. Section C was chosen because it closely approximates to the crest-line, and because there is a more continuous record of values from this section. One striking factor is the degree of variability, with alternating high and low sphericity values along the ridge. However, both the high values (6C and 9C) are lower and the low values are lower than the corresponding values to the north end of the ridge, which has relatively high, high values (13C and 18C) together with relatively high low values (15C and 19C). This would indicate that, although the overall picture is one of variability and fluctuation between the sections, there is some (not a marked) overall trend towards an increase in sphericity towards the north end of the ridge. This is clearly shown on the graph. Only the samples which were approximately 2 feet below the surface were measured.

b. Variations E - W across the ridge. Because of the paucity of pebbles and granules in some sections, a complete record of sphericities cannot be shown. Although there is variability in the data, as shown in Table 8, some overall tendency is shown on Figs. 3-13 and 3-14. In Fig. 3-13, Section 3 shows that the pebble sphericity increases from the western edge toward the ridge crest. The values become relatively low at 3D and higher again at 3E. The second diagram, Section 6, shows a similar increase in sphericity between the B and C sections. The increase between B and C is shown in Section 5. The decrease between C and D can be seen in both Sections 5 and 9. In Fig. 3-14, certain similar trends are again recognized. In Section 13, (as in Section 5) there

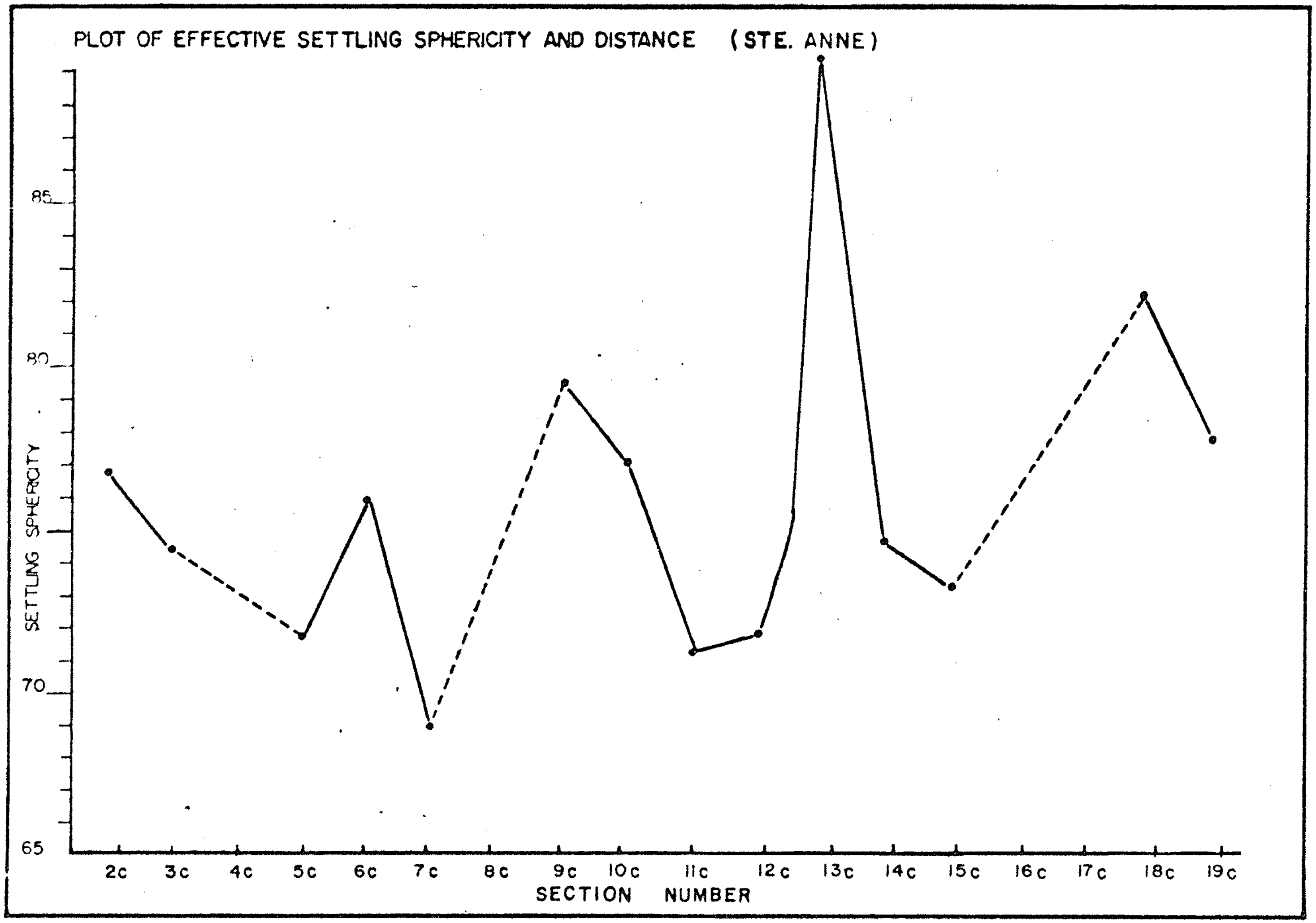

PLOT OF EFFECTIVE SETTLING SPHERICITY AND DISTANCE (STE. ANNE)
SETTLING SPHERICITY
85
80
70
65
2c 3c 4c 5c 6c 7c 8c 9c 10c 11c 12c 13c 14c 15c 16c 17c 18c 19c
SECTION NUMBER

Fig. 3-12

Table 8

Sphericity measurement Data (Ste. Anne)

Section Number	Mean	Median	Range	Variance	Standard Deviation
2A	0.822	0.728	0.163	0.0084	0.09
2C	0.769	0.732	0.391	0.018	0.134
3B	0.722	0.670	0.210	0.008	0.090
3B	0.771	0.757	0.176	0.006	0.078
3C	0.745	0.769	0.431	0.018	0.134
3D	0.680	0.624	0.414	0.121	0.015
3E	0.720	0.760	0.274	0.007	0.082
4D	0.748	0.776	0.285	0.023	0.152
4D	0.676	0.667	0.440	0.016	0.126
5B	0.757	0.786	0.498	0.001	0.034
5C	0.796	0.838	0.138	0.006	0.078
5C	0.719	0.751	0.470	0.078	0.279
5D	0.688	0.734	0.313	0.089	0.298
6C	0.760	0.770	0.377	0.025	0.159
6B	0.712	0.702	0.438	0.016	0.125
7C	0.690	0.666	0.426	0.038	0.195
8D	0.800	0.845	0.376	0.018	0.133
8E	0.795	0.810	0.099	0.002	0.043
9D	0.721	0.721	0.300	0.008	0.091
9C	0.794	0.774	0.118	0.008	0.091
Left 10C	0.771	0.734	0.320	0.015	0.122

Table 8 (continued)

Section Number	Mean	Median	Range	Variance	Standard Deviation
Right 10C	0.668	0.574	0.252	0.014	0.117
11B	0.644	0.568	0.390	0.042	0.205
11C	0.712	0.800	0.317	0.013	0.116
11E	0.793	0.850	0.206	0.007	0.085
12C	0.718	0.681	0.298	0.022	0.147
12D	0.696	0.693	0.162	0.003	0.052
13A	0.812	0.794	0.266	0.008	0.0918
13C	0.895	0.944	0.148	0.008	0.087
13D	0.772	0.789	0.185	0.004	0.077
14B	0.782	0.747	0.284	0.01	0.097
14C	0.746	0.735	0.261	0.008	0.088
14D	0.725	0.710	0.178	0.006	0.075
15C	0.731	0.755	0.113	0.003	0.05
15D	0.729	0.709	0.175	0.004	0.064
West 16B	0.708	0.706	0.146	0.002	0.045
East 16B	0.731	0.743	0.254	0.009	0.093
17D	0.755	0.760	0.381	0.010	0.099
18C	0.822	0.799	0.233	0.013	0.113
18D	0.715	0.714	0.184	0.013	0.112
19A	0.781	0.788	0.119	0.003	0.053
19C	0.778	0.770	0.195	0.005	0.067
19D	0.796	0.791	0.129	0.002	0.039

is an increase in sphericity from A to C, and a sharp decrease to D. Section 14 shows a decline eastwards from B to E. A similar trend is shown in Section 9. A reverse trend, showing an increase in values from B to E, occurs in Section 11. Section 19 resembles Section 3 with respect to its lowering of sphericity values near the center of the ridge. Generally four major trends may be recognized. The trend for the sphericity to increase towards the crest of the ridge from the western extremity is found in 5 cases (Sections 3, 6, 5, 11 and 13). The trend for the sphericity values to decrease from the crest to the eastern extremity occurs in 4 cases (Sections 5, 9, 13 and 14). The trend showing both the increase and decrease in the same cross profile is shown in Sections 5 and 13. There is also a tendency for the sphericity values to increase towards the eastern extremity of the ridge, that is, away from Lake Agassiz.

The sphericity determinations from the Ponton ridge will now be considered. Because of the relative paucity of stones in the granule-pebble size range there is a scarcity of data in this area. One sample of pebbles was taken from 700A in R3. Otherwise a few pebbles which occur at the junction of the sand and clay (probably due to their exposure by the roadside), were chosen randomly along the western extremity of R2. All the measurements were made on igneous and metamorphic rocks. These can be found in Table 9.

The sample taken from 700A indicates an average sphericity not unlike some of the mean values ascertained for the Ste. Anne ridge, but conclusions cannot be drawn from these two samples alone.

The random sample from R2 has a lower sphericity value than the majority of those found at Ste. Anne. The decrease in this value is to some extent related to the various lithologies. In the northern ridges the fragments are entirely shield-derived igneous and gneissic pebbles, which contrast to the Ste. Anne sedimentaries.

Table 9

Sphericity Measurement Data (Ponton)

Section Number	Mean	Median	Range	Variance	Standard Deviation
700A	0.775	0.751	0.220	0.0045	0.068
Random R2	0.684	0.665	0.232	0.0067	0.082

These values are not very useful in determining the origin of the ridges at Ponton because of the scarcity of pebble fragments in the sands, which would probably indicate a considerable amount of re-working. For this reason (the paucity of pebbles) there are no roundness measurements of orientation studies done on the Ponton pebbles.

3. <u>Evaluation of the Ste. Anne Data from Sphericity Form Triangles</u>. The method of computation of sphericity form data from the long, intermediate and short axes of pebbles has previously been described in this section. The values for the following sections were measured and plotted on sphericity form triangles. The sections involved are the crest (c) sections in every case. The samples are numbered 3, 4, 5, 7, 10, 11, 12, 13, 15, 16, 18, and 19. In Section 3C there are two marked areas where the points cluster together. This is shown on Fig. 3-15. There is a tendency for the pebbles to be either compact-elongated

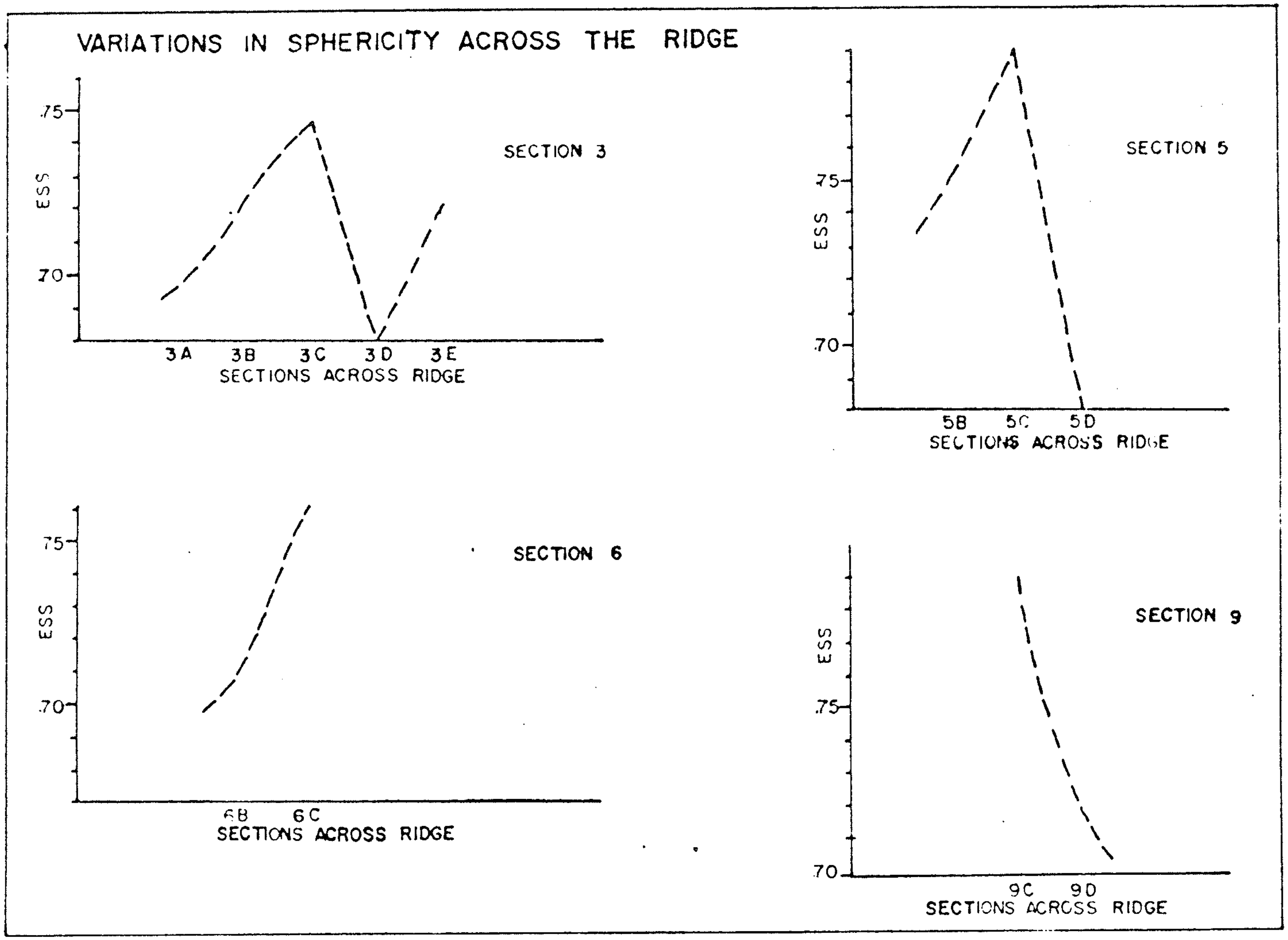

VARIATIONS IN SPHERICITY ACROSS THE RIDGE
SECTION 3
ESS
.75
.70
3A 3B 3C 3D 3E
SECTIONS ACROSS RIDGE
SECTION 5
ESS
.75
.70
5B 5C 5D
SECTIONS ACROSS RIDGE
SECTION 6
ESS
.75
.70
6B 6C
SECTIONS ACROSS RIDGE
SECTION 9
ESS
.75
.70
9C 9D
SECTIONS ACROSS RIDGE

Fig. 3-13

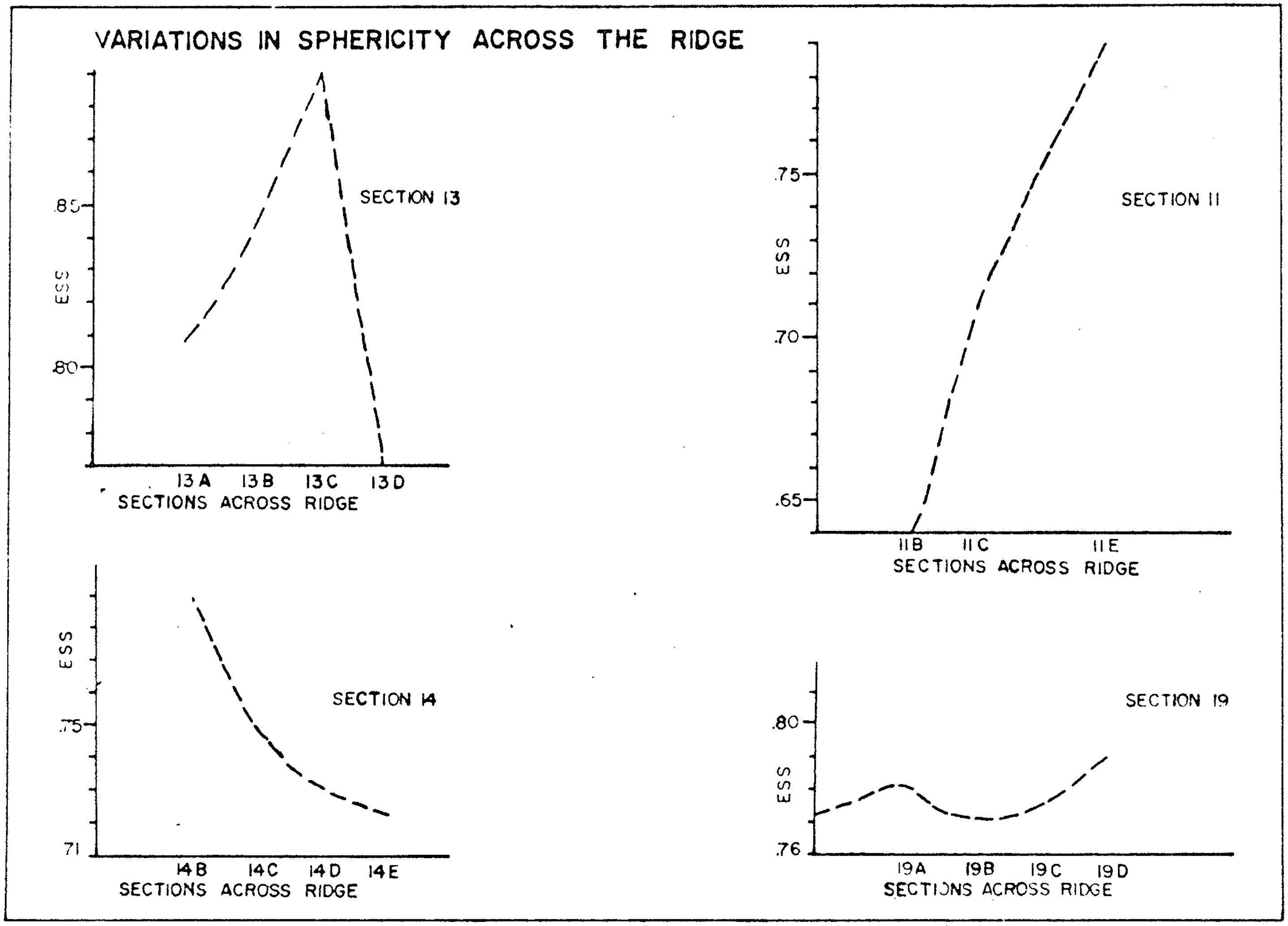

VARIATIONS IN SPHERICITY ACROSS THE RIDGE
SECTION 13
ESS
.85
.80
13 A
13 B
13 C
13 D
SECTIONS ACROSS RIDGE
SECTION 11
ESS
.75
.70
.65
11 B
11 C
11 E
SECTIONS ACROSS RIDGE
SECTION 14
ESS
.75
.71
14 B
14 C
14 D
14 E
SECTIONS ACROSS RIDGE
SECTION 19
ESS
.80
.76
19A
19B
19C
19D
SECTIONS ACROSS RIDGE

Fig. 3-14

or compact-bladed, with a smaller percentage becoming more platy. In Fig. 3-16, Section 5, there are distinctly fewer elongated and platy pebbles. The predominant area of cluster occurs in the compact-bladed to bladed area. In Fig. 3-17, Section 10, the compact-elongated pebbles predominate, with secondary clusters of bladed, platy and compact pebbles. In Fig. 3-18, Section 13, there is no particular point where the pebbles cluster on the diagram, since there are some in the major categories of compact-platy, compact-bladed and compact-elongated, with secondary clusters in the compact and bladed areas. A similar representation occurs in Section 16, Fig. 3-19, although here there are relatively more elongated pebbles. In Section 19, Fig. 3-20, the greatest number of pebbles occur in the compact-bladed area, with others becoming more compact-platy or bladed. In short, the following generalization can be made:

Section	3	compact bladed-platy—compact-elongated
	5	compact-bladed—bladed
	10	compact elongated
	13	compact
	16	compact
	19	compact-bladed.

The data from which these figures were drawn and the values for the following section occur as Table 10b.

4. <u>Some Measure of the Subjectivity of the Sphericity Form Triangle</u>. In order to test the validity of the sphericity form triangle as a means of determining sphericity values, 25 pebbles were measured (the long, intermediate and short diameters of each) at each chosen

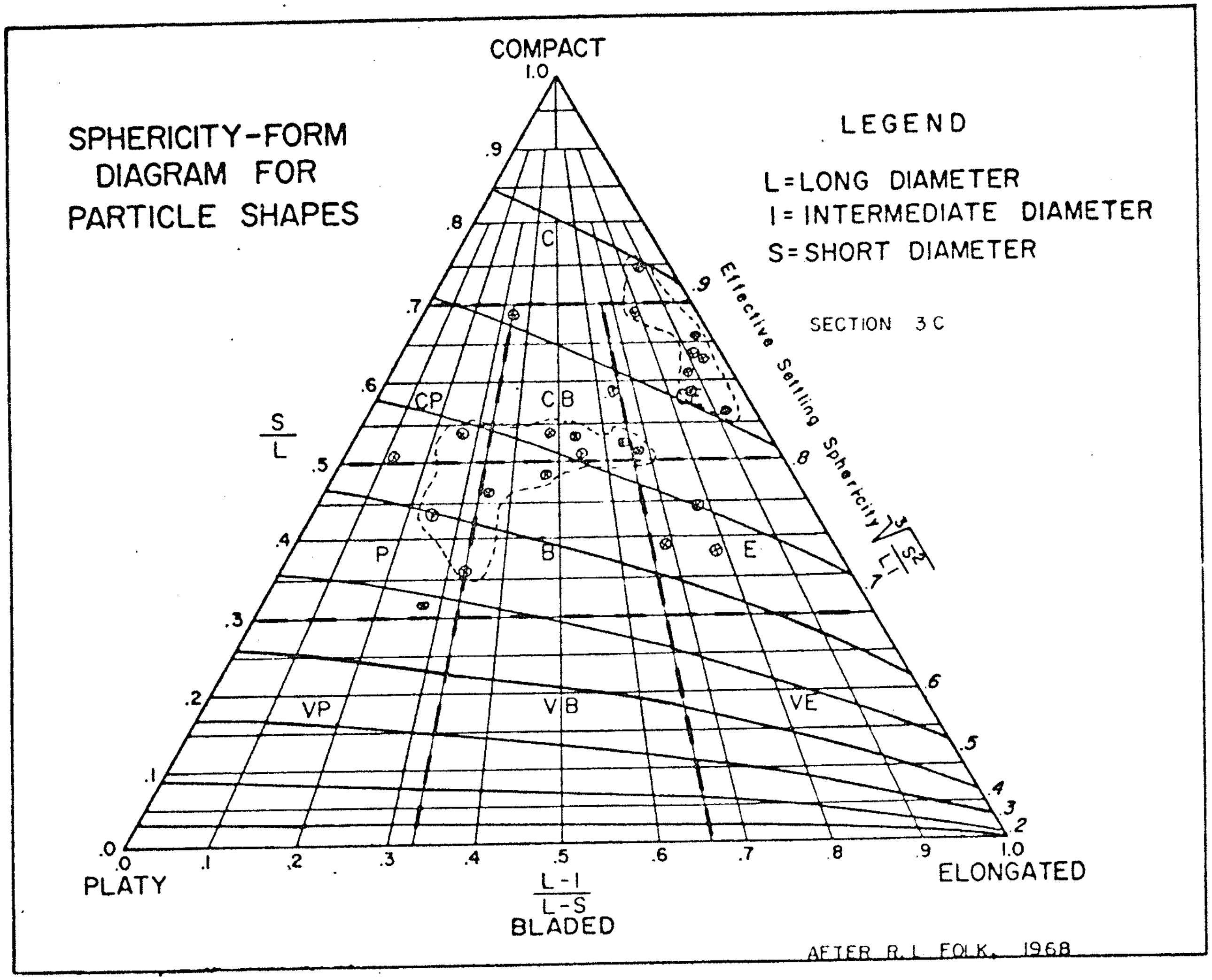

SPHERICITY-FORM
DIAGRAM FOR
PARTICLE SHAPES
COMPACT
LEGEND
L=LONG DIAMETER
I=INTERMEDIATE DIAMETER
S=SHORT DIAMETER
SECTION 3C
Effective Settling Sphericity $\sqrt[3]{\frac{S^2}{LI}}$
$\frac{S}{L}$
$\frac{L-I}{L-S}$
C
CP
CB
CE
P
B
E
VP
VB
VE
PLATY
BLADED
ELONGATED
AFTER R.L. FOLK, 1968

Fig. 3-15

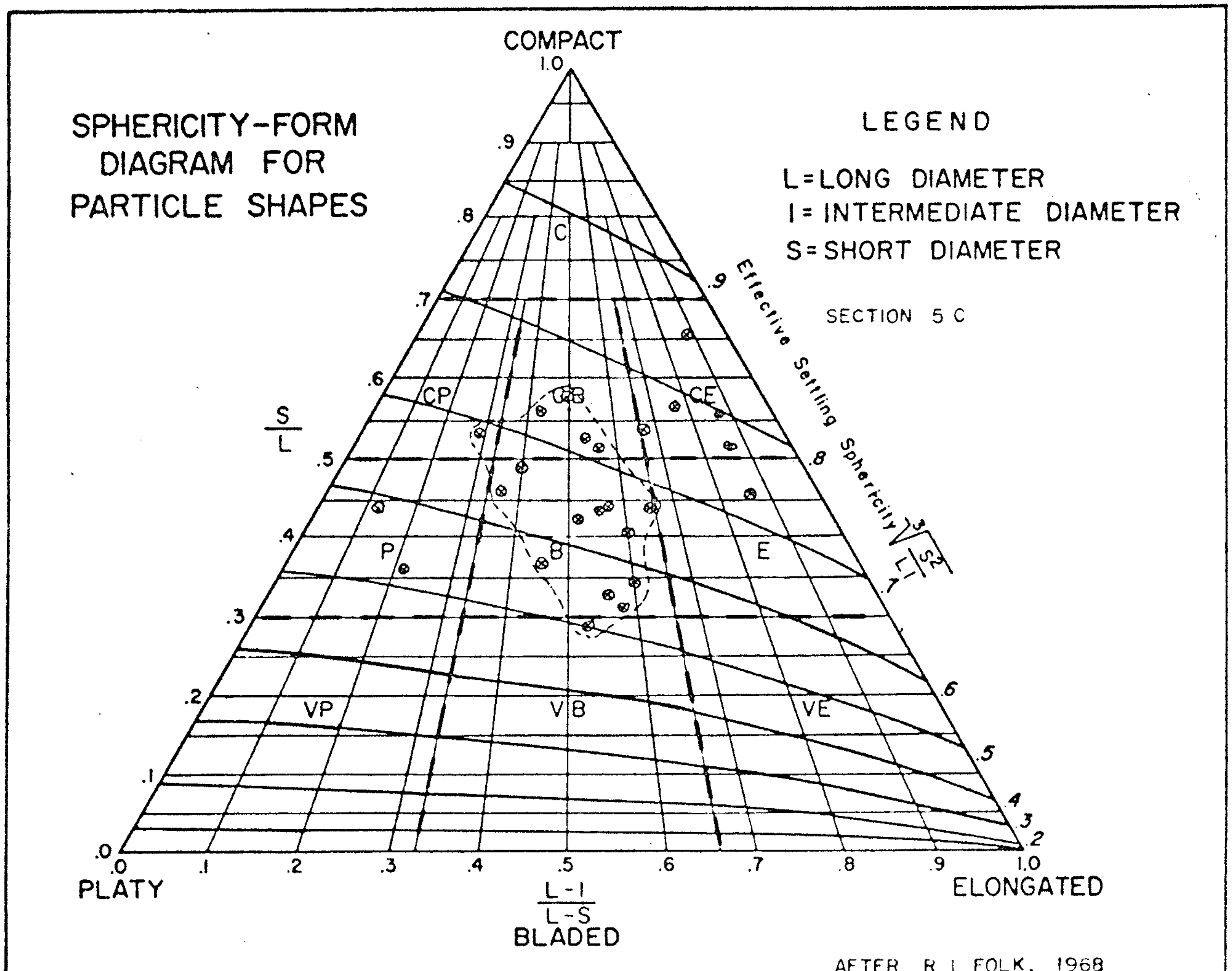

SPHERICITY-FORM
DIAGRAM FOR
PARTICLE SHAPES
LEGEND
L=LONG DIAMETER
I=INTERMEDIATE DIAMETER
S=SHORT DIAMETER
SECTION 5 C
COMPACT
PLATY
ELONGATED
BLADED
S/L
(L-I)/(L-S)
Effective Settling Sphericity $\sqrt[3]{\frac{S^2}{LI}}$
C
CP
CB
CE
P
B
E
VP
VB
VE
AFTER R L FOLK, 1968

Fig. 3-16

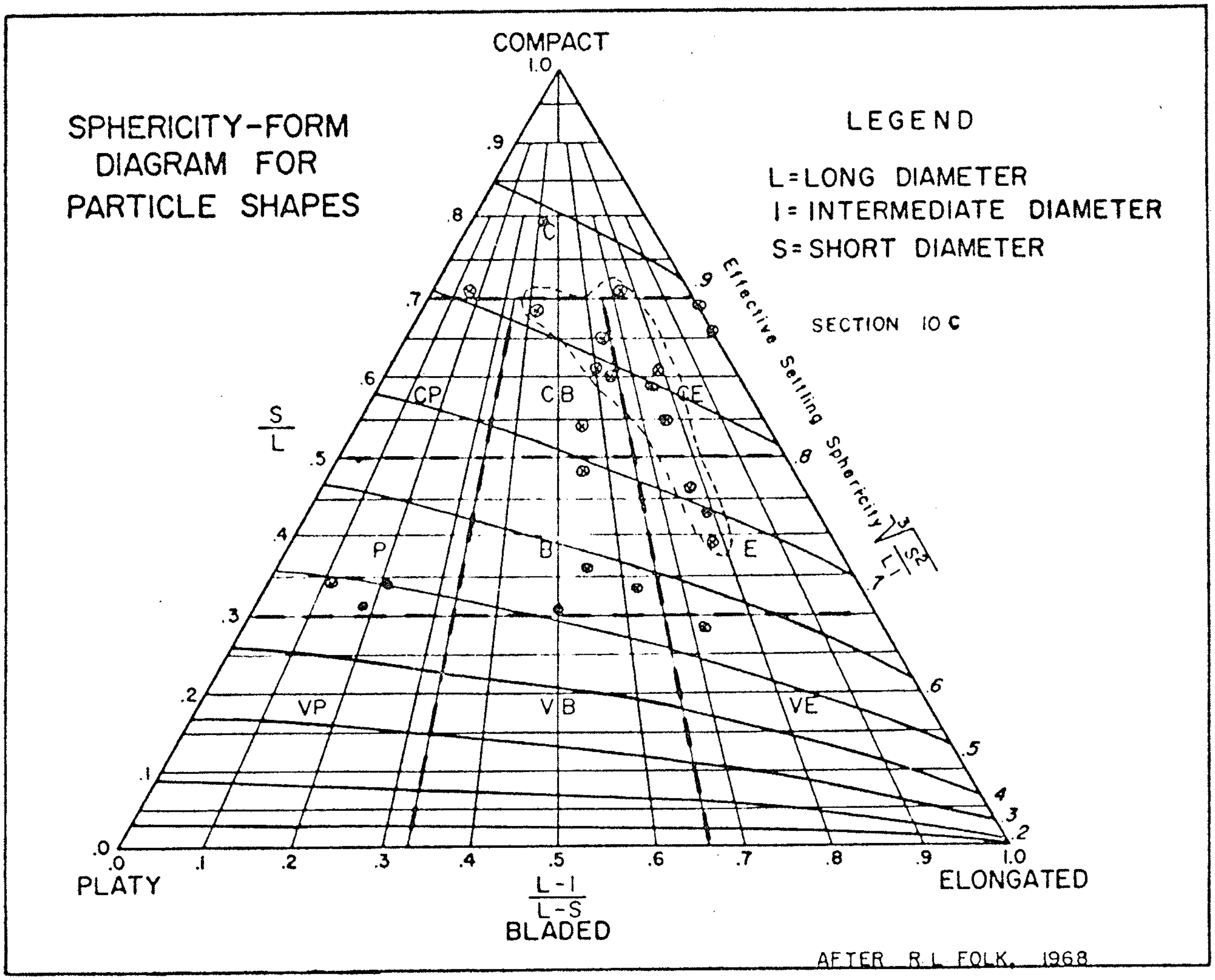

SPHERICITY-FORM
DIAGRAM FOR
PARTICLE SHAPES
LEGEND
L=LONG DIAMETER
I=INTERMEDIATE DIAMETER
S=SHORT DIAMETER
SECTION 10 C
COMPACT
PLATY
ELONGATED
BLADED
S/L
(L-I)/(L-S)
Effective Settling Sphericity $\sqrt[3]{\frac{S^2}{LI}}$
C
CP
CB
CE
P
B
E
VP
VB
VE
AFTER R.L. FOLK, 1968

Fig. 3-17

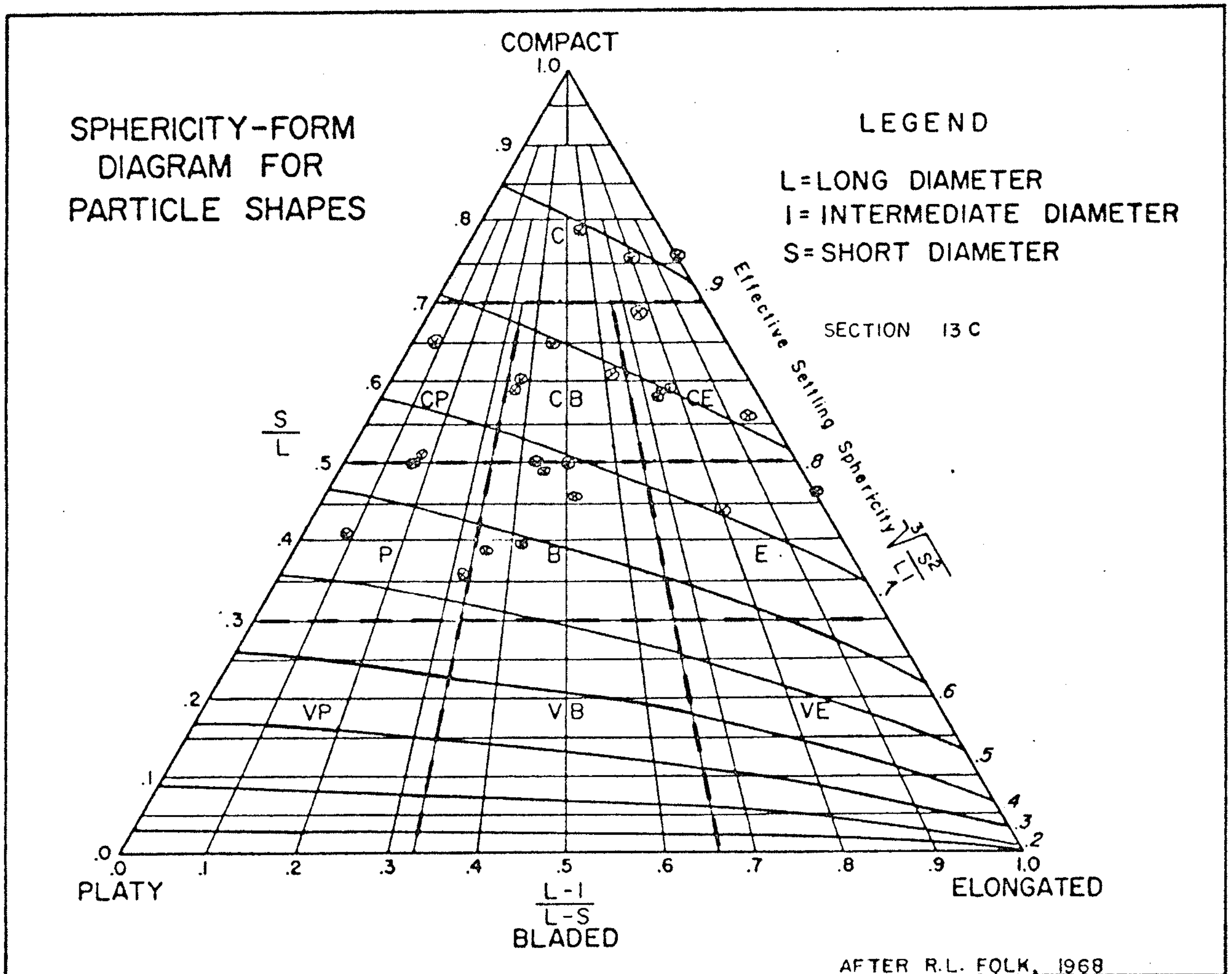

SPHERICITY-FORM
DIAGRAM FOR
PARTICLE SHAPES
COMPACT
LEGEND
L=LONG DIAMETER
I=INTERMEDIATE DIAMETER
S=SHORT DIAMETER
SECTION 13 C
Effective Settling Sphericity $\sqrt[3]{\frac{S^2}{L \cdot I}}$
$\frac{S}{L}$
C
CP
CB
CE
P
B
E
VP
VB
VE
PLATY
ELONGATED
$\frac{L-I}{L-S}$
BLADED
AFTER R.L. FOLK, 1968

Fig. 3-18

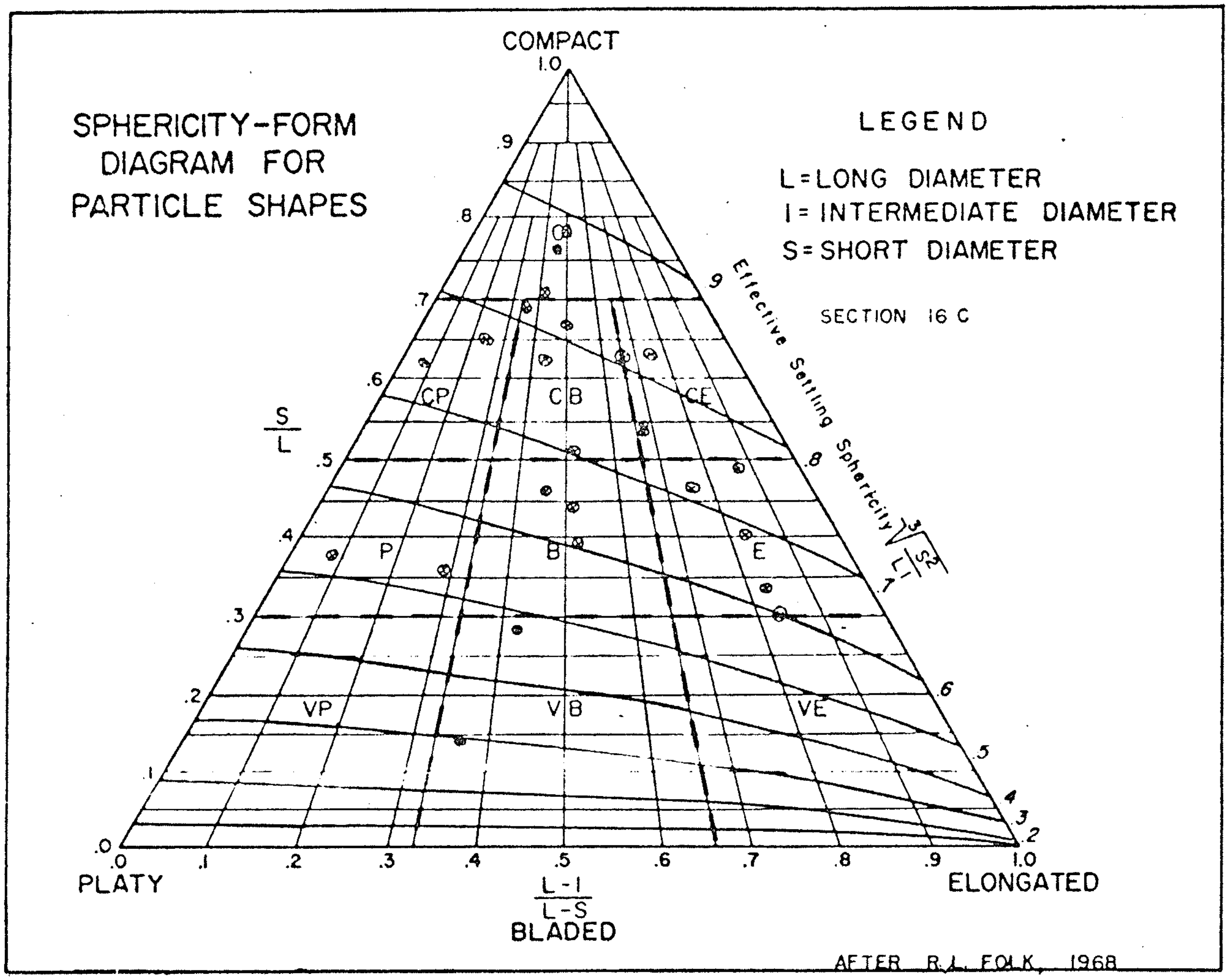

SPHERICITY-FORM DIAGRAM FOR PARTICLE SHAPES
COMPACT
LEGEND
L=LONG DIAMETER
I=INTERMEDIATE DIAMETER
S=SHORT DIAMETER
SECTION 16 C
Effective Settling Sphericity $\sqrt[3]{\frac{S^2}{LI}}$
$\frac{S}{L}$
CP
CB
CE
P
B
E
VP
VB
VE
PLATY
ELONGATED
$\frac{L-I}{L-S}$
BLADED
AFTER R.L. FOLK, 1968

Fig. 3-19

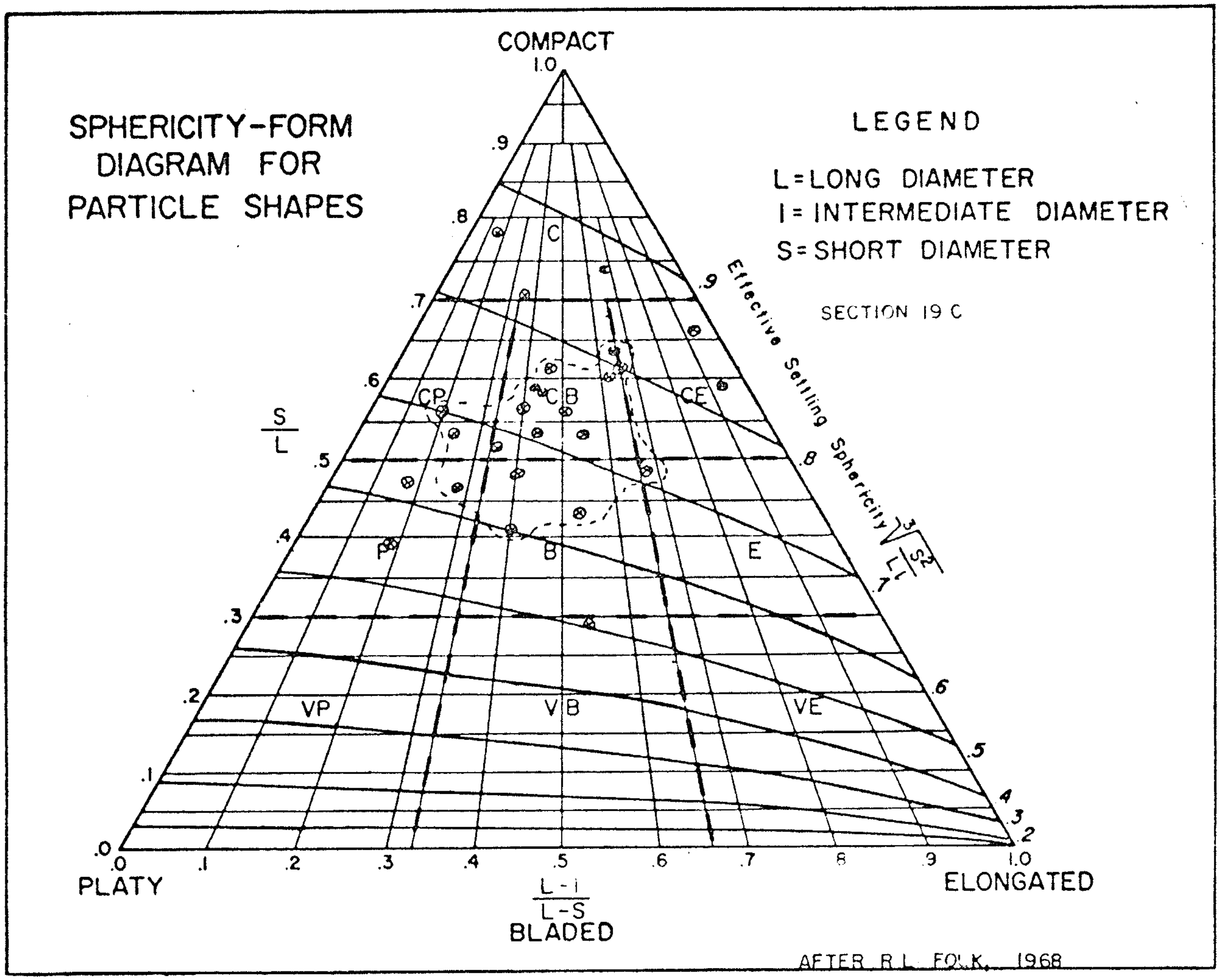

SPHERICITY-FORM
DIAGRAM FOR
PARTICLE SHAPES
COMPACT
LEGEND
L=LONG DIAMETER
I=INTERMEDIATE DIAMETER
S=SHORT DIAMETER
SECTION 19 C
Effective Settling Sphericity $\sqrt[3]{\frac{S^2}{LI}}$
$\frac{S}{L}$
C
CP
CB
CE
P
B
E
VP
VB
VE
PLATY
$\frac{L-I}{L-S}$
BLADED
ELONGATED
AFTER R.L. FOLK, 1968

Fig. 3-20

section by two different students in each case. These were taken from Sections 3, 4, 5, 7, 10, 11, 12, 13, 15, 16, 18 and 19. All C or crest sections were used. The measurements were made with similar vernier calipers, and all the students were equally experienced. The $\frac{S}{L}$ and $\frac{L-I}{L-S}$ values were plotted on the triangular diagram of Folk (1968) and the effective settling sphericity was determined. Each student measured the same 25 pebbles from each section. The two effective settling sphericities, the difference (di) and differences squared (di^2), are to be found in Tables 10b and 10c. The Student "t" Test was run on the data and a "t" value was found for each. The test is shown on Table 10a. The formula used for the calculation of the "t" value was

$$t = \frac{\bar{d} - \mu D}{S_d/\sqrt{n}}$$

where d = the differences between sphericity measurements

n = the number of pairs of measurements

S_d = the variance

μD = the mean.

From the 12 samples measured by different students only 9 indicate that, within the .05 level of significance, the sphericity values measured by the calipers are similar. In three cases there was too great a variation within the pairs of results for a significant similarity to exist. Therefore, it is possible that with any given sample the measurement of the effective settling sphericity, using Folk's triangle, is objective 83% of the time. Similarly 68% objectivity was obtained by W. C. Krumbein (1955) when, out of 100 students measuring a pebble of sphericity 0.75, 68 obtained values between 0.73 and 0.77. The experimental error in this case was considered by Krumbein as being negligible.

Table 10a

Testing the null hypothesis that the effective settling sphericity of 25 pebbles measured by one student is the same as the sphericity measured on the same pebbles by a second student, using the triangular method outlined by R. L. Folk (1968)

Null Hypothesis: Ho: ESS (1) = ESS (11)

Hi: ESS (1) = ESS (11)
= 0.025

Critical Region (N = 25)
t = ±2.064

Sample number		
3	t = +0.924	A
4	t = +0.019	A
5	t = +0.125	A
7	t = -0.435	A
10	t = -0.068	A
11	t = +2.220	R
12	t = +4.554	R
13	t = +1.283	A
15	t = -1.073	A
16	t = -1.243	A
18	t = -0.200	A
19	t = +0.553	A

A = accept the Ho
R = reject the Ho

Table 10b

Sphericity Measurements (Ste. Anne)

Section 3

L	I	S	$\frac{S}{L}$	$\frac{L-I}{L-S}$	(1) ESS	(2) ESS	di	di^2
1.95	1.56	0.62	.32	.30	.49	.64	+.15	.023
1.71	1.60	0.88	.51	.13	.65	.58	.07	.005
1.38	0.70	0.51	.37	.78	.64	.68	-.04	.002
1.07	0.72	0.70	.65	.95	.86	.52	.34	.116
0.78	0.68	0.42	.54	.28	.68	.68	00	.000
1.09	0.88	0.39	.36	.30	.53	.46	.07	.005
0.78	0.57	0.40	.51	.55	.71	.63	.08	.006
0.70	0.45	0.41	.59	.86	.81	.74	.07	.005
0.99	0.85	0.43	.43	.25	.59	.67	-.08	.006
0.73	0.47	0.45	.62	.93	.84	.73	.11	.012
0.84	0.56	0.53	.63	.90	.85	.66	.19	.036
0.83	0.62	0.56	.68	.78	.85	.65	.20	.040
0.81	0.53	0.49	.61	.88	.83	.63	.20	.040
0.72	0.56	0.39	.54	.49	.71	.77	-.06	.004
0.88	0.52	0.35	.40	.68	.63	.86	-.23	.053
0.70	0.52	0.37	.53	.55	.72	.70	.02	.000
0.71	0.43	0.40	.56	.90	.81	.61	.14	.020
0.93	0.63	0.48	.52	.67	.73	.68	.05	.003
0.53	0.40	0.25	.47	.46	.67	.72	-.05	.003
0.55	0.43	0.41	.75	.86	.89	.82	.07	.005
0.93	0.68	0.54	.58	.64	.78	.88	-.10	.010
0.99	0.57	0.45	.46	.78	.71	.72	-.01	.000
0.83	0.57	0.43	.52	.65	.54	.88	-.34	.116
0.63	0.51	0.29	.46	.35	.79	.79	00	.000
0.56	0.50	0.38	.68	.33	.73	.61	.12	.014
							+.67	+.524

$S_d = .145$
$t = .924$

L = long axis

I = intermediate axis

S = short axis

Table 10b (continued)

Section 5

L	I	S	$\frac{S}{L}$	$\frac{L-I}{L-S}$	$\frac{(1)}{ESS}$	$\frac{(2)}{ESS}$	di	di^2
1.95	1.18	1.08	.557	.884	.80	.67	.13	.017
1.64	1.33	.94	.573	.443	.75	.70	.05	.003
1.53	1.05	.83	.542	.686	.75	.78	-.03	.001
1.43	1.0	.94	.657	.878	.86	.58	.28	.078
1.02	.65	.45	.441	.649	.67	.63	.04	.002
1.01	.80	.41	.406	.600	.64	.61	.03	.001
.83	.61	.44	.530	.564	.72	.75	-.03	.001
.82	.62	.36	.439	.556	.65	.58	.07	.005
.95	.50	.43	.453	.865	.73	.67	.06	.004
.88	.62	.38	.432	.520	.63	.63	00	000
.75	.70	.33	.440	.120	.58	.82	-.24	.058
.76	.60	.36	.474	.400	.65	.71	-.06	.004
.74	.52	.42	.568	.486	.78	.74	.04	.002
.72	.62	.38	.528	.204	.68	.58	.10	.010
.83	.57	.37	.446	.565	.65	.53	.12	.014
.77	.54	.28	.364	.470	.58	.70	-.12	.014
.76	.51	.43	.566	.758	.79	.68	.11	.012
.72	.42	.37	.514	.857	.78	.54	.24	.058
.66	.53	.30	.455	.361	.63	.62	.01	000
.69	.42	.24	.348	.600	.58	.48	.10	.010
.65	.55	.23	.354	.238	.53	.75	-.22	.048
.74	.44	.22	.298	.577	.51	.78	-.27	.013
.77	.46	.24	.317	.585	.54	.57	-.03	.001
.68	.42	.22	.324	.565	.53	.62	-.09	.008
.61	.46	.32	.525	.517	.71	.58	.13	.017
							-.42	-.381

$S_d = .125$
$t = .672$

Table 10b (continued)

Section 10

L	I	S	$\frac{S}{L}$	$\frac{L-I}{L-S}$	$\frac{(1)}{ESS}$	$\frac{(2)}{ESS}$	di	di^2
2.12	1.45	1.23	.58	.753	.52	.78	-.26	.068
.96	.83	.33	.34	.206	.69	.46	.23	.053
1.64	.80	.46	.28	.712	.95	.54	.41	.168
1.26	.86	.86	.68	1.000	.60	.88	-.28	.078
1.80	1.16	.64	.36	.552	.75	.59	.16	.026
1.10	.76	.67	.61	.79	.63	.84	-.21	.044
1.12	.83	.67	.60	.64	.88	.78	.10	.010
1.77	1.32	.96	.54	.56	.79	.67	.12	.014
.92	.71	.57	.62	.60	.60	.73	-.13	.017
.96	.63	.30	.31	.50	.57	.51	.06	.004
.67	.64	.48	.72	.16	.56	.82	-.26	.068
.67	.53	.48	.72	.74	.86	.87	-.01	000
.89	.58	.58	.66	1.00	.84	.86	-.02	000
.95	.83	.31	.33	.19	.75	.48	.27	.073
.94	.82	.65	.69	.41	.50	.82	-.32	.102
.82	.54	.45	.55	.76	.74	.78	-.04	.002
.72	.51	.34	.47	.55	.47	.69	-.22	.048
.82	.45	.35	.43	.79	.81	.68	.13	.017
.92	.53	.30	.33	.63	.70	.58	.12	.014
.54	.42	.35	.65	.64	.54	.80	-.26	.068
.54	.32	.35	.46	.76	.72	.70	.02	000
.73	.67	.25	.34	.13	.78	.48	.30	.090
.81	.42	.31	.38	.78	.79	.64	.15	.023
.56	.51	.44	.78	.42	.71	.88	-.17	.029
.32	.31	.16	.50	.06	.68	.64	.04	.002
							-.07	1.018

S_d = .2059
t =-.0680

Table 10b (continued)

Section 13

L	I	S	S/L	(L-I)/(L-S)	(1) ESS	(2) ESS	di	di^2
2.80	2.14	1.09	.35	.36	.58	.58	00	000
1.71	1.19	.50	.39	.43	.48	.88	-.40	.160
1.09	.92	.62	.57	.36	.74	.77	-.03	.001
1.05	.91	.55	.52	.28	.68	.73	-.05	.003
.81	.55	.47	.58	.77	.80	.65	.15	.023
.95	.92	.62	.65	.09	.77	.48	.29	.084
.85	.68	.55	.65	.57	.83	.74	.09	.008
.75	.59	.27	.36	.33	.54	.61	-.07	.005
.85	.69	.65	.76	.80	.90	.65	.25	.063
.65	.50	.45	.69	.75	.87	.88	-.01	000
.71	.55	.55	.76	1.00	.91	.75	.16	.026
1.00	.78	.50	.50	.44	.68	.82	-.14	.020
.65	.55	.39	.60	.39	.78	.65	.13	.017
.88	.40	.40	.46	1.00	.77	.50	.27	.073
.69	.50	.32	.46	.51	.67	.75	-.08	.006
.89	.49	.39	.44	.80	.71	.78	-.07	.005
.62	.42	.35	.57	.74	.78	.74	.04	.002
.68	.59	.52	.77	.56	.88	.49	.39	.152
.77	.59	.48	.62	.62	.80	.57	.29	.084
.68	.45	.39	.57	.79	.79	.67	.12	.014
1.80	1.35	.90	.50	.50	.69	.78	-.09	.008
1.80	1.04	1.00	.56	.95	.81	.80	.01	000
2.72	2.48	1.39	.50	.18	.65	.69	-.04	.002
1.88	1.78	.77	.41	.09	.56	.80	-.24	.058
.57	.44	.28	.49	.45	.68	.48	.20	.040
							1.17	.854

$S_d = .1825$
$t = 1.2822$

Table 10b (continued)

Section 16

L	I	S	S/L	(L-I)/(L-S)	(1)/ESS	(2)/ESS	di	di^2
1.53	1.04	.42	.269	.438	.46	.825	-.37	.137
1.39	.93	.20	.144	.387	.39	.88	-.58	.336
1.45	.79	.69	.476	.868	.75	.81	-.06	.004
.76	.38	.31	.405	.844	.70	.72	-.02	000
.95	.71	.48	.505	.511	.70	.69	.01	000
.40	.38	.15	.375	.080	.54	.53	.01	000
.45	.39	.17	.354	.290	.52	.735	.22	.048
.92	.69	.43	.464	.469	.65	.68	-.03	.001
.93	.63	.50	.538	.698	.78	.77	.01	000
1.04	.65	.41	.394	.619	.63	.61	.02	000
.60	.53	.43	.717	.412	.52	.69	-.17	.029
1.08	.45	.33	.306	.840	.61	.777	-.17	.029
.60	.50	.40	.667	.500	.54	.79	-.25	.063
.60	.58	.38	.633	.091	.75	.74	.01	000
.56	.40	.25	.446	.516	.65	.78	-.13	.017
.68	.40	.31	.456	.757	.71	.81	-.10	.010
.55	.49	.43	.782	.500	.89	.82	.07	.005
.93	.63	.50	.538	.698	.76	.68	.08	.006
.55	.72	.55	.625	.438	.79	.62	.17	.029
.69	.62	.53	.768	.485	.87	.82	.05	.003
.64	.48	.40	.625	.661	.82	.68	.14	.020
1.30	.58	.43	.331	.828	.68	.90	-.22	.048
.68	.60	.47	.691	.381	.82	.65	.17	.029
.58	.51	.38	.655	.350	.79	.76	.03	.001
.55	.40	.35	.636	.750	.83	.83	00	000
							-1.11	.815

S_d = .1786
t = -1.243

Table 10b (continued)

Section 19

L	I	S	$\frac{S}{L}$	$\frac{L-I}{L-S}$	$\frac{(1)}{ESS}$	$\frac{(2)}{ESS}$	di	di^2
2.14	1.61	1.285	.60	.62	.79	.46	.33	.109
1.22	.75	.72	.59	.94	.84	.30	.54	.292
.83	.67	.475	.572	.45	.74	.75	-.01	000
.955	.74	.49	.513	.355	.68	.69	-.01	000
1.69	1.39	1.05	.621	.469	.78	.76	.02	000
1.03	.94	.58	.563	.20	.70	.52	.18	.032
.75	.68	.35	.467	.175	.61	.53	.08	.006
2.12	1.61	1.32	.624	.639	.80	.65	.15	.023
.76	.47	.22	.289	.537	.50	.76	-.26	.068
.653	.58	.35	.536	.241	.69	.63	.06	.004
.82	.68	.61	.744	.667	.86	.84	.02	000
.69	.61	.21	.391	.190	.54	.61	-.07	.005
1.14	.73	.54	.474	.683	.71	.81	-.10	.010
.75	.72	.58	.773	.176	.84	.74	.10	.010
.75	.525	.32	.427	.523	.64	.65	-.01	000
.66	.52	.31	.47	.40	.65	.71	-.06	.004
.60	.51	.28	.467	.281	.63	.89	-.26	.068
.58	.41	.24	.414	.50	.62	.74	-.12	.014
.75	.56	.46	.613	.655	.79	.78	.01	000
1.77	1.22	1.17	.661	.917	.88	.87	.01	000
1.70	1.52	1.20	.706	.36	.83	.81	.02	000
1.92	1.53	1.03	.536	.438	.71	.64	.07	.005
1.78	1.32	.94	.528	.548	.72	.83	-.11	.012
1.71	1.35	1.02	.596	.522	.77	.78	-.01	000
.59	.46	..33	.559	.50	.73	.84	-.11	.012
							.46	.674

S_d = .1664
t = .5529

Table 10c

Student Measures for "t" Test

Section 4

(1) ESS	(2) ESS	di	di^2
.93	.85	.08	.006
.79	.76	.03	.001
.86	.50	.36	.130
.81	.75	.06	.004
.68	.82	-.14	.020
.85	.71	.14	.020
.68	.81	-.13	.017
.68	.89	-.21	.044
.39	.76	-.37	.137
.76	.51	.25	.063
.77	.55	.22	.048
.74	.78	-.04	.002
.73	.66	.07	.005
.58	.73	-.15	.023
.78	.53	.25	.063
.75	.50	.25	.063
.68	.74	-.06	.004
.47	.82	-.35	.123
.64	.68	-.04	.002
.75	.80	-.05	.003
.87	.73	.14	.020
.93	.63	.30	.090
.69	.91	-.22	.048
.75	.83	-.08	.006
.46	.75	-.29	.084
		+.02	+1.026

S_d = .207
t = .019

Table 10c (continued)

Section 7			
(1) ESS	(2) ESS	di	di^2
.76	.62	.14	.020
.57	.65	-.08	.006
.77	.53	.24	.058
.65	.83	-.18	.032
.68	.65	.03	.001
.86	.76	.10	.010
.90	.80	.10	.010
.82	.82	00	000
.60	.82	-.22	.048
.54	.89	-.35	.123
.71	.65	.06	.004
.67	.68	-.01	000
.71	.65	.06	.004
.67	.82	-.15	.023
.71	.79	-.08	.006
.81	.69	.12	.014
.65	.63	.02	000
.79	.80	-.01	000
.75	.70	.05	.003
.69	.94	-.25	.063
.87	.78	.09	.008
.79	.87	-.08	.006
.87	.85	.02	000
.83	.81	.02	000
.80	.74	.06	.004
		-.30	.443

S_d = .1353
t = -.4435

Table 10c (continued)

Section 11

(1) ESS	(2) ESS	di	di^2
.71	.67	.04	.002
.84	.69	.15	.023
.79	.79	00	000
.75	.58	.17	.029
.74	.62	.12	.014
.67	.60	.07	.005
.63	.75	-.12	.014
.69	.56	.13	.017
.68	.67	.01	000
.80	.61	.19	.036
.55	.82	-.27	.073
.68	.71	-.03	.001
.69	.72	-.03	.001
.73	.58	.15	.023
.75	.54	.21	.044
.73	.70	.03	.001
.64	.68	-.04	.002
.62	.55	.07	.005
.52	.63	-.11	.012
.80	.48	.32	.102
.87	.74	.13	.017
.69	.78	-.09	.008
.73	.58	.15	.023
.65	.59	.06	.004
.68	.58	.10	.010
		1.41	0.466

$S_d = 0.127$
$t = 2.220$

Table 10c (continued)

Section 12

(1) ESS	(2) ESS	di	di^2
.88	.82	.06	.004
.77	.71	.06	.004
.82	.78	.04	.002
.72	.64	.08	.006
.69	.48	.21	.044
.75	.65	.10	.010
.68	.55	.13	.017
.61	.65	-.04	.002
.65	.44	.21	.044
.74	.45	.29	.084
.67	.64	.03	.001
.76	.38	.38	.144
.75	.57	.18	.032
.68	.63	.05	.003
.76	.65	.11	.012
.78	.73	.05	.003
.74	.65	.09	.008
.68	.61	.07	.005
.85	.53	.32	.102
.68	.64	.04	.002
.64	.62	.02	000
.72	.65	.07	.005
.88	.75	.13	.017
.74	.87	-.13	.017
		2.55	.568

S_d = .1131
t = 4.554

Table 10c (continued)

Section 15

(1) ESS	(2) ESS	di	di^2
.67	.68	-.01	000
.75	.87	-.12	.014
.73	.73	00	000
.72	.90	-.18	.032
.87	.92	-.05	.003
.78	.78	00	000
.65	.69	-.04	.002
.65	.70	-.05	.003
.66	.83	-.17	.029
.80	.86	-.06	.004
.77	.65	.12	.014
.69	.69	00	000
.78	.75	.03	.001
.74	.75	-.01	000
.88	.65	.23	.053
.63	.80	-.17	.029
.59	.52	.07	.005
.65	.66	-.01	000
.87	.69	.18	.032
.68	.62	.06	.004
.78	.79	-.01	000
.69	.86	-.17	.029
.78	.72	.06	.004
.76	.86	-.10	.010
.59	.78	-.19	.036
		-.59	.304

S_d = .110
t = -1.0727

Table 10c (continued)

Section 18

(1) ESS	(2) ESS	di	di^2
.79	.78	.01	000
.84	.85	-.01	000
.74	.60	.14	.020
.68	.72	-.04	.002
.78	.83	-.05	.003
.70	.77	-.07	.005
.61	.74	-.13	.017
.80	.53	.27	.073
.50	.64	-.14	.001
.67	.79	-.12	.014
.86	.77	.09	.008
.70	.70	00	000
.83	.52	.31	.096
.64	.83	-.19	.036
.65	.83	-.18	.032
.62	.61	.01	000
.61	.73	-.12	.014
.81	.86	-.05	.003
.88	.54	.34	.116
.84	.87	-.03	.001
.71	.79	-.08	.006
.72	.69	.03	.001
.77	.72	.05	.003
.72	.77	-.05	.003
.55	.68	-.13	.017
		-.14	.471

S_d = .140
t = .200

5. Comparison with Pre-existing Literature and the Formulation of Tentative Conclusions. It is now necessary to consider the past literature with the intention of determining a possible origin at least for the Ste. Anne ridge, based on previous work done with comparable sphericity measurements.

An interesting study on the Lake Erie sand was written by F. J. Pettijohn and A. C. Lundahl (1943). They found, having taken samples along the south side of Lake Erie, that the sphericity declined slightly in the direction of sand shift. Simple abrasion was not considered accountable for the observed trends. The sands are sorted in a down current direction, the less spherical grains being carried further than the more spherical ones.

As W. J. Morris (1957, p. 31) has pointed out, there is a paucity of work to date on the exact relationship between certain particle attributes and the fluid laws governing the transporting medium. Once this is ascertained, more knowledge can then be accummulated on the determination of the characteristics of a sedimentary deposit—and hence the environment. Certain conclusions arrived at by Morris in his experiment include the fact that conditions of intermediate flow rates of water cause a high rate of transportation for grains having high sphericities (0.8-1.0) and low sphericities (less than 0.6).

In 1958, E. D. Sneed and R. L. Folk produced their work on particle morphogenesis in the lower Colorado River of Texas. Here the concept of the maximum projection sphericity was first introduced. Particle size, even within the narrow range of between 32 - 64 mm. was found to have a greater effect on sphericity than 200 miles of fluvial transportation. Large quartz pebbles were discovered to become more rodlike, smaller ones more discoidal. Limestone pebbles in the Colorado River maintain a low sphericity, and this does not significantly change with distance. In the fluvial environment an additional point is the dominance of bladed forms, except in the limestone pebbles which are more discoidal. Sphericity is a function of pebble size and distance with the lithology involved.

Later work by H. Blatt (1959) (substantiated, in so far as only isotropic rocks were measured, by C. W. Sames, 1966) saw a larger variety of size grades used when analyzing beach sediments. The method of finding the maximum projection sphericity is essentially similar to that used by Sneed and Folk. Blatt places a great deal of emphasis on the type of quartz and indicates that sphericity variations reflect, in large part, the quartz varieties. The New Jersey beach deposits are discoidal, contrasting with the rods found in a fluvial environment such as those investigated by Sneed and Folk. The sliding motion of wave wash is quoted as the cause, compared with the turbulent rolling action of river water. The latter process develops to a more elongate form in smaller particles. Blatt also points out that "river and beach pebbles are apparently indistinguishable by form in sizes finer than -2.5ϕ" (p. 205).

Detailed work on the sedimentation of beach gravel in South Wales was carried out by B. J. Bluck (1967). The classification of shape was carried out according to the Zingg (1935) and Krumbein (1941) methods. The surface layers of pebbles in South Wales are divided into four zones:

a. a large disc zone - landward

b. imbricate disc zone - approaching seaward

c. an infill zone of spherical and rod-shaped pebbles

d. spherical cobbles on the seaward margin.

The shape-area system relates to the settling velocity and pivotability of the gravels rather than the energy of marine erosion as such. The size frequency of the pebbles and cobbles along and across the ridge reflect a reworking of the boulder-clay parent material. The disc shaped pebbles occur as a result of "lag" deposition (when this coincides with the modal size). Spherical or rod-shaped particles are found when there is rolling caused by backwash.

C. A. M. King and J. T. Buckley (1968) have measured the shapes and sizes of a number of pebbles from different environments in the Arctic Tundra. Shape measurements were ascertained using the W. C. Krumbein (1941) method. Beaches, deltas, eskers, kames, areas subjected to periglacial activity, moraines, and features of unknown origins were studied by using the non-parametric Kologorov-Smirnov test. It was found that mean size alone could provide a criterion by which deltas, eskers and ice-contact deposits could be differentiated from each other. Beaches could not be readily distinguished by the shape method. Because of the lack of overall environmental differentiation, this method was not adopted.

Following the review of the literature, certain tentative conclusions can now be made.

a. Despite dissimilarities in grain size, the fact that F. J. Pettijohn and H. C. Lundahl's (1943) sphericities decreased along a lake beach, due to sediment sorting, is seen to be similar to the generalized trend of a decrease from north to south in the overall sphericities found on the Ste. Anne ridge. This suggests a shifting of grains, due to a long-shore wind in a beach environment.

b. Although the pebble-granule sizes measured at Ste. Anne cover a greater range than those measured in the Colorado River by E. D. Sneed and R. L. Folk, certain generalizations can be made.

i. The limestones/dolomites of the Ste. Anne ridge were relatively consistent in value, despite local fluctuations.

ii. Most of the rod-like pebbles at Ste. Anne fall in the compact-elongated class, which itself is not dominant.

iii. There are no discoidal pebbles at Ste. Anne, despite the fact that they are predominantly limestones and dolomites.

c. To some extent contradicting the analysis of beach sediments of H. Blatt (1959), the Ste. Anne pebbles are rarely discoidal and tend to be more rod-like, such as would be found in a fluvial environment.

d. The Ste. Anne pebbles more closely coincide with the seaward margin cobbles and pebbles as described by B. J. Bluck (1967). Here there is an infill zone of spherical and rod-shaped rod-shaped pebbles, which is analogous to the compact-bladed and compact-elongated pebbles found at Ste. Anne.

Although the evidence as demonstrated here does not conclusively prove any particular environment of deposition based on the sphericity alone of the supposed Lake Agassiz ridge gravels, there is some indication:

a. that it may be a beach because of the sphericity variations along the ridge, and because of the spherical (compact) and rod-shaped pebbles (as in points a and c above).

b. that the ridge also may be fluvial because of the decrease in size of limestone rapidly with transportation, because of the variation in sphericity across the ridge (shown in Figs. 3-13 and 3-14), and because of the elongated rod-like forms (as in point b above).

Section C. An Evaluation of Roundness Data

Observations of roundness data were made on the pebble and granule sizes of the Ste. Anne ridge. An outline of this section is as follows:

1. A Review of Some of the Past Literature of Roundness Measurement Methods.

2. Presentation of Roundness Data from the Ste. Anne Ridge.

3. A Review of the Past Literature and the Interpretation of the Ste. Anne Ridge Data.

1. A Review of Some of the Past Literature of Roundness Measurement Methods. Roundness was defined by H. Wadell (1932, 1933, 1935) as "the ratio of the radius of the corners and edges to the radius of curvature of the maximum inscribed sphere when projected to a standard diameter of 70mm". Roundness is directly related to the sharpness of the corners and edges of the particle, and, as such, is distinguished from sphericity. The author also suggested that roundness is an index of the maturity of a sediment, with distance of transportation.

Later authors, R. D. Russell and R. E. Taylor (1937), measured the roundness and shape of certain Mississippi River sands. Their values were based on sand grains which showed no evidence of becoming rounded as a result of attrition during transportation. In order to determine the roundness of the particles a visual method was used, the comparison of grains with a photomicrograph, in addition to a descriptive index. No measure of the subjectivity of the index was given.

W. C. Krumbein (1941) amplified the visual representation method of particle roundness. In this method, the pebble is compared with standard images of known roundness. Once put in a certain category, a roundness value is assigned to it. The images which are used in the comparison have been drawn from pebbles measured by Wadell's method. Krumbein states that statistical studies between the two methods indicate a reasonable similarity. The plate with the set of standard images is shown in the article. The largest projection of the pebble is compared to the images, the most similar ones are identified, and the roundness value recorded. The roundness categories vary from 0.1 - 0.9, with increasing roundness.

M. C. Powers (1953) suggested a new roundness scale, defined by six roundness classes. He attempted an improvement on the pre-existing Russell and Taylor (1937) method. Because the arithmetic means of the intervals were used as mid-points and the values did not provide the smaller sub-divisions that are needed in the lower roundness values, F. J. Pettijohn (1949) sought to improve it by using a geometric scale. There was still a paucity of divisions in the lower part of the scale. Powers added a further roundness category to the scale, so that it became more sensitive. The 6 categories consisted of very angular, angular, sub-angular, sub-rounded, rounded and well-rounded. These have geometric class intervals and means. A visual comparison is made between photographs of clay models which fall near the geometric mean. To determine an average roundness, the number of particles in each class is multiplied by the geometric mean of that class. The sum of the products is then divided by the total number of particles counted.

M. A. Beal and F. P. Shepard (1956) considered the scales set up by W. C. Krumbein (1941) and M. C. Powers (1953) to determine their relative validities when using a microscope. Power's scale was chosen for quartz grains, but difficulty was encountered when comparing these quartz with the silhouettes on the Krumbein scale. J. D. Waskom (1958), following the work of Beal and Shepard, also used the Power's roundness scale for quartz grain analysis.

A further method was introduced by D. A. Robson (1958). This was devised because the Wadell system was considered to be too laborious. Another method is preferred by which a measured granule is fixed to a microscope. The circles of known size are then compared directly to minerals, using transmitted light. The relative efficiencies of this and the Power's scale have not been tested.

A further method of assessing roundness has been described by I. J. Smalley (1967). It was the Szadeczky-Kardoss (1933) technique. This was used by Smalley to supplement general shape data. The method necessitates an estimate being made of the proportions of the particle surface which can be described (subjectively) as being, flat, convex and concave. The several results are then expressed as a point on a triangular net.

Finally, a method was used by C. A. M. King and J. T. Buckley (1968) following a technique devised by M. Blenk (1960). When measuring the size and shape of stones in arctic environments this Callieux Index is applied. The roundness is calculated from the formula

$2R/a \times 1000$, where R is the minimum radius of curvature in the principal plane and a is the long axis. For a completely round stone, the roundness = 1000 or $2R = a$. The values can be calculated by using a reference set of arcs of different radii to fit the individual stone. This method is less subjective than the use of the Krumbein scale, and is therefore adopted in the present study.

The Power's scale was not used because it has been used mainly to measure sand size grains, and therefore no direct comparison can be made between the results obtained here and other results in the literature. The Robson technique is disregarded for the same reason.

The method suggested by W. C. Krumbein (1941) is used and, if sufficiently objective, is preferrable because the scale is more readily adaptable to variable pebble sizes. It is easy to use by relatively inexperienced students, and the results are similar to those derived from the Power's scale.

2. <u>Presentation of Roundness Data from the Ste. Anne Ridge</u>. Because the roundness scale used here is based on the method first proposed by W. C. Krumbein (1941), a test of the subjectivity of the technique is necessary.

a. <u>The Chi-Square Test on roundness data, using the Krumbein Scale</u>. Approximately twenty pebbles/granules were measured from each of the Ste. Anne sections by 5 equally experienced students independently, using the Krumbein scale of roundness. The results are shown on Table 11.

i. Null Hypothesis: Ho: the different roundness values measured by 5 students independently give essentially the same results, if the same technique is used.

ii. Hi: the results obtained by the 5 students are dissimilar

iii. The test is chosen because the students and the values obtained are independent and because the values are frequencies in discrete categories. A grouping of the data was required so that the categories, formerly 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, were put into groups 0.1 - 0.3, 0.4 - 0.6, 0.7 - 0.9. There were no broken pebbles.

iv. Significance level: Let $\alpha = .05$

N is variable between 88 - 108

v. Sampling distribution: χ^2 as computed from the following formula:

$$\sum_{i=1}^{r} \sum_{j=1}^{k} \frac{(Oij - Eij)}{Eij}$$

where $Eij = \frac{Ri \times Ki}{N}$

and where

Oij = observed values

Eij = expected values

The degrees of freedom are as follows:

$$df = (r-1)(k-1)$$
$$r = \text{number of rows}$$
$$k = \text{number of columns}$$

$$df = (5-1)(3-1) = 8$$

vi. Rejection Region:

After consulting the appropriate Table for χ^2 values in S. Siegel (1956, p. 249), the region of rejections is

$$(-2.18 \leqslant x \leqslant +17.5)$$

a total number of 18 tests were conducted and the following results obtained, such that the Null Hypothesis was either accepted or rejected:

Section	2 - reject	Section	11 - reject
	3 - reject		12 - accept
	4 - accept		13 - reject
	5 - reject		14 - reject
	6 - reject		15 - accept
	7 - reject		16 - accept
	8 - accept		17 - accept
	9 - accept		18 - reject
	10 - accept		19 - reject

The overall results show that 45% of the time the Null Hypothesis was accepted, and 55% of the time it was rejected, at the .05 level of significance. The results are therefore inconclusive.

b. <u>The roundness data from the Ste. Anne ridge</u>. The roundness data taken from the Ste. Anne ridge is found in Table 12. The average value from each section is calculated to determine the trend in roundness values along the length of the ridge. A plot of this data, against distance, is shown on Fig. 3-21. This plot was based on similar axes as Fig. 3-12, "Plot of Effective Settling Sphericity with Distance". A similar degree of variation is shown in both. An overall trend can be

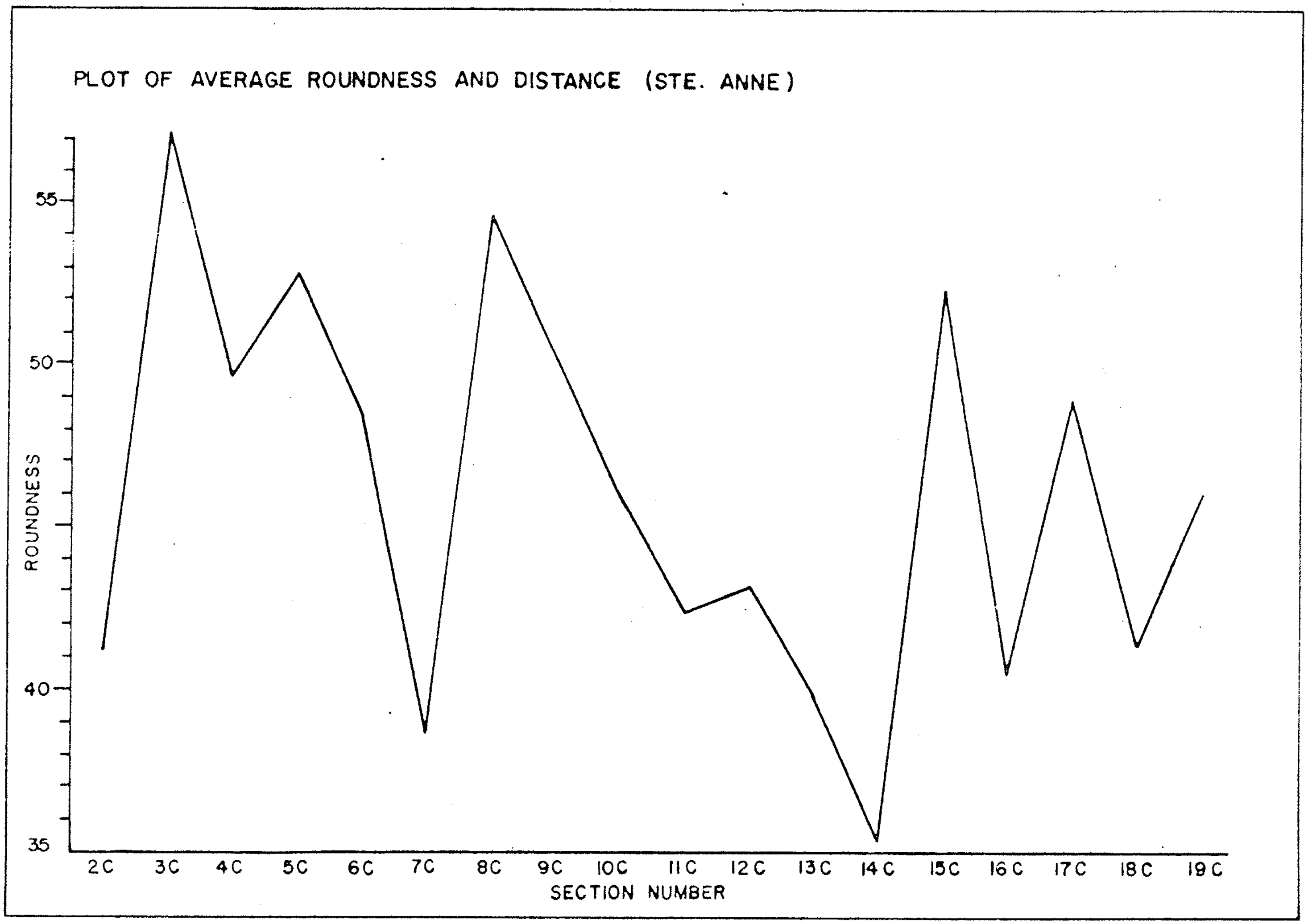

PLOT OF AVERAGE ROUNDNESS AND DISTANCE (STE. ANNE)
ROUNDNESS
55
50
40
35
2C
3C
4C
5C
6C
7C
8C
9C
10C
11C
12C
13C
14C
15C
16C
17C
18C
19C
SECTION NUMBER

Fig. 3-21

Table 11

The Chi-Square Test on Roundness Data (Ste. Anne)

	Students	Roundness values						
		.1 - .3		.4 - .6		.7 - .9		
		0	χ^2	0	χ^2	0	χ^2	
Sample 2 (total: 22.63)	1	5	.06	6	2.00	9	7.12	20
	2	5	.06	8	0.64	7	2.69	20
	3	6	.0286	14	1.09	0	3.8	20
	4	6	.0286	11	0.02	3	0.17	20
	5	6	.0286	14	1.09	0	3.8	20
		28		53		19		100
Sample 3 (total: 27.15)	1	1	1.59	14	.05	7	1.36	22
	2	6	3.03	12	.06	2	1.08	20
	3	2	.51	19	1.63	1	2.74	22
	4	7	5.38	8	1.86	5	.19	20
	5	0	3.44	16	.09	7	4.14	23
		16		69		22		107
Sample 4 (total: 12.06)	1	9	.67	5	1.58	6	.54	20
	2	7	.01	9	.00	5	.02	21
	3	8	.19	11	.61	1	2.67	20
	4	8	.01	13	.63	3	1.02	24
	5	5	1.05	9	.10	9	2.96	23
		37		47		24		108

Table 11 (continued)

	Students	Roundness values						
		.1 - .3		.4 - .6		.7 - .9		
		0	χ^2	0	χ^2	0	χ^2	
Sample 5 (total: 37.28)	1	2	.61	5	3.07	12	10.81	19
	2	3	.06	15	1.68	1	3.01	19
	3	4	.04	14	.64	2	1.84	20
	4	0	3.82	13	.11	8	1.37	21
	5	9	7.91	9	.47	2	1.84	20
		18		56		25		99
Sample 6 (total: 23.72)	1	6	.33	9	.01	6	.90	21
	2	11	1.54	7	.58	3	.29	21
	3	6	.64	15	2.23	2	1.37	23
	4	3	3.39	11	.15	9	4.58	23
	5	13	4.62	6	.94	1	2.15	20
		39		48		21		
Sample 7 (total: 26.75)	1	12	4.15	5	1.28	2	1.02	19
	2	9	.53	6	.83	5	.14	20
	3	6	.27	13	1.65	2	1.35	21
	4	1	4.87	8	.01	10	8.84	19
	5	7	.00	11	.62	2	1.19	20
		35		43		21		99

Table 11 (continued)

	Students	Roundness values						
		.1 - .3		.4 - .6		.7 - .9		
		0	χ^2	0	χ^2	0	χ^2	
Sample 8 (total: 15.58)	1	3	.05	9	.33	8	.36	20
	2	1	.90	14	1.28	4	.75	19
	3	7	7.28	8	.78	5	.33	20
	4	1	1.01	13	.40	6	.03	20
	5	1	1.01	10	.08	9	.99	20
		13		54		32		99
Sample 9 (total: 9.60)	1	5	2.51	13	.17	3	.23	21
	2	0	2.38	15	.09	5	.41	20
	3	2	.06	16	.33	2	.83	20
	4	4	1.11	12	.25	4	.02	20
	5	1	.80	14	.00	5	.41	20
		12		70		19		101
Sample 10 (total: 12.52)	1	2	.02	8	1.80	10	3.92	20
	2	2	.02	16	.80	2	2.14	20
	3	0	1.80	15	.38	5	.03	20
	4	3	.80	11	.25	6	.07	20
	5	2	.02	14	.11	4	.36	20
		9		64		27		100

Table 11 (continued)

	Students	Roundness values						
		.1 - .3		.4 - .6		.7 - .9		
		0	χ^2	0	χ^2	0	χ^2	
Sample 11 (total: 27.30)	1	6	.03	9	.10	5	.54	20
	2	13	6.81	6	1.60	1	1.88	20
	3	8	.40	11	.10	1	1.88	20
	4	0	6.40	16	3.60	4	.04	20
	5	5	.31	8	.40	7	3.21	20
		32		50		18		100
Sample 12 (total: 15.54)	1	3	.11	11	.17	5	.48	19
	2	4	1.43	11	.62	2	2.75	17
	3	3	.01	13	.28	6	.45	22
	4	2	.02	6	.83	9	1.38	17
	5	0	2.22	6	.83	11	3.94	17
		12		47		33		92
Sample 13 (total: 26.98)	1	10	2.08	5	.17	1	1.91	16
	2	7	.00	4	1.12	7	2.07	18
	3	9	.47	8	.23	1	2.34	18
	4	9	.47	3	2.08	6	.89	18
	5	0	7.16	13	5.79	5	.20	18
		35		33		20		88

Table 11 (continued)

	Students	Roundness values						
		.1 - .3		.4 - .6		.7 - .9		
		0	χ^2	0	χ^2	0	χ^2	
Sample 14 (total: 21.89)	1	8	.60	12	1.95	0	1.24	20
	2	7	.89	8	.02	4	6.79	19
	3	13	.91	6	.35	0	7.18	19
	4	10	.00	8	.02	1	.03	19
	5	13	.97	5	.91	1	.03	19
		51		39		6		97
Sample 15 (total: 16.54)	1	7	1.01	7	.53	6	0.00	20
	2	4	.13	11	.35	5	.17	20
	3	5	.01	7	.53	8	.67	20
	4	7	1.01	5	1.92	8	.67	20
	5	1	3.01	16	5.03	3	1.50	20
		24		46		30		100
Sample 16 (total: 11.16)	1	10	.13	7	.69	4	.91	21
	2	11	.73	7	.49	2	.06	20
	3	5	1.45	15	3.81	0	2.38	20
	4	9	.03	8	.13	3	.16	20
	5	8	.03	9	.00	3	.16	20
		43		46		12		101

Table 11 (continued)

	Students	Roundness values						
		.1 - .3		.4 - .6		.7 - .9		
		0	χ^2	0	χ^2	0	χ^2	
Sample 17 (total: 15.16)	1	3	.10	9	.14	8	.52	20
	2	9	8.10	8	.47	3	1.65	20
	3	1	1.88	12	.32	7	.10	20
	4	3	.10	12	.32	5	.23	20
	5	2	.71	10	.00	8	.52	20
		18		51		31		100
Sample 18 (total: 23.26)	1	8	.04	4	2.44	8	9.26	20
	2	11	.69	7	.29	2	.26	20
	3	10	.11	11	.44	0	3.00	21
	4	6	1.00	10	.11	5	1.33	21
	5	10	.00	13	1.00	0	3.29	23
		45		45		15		105
Sample 19 (total: 47.52)	1	4	2.23	8	1.84	14	17.45	26
	2	10	2.04	6	1.53	4	.02	20
	3	8	1.21	9	.04	0	3.15	17
	4	1	3.62	16	6.84	0	3.15	17
	5	8	1.21	9	.04	0	3.15	17
		31		48		18		97

Table 12

Roundness Values (Average of 5) Ste. Anne (W. C. Krumbein)

Section	.1	.2	.3	.4	.5	.6	.7	.8	.9	Average Roundness Value for Sample
2c	0.12	0.44	0.66	0.88	1.8	2.88	1.12	1.16	0.18	0.412
3c	0.04	0.32	0.36	1.12	1.90	4.32	1.68	1.28	0.36	0.571
4c	0.18	0.52	0.9	1.36	1.4	1.92	1.82	1.12	0.72	0.497
5c	0.04	0.2	0.66	1.04	2.40	2.28	1.54	0.8	1.62	0.529
6c	0.12	0.6	1.08	1.2	1.8	1.56	1.82	0.8	0.72	0.485
7c	0.12	0.32	1.02	0.96	0.14	2.04	1.68	1.28	0.18	0.387
8c	0.0	0.12	0.6	0.64	1.55	3.24	2.66	1.76	0.36	0.547
9c	0.04	0.0	0.6	1.2	2.8	3.48	1.68	0.9	0.18	0.565
10c	0.02	0.04	0.42	0.88	0.22	3.48	1.82	1.6	0.72	0.460
11c	0.01	0.36	1.08	1.12	2.4	1.44	1.26	0.08	0.72	0.424
12c	0.04	0.12	0.42	0.4	0.9	1.92	3.22	1.44	0.18	0.432
13c	0.04	0.6	1.08	1.12	1.0	1.08	1.82	0.32	0.9	0.398
14c	0.12	0.76	1.56	1.42	1.6	0.72	0.42	0.48	0.0	0.354
15c	0.12	0.36	0.54	1.44	1.0	2.16	0.98	2.24	1.62	0.523
16c	0.2	0.64	1.02	1.76	1.7	0.96	0.98	0.64	0.18	0.404
17c	1.0	0.16	0.54	1.04	1.6	1.76	2.1	1.76	0.72	0.489
18c	0.32	0.6	0.84	1.28	1.3	1.56	0.98	0.48	0.9	0.413
19c	0.08	0.56	0.78	0.8	1.9	2.28	0.56	2.24	0.0	0.460

here recognized, which is dissimilar from the sphericity plot; there is a tendency for the pebbles and granules to decrease in roundness northwards along the ridge.

Local decreases in sphericity correspond with roundness decreases, for instance at 7c and 11c in both Figs. 3-12 and 3-21. There is also a correspondence of peaks in the roundness graph (15c) with troughs in the sphericity graph (15c). The degree of variability of the roundness corresponds with the variability in the sphericity, such that the task of recognizing overall trends from the data is complicated.

A further test was also used to compute the roundness of pebbles in random samples from the Ste. Anne ridge. Here the Caillieux method was employed. Average roundness values of individual pebbles from different sections are 472, 478, 645, 364, 308, 222, 601, 444, 415, 364, 296, 625, 424, 280, 432, 439, 397, 256, 262, 227, 418, 372, 299, 295 and 360. The values again represent a considerable amount of variety throughout the sections, as the average roundness value for all the ridge pebbles sampled is 387.8, compared with a maximum and minimum of 645 and 222 respectively.

3. <u>A Review of the Past Literature and the Interpretation of the Ste. Anne ridge data.</u>

a. A considerable amount of literature has been written on the interpretation of roundness data. S. D. Russell and R. E. Taylor (1937) considered the roundness of certain Mississippi River sands and found that there was no evidence of increased roundness with distance downstream. In fact, the larger sand particles become slightly more angular downstream, due to the chipping and fracturing of grains. There is no definite longitudinal trend in roundness values along the Ste. Anne ridge, so current directions cannot be determined. Russell and Taylor expressed the fact that in their area of analysis there was a fluctuation of roundness values concomitant with the directional trend. A further similarity with the Ste. Anne data is the overall tendency for roundness values to decrease northwards. A valid comparison cannot take place, however, because Russell and Taylor analyzed sand particles, and in the present study pebbles were measured.

b. According to W. C. Krumbein (1941), degree of roundness is the product of modification by the abrasion to which the particles are subjected. It is not a reflection of conditions of transportation or deposition. The attainment of roundness is relatively rapid in the early stages of transportation, after which further rounding becomes much slower. F. J. Pettijohn and A. C. Lundahl (1943), as a result of their measurement of Lake Erie sands, concluded that roundness and sphericity were closely associated there and, that whereas sphericity declined slightly in the direction of sand shift, roundness declined considerably. They maintained that the decreased roundness in this case is due to the sorting of sands by water movement in a down current direction, which carries the less round grains further along the beach. The results here cannot be directly compared with those found by Krumbein or Pettijohn and Lundahl, because of the extreme fluctuation in values throughout the length of the Ste. Anne ridge.

c. The work of M. A. Beal and F. P. Shepard (1956) is of importance in so far asroundness is used to determine depositional environments. However, it relates mainly to sand size deposits. A difference was shown in the results of roundness analysis between beach and

Table 13

a. Orientation Direction by Section Numbers (Ste. Anne)

Section	Primary	Secondary	Tertiary
2B - 3C	60 - 80	80 - 100	5 - 20
4D	120 - 140	100 - 120	5 - 20 40 - 60
10C	80 - 100	100 - 120	60 - 80
14B	5 - 20	20 - 40	160 - 180
16B	100 - 120	120 - 140	140 - 160
18D	120 - 140	100 - 120	140 - 160

b. Test of Orientation Strength after S. A. Harris (1969)

Section	Number of pebbles	Orientation direction	Observed frequency in modal class	Result
2B - 3C	103	60 - 80	19	NS
4D	100	120 - 140	17	NS
10C	102	80 - 100	27	S
14B	104	5 - 20	20	NS
16B	106	100 - 120	24	NS
18D	100	120 - 140	29	S

S = significant NS = not significant

c. Chi-Square Test taking Average Values

	Frequency 0 - 60	60 - 120	120 - 180	Total	Expected Values
2B - 3C	32	49	22	103	34.33
4D	30	25	45	100	33.33
10C	15	64	23	102	34.00
14B	40	21	43	104	34.67
16B	12	42	52	106	35.33
18D	16	34	50	100	33.33
Total	145	235	235	615	204.99

Oi = $\bar{x}$ - each category	24.17	39.17	39.17
Ei = expected frequency	34.17	34.17	34.17

$$\chi^2 = \sum_{i=1}^{k} \frac{(Oi - Ei)}{Ei} = 4.39$$

dune sands. The difference is thought to be due to selective sorting by wind. Part of their work involved sampling of grains that were taken from beach-dune traverses on Padre Island and Mustang Island, Texas. In Padre Island the roundness of sands in the beach berm is approximately .34, that of the beach backslope .31, and the dune sands .39. If a comparison can be made between the Ste. Anne data and that of Beal and Shepard, the Ste. Anne ridge appears to be more comparable to dune ridge deposits. But it must be noted that sand and pebbles cannot be directly compared.

J. D. Waskom (1958) took 59 sand samples from the Panhandle coast of Florida. From different environments of deposition the results show that the average roundness value of quartz grains for the offshore environment = .260, in the open swash zone = .268, dune = .269, beach ridge = .287, and marsh = .243. Hence, the open swash zone, dune and beach-ridge environments have relatively high values compared to the offshore environment and marsh samples. A comparison between these results and the ones obtained at Ste. Anne is inaccurate because of the distinction between sand and pebble grain sizes. However, the beach-ridge value obtained by Waskom is closer to the pebble values found at Ste. Anne than the values obtained by him for other environments of deposition.

When considering pebble associations, C. S. Sames (1966) states that only littoral, fluvial and detrital ones can be differentiated. The data he analyzed showed that littoral and fluvial associations share the medium grades of roundness. The fluvial associations, however, have a certain percentage of angular components and show a wider variety of pebble shapes than do the littoral deposits, which tend to be more uniform and show higher degrees of roundness since angular particles are eliminated. By comparison, the Ste. Anne roundness values are quite uniform since the range is not extreme.

d. A different roundness method was used in the work of C. A. M. King and J. T. Buckley (1968) and environments of deposition were equally well able to be differentiated. The roundness factor is claimed by the authors to be the most valuable tool of environmental differentiation. Moraines (138), kames (238), eskers (332), beaches (398) can be distinguished because of the different roundness values of their constituents. The values for eskers and deltas (334) are almost identical; therefore presumably the two cannot be clearly differentiated. Of the values obtained for the Ste. Anne data, the average 387.8 most closely corresponds to a beach pebble value, when compared with the table in King and Buckley's article (p. 211).

Therefore this section is inconclusive because roundness values which occur in the literature are taken on sand size particles and here pebbles are used. If one can consider trends in roundness variation there are similarities between the Ste. Anne pebbles and the Mississippi River sands, discussed in part a, above.

There is no evidence of rapid attainment of roundness and subsequent drop-off as described by Krumbein. The overall increase in roundness to the north at Ste. Anne resembles the trend described by Pettijohn and Lundahl. The direction of a current in this section of Lake Agassiz may have been northwards at this time.

The Ste. Anne data may indicate that the ridge is a dune when compared with Beal and Shepard's data, or a beach-ridge when compared with Waskom's data, the uniformity obtained by Sames, and the values found by King and Buckley.

The inference is therefore that the Ste. Anne ridge is most probably a beach, but it may possibly be an esker or a dune deposit.

Section D. An Evaluation of Orientation Data

The last section of Chapter 3 consists of the following sub-sections:

1. A Review of the Past Literature on Orientation Methods and Results.

2. A Consideration of the Long Axis Data from the Ste. Anne ridges.

3. Interpretation of the Orientation Data from the Ste. Anne ridge and Tentative Conclusions.

1. A Review of the Past Literature on Orientation Methods and Results. Some of the earliest works on orientation studies are reviewed in W. C. Krumbein and F. J. Pettijohn's book (1938). In general the aim of orientation studies is to determine the direction of transport of a pebble by measuring the orientation of its long axis, and, if any, its dip. K. Richter (1932) measured the long axes of till pebbles with a compass to determine the direction of ice movement. This study lead the way to a number of other petrofabric analyses.

Methods of collection of samples and laboratory analysis are described by W. C. Krumbein and F. J. Pettijohn (1938). A Brunton pocket compass was suggested, plus lacquer to mark the pebbles. The samples are then measured with an "ordinary two-circle contact gonio-meter". The long axis and dip are then readily read off.

Methods of presenting the data include a histograph or frequency diagram of strike or dip direction, or polar co-ordinate diagrams. Linear statistical methods are advised for use in computing the moment measures.

N. V. Karlstrom (1952) developed a new method of measuring orientation data in the field. By substituting a 5" x 4" template instead of Wadell's drawing method. However, the use of the goniometer is basically the same.

J. R. Curray (1956) described the analysis of two dimensional orientation data, and suggested different statistical methods to indicate the preferred orientation direction, degree of preferred orientation and the probability that a preferred orientation is real and not due to chance. The resultant vector method is preferred over linear statistical methods because of the circular distribution of the data. The vector direction is the preferred orientation direction of the long axes, and the vector magnitude provides a measure of dispersion. When trying to ascertain if the frequency is due to chance alone, Curray discounted the use of the Chi-Square Test because the "deviations from randomness which produce a significant result do not necessarily represent a preferred orientation" (p. 125). This is basically true of most statistical tests of this type. Curray prefers the use of the Rayleigh Test (originally used for describing random phases in sound waves) because each observation can be represented by a vector, with direction and magnitude, and analyzed from a graph.

Later work by J. R. Curray (1956) undertook an analysis of sands, taken from various locations around the Gulf of Mexico. The data showed a tendency for elongate sand grains to align themselves with their long axes parallel to the backwash direction of waves on the beach and therefore perpendicular to the latter's trend.

T. A. Jones (1968) suggests that linear distributions may not be used in order to estimate the significance of the circular distribution. Vector mean and vector strength are defined following a previous description of a vector mean by W. H. Wood and R. M. Wood (1966). Jones suggests the use of other statistics which are derived from a circular distribution.

The supposition that mechanical forces do lead to an orientation of grains has often been assumed, rather than proven. However, laboratory work by E. A. Rusnak (1957) has demonstrated that, under unidirectional flow, the most stable position for sand particles is with their long axes parallel to the direction of fluid motion. Furthermore, they possess some imbrication, dipping slightly into the current. The preferred orientation in this case was determined statistically by the use of the Chi-Square Test.

The orientation of pebbles in running water has been examined by C. E. Johansson (1963). The basic unit examined is the deltaic form. In the top-set beds the orientation of pebbles is seen to depend on the form of the bed and mode of transportation. A primarily transverse orientation (and some longitudinal orientation) occurs when pebbles are transported as contact load along a bed without obstacles. A longitudinal orientation results from long jumps, or when the particles turn round obstacles during bed-load transportation. The foreset beds are thought to be more comparable to the Ste. Anne pebbles than top-set and bottom-set beds, described by Johansson.

Therefore there are a number of techniques described in the literature. The results obtained may vary with the techniques chosen. A relatively early writer (H. Wadell, 1936) used the clinometer method and plotted his data on a histogram. He compared the orientations of pebbles in an esker with those from an outwash delta. These were found to differ with respect to the beds in which they were contained.

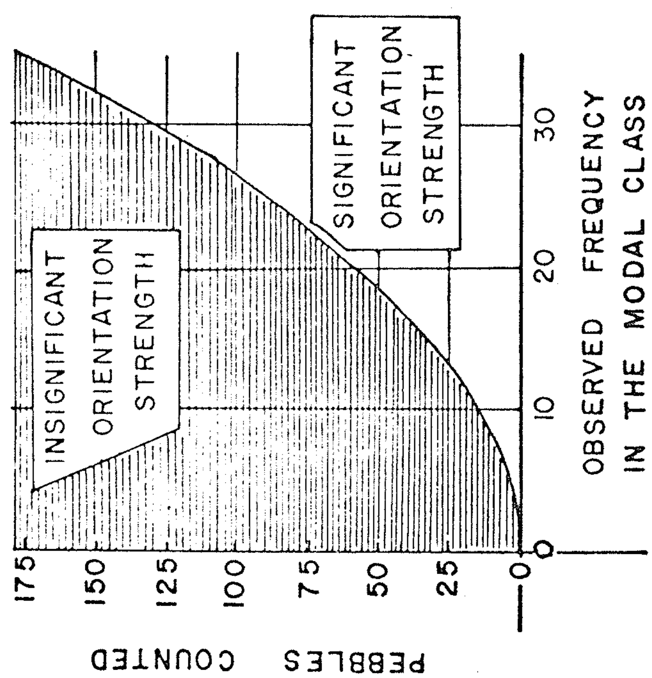
W. C. Krumbein, stimulated by the work of Wadell and Richter, suggested that equiarea polar co-ordinate paper be used in conjunction with petrofabric (shaded) diagrams. In this way both the relatively raw data and the interpretation may be seen. He found that a drumlin contained a number of pebbles with their "A" axes parallel to the direction of ice movement. The mean direction was found by using the standard radius - vector summation method. Histograms were drawn showing the azimuthal distribution of till pebbles ("A" axis measurements). Results from petrofabric diagrams showed that, in the case of outwash pebbles, there was a considerable amount of scatter and weak orientation, with some indication of streamflow. Beach pebbles and disc-shaped dolomites were also analyzed. The long axis analysis showed a tendency for the pebbles to lie parallel to the shoreline. It is therefore assumed that they are transported with their "A" axes normal to wave direction.

Orientation work has been extended in the area of till fabric analysis by various authors, including R. G. West and J. J. Donner (1965), in East Anglia, England. In their work, proof of ice-direction is drawn from inconclusive evidence. New methods of obtaining till fabric data, including detailed accounts of field and laboratory procedures, have been described by P. W. Harrison (1957a) and their employment described in a later article (1957b). Using samples from ground moraines and end moraines, it was shown that disc and blade shaped particles have a preferred imbrication upstream to former glacier movement directions. Other till fabric studies include work by A. Shrirmadas (1957) and R. B. Rains (1969). Mainly these consist of detailed analytical works which are based on the assumption that the preferred orientation of particles in till deposits is accordant with the direction of ice flow.

Recent work on till fabric analyses has been completed by S. A. Harris (1969). Here the method of plotting the data involves the use of rose diagrams as opposed to the more common alternative, the three dimensional polar stereographic protection, because of the relative ease with which statistics might be applied to the data. Also the rose diagram is easier to comprehend visually, and preferred orientations are more readily discerned. A disadvantage of this method was pointed out by J. T. Andrews and K. Shimizu (1966). This is because the data needs to be grouped so generalizations occur, their extent depending on the size of the class interval used.

Harris (p. 319) uses the Chi-Square Test to analyze his results because the observed and expected results in each class can be compared, and an .05 level of significance can be evaluated for the primary mode. Also this test has been used in other studies, so the results may be compared. The graph, which is used in Harris' work to determine whether or not the primary mode is significant, is adopted for use in the present study in Section b.

2. <u>A consideration of the Long Axis Data from the Ste. Anne ridge</u>. As can be discerned from the past literature, a large proportion of orientation studies involve the use of varied statistical analytical techniques. A particularly valuable technique because of its



after S.A. Harris (1969)

Fig. 3-22

statistical validity and ease of calculation is that outlined by S. A. Harris (1969). In this work the graph showing the number of pebbles needed in the primary modal group to give a .05 significance level value against a given total frequency of pebbles is shown. This is adopted in the present study as Fig. 3-22.

In the Ste. Anne area at least 100 pebbles were measured from Sections 2B and 3C combined, 4D, 10C, 14B, 16B and 18D. These particular locations were chosen at random from the sites which contained pebbles. Only the long axes of pebbles were measured, 100 to 106 being taken in each case. The face was first cleaned off with a brush, the long axis was determined <u>in situ</u> and its orientation measured with the use of a Brunton compass. Only the orientations of pebbles in horizontal beds were measured.

The results of the orientation analysis are shown on Fig. 3-23 (in pocket). Some inaccuracies occur as the pebbles are grouped in 20° arcs. The radial scale shows the number of pebbles counted, and the values for each section are shown in the figure. The modal frequencies here are to some extent obvious. Towards the southern part of the ridge the orientation of the pebbles is variable, a primary mode occurring between 60 and 80 degrees east of north, and a secondary mode between 80 and 100 degrees. At 4d there is also a high degree of variability, but the primary modal area occurs between 120 - 140 degrees, the secondary mode occurs between 100 - 120 degrees. At Section 10c, towards the center of the ridge, the modal area is more pronounced, occurring between 80 and 100 degrees. At 14b more variability is again introduced, with a greater north-south orientation as opposed to the predominantly east-west one found in the previous 3 Sections. The primary modal frequency occurs between 0 - 20 degrees and the second most populated class is between 160 - 180 degrees. At 16b and 18d there is a greater tendency towards an WNW - ESE orientation, with the primary modal frequency in 16b being between 100 - 120 degrees and secondary grequency between 120 - 140 degrees. In 18d there is a very large primary modal frequency between 120 - 140 degrees. The Table 13a is taken directly from a visual inspection of Fig. 3-23. Relative division of the rose diagram results shows certain primary, secondary and tertiary orientation modes in each section. The frequency of appearance in each orientation group, when all are taken together, indicates the dominance of the 100 - 120 degree class. The second most dominant class is that between 0 - 20 degrees.

However, as stated above, there is a considerable amount of variability in the data. Therefore the significance of these values can only be ascertained if the Chi-Square Test is run. The method used is that described by Harris (Fig. 3-22) to find the significant orientation strength. The results of this test are found in Table 13b. Only in two cases, 10c and 18d, are the primary modal frequencies high enough to have a significant orientation strength. Therefore the preferred orientations are weak and rather inconclusive except at the center and northern limits of the ridge (where it is oriented NE - SW). Yet there is no consistency in the preferred orientations at 10c (80 - 100 degrees) and 18d (120 - 140 degrees). Therefore there may have been no dominant current direction.

Because of the variability of the data and because the secondary modal frequency often occurs in a class contiguous with the primary class larger groupings had to be taken to attempt to achieve more significant results. The larger orientation groupings are 0 - 60, 60 - 120, 120 - 180 degrees. The relevant data are shown on Table 13c. The test is run as follows:

a. Null Hypothesis: Ho: there is no difference in the modal frequency in the 3 orientation directions (using average values from six sites)

Hi: there are differences in the modal frequencies of the three groups.

b. Test: the Chi-Square Test is used because the observed and expected frequencies occur in discrete categories.

c. Significance level: $\alpha = .05$

$N = 102.5$

The sampling distribution of χ^2 is computed from the formula

$$\chi^2 = \sum_{i=1}^{k} \frac{(Oi - Ei)}{Ei}$$

where Oi = the observed values
Ei = the expected values
df = degrees of freedom
k = number of categories

df = k-1

The result of the computations = 4.39

The relevant χ^2 value (S. Seigel, p. 249) = 5.99

Therefore the Null Hypothesis cannot be rejected, so there is no significant difference in the different modal frequencies, when all are taken together, and there is no significant orientation along the Ste. Anne ridge.

The only statistically significant orientation results are obtained from individual sections 10c and 18d, which have significant orientation strengths at 80 - 100 degrees and 120 - 140 degrees respectively or E - W and NE - SW across the ridge.

3. <u>Interpretation of the Orientation Data from the Ste. Anne Ridge and Tentative Conclusions</u>. Because of the lack of significant orientation strengths throughout the ridge it may be assumed that there is no significant preferred orientation in the Ste. Anne ridge, or the sample taken was too small.

However, in two locations there are significant orientation strengths involving E - W and SE - NW components. If the Ste. Anne ridge were an esker and therefore subjected to uni-directional flow, there should be a relatively strong north-south component of orientation, in spite of a slightly winding course. This is assuming that E. A. Rusnak's (1957) work on sand particles is applicable to the pebbles here studied. Although, if there were no obstacles in the bed, an E - W component is equally likely. This is assuming a similarity with C. E. Johansson's (1963) work when he was discussing a delta type of situation. On this basis, therefore, no tentative conclusions can be drawn.

W. C. Krumbein (1939) found that there was a considerable scatter on pebbles from outwash deposits. The degree of scatter is not stated, but that at Ste. Anne is similarly large. The same author also determined that beach pebbles lay parallel to a shoreline. The pebble orientations at Ste. Anne have preferences which, except in the case of 14b, do not even approximately parallel the ridge.

Work by J. R. Curray (1956b) showed that beach sands align themselves with their long axes parallel to the backwash direction. If this effect is applicable to pebbles, then there is evidence in the form of preferred orientations that the Ste. Anne ridge may have been deposited in a beach environment.

The various till fabric analyses in the literature cited in section a tend to indicate that a preferred orientation of pebbles does occur, although the study areas are much larger than the Ste. Anne ridge. Localized scatter occurs in these areas, as exemplified by the results of S. A. Harris' work (1969). So, assuming a low degree of modification by reworking processes, then basically the Ste. Anne ridge may consist of a till deposit. Although at a depth of 2 ft., this is extremely unlikely. The evidence of the Ste. Anne data is not strong but some orientation is preserved in the ridge.

The conclusions drawn here are extremely tentative, and more work is required on this aspect of environmental determination, both on the supposed Agassiz beach ridges and elsewhere. However, the evidence suggests that the Ste. Anne ridge may be a shoreline feature or an end-moraine deposit.

Chapter 4

MICROSCOPIC ELEMENTS OF SEDIMENTARY ANALYSIS

In Chapter 4 two aspects of sedimentology are discussed.

A. The Textural Analysis of the Ste. Anne and Ponton Sands.

B. An Evaluation of the Percent Heavy Mineral Content at Ste. Anne and Ponton.

A. <u>The Textural Analysis of the Ste. Anne and Ponton Sands</u>

This section of the chapter is presented under the following headings:

1. Methods of particle size analysis
2. Theory of particle size analysis
    a. Grade scales
    b. The size distribution of sediments
    c. Populations in sedimentary analysis
3. Literature on the validity of certain particle size parameters in the interpretation of depositional environments
4. The presentation of the particle size data from Ste. Anne and Ponton
5. Conclusions based on an interpretation of the data, and comparisons with the past literature

1. <u>Methods of particle size analysis</u>. Samples of sand were taken from both the Ste. Anne and Ponton areas. In each case a homogeneous sample was obtained, complying with G. H. Otto's (1938)

sedimentation unit, as this was redefined by A. V. Jopling (1964). Samples were taken such that a group of representative values may be determined for the A, B, C, D and E sections at Ste. Anne. As the variation in particle size with depth is important, samples were taken from different beds at a number of sections. In the Ponton area, samples were taken from each ridge so that variations may be revealed.

A number of different methods of particle size analysis had to be considered prior to sampling. A lengthy review on the principles and methods of mechanical analysis is found in W. C. Krumbein and F. J. Pettijohn's book (1938) "Manual of Sedimentary Petrography".

Sand size particles can be measured by the following methods:

a. The microscopic measurement of loose grains (W. C. Krumbein, 1935, J. C. Griffiths, 1958, 1961) tends to be tedious compared to other methods, hence inaccuracies are due to the small sample size.

b. The settling tube has the advantage of speed, but is considered to be a rather inaccurate method. D. M. Poole (1957) stated that the settling tube method used in the size analysis of sand has advantages over other techniques because the fluid media involved permits a close approximation to the hydrodynamic conditions of sedimentation. It is admitted that the sediment diameters discerned by this method are generally coarser than the equivalent sieve diameter. They are also finer than the microscopically measured diameters. C. L. Bascombe (1968) developed a new method to determine the size analysis of sediments by sedimentation. This involves the use of a manometer and transducer which follow the drop in hydrostatic pressure near the bottom of a column of soil suspension during sedimentation. The electrical current is fed onto a recorder, which traces an accumulation curve. This method is as accurate as both sieving and pipette analyses, over the 20 - 200 μ range. A similar method, involving a Hand settling tube and event recorder, has been described by H. G. Modarresi (1968), and is also used for sand size particles. These methods are not yet widely used.

c. Sieving is considered by R. L. Folk (1964) to be probably the most accurate method for the general analysis of sand and gravel. It is not as fast as the settling tube method, but it has the advantage of accuracy. A close analysis can be made provided that screens of $\frac{1}{4}\phi$ intervals are used. Methods of sieve analysis are given in detail by W. C. Krumbein and F. J. Pettijohn (1938) and R. L. Folk (1968). Possible variations within the method itself may be reflected in the type of sieve-shaker used. In 1946, A. Swineford and F. Swineford compared three types of sieve-shakers with a different action. The mechanical sieve-shaker with a jarring action was found to be superior to two others which had only a horizontal motion. Because of its accuracy, wide acceptance, and usage in general, sieve analyses were made on the sand-size fraction of the sediments from Ste. Anne and Ponton.

2. Theory of particle size analysis.

a. Grade scales. One of the first geometric grade scales was introduced by J. A. Udden (1898). The intervals decreased by the ratio of $\frac{1}{2}$ and originally included twelve grades from 16mm. diameter to 1/256 mm. This scale was later modified by C. K. Wentworth (1922). Certain definitions were also suggested so that use of the terms pebbles sand, silt and clay might be standardized. This had been done to a lesser extent in both Atterberg's Size Classification and the classification used by the U. S. Bureau of Soils. In 1934 W. C. Krumbein modified the Wentworth Scale into its logarithmic equivalent by means of a transformation equation $\phi = -\log_2 \xi$ (where ξ = the diameter in millimeters). The scale was developed so that conventional statistics could be applied to sedimentary data. In 1938, W. C. Krumbein considered the value of the normal phi-curve. The Phi-Scale is used almost entirely in recent work in particle size analyses. The different scales are shown on Table 13, after R. L. Folk (1968). A criticism of particular uses of the phi-notation was discussed by D. A. McManus (1969). Among other errors, inaccuracies in the literature included the correlation of ϕ with the equivalent mms. instead of with the symbol ξ, and the log value was not being considered a dimensionless number. The general acceptance and usage of the particle size scale has been reviewed by W. F. Tanner (1969) for an S.E.P.M. report. Complimentary assets include the flexibility of the scale, which may extend to any extreme, the geometric basis allowing all parts of the size range spectrum to be observed, and the fact that the major dividing points coincide with natural class boundaries (approximately).

b. The size distribution of sediments. The size distribution curve, which was developed by W. C. Krumbein (1934, 1938) was based on the assumption that sedimentary particles are normally distributed such that a curve is easily defined by the mean and standard deviation. The logarithmic probability law (the normal phi-curve) has the same attributes. Determinations of normalcy may be made by consideration of the first 4 moments--mean diameter ($M\phi$), standard deviation ($\sigma\phi$), skewness (α_3) and kurtosis (α_4). Once sieved, the resulting data is generally plotted on Arithmetic Probability Paper. The Cumulative

Table 13 A

The Particle Size Scale

	Millimeters	Phi (ø)	Wentworth Size Class	
	4096	-12		
	1024	-10	Boulder (-8 to -12o)	
	256	-8	Cobble (-6 to -8o)	
	64	-6		
	16	-4	Pebble (-2 to -6o)	GRAVEL
	4	-2		
	3.36	-1.75		
	2.83	-1.5	Granule	
	2.38	-1.25		
	2.00	-1.0		
	1.68	-0.75		
	1.41	-0.5	Very coarse sand	
	1.19	-0.25		
	1.00	0.0		
	0.84	0.25		
	0.71	0.5	Coarse sand	
	0.59	0.75		
1/2	0.50	1.0		
	0.42	1.25		
	0.35	1.5	Medium sand	
	0.30	1.75		SAND
1/4	0.25	2.0		
	0.210	2.25		
	0.177	2.5	Fine sand	
	0.149	2.75		
1/8	0.125	3.0		
	0.105	3.25		
	0.088	3.5	Very fine sand	
	0.074	3.75		
1/16	0.0625	4.0		
	0.053	4.25		
	0.044	4.5	Coarse silt	
	0.037	4.75		
1/32	0.031	5.0		
1/64	0.0156	6.0	Medium silt	
1/128	0.0078	7.0	Fine Silt	
1/256	0.0039	8.0	Very fine silt	
	0.0020	9.0		
	0.00098	10.0	Clay	MUD
	0.00049	11.0		
	0.00024	12.0		
	0.00012	13.0		
	0.00006	14.0		

After R. L. Folk, 1968.

Frequency (0-100%) occurs on the Y axis, and the Phi-Unit values on the X axis. The latter may be geometrically spaced, giving the size distribution curve an open "S" appearance. Alternatively, it may be a log scale, such that if the data is normally distributed the curve becomes a straight line. G. H. Otto (1939) was probably among the first to use a Log Probability graph. Different theoretical curves can be drawn from the distributions found on Log Probability Paper. Certain of these are discussed by W. C. Krumbein and F. J. Pettijohn (1938) and E. A. Lohse (1955). S. A. Harris (1958) also found that certain deposits obeyed the Log Probability function. The resulting lines assisted in the recognition of the adjustment of present day and past deposits to their depositional environment.

W. F. Tanner (1958) discussed the fact that many distributions of sedimentary data are non-normal. Using nine examples, each was plotted as a zig-zag line consisting of two or more straight line segments, the inference being that more than one population is involved. The pattern is caused by the deficiency of particles of certain sizes. Later Tanner (1959) devised the method of differences to ascertain the nature and properties of the combined populations, although Tanner does not guarantee that the procedure always works.

As will be demonstrated in a later section, the distinction of certain environments of deposition in many cases is thought to be reflected in the third moment. G. M. Freidman (1962a) stated that dune sands are generally positively skewed and beach sands negatively skewed. This skewness, which occurs in different forms varying with the sediment, is indicative of a non-normal distribution. In 1963, J. Brezina detailed a method of converting a normal distribution into a log-normal type using Kapteyn's transformation. This is done graphically by means of a Log-Hydrodynamic Probability Chart, which utilises logarithms of settling velocity. The ideal Log-Hydrodynamic Probability Chart would remove from the cumulative grain size distribution curves the negative skewness caused by water deposition. The deviations in the transformed distributions may then be interpreted as being due to local aberrations in the geological or hydrodynamic environment.

c. Populations in sedimentary analysis. As becomes apparent from Section b, complications to grain size analyses occur when the geological populations are mixed. Early work on populations includes that of D. J. Doeglas (1946) who recognized three main types of transported detritus which are dependent on energy conditions at the site of deposition. The concept of geological populations has been reviewed by a number of workers, including W. C. Krumbein (1960). A. J. Moss (1962) distinguishes these discrete populations in nature, which he referred to as A, B and C. Only A, a water laid deposit, occurs in an unmixed state. Remaining deposits are made up of combinations of the three. Six combination types are common and are found in different environments, ranging from coarser to finer. J. N. J. Visser (1966) showed that certain grain sizes were deficient in nature, depending on the depositional environment. These values include ranges of 4 - 1 and 1/8 - 1/16 mm. for particles in fluvial deposits, 2 - 1 and 1/32 - 1/128 mm. for marine deposits, 1/32 - 1/128 mm. for lacustrine deposits, 1/8 - 1/16 mm. for aeolian deposits and 1/8 - 1/32 mm. for glacial deposits. Assuming that all sizes of material are produced in equal amounts, then certain size grades tend to be more abundant due to various processes transporting and modifying the grains prior to deposition. This knowledge is supported by the fact that certain size grades are unstable during transportation.

R. L. Folk (1968) graphically developed a "population" diagram by plotting mean sediment size (of all sediments) against sorting. Well sorted areas occur at -4ϕ, between 0 ϕ and 4 ϕ and at approximately 10ϕ. Badly sorted deposits occur at -2ϕ and 8ϕ. Three similar populations were recognized by D. W. Spencer (1963) since he divided geological populations into gravel, sand with coarse silt, and clay. The factors which characterize a sedimentary population are therefore:

i. the mean size which is dependent, among other things, on the parent materials and the competence and capacity of the transporting media.

ii. sorting, which depends on the source material and probably the consistency of the transporting media, the type of transport and the lack of disturbance <u>in situ</u>. According to R. L. Folk (1968), a beach produces better sorting values than a river for the same size values, because the currents of the former resort the same deposits continuously. Variations can be seen in the sorting values of sands between 1 ϕ and 3ϕ. In beach sands, the standard deviation is between 0.25 and 0.5ϕ, and in river sands the standard deviation is between 0.35 and 1.0ϕ.

iii. skewness and kurtosis, considered in detail in the next section.

3. <u>Literature on the validity of certain particle size parameters in the interpretation of depositional environments</u>. One of the first analyses of sediments which was made in terms of a cumulative frequency distribution was written in 1937 by W. C. Krumbein and

E. J. Aberdeen. In considering the sediments of Barataria Bay, Louisiana five main types of sedimentary curves were found, showing a characteristic variation from the deeper to the shallower parts of the bay. A form of distinction between beach and dune sands occurred in the work of W. D. Keller (1945). He postulated a differentiation of environments based on an F/C Ratio (the proportion of pebble sizes to the maximum grade size). From this modern beaches are distinguished from dune sand and sandstone formations on the basis of size distribution. Ming-Shan Sun (1956) is responsible for a grain size analysis of Jacksonian sediments. Again, a relationship between mean size and energy conditions in a shoreline environment is seen. The Jacksonian Sea is thought to have been rapidly regressive because coarse beach deposits occur immediately above the fine deposits.

Following on from the work of P. D. Trask (1930) and G. H. Otto (1939), various parameters have been described by geologists to define sediments in certain environments. These are reviewed in detail in R. L. Folk's (1966) article. The parameters, mean grain size, sorting (standard deviation), skewness and kurtosis, are used to distinguish certain environments of deposition as a result of hydrodynamic variations. A relatively unused method has been described by R. Passega (1957). By using an approximation to the maximum grain size (C) and the median (M), CM Patterns were drawn which are seen to vary with the depositional agent. C. F. Royse (1968) recognized fluvial facies as defined by CM Patterns. Channel proximal, flood plain and basin environments were distinguished.

Sedimentary analyses of deposits in shoreline environments include the work of J. L. Hough (1942), J. C. Griffiths (1951),

D. L. Inman (1949) and D. L. Inman and T. K. Chamberlain (1955). In their work on the Brazos River Bar, R. L. Folk and W. C. Ward (1957) considered the quantities of sand and gravel in terms of their particle size distribution, and concluded that there is a lack of correlation between the current strength and the modal grain size of gravel and sand. Therefore the control from the source area is little affected by stream action. The parameters introduced by the authors are modified after P. D. Trask (1930), G. H. Otto (1939) and D. L. Inman (1952), are graphically determined, then computed as follows:

a. mean grain size

$$Mz = \frac{(\phi 16 + \phi 50 + \phi 84)}{3}$$

b. sorting

$$\sigma_I = \frac{(\phi 84 - \phi 16)}{4} - \frac{(\phi 95 - \phi 5)}{6.6}$$

c. skewness

$$Sk_I = \frac{\phi 84 + \phi 16 - 2\phi 50}{2(\phi 84 - \phi 16)} - \frac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

d. kurtosis

$$Kg = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

For one Brazos River Bar the mean size ranged from -1.7ϕ to $+3.2\phi$ for different samples, the sorting from $0.40\,\phi$ to $2.58\,\phi$, skewness from $-68\,\phi$ to $+ .53\phi$, Kurtosis (depending on whether the sample was the channel or spot variety) was either $0.36 - 0.47\phi$ or 0.96ϕ, respectively.

In 1958, C. C. Mason and R. L. Folk distinguished beach, dune and aeolian flat environments on Mustang Island, Texas, by size analysis. The beach deposits showed a nearly normal distribution, with mean size averaging 2.82ϕ. The average dune mean was 2.86ϕ, the aeolian flat mean was 2.83ϕ. Sorting was measured, using the inclusive graphic standard deviation. Beach sands are relatively poorly sorted (0.3 to 0.35ϕ), whereas dune sands have the best sorting (0.21 to 0.26ϕ) and aeolian flat samples have an intermediate sorting (0.26 to 0.28ϕ).

Skewness measured the symmetry of the distribution around 0.00, with the range of skewness being $\pm$ 1.00. Beaches have a skewness of -0.20 to -0.02ϕ, dunes or beaches -0.02 to -0.05ϕ and the aeolian flat environment was a skewness of -0.13 to -0.30ϕ. Positive skewness reflects a number of fine grains in the tail of the distribution. The kurtosis values have been converted by a normalised function,

$$Kg' = \frac{Kg}{Kg - 1}$$

and are as follows: beach or dune sands are 0.47 to 0.53 (mesokurtic) and aeolian flat sands 0.55 to 0.61 (leptokurtic). This is a measure of normality since it compares the sorting in the central part of the curve with that in the tails. Therefore the three environments can be distinguished by size analysis. Mason and Folk found that the clearest distinction occurs when skewness is plotted against kurtosis.

To some extent supporting the work of Mason and Folk, S. A. Harris (1959) stated that the effect of wave action, without longshore drift, on the mechanical composition of sands mainly consists of the removal of the finest grades of material from the beach face (leading to negative skewness). According to Harris, the mechanical composition of the parent material, and not any sorting process, is the primary influence in controlling the range of grain sizes in the coarser fractions. Beach and dune sands were distinguished. F. P. Shepard and R. Young (1961) were able to distinguish between beach and dune sands on the basis of roundness, heavy mineral content (for dunes), shells and mica content for beaches. They stated that beaches are mainly negatively skewed, and dunes positively skewed.

In 1961, G. M. Friedman discussed the use of the method of moments, which is defined by functions rather than graphical interpretations, claiming that previous graphical methods were unsatisfactory. As in other works, the dune sands are seen to be mainly positively skewed and the beach sands negatively skewed. The formulae used are given in Friedman's works. Environmental differentiation occurs when the 1st, 2nd, 3rd and 4th moments (mean, standard deviation, skewness and kurtosis) are plotted against each other in various combinations. Most of the dune sand samples have a mean grain size higher than 1.49 ϕ , and 40% of the beach sand samples have mean values lower than this amount.

A review of diagnostic textural parameters of beach and river sands was written by G. M. Friedman in 1966. Two environments of deposition are contrasted, the backwash and swash of the beach, where the fine particles are removed seaward, and the sediments of a river. Environmental differentiation is determined by the calculation and plotting in various combinations of the Third Moment, Mean Cubed Deviation, Standard Deviation, Graphic Skewness, Graphic Standard Deviation, together with the Simple Skewness Measure and Simple Sorting Measure. Results obtained earlier by Friedman are similar to those found by D. B. Duane (1964). In a beach deposit off northern Carolina the Method of Moments was applied to the size distribution. Skewness was seen to be environmentally sensitive due to the winnowing action produced in the sediments of beaches, littoral zones and tidal inlets. R. A. Gees (1965) also used Friedman's moment measures when considering the depositional environment of river sands, and concluded that they were not totally reliable.

A criticism of moment measure has been written by R. B. McCammon (1962), who claimed that the low order moments do not necessarily characterize the shape of the distribution. R. L. Folk (1964) lists the disadvantages of the Moment Method of calculation (G. M. Freidman, 1962a and b) when compared to the Percentile-Intercept Method, which is generally a more flexible measure. The relative efficiencies of this latter method have been assessed by McCammon. The efficiencies of the different intercept methods used to obtain the mean, standard deviation, skewness and kurtosis increase with the number of percentiles used as the numerator. An example is the approximation to the mean. P. D. Trask's (1930) median (ϕ 50) is 64% efficient compared to R. L. Folk and W. C. Ward's (1957) formulae (described above) which is 88% efficient. An extended numerator, introduced by McCammon, ranging from 5 - 95 (increasing by increments of five) / 10, is 97% efficient since it includes the entire range of the distribution.

In considering the use of certain textural parameters, R. J. Moiola and D. Weiser (1968) stated that a plot of mean diameter versus skewness is the most sensitive method of distinguishing between beach and dune sands. Other methods distinguish river sands from beach and dune sands. J. S. Mothersill (1968, 1969) analyzed samples of longshore bars and troughs in Lake Superior, Ontario. There were found to be distinct differences between the longshore bar sands, which were better sorted and finer grained than the shoreward longshore trough sands. R. L. Folk and W. C. Ward's (1957) Percentile-Intercept Method was used. The longshore bar sands were unimodal and tended to be positively skewed whereas the longshore trough sands were either unimodal or bimodal and tended to have strong negative skewness. The finer grains are considered to have been moved from the trough area where they were dislodged by wave action, transported lakeward by the undertow and deposited onto the longshore bars.

Similarly skewness was found to be the only single parameter which would differentiate environments of deposition along the coast of New South Wales, Australia, (J. R. Hails, 1967). This is because the beach, barrier and dune sands are all polygenetic in origin.

Later work by J. R. Hails and J. H. Hoyt (1969) demonstrates variations in the lower coastal plain of Georgia. In the barrier island environment, about 70% of the samples of the coarsest sediments were negatively skewed. A small percentage of positively skewed barrier island sands, in the author's opinion, reflected the diagenesis of these sands. Approximately 90% of the Holocene beach sands are negatively skewed, and 70% of the dune sands show positive skewness. The Folk and Ward measures were used.

When attempting to recognize fossil strandlines in New Zealand, using the Graphic-Intercept Method of Folk and Ward, J. C. Chappell (1967) was not completely successful. The beach sands were negatively skewed, the dune sand positively skewed, although the values became less apparent in direct proportion to the increased lithification in the Pleistocene sediments.

A further alternative method of analyzing clastic sediments has been described by B. K. Sahu (1964). It is related to the formulation of several discriminate functions, with their levels of significance established by multivariate discriminatory analysis, to distinguish between environments with closely similar energy conditions. One particular method, using a multivariate statistical technique, is the factor analysis of J. E. Klovan (1966). The data is analyzed by means of vectors. W. C. Krumbein and E. J. Aberdeen (1937) provided the original grain-size frequency distributions of sediments in Barataria Bay. The analysis showed that, of the three types of energy conditions prevalent in the Bay, wave energy was the most prevalent, current energy the second prevalent component, while gravitational energy was comparatively minimal. In a recent article by J. H. Solohub and J. E. Klovan (1970) the various techniques of grain-size analysis were applied to Lake Winnipeg, Manitoba, sands. The size parameters of R. Passega (1957), C. C. Mason and R. L. Folk (1958), G. M. Freidman (1961) and B. K. Sahu (1964) were insensitive in determining environments of deposition compared to the factor analysis method. The authors concluded that grain-size distributions reflect depositional processes rather than the environment of deposition; the two should be considered as being distinct.

4. <u>The presentation of the particle size data from Ste. Anne and Ponton.</u> With such a considerable wealth of conflicting information on the relative value of methods of evaluating grain-size parameters , a choice of suitable parameters applicable to the Ste. Anne and Ponton areas needs to be based on certain important considerations:

a. the arithmetic suitability of the method

b. the widespread use and general acceptability of the method

c. the value of the method when an unknown depositional agent is involved

d. the publication of comparable results so that modern and ancient depositional environments can be compared.

Reference should here be made to the previous section (3) where the relative values of the various textural parameters are discussed. Briefly, the Passega CM Pattern method does not comply with points b and c, and factor analysis does not comply with point c (J. E. Klovan, 1970 personal communication) unless a control is used. The moment methods of G. M. Friedman (1961) and R. L. Folk and W. C. Ward (1957) both comply with the points mentioned. The Folk and Ward Percentile-Intercept Method has certain advantages in so far as it is more flexible (adjustments can be made for variations in screen size, Folk 1966), and deposits in ancient environments have been determined by this method (J. Chappell, 1967).

a. Sand Analysis. In total 152 sand and gravel samples were analyzed in the Ste. Anne and Ponton areas, 89 from the former location and 63 from Ponton. Standard sedimentary analytical procedures took place in each case.

i. The clean and completely unconsolidated samples were split in a sample splitter.

ii. A nest of sieves was prepared and sieving took place at $\frac{1}{4}$ phi intervals.

iii. After 15 minutes each sample was weighed to 0.01 gram.

In each case, the weight percent data was converted to a cumulative frequency distribution and plotted on Arithmetic Probability Paper. The plots (152) were drawn up and these were grouped in the following manner. The Ste. Anne curves were seen to vary in relation to their position across the ridge (A, B, C, D and E) and in relation to the depth from which the sample was taken. Therefore the single sample data was generalized so that these variations might be distinguished in graphical form. At Ponton possible variations which may have occurred between the three ridges, R1, R2 and R3, lead to the generalization of the data on these three. An average value for the inter-ridge area is also taken.

On the original 152 plots, the Folk and Ward (1957) parameters were deduced by the Percentile-Intercept Method. The different formulae are shown on page 176. The four measurements are:

i. the graphic mean (Mz)

ii. the inclusive graphic standard deviation (σ_I)

iii. the inclusive graphic skewness (Sk_I)

iv. the graphic kurtosis (Kg) and transformed kurtosis (Kg′) R. L. Folk (1968).

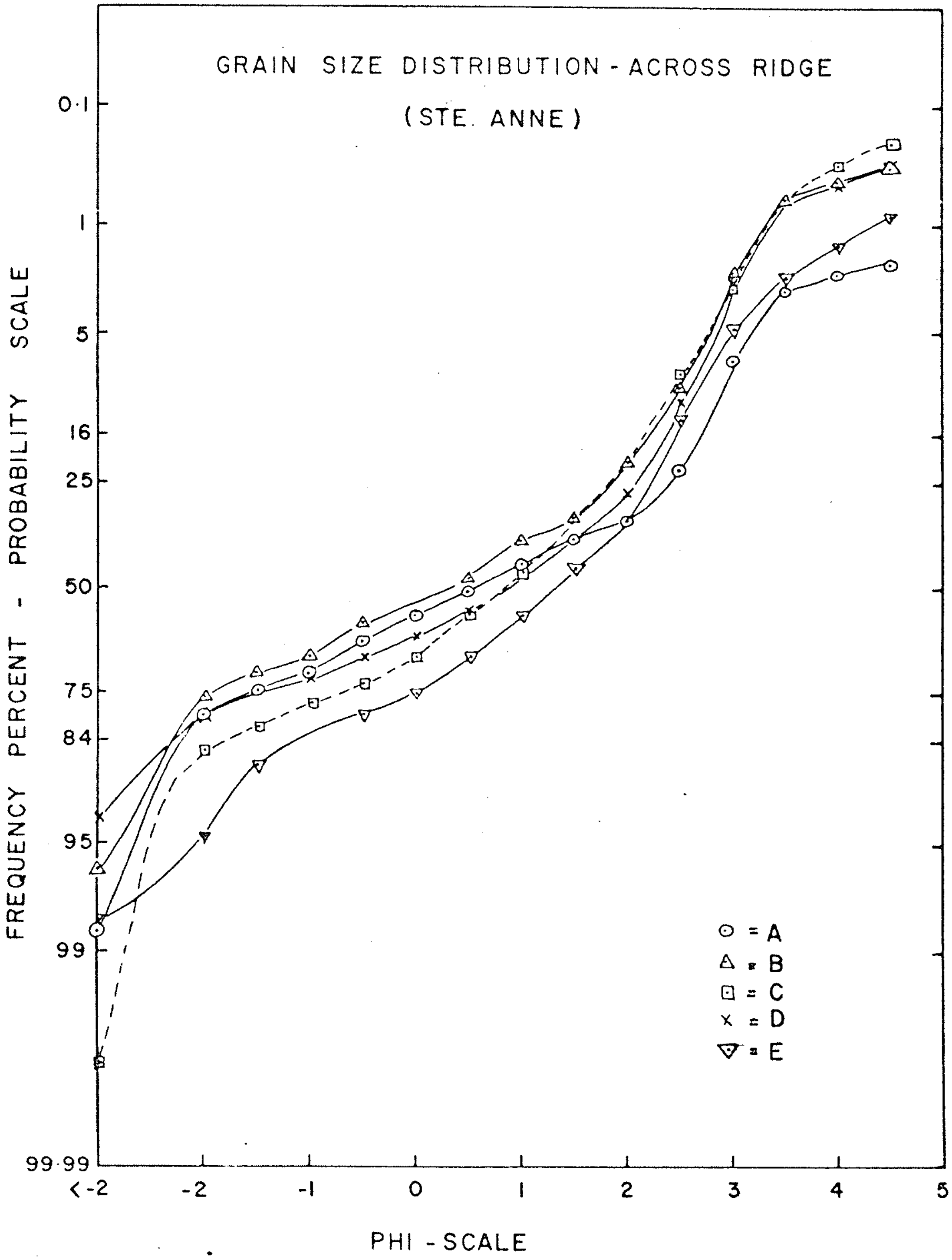
All the moments were determined from the individual graphs for each sediment. Averages were taken to correspond with variations across the ridge and with depth at Ste. Anne, and variations within the three ridges and beyond at Ponton. The generalized data, cumulative frequency and moment measures are shown on Tables 14, 15 and 16. All the values were calculated by means of a Hewlett-Parkard Desk Calculator.

i. Variation by Section (Ste. Anne). The first grain size distribution graph (Fig. 4-1, Table 14) shows some variation in size distribution across the various ridge sections. As stated in Chapter 2, A occurs on the so-called lakeward side of the beach ridge, and E on the landward size. Curve A reveals a higher frequency of finer grains than do the other curves. Marked inflexion points occur at

3.3ϕ and -2.0ϕ, with good sorting between the two, in the fine sand to very fine sand range. Relatively poor sorting characterizes the remaining distribution from the -2ϕ point, where the curve again becomes steeper. The curve representing the B sections has a relatively low frequency of finer, poorly sorted grains. The steeper portion of the curve in this case occurs between 3.3ϕ to 1.3ϕ, incorporating more medium sand than in the case of curve A. Relatively badly sorted material occurs between 1.3ϕ and -2ϕ. Curve C reveals the lowest frequency of very fine sand. The higher point of inflexion is similar to curve B, but the remainder of the curve is more evenly unsorted to approximately 0ϕ. Curve D has a similar distribution to curve C, although it has a high frequency of extremely coarse grains as well as a high frequency of fine-grained sands. Curve E is intermediate in appearance, with minor inflexions at 3.2ϕ and 1.8ϕ. It has a lower frequency of relatively badly sorted grains between +1.8ϕ and -1.2ϕ, and a low proportion of coarse grains beyond this point.

Table 17 shows the variation in mean grain size with the position of sections A to E across the ridge. Relatively fine coarse sand occurs at point A (0.422ϕ) and coarser coarse sand is found at B (0.311ϕ). The sand then becomes increasingly fine from C (0.583o - coarse sand) to D (0.617ϕ - finer coarse sand) and E (0.802ϕ - very fine coarse sand).

The sorting indeces are not extremely variable according to the R. L. Folk (1968) classification. All the average values of σ_I for A, B, C, D and E indicate poorly sorted deposits. The skewness values (Folk) may be categorized as follows. The A sections, with a skewness of +0.031ϕ is said to be near-symmetrical, the B sections, skewness -0.103ϕ, are coarse-skewed, the C sections, skewness +0.066ϕ, are near-symmetrical,



GRAIN SIZE DISTRIBUTION - ACROSS RIDGE
(STE. ANNE)
FREQUENCY PERCENT - PROBABILITY SCALE
0·1
1
5
16
25
50
75
84
95
99
99·99
<-2
-2
-1
0
1
2
3
4
5
PHI - SCALE
⊙ = A
△ = B
⊡ = C
× = D
▽ = E

Fig. 4-1

Table 14

Generalized Cumulative Frequency Data (Ste. Anne)
Variation by Section

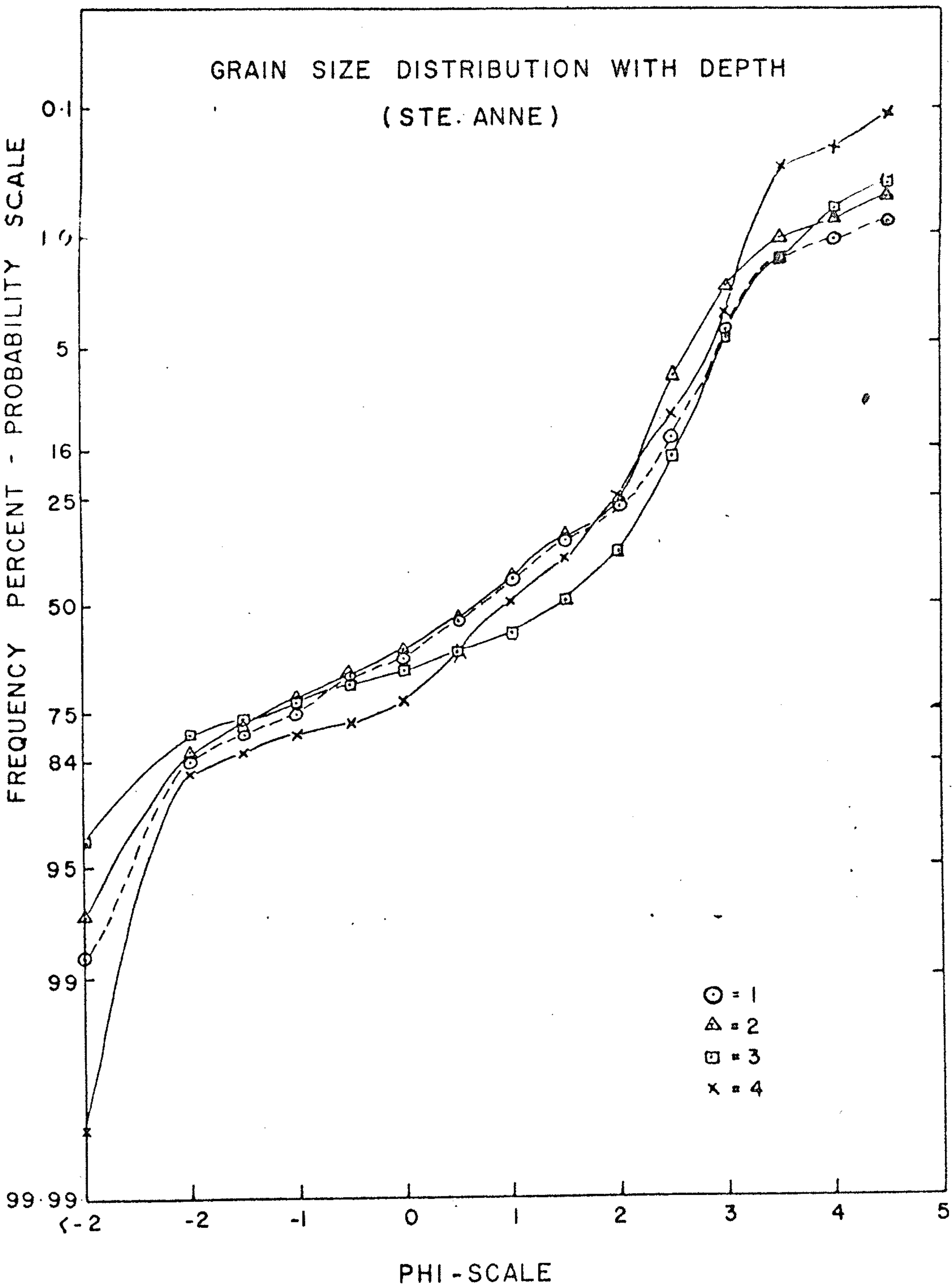
Phi Scale	A	B	C	D	E
4.5	1.90	0.39	0.21	0.37	0.87
4.0	2.38	0.49	0.36	0.51	1.42
3.5	2.83	0.63	0.65	0.69	2.33
3.0	7.08	2.04	2.78	2.76	4.86
2.5	22.01	9.94	8.3	11.65	13.66
2.0	32.56	21.17	21.34	27.27	32.89
1.5	37.63	30.23	32.89	36.69	44.57
1.0	43.86	37.99	46.81	46.53	57.48
0.5	50.37	46.78	57.51	55.04	67.11
0.0	57.15	56.22	67.51	62.10	75.19
-0.5	63.55	59.67	73.33	67.39	79.46
-1.0	70.05	67.69	77.40	72.64	84.92
-1.5	74.43	71.90	81.35	75.70	87.74
-2.0	79.55	75.88	85.50	79.26	90.46
>2.0	98.60	96.48	99.67	93.90	98.34

Percent sand in $\frac{1}{2}\phi$ size fractions from Sections A to E.

the D sections, skewness +0.139ϕ, are fine-skewed, and the E sections, with a skewness of +0.029ϕ, are near-symmetrical. Therefore most of the curves are nearly symmetrical, but B has an excess of coarse material and D has an excess of fine material.

The transformed kurtosis values are also quite variable. In the A section the average Kg$'$ is 0.556ϕ or leptokurtic, in the B section the value is 0.645ϕ or leptokurtic, in the C section the Kg$'$ is 0.511ϕ or mesokurtic, in the D section the Kg$'$ is 0.492ϕ or mesokurtic, and in the E section the transformed kurtosis is 0.479ϕ or platykurtic.

ii. Variation by Depth (Ste. Anne). The grain size distribution (shown on Fig. 4-2, Table 15) shows a slight variation with depth. In the figure, the values 1 to 4 refer to the depths 1-1.9', 2-2.9', 3-3.9' and greater than 4', respectively. In curve 1 there is a lack of sorting between 3-4.5ϕ and a relative abundance of grains at the fine end of the curve. Better sorting occurs between the two inflexion points at 3ϕ and 2ϕ. Lack of sorting characterizes the distribution between 2ϕ and -2ϕ, with increased sorting beyond the -2ϕ point. Curve 2 follows a similar pattern, indicating the degree of similarity between these two depths of deposits. Curve 3 is generally more open. With increasing depth, the percentage of fine grains decreases. The better sorted area again occurs between approximately 2-3ϕ, but the point of inflexion between the fine, medium and coarse sands is not as clearly evident. Curve 4, representing the greatest depth, is the most distinct. A lower percentage of fine grains characterize the right hand side of the curve. The higher inflexion point occurs around 3.5ϕ with the steeper portion of the curve between 0.5 and 3.5ϕ. Hence the sorting is reasonably good, but over an extended medium-fine range between 0.5 and



GRAIN SIZE DISTRIBUTION WITH DEPTH
(STE. ANNE)
FREQUENCY PERCENT - PROBABILITY SCALE
0·1
1·0
5
16
25
50
75
84
95
99
99·99
<-2
-2
-1
0
1
2
3
4
5
PHI-SCALE
⊙ = 1
△ = 2
⊡ = 3
x = 4

Fig. 4-2

Table 15

Generalized Cumulative Frequency Data (Ste. Anne)
Variation by Depth

Phi Scale	1 1-1.9'	2 2-2.9'	3 3-3.9'	4 >4
4.5	0.81	0.53	0.43	0.12
4.0	1.10	0.79	0.69	0.23
3.5	1.47	1.01	1.52	0.33
3.0	4.27	2.27	4.72	3.27
2.5	14.35	7.65	17.82	11.58
2.0	26.02	20.67	37.17	25.80
1.5	33.88	30.26	49.19	38.31
1.0	43.62	42.56	56.90	49.80
0.5	53.83	52.53	61.78	62.19
0.0	62.90	61.05	66.00	72.78
-0.5	67.17	66.48	68.61	76.64
-1.0	75.66	72.32	73.26	79.71
-1.5	79.36	76.50	76.15	82.77
-2.0	83.68	80.53	78.90	85.78
>2.0	98.56	97.46	93.08	99.96

-2ϕ the deposits are unsorted. Better sorting occurs above the -2ϕ boundary.

Table 18 shows that, whereas the mean grain size does decrease with depth from 0.472ϕ to 0.724ϕ, the coarsest grains are to be found approximately 2.0' down (0.406ϕ), and finest grains at 3 to 3-9' (0.959). All these fall within the coarse sand category. The sorting is variable becoming better with depth, except at 3 to 3.9' where the best sorting occurs. According to the definitions found in R. L. Folk (1968), the sorting may be categorized as follows: the 1-1.9' depth, with a value of 1.331ϕ, is poorly sorted, the 2-2.9' depth, with a value of 1.181ϕ, is poorly sorted, the 3-3.9' depth, with a value of 0.977ϕ, is moderately sorted and the greater than 4' depth, with a value of 1.100ϕ, is also poorly sorted.

The skewness values are all positive and low which indicates an excess of fine material. Verbal limits are also placed on these values by R. L. Folk. The 1-1.9' depth is $+0.017\phi$ and is described as near symmetrical. The 2-2.9' and the 3-3.9', with values of $+0.03\phi$ and $+0.025\phi$, are also near-symmetrical. The greater than 4' value, which is $+0.185\phi$, is described as being fine-skewed. Therefore near-symmetry is constant with depth until the 4.0' mark is reached, and a more positive skewness occurs.

The kurtosis indicates that the curves tend to be normally distributed. The limits placed on the transformed kurtosis indicate that at a value of 0.516ϕ at 1-1.9' depth the distribution is mesokurtic, at 2-2.9' depth, with a value of 0.520ϕ, the same distribution occurs. Between 3-3.9', with a value of 0.653ϕ, the distribution is leptokurtic, and at 4' and below, with a value of 0.522ϕ, the distribution is mesokurtic.

iii. Variation by Ridges (Ponton). Cumulative grain size frequencies for the Ponton ridges are given in Table 16, and curves for the ridges and inter-ridge areas are shown on Fig. 4-3. One outstanding feature is the lack of variation between the 4 curves. There is a higher frequency of finer grains in the inter-ridge area and the fines become progressively less frequent from R3 to R2 and R1. Points of inflexion occur between 3.5ϕ and 2.0ϕ. The steepest portions of the curves between these two points indicate better sorting within the size range. From 3.5ϕ to $< -2\phi$ the sediments consist of unsorted particles. There is a higher frequency of coarse grains in the inter-ridge area, and the lowest proportion of coarse grains occurs in R3 and R1.

The Table 17 indicates a variation in mean grain size with the location (Ch. 2) of the three ridges. R1 may be considered to be lakeward of R2 and R3. The mean grain size of R1 is 2.427ϕ, a medium fine sand; R2 is 2.474ϕ, a fine fine sand, and R3 is 2.726ϕ, a very fine, fine sand. The inter-ridge area is made up of an even finer sand of 2.758ϕ. The sorting values for the ridges do not vary considerably. R1, R2 and R3 are all moderately well sorted. The inter-ridge area is not as well sorted, and falls in the moderately sorted category of R. L. Folk (1968). Similarly the skewness values for the three ridges (-0.087ϕ, +0.050ϕ and +0.063ϕ for R1, R2 and R3 respectively) are all low positive values, falling in the near-symmetrical category. The skewness for the inter-ridge area (+0.108ϕ) falls into the fine-skewed category, because of its excess of fine materials.

The kurtosis value for R1 is 0.530ϕ and the distribution is mesokurtic. That for R2 and R3 is 0.756ϕ and 0.563ϕ respectively and is

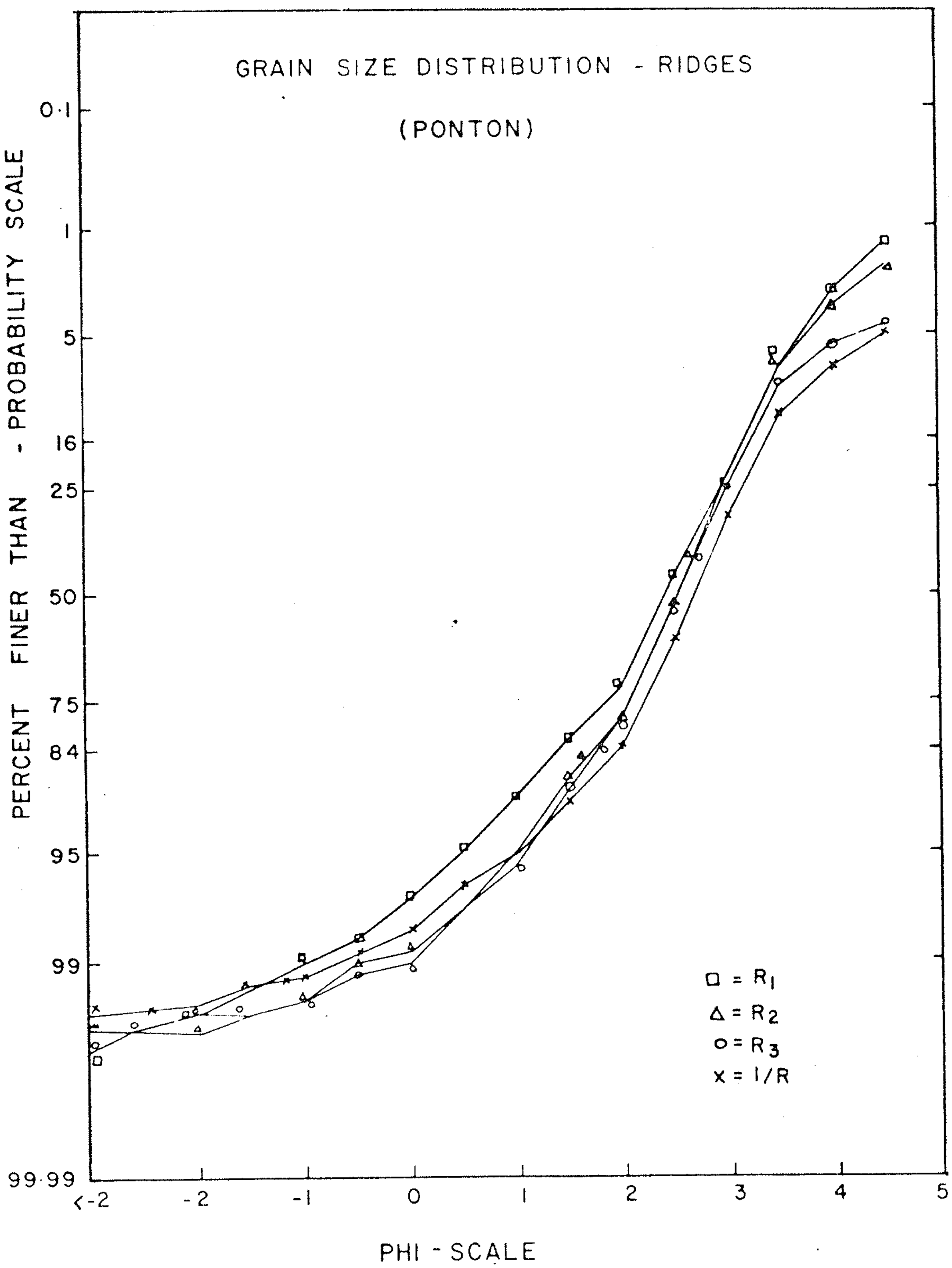

GRAIN SIZE DISTRIBUTION - RIDGES
(PONTON)
PERCENT FINER THAN - PROBABILITY SCALE
0·1
1
5
16
25
50
75
84
95
99
99·99
<-2
-2
-1
0
1
2
3
4
5
PHI - SCALE
□ = R_1
Δ = R_2
o = R_3
x = 1/R

Fig. 4-3

Table 16

Generalized Cumulative Frequency Data (Ponton)

Phi Scale	R1	R2	R3	I/R
4.5	1.341	1.954	4.287	5.062
4.0	2.871	3.408	5.916	7.422
3.5	7.435	7.684	9.778	12.493
3.0	23.759	24.493	25.551	31.278
2.5	44.37	52.768	54.492	61.329
2.0	72.09	80.106	78.432	83.432
1.5	81.95	89.756	88.034	90.715
1.0	90.005	95.631	95.041	95.032
0.5	94.771	97.831	97.783	96.962
0.0	97.199	98.717	98.845	98.162
-0.5	98.455	99.191	99.078	98.808
-1.0	99.071	99.464	99.500	99.178
-1.5	99.365	99.587	99.579	99.495
-2.0	99.588	99.703	99.588	99.495
>2.0	99.722	99.703	99.691	99.59

R1 = Ridge 1 (as defined in Ch. 2)
R2 = Ridge 2
R3 = Ridge 3
I/R = the inter-ridge areas

Table 17

Data in Phi-Units

A. Section Data (Ste. Anne)

Section	Mz	σ_I	Sk	Kg
A	0.422	1.226	-0.031	0.556
B	0.311	1.193	-0.103	0.645
C	0.583	1.085	-0.066	0.511
D	0.617	1.256	-0.139	0.492
E	0.802	1.211	-0.029	0.479

B. Depth Data (Ste. Anne)

Depth Categories	Mz	σ_I	Sk	Kg
1	0.472	1.331	-0.017	0.516
2	0.406	1.181	-0.03	0.520
3	0.959	0.977	-0.025	0.653
4	0.724	1.100	-0.185	0.522

C. Ridge Data (Ponton)

Ridge	Mz	σ_I	Sk	Kg
R1	2.427	0.703	-0.057	0.530
R2	2.474	0.695	-0.050	0.756
R3	2.726	0.644	-0.063	0.563
	2.758	0.728	-0.108	0.557

leptokurtic. The value for the inter-ridge area, 0.557ϕ, is also leptokurtic.

5. <u>Conclusions based on an interpretation of the data, and comparisons with the past literature</u>. Assuming that the ridge deposits were originally morainic, as described in Chapter 2, they must represent a reworked fraction of unsorted drift deposits. The agents chiefly responsible for the resorting process may be reflected in the grain size distribution of the sediments and the four moment measures.

a. Variation by section. Throughout the sections coarse sands predominate. If the source material was unsorted drift, then the predominantly coarse sand fraction may be a result of paucity of medium or fine sands in the parent material, or the relatively fine material may have been removed.

By considering the variation in the grain size characteristics by section at the Ste. Anne site it might be possible to determine whether there is evidence of wind or wave action on one or both sides of the ridge, and how these may be seen to vary with distance. The size distribution curve gives no indication of systematic change from A - E across the ridge, although changes in the constituent sediments do take place as indicated above in Section 4a i. Section C has more grains in the central portion of the distribution than A, B, D or E (see Table 14, Fig. 4-1). The coarse sand at Section A is relatively fine and at B is quite coarse. Therefore it is possible that the finer constituents were being introduced from the A or E sections of the ridge, towards the center. This is not only reflected on the so-called lakeward edge (A) but also on the landward periphery. From C through D and E this same tendency is reflected at a more pronounced rate. Hence whatever causes the progressive coarsening of grains towards B and C does so, unequally, on either side of the ridge, that is, on both the landward and lakeward edges. W. C. Krumbein and E. J. Aberdeen (1937) suggest that the deposition of finer particles occurs in deeper water, the finest being laid down in areas farthest removed from the currents, so there was relatively deep water on both sides of the Ste. Anne ridge. In 1966, G. M. Friedman stated that fine particles are removed by the backwash-swash action, prevalent on the shore.

If water action were prevalent, both the uni-directional flow of a stream or the two-directional flow in a shoreline environment (assuming a constant source material) would sort the sediment. On the Brazos River Bar (R. L. Folk and W. C. Ward, 1957) sorting was found to vary from 0.40ϕ to 2.58ϕ, or from well to poorly sorted. The sorting in the various sections across the Ste. Anne ridge has a relatively low range, from 1.085ϕ at C, where the material is better sorted, to 1.256ϕ at D where the poorest sorting occurs. The lack of substantial variation in the sorting values would tend to signify that the conditions of deposition were constant across the ridge. When considering the sorting of particles on Mustang Island, Texas, C. C. Mason and R. L. Folk (1958) found sorting of beach sands varied between 0.3 and 0.35ϕ, while dune particles had between 0.21 and 0.26ϕ. These values indicate a much better sorting than the ones found at Ste. Anne. However, it is evident from previous studies that sorting has not been found to be a good indicator of sedimentary environmental differentiation.

By contrast skewness has been found by a number of writers to be the only moment measure sensitive enough to reflect the environment of deposition of the constituent sands. The Ste. Anne data by section shows that the skewness values vary across the ridge. The positive (near-symmetrical) skewness at A is followed by the only negative skewness. At B sections (on the lakeward side of the ridge) this is followed by three more low positive skewness values at C, D and E. Hence there is a change from coarse-skewed to fine-skewed across the ridge.

Skewness values found in river deposits, namely the Brazos River Bar (Folk - Ward, 1957), showed a range between -0.68ϕ to $+0.53\phi$, which is too wide a range to suggest identification. Considering the values suggested by Mason and Folk (1958) for the Mustang Island beaches, dunes and aeolian flats, the skewness in sediments of sections A and C of the Ste. Anne ridge indicates that they may be beach or dune deposits, whereas the skewness in B and D indicates a definite beach deposit. the skewness at C is not particularly conclusive. Many authors, for example S. A. Harris (1959), G. M. Friedman (1961), A. O. Fuller (1962), D. B. Duane (1964), and J. R. Hails and J. H. Hoyt (1969), agree that a beach deposit either has a negative skewness (generally) or a low near-symmetrical positive skewness because of the winnowing effect of the backwash and swash, removing the finer sand size. The longshore bars described by J. S. Mothersill (1968, 1969) also tended to be positively skewed.

The kurtosis values found across the sections are quite variable. The values do not compare with river channel kurtosis values found by Folk and Ward (1957) on the Brazos River Bar. When compared with the Mustang Island data of Mason and Folk (1958, p. 219), Section A is found to be within the aeolian flat range, Section B is indistinct and C, D and E may be either beach or dune deposits.

Therefore, although there are variations in mean grain size (suggesting a shoreline environment east and west), sorting (with one depositional agent or constant source), skewness (a shoreline or dune environment with more evidence of the lake being on the west side in the former case) kurtosis(either beach, dune or aeolian flat environment), there are no consistent variations across the ridge. The possibility of a number of depositional environments is still suggested.

b. Variation by depth. Because the deposit consists of a reworked zone, a number of different depositional environments are suggested. The variation in sedimentation is discussed in Chapter 3.

The mean grain size tends to decrease with depth, so that finer deposits are found below and coarser deposits above. The finer deposits are laid down in a period of relative quiescence, the coarser deposits in a high energy environment. There are no comparable sizes found in the literature, so a unique depositional environment may here be involved.

The sorting is also inconclusive. The top two feet are comparatively unsorted; this coincides with the coarser overall grain size and again suggests a higher energy, turbulent environment. The lower beds are better sorted which suggests a more regular sequence of depositional events. The poorer sorting, at depths exceeding 4 feet, may indicate the influence of the underlying deposits.

The skewness values are all positive and low. The lowest skewness is exhibited by the uppermost beds, the highest by the deepest bed. This may reflect to some extent the time involved in the reworking of the deposit, since more finer material is found at depth. With reference to the work of Mason and Folk (1958) on Mustang Island, depth category 1 at

Ste. Anne may be identified as a beach, categories 2 and 3 as a beach or dune and 4 as an aeolian flat or dune. With this evidence, and the grain size evidence, one may be lead to conclude that:

i. category 1 is a beach formed in a high energy environment (storm beach)

ii. category 2 is a reworked portion of 3, also formed in a high energy environment (aeolian)

iii. category 3 is a beach formed in a low energy environment (foreshore)

iv. category 4 is a reworked wind deposit, on the original drift.

This is rather inconclusively supported by the kurtosis results. Beds category 1, 2 and 4, in comparison with the Mustang Island data, may be either beach or dune deposits, while depth category 3 kurtosis value points to an aeolian flat situation.

Therefore variation in deposition occurs with depth. The evidence is not conclusive as most of the beds may be either water or wind laid deposits. Writers (quoted above) who agree that low negative skewness or a near-symmetrical distribution characterizes a beach deposit, might consider that the Ste. Anne ridge was in fact a beach deposit. The positive skewness might equally indicate dune deposition.

c. The Ponton Ridge data. The Ponton ridge data differs in many ways from the Ste. Anne ridge, reflecting a variation in source material and a large distance between the two areas.

As stated previously (Chapter 2), the Ponton ridge may have its sediment source in pro-glacial deposits, which have been reworked, possibly by the waters of Lake Agassiz. The size distribution curves for the three ridges and the inter-ridge area demonstrates a close similarity which reflects that the same source material was responsible for the construction of all of the ridges.

The mean grain size of the data all falls into the fine sand category. There is a variation in sand sizes throughout the ridges. The coarsersediments are found in R1 and the finest sizes in R3. If wave action, as stated above, removes the finer grains, then, assuming a shoreline environment, R3 may have been exposed for a shorter period of time to the backwash and swash action than R2. R1 may have been exposed for the greatest duration. The latter point is not inconsistent with the fact that R1 is closest to the "lakeward" margin.

When the particle size data is compared with that of Mason and Folk's (1958) on Mustang Island the Ponton values are found to be consistently coarser than the coarsest deposit (the beach sands) recognized here. This is only by a small fraction, and the Ponton sediment may be said to more closely approximate to beach sands than to dune or aeolian flat deposits.

The three ridges are all moderately well sorted (Folk, 1866). R3 is better sorted than R2, which in turn is better sorted than R1. The worst sorting occurs in the inter-ridge areas. Whatever depositional agent (assuming a constant size source) caused these features, R3 has been exposed the longest, and presumably has been subjected to the most winnowing by wind or water. This is consistent with the decline of the level of Lake Agassiz, causing a prograding shoreline sequence from SW to NE. The sorting values are not similar to the ones found in the literature.

The skewness values are again all low and fall into the near-symmetrical category, except the inter-ridge area, which has a higher frequency of fine grains. The skewness values do not vary systematically from ridge to ridge, for R1 and R3 have the highest values. In comparison with the data of Mason and Folk (1958), the results are indeterminate, with the exception of R2 which may have been formed in a beach or dune environment.

Likewise the kurtosis values do not vary systematically with the ridges. Most of the results show a tendency towards a leptokurtic type of distribution, except R1 which is mesokurtic. This would tend to indicate that R1 was either a beach or dune (compared to Mason and Folk's data), R3 and the inter-ridge area tend towards the aeolian flat category. R2 is prominently leptokurtic, which may indicate that this too was formed in an aeolian environment.

Therefore there is apparently reasonable evidence at this point (if comparisons are valid) that the Ponton ridges may have been formed in a similar manner. On the basis of mean particle size and sorting, R3 was formed first (being exposed the longest) and R1 was the last to be formed. The sands indicate that the ridges may be either beaches or aeolian features.

No clear conclusions can be reached as to a definite origin of the Ste. Anne and Ponton "supposed" Agassiz beach ridges on the basis of particle size analyses. The weight of the evidence indicates that the Ste. Anne ridge is a moraine which has been reworked in different stages by wind or water, and with a directional force perpendicular to the N - S orientation of the ridge. At Ponton, the evidence suggests either a modified aeolian or water laid deposit. The fact that R3 may have been exposed longer to modifying processes tends to indicate that the three ridges may have been beaches in a regressive shoreline sequence. Subsequent aeolian modification may also have taken place.

B. An Evaluation of the Percent Heavy Mineral Content at Ste. Anne and Ponton

This section consists of descriptions of heavy mineral analyses taken from the Ste. Anne and Ponton ridges. The following sub-sections are included:

1. A review of the relevant literature on heavy mineral analysis
2. Presentation of data from Ste. Anne and Ponton
3. Tentative conclusions based on the data in relation to findings described in the past literature.

1. A review of the relevant literature on heavy mineral analysis. Much of the work done on the analysis of the heavy minerals of sedimentary rocks has tended to vary in terms of both the techniques used and the conclusions drawn from the results. Most writers tend to suggest that either heavy minerals reflect the source rock from which the sediment was derived or the process factors which are involved during transportation and deposition.

A number of heavy mineral analyses have been used to evaluate the original sediment sources of the deposit in question. Attempts were made in 1942-43 by G. Rittenhouse to demonstrate the validity of the assumption that the mafic content of a sediment is a direct reflection of the provenance material. After analyzing samples from a transverse section of the middle Rio Grande Valley, Rittenhouse concluded that the size distribution of heavy minerals in a fluvial deposit depends more on the hydraulic conditions at the time and place of deposition and the size of the minerals available than on source materials. Therefore, unless such factors as sediment size and the competence and capacity of the transporting agent are accounted for in the analysis, a true reflection of the source material can hardly be validly assessed.

Another attempt to determine the source rocks from which certain heavy minerals were derived is that completed by D. C. Carroll (1957), J. J. W. Rogers and W. F. Powell (1958). The latter authors stated that the types and distributions of heavy minerals (especially zircon) found in the Beaumont clay in Texas are largely controlled by their source rocks. Similarly W. P. F. H. de Graaff and C. F. Woensdrect (1963), in the Coruna Province of Spain, analyzed two beaches for their heavy mineral content. The littoral zone was divided longitudinally into three zones, with certain outstanding heavy minerals in each. This division accords with the local disposition of igneous and metamorphic rocks and the heavy mineral content relates to each. The work of D. M. Poole (1958) indicates that the hydraulic index may have had a greater control on the distribution of certain heavy mineral types than would source materials.

The fact that heavy and light minerals settle at different rates, and therefore dominate in different depositional environments in relation to prevalent energy conditions, is shown in the work of B. M. Hand (1967) who used delta values to differentiate beach foreshore and dune sands. In 1941, F. J. Pettijohn related the persistence of heavy minerals in certain stratigraphic horizons with geological age, and concluded that younger arenaceous rocks have a more diverse mineral assemblage (probably by inference, a higher percentage of heavy minerals) than older rocks. This is because the less stable heavy minerals in the older deposits tend to disappear by solution.

Perhaps it should be concluded that, when determining the source rocks from which heavy minerals are derived, extreme care should be exercised because of the variations inherent in the transportation and sedimentation (and possible further reworking) of the deposit.

As regards the aim of the present work, to determine the environment of deposition of supposed Lake Agassiz beach ridges, it is proposed that heavy mineral studies, not necessarily of a detailed nature, should be used for environmental differentiation. This type of work has previously been undertaken by J. S. Bradley (1957) on Mustang Island, Texas. Here, barrier island sediments are distinguished from gulf sediments on the basis of their heavy mineral content (0.45% and 0.05%) by volume, respectively. The berm zone is intermediate in value between the two (0.34%).

2. <u>The presentation of data from Ste. Anne and Ponton</u>. The samples for heavy mineral analysis from Ste. Anne and Ponton were taken according to the stratified method described in Chapter 2. Not all the sections were sampled. Certain sections were eliminated because of the unsuitability of the sediment. From the remaining sections samples were chosen at random. The laboratory procedure was as follows:

a. The sample was sieved so that 4 fractions corresponding to the amount of sediment retained on the 35, 50, 70 and 100 sieves was used.

b. The sample was passed through a sample splitter.

c. Half the sample was then washed by decantation and dried thoroughly.

d. The magnetic minerals were removed by a hand magnet.

e. The sample was run through a Franz Isodynamic Magnetic Separator twice to ensure maximum separation.

f. The light and heavy minerals were weighed separately to determine the percentage of each. The results obtained are found in Tables 18 and 19.

No mineralogical check was made on the heavy minerals since this is not necessarily consistent with the determination of the environment of deposition.

The results given in Table 18 (Ste. Anne) show an average value for the heavy mineral content is relatively high in the 35 sieve, and relatively low in the 70 sieve. The average percent of heavy minerals in the Ste. Anne area is therefore between 4.28 and 8.49. In Table 19 (Ponton) the values show a much higher percent than the ones for Ste. Anne. As on the Ste. Anne ridge, there is a similar proportional decrease from the sieve 35 (19.31% at Ponton) to sieve 70 (13.93%) and increase to sieve 100 (20.91%).

Tests were run on the data to determine what possible differences in the values related to the sieve sizes, rather than to the heavy mineral content itself. The two extreme sieve sizes were used, because any significant difference should be closely reflected in these. Details of the test are shown on Table 20 and 21.

a. Null Hypothesis: Ho: the heavy mineral content of the 35 sieve does not differ from that in the 100 sieve

Hi: the mineral percent in the 35 sieve is different from that in the 100 sieve

Table 18

Heavy Mineral Data (Ste. Anne)

Section Number	Percent Heavy Minerals (sieve sizes) 35	50	70	100
2B III	7.407	4.486	4.310	9.396
2D I	8.832	16.626	4.208	5.639
3C I	7.321	5.028	4.102	8.312
4D II	8.019	3.259	4.191	7.090
4D IV	7.826	4.920	7.829	4.107
6C II	8.281	6.725	3.712	4.739
7B I	8.311	4.630	4.781	8.256
7C I	8.100	5.309	3.768	5.855
8A II	8.327	5.061	3.047	4.507
8D III	9.712	4.681	3.619	4.719
8E V	12.353	5.313	4.154	6.254
9C II	8.882	4.560	3.269	4.638
16C II	8.576	6.725	4.382	4.101
17B I	6.857	4.630	4.558	16.073

From an average depth of 2 - 3 ft.

$\bar{x}$ 35 = 8.4860
$\bar{x}$ 50 = 5.8538
$\bar{x}$ 70 = 4.2807
$\bar{x}$ 100 = 6.6919

Total number analyzed = 56

Table 19

Heavy Mineral Data (Ponton)

	Percent Heavy Minerals (sieve sizes)			
Section Number	35	50	70	100
-400B	18.703	12.644	13.712	33.524
-400C	18.264	14.028	11.396	15.028
-400E	19.276	12.728	10.554	14.990
-400L	21.624	12.282	14.181	15.623
200A	26.236	10.763	15.926	14.850
200H	16.505	10.836	12.083	13.506
200M	25.801	25.255	8.742	12.412
600E	20.146	18.212	17.195	16.528
900A	9.813	13.791	14.368	13.082
900G	16.508	13.149	30.339	13.150
900L	10.01	12.428	12.475	13.064
1300C	28.540	15.482	10.714	10.394
1300J	19.545	16.187	15.381	15.532

From an average depth of 2 - 3 ft.

$\bar{\bar{x}}$ 35 = 19.305
$\bar{\bar{x}}$ 50 = 14.137
$\bar{\bar{x}}$ 70 = 13.928
$\bar{\bar{x}}$ 100 = 20.910

Total number analyzed = 52

Table 20

Wilcoxon Matched Pairs Signed Ranks Test

Ste. Anne

	35	100	d	Rank of di	Rank with less frequent sign
2B III	7.41	9.40	-1.99	-4	-4
2D I	8.83	5.64	3.19	+6	
3C I	7.32	8.31	-.99	-3	-3
4D II	8.02	7.09	.93	+2	
4D IV	7.83	4.11	3.72	+9	
6C II	8.28	4.74	3.54	+7	
7B I	8.31	8.26	.05	+1	
7C I	8.10	5.86	2.24	+5	
8A II	8.33	4.51	3.82	+8	
8D III	9.71	4.12	5.59	+12	
8E V	12.35	6.25	6.10	+13	
9C II	8.88	4.64	4.24	+10	
16C II	8.58	4.10	4.48	+11	
17B I	6.86	16.07	-9.21	-14	-14
					T = 21

T = 21
N = 13

At α = 0.5 = 17

∴ There is no significant difference between the percentages in the 35 or 100 sieve.

Table 21

Wilcoxon Matched Pairs Signed Ranks Test

Ponton	35	100	d	Rank of di	Rank with less frequent sign
-400B	18.70	33.52	-14.82	-12	-12
-400C	18.26	15.03	3.23	+3	
-400E	19.28	14.99	4.29	+8	
-400L	21.62	15.62	6.00	+9	
200A	26.24	14.85	11.39	+10	
200H	16.51	13.51	3.00	+1	
200M	25.80	12.41	13.39	+11	
600E	20.15	16.53	3.62	+6	
900A	9.81	13.08	-3.27	-4	-4
900G	16.51	13.15	3.36	+5	
900L	10.01	13.06	-3.05	-2	-2
1300C	28.54	10.39	18.15	+12	
1300J	19.55	15.53	4.02	+7	
					T = 18

T = 21
N = 13

At $\alpha = 0.5 = 17$

∴ There is no significant difference between the percentages in the 35 or 100 sieve.

b. The Wilcoxon Matched Pairs Signed Ranks Test was chosen because the samples were related.

c. The values for the tests are found in Tables 20 and 21.

d. In both cases, therefore, it is necessary to accept the Null Hypothesis and assume there is no variation in heavy mineral content with grain size.

From the values found on the Ponton ridges (Table 22) the results of the samples taken from each ridge were computed separately to determine any possible variation in the heavy mineral content between ridges 1, 2 and 3. The results are tabulated as follows:

Table 22

Ridge	Sieve Size			
	35	50	70	100
R1	19.14	16.66	11.80	13.70
R2	18.39	14.22	17.11	14.74
R3	20.31	13.34	13.22	17.38

The average heavy mineral percent for R1 is 15.33%, for R2 is 16.12% and for R3 is 16.10%. One outstanding feature is that there is very little variation in the overall heavy mineral content between R2 and R3 and only a slight variation between these and R1.

3. <u>Tentative conclusions based on the data in relation to findings described in the past literature</u>. A particularly characteristic feature in the results is the abundance of heavy minerals in the

Ste. Anne and Ponton ridges. These far exceed the values obtained by J. S. Bradley (1957). Therefore comparison of environments, based on the percentage of heavy minerals, cannot be made.

Following the work of F. J. Pettijohn (1941), a younger deposit may contain a greater diversity of heavy minerals than an older one of similar environmental deposition. Therefore it would seem plausible that the Ponton ridge is younger than the Ste. Anne ridge. Also, if this inference is correct, R1 may have been formed before R2 and R3. Although the short length of time here taken in sedimentation could negate this conclusion.

In terms of sediment sources, it is perhaps valid to suggest that the Ponton ridges may have greater proximity to the source of heavy minerals than does the Ste. Anne ridge. Heavy minerals in both areas probably originated from the Pre-Cambrian Shield areas, but are most probably derived by reworking of till. So, because of the differences in heavy mineral content, the Ponton sediments may be further away from their source material than those at Ste. Anne. The assumption, following the work of G. Rittenhouse (1942-3), that hydraulic conditions at the time of deposition are more important than source areas cannot be accurately checked in the case of the Ste. Anne and Ponton data. As seen by the statistical test run, there is no apparent significant relationship between the sieve sizes used and the respective heavy mineral contents. Nevertheless, taking the first three sieve sizes only (35 - 70), there is a decrease in the average percentage of heavy minerals in both areas. So there are more heavy minerals in the coarser size grades. Energy conditions may have been more important controls than the source areas.

B. C. Rao (1957) suggested that there is a dense accumulation of heavy minerals in the littoral environment caused by the reworking of the sands and the washing away of light minerals during certain periods of coastal erosion and deposition. The accumulation of heavy minerals in the case of Ste. Anne would suggest reworking by some agent that had caused the minerals to be laid down in laminations, as described in Section A of Chapter 3. Following the work of B. M. Hand (1957), the evidence of laminations would strengthen the fact the Ste. Anne ridge was made up of water laid deposits. The higher heavy mineral content at Ponton also suggests reworking by some agent, possibly either water or wind.

Definite conclusions regarding the environments of deposition of the ridges at Ste. Anne and Ponton cannot be made on the basis of the percent heavy mineral content. Some evidence points towards a littoral environment in both cases (simply based on the noted accumulation of heavy minerals). More reworking is indicated in the Ponton case because the accumulation there is higher.

Chapter 5

CONCLUSIONS

The aims of this thesis, as stated in Chapter 1, were to provide meaningful criteria for the recognition and distinction of certain examples of supposed Lake Agassiz beach ridges, and to discern the origin, if possible, of the ridges at Ste. Anne and Ponton.

Certain authors, quoted in Chapter 1, have amassed facts on the Lake Agassiz beach ridges in Manitoba, but have not stated how these features may be specifically identified in the field. Although the sample at Ste. Anne and Ponton is very small, and perhaps not representative of the population of beach ridges as a whole, a number of characteristics exist which provide evidence of the original environment(s) of deposition.

When considering the morphology, the overall height of the ridges over a short distance varies. In the case of Ste. Anne the longitudinal variation is quite small, being only 5.5' in 2.5 miles; steeper height variations occur at Ponton, where at R1 there is a difference of 12' in 1900', and R3 has a difference of 21' in 1900'. The maximum variation can be seen in R2 with 21' in 1900'.

The ridges may be smoothly rounded in form with the slope angles equal on either side, as in the case of R2 at Ponton, or, more often, they may have one slope steeper than the other, as in the case of R1 and R3 at Ponton and the ridge at Ste. Anne.

The maximum width varies for the measured portions of the ridges. The widest ridge is R1 at Ponton with a width of 197'. R2 is 133' across.

and R3 is 100 ft. across at the widest point. The Ste. Anne ridge is the widest feature, having a maximum width of 608 ft. and average width of 344 ft.

When the above facts are compared to morphologically similar features of known origin, described in the literature, certain tentative conclusions can be made. The fact that the slope angles on both sides of the Ste. Anne ridge are unequal indicates that it cannot be identified as an esker or a transverse dune. It may be a morainic feature or some land form found in the beach, off-shore bar or berm type of environment. Similar possible environments of deposition are suggested for the ridges at Ponton. R2, because of the equality of slopes on either side, may also be an esker.

The sediment descriptions are variable and there is little similarity between the stratigraphy in the Ste. Anne ridge and that found at Ponton. At Ste. Anne coarser particles tend to occur towards the center of the ridge, in the C, B and D sections. These become gradually finer towards the A sections on the western presumed "lakeward" side of the ridge and towards the E sections on the eastern "landward" side. Assuming the entire area consists of a morainic ridge, the reworking has caused coarser particles to accumulate towards the center of the ridge, while removing the finer deposits. The sizes of the coarse particles generally occur within the granule-pebble range, therefore a high energy environment is suggested. Possibly a storm beach would fulfill this type of requirement. By inference, the finer deposits would then be removed to the sides by the winnowing effect and be deposited in deeper water.

Immediately below these coarser sediments and again towards the center of the ridge, medium to coarse sands are found which are intermittently interbedded with silty clay. These may represent the type of sands found elsewhere as foreshore deposits, and the silty clay may indicate minor fluctuations in lake level. If this were so, then the foreshore sands were deposited at an earlier stage than the overlying coarse sediments, which is accordant with the theory of a prograding shoreline sequence. The evidence for a shoreline environment is supported by the graded bedding, sorting and laminations which occur. The high angle stratification also supports the above hypothesis. The same evidence suggests that the Ste. Anne ridge may have been deposited as an esker.

The ridges at Ponton, by contrast, have a degree of homogeneity in their stratigraphy. They consist of medium to fine sands, with the occasional pebble or granule horizons, and very slight indications of lamination in R2. Therefore there is a lack of stratigraphical evidence which might suggest an environment of deposition. There is nothing to favor the theory that any of the ridges is an esker. The homogeneous sand is consistent with an aeolian environment. The material may have been sorted by freeze-thaw activity in a periglacial environment, and the boulders which occur on the terraced portions of the ridges may owe their positions to the ice-push effect. The latter would in turn suggest that the ridges were constructed during, or prior to, lake formation.

Sphericity values were determined for certain samples mainly at Ste. Anne, and for two samples only at Ponton. For the Ste. Anne ridge, the range of sphericities is between 0.668 and 0.895; this is not dissimilar to the value obtained from the Ponton ridges, (R2 and R3), where an average sphericity of 0.728 was obtained. As well as the absolute values, certain trends were recognized. The generalized trend of a decrease from north to south in the overall sphericities is evidence to suggest a shifting of grains, possibly due to longshore drift, or other current effects in a beach environment. The Ste. Anne pebbles were plotted on sphericity-form diagrams which, when compared to others in the literature, indicated that the deposits here, because of the constituent spherical (compact) and rod-shaped pebbles, may owe their shape to the backwash and swash action. However the same evidence could indicate that the ridge was formed in a fluvial environment. This is substantiated by the decrease in the sphericity values of limestone rapidly with transportation, and because of the east - west variation in sphericity across the ridge.

Roundness indeces were determined for the Ste. Anne ridge. According to the Krumbein Scale, the value varies from 0.354 to 0.571, and between 222 and 601 by the Callieux Method. The roundness values are more consistent which contrasts with the sphericity measurements, reflecting the different samples which were used in each case. Similar trends are described in the literature and, assuming a beach environment, the current direction may have been northwards. The values obtained also indicate that the rounding occurred in beach deposits.

The long axis orientation of pebbles taken from certain sections in the Ste. Anne ridge is, in many cases, statistically insignificant. Only two significant directions were found. These were in the ranges of 80 - 100 degrees and 120 - 140 degrees in the central and northern portions of the ridge, respectively. When compared to long axis studies in the literature, the Ste. Anne ridge may not be an esker. There is no evidence of a north - south component suggesting uni-directional flow. In previous works, beach pebbles have been reported as lying parallel to the shoreline. This trend is not significantly shown at Ste. Anne. There is evidence that the pebbles may have been deposited in a beach environment, if they (like sands) have their long axes parallel to the backwash direction. The high degree of scatter in the data is similar to that found in outwash deposits.

Textural analyses were performed on samples from both the Ste. Anne and Ponton ridges. The Moment Measures which are cited in the literature are used as evidence for the depositional environments of sediments. These are the Mean, Standard Deviation (Sorting), Skewness and Kurtosis. These measures vary with respect to section position on the ridge at Ste. Anne, and with respect to depth. The variations, A - E across the ridge, indicate that coarser material occurs towards the center. The mean grain size in the various sections suggests a shoreline environment, the sorting is inconclusive, the skewness indicates a shoreline or dune environment, and the kurtosis suggests either a beach, dune or aeolian flat environment. Between 2 and 2.9' the sediments may have been deposited in an aeolian environment. Between 3 and 3.9' the sediments show evidence of having been deposited as a beach, formed as a low-energy foreshore deposit or aeolian flat. Below 4' there is evidence of aeolian modification of the original till (parent material).

When considering particle size data, the Ponton sediment may more closely approximate beach sands than dune or aeolian flat deposits. The sorting varies from R1 to R3, the latter having been exposed the longest, which is consistent with a decline in Lake Agassiz from SW to NE. The skewness values are mainly indeterminate, except in the case of R2, which may have been formed in a beach or dune environments. Similarly, the kurtosis values indicate that the ridges were deposited either as beaches or dunes.

The heavy mineral data is inconclusive. The evidence points to reworking, which is more prevalent in Ponton than at the Ste. Anne ridge.

On the basis of morphology the Ste. Anne ridge may be a morainic feature or some landform found in the beach, offshore bar or storm beach environment. The storm beach, or off shore bar, hypothesis is supported by a study of the stratigraphy in the central sections since finer material is found on the east and west edges, indicating that deeper water surrounded the feature. Off-shore bar or foreshore sands are found below the coarse storm beach sediments. The same bedded sequence could be evidence that the ridge is an esker.

The generalized trend on the sphericity data is not dissimilar to that found to result from longshore drift. But the sphericity form diagrams indicate that a fluvial environment is also plausible. The roundness values decrease in an opposite direction from the sphericities indicating a different current direction. The values indicate that the rounding occurred in beach deposits. Evidence from the long axis orientation is inconclusive but suggests that the pebbles were deposited as outwash or glacial till.

Different evidence again is derived from the textural analyses. Some parameters suggest a shoreline or dune environment, others indicate deposition within a dune or aeolian flat environment. Deposition as a beach is suggested for the upper coarse deposit, and the remainder may have been subjected to either water or wind reworking. The reworking is also suggested by the heavy mineral analyses.

The evidence tends to be contradictory and therefore inconclusive. The Ste. Anne ridge is a modified till deposit, reworked by wind and water. Evidence for the latter is stronger because of the coarse pebble horizons, suggesting a high energy environment. The ridge may be polygenetic in origin.

The morphology of the Ponton ridges differs. All the three ridges may have been formed as a beach or off-shore bar. In addition R2 may have been deposited as an esker. The stratigraphy in all three Ponton ridges is made up of homogeneous sands, consistent with an aeolian environment. The degree of sorting, and the fact that boulders are perched on the terraces, suggests modification in a periglacial environment.

The textural analyses show the sediment more closely resembles beach than dune or aeolian flat sands, although there is some suggestion that each of the ridges may have been deposited as beaches or dunes, The heavy mineral analyses indicate a high degree of reworking, which could take place either by water or wind.

As with the findings at Ste Anne, the results for Ponton are inconclusive. There is evidence to suggest a beach or an aeolian environment of deposition. The ridges may be polygenetic.

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Appendix 1

THE STE. ANNE RIDGE

Section 2A Pit

Depth (ft.)	Description
0.0 - 1.3	Soil horizon.
1.3 - 2.3	Unbedded granules, mixed sand and coarse silt. 10 YR 7-2.

Section 2B Quarry perpendicular to the long axis of the ridge

Depth (ft.)	Description
0.0 - 1.8	Contorted area, mixed by quarrying.
1.8 - 2.0	Unsorted granules, very coarse and medium sand.
2.0 - 2.15	Laminated medium sand, with a few granules.
2.15 - 2.3	Granules, very coarse sand and medium sand.
2.3 - 2.4	Finely laminated medium sand.
2.4 - 2.7	Predominantly medium sand, with very coarse sand laminae, and granules.
2.7 - 2.8	Medium sand with coarse sand laminae.
2.8 - 3.2	Very coarse sand lamina.
3.2 - 3.5	Laminated fine sand and coarse silt. 2.5 Y 7-2.
3.5 - 4.4	Predominantly medium sand, with fine granules and pebbles.
4.4 - 4.65	Medium sand, with coarse laminae and granules.
4.65 - 4.85	Coarse sand lamina - graded.
4.85 - 5.1	Dark clay horizon, with granules.
5.1 - 5.3	Coarse sand lamina.
5.3 - 5.4	Dark clay horizon, with granules.
5.4 - 5.6	Very coarse sand lamina.
5.6 - 5.7	Dark clay horizon, with granules.

Structures:

I	Beds	1.8 - 2.8	dipping 3 degrees downward to east.
II	Bed	2.8 - 3.2	dipping 30 degrees downward to east.
III	Bed	3.5 - 4.4	dipping 30 degrees downward to east.

Section 2C   Quarry perpendicular to the long axis of the ridge

Depth (ft.)	Description
0.0 - 1.4	Soil horizon.
1.4 - 2.2	Coarse sand lamina, interbedded with medium sand. Few granules.
2.2 - 2.7	Graded sand horizon, with coarse sand above and fine sand and coarse silt below. 2.5 Y 7-2.
2.7 - 3.05	Unsorted medium and coarse sand. Some lamina development.
3.05 - 3.6	Medium sand, with very coarse sand lamina at 3.1 and 3.2. Coarse sand lamina at 3.35 and 3.45.
3.6 - 4.45	Unsorted granules and medium sand.
4.45 - 4.85	Interbedded medium and coarse sand with coarse silt and fine sand. 2.5 Y 7-2.
4.85 - 5.2	Predominantly coarse granules, with medium and coarse sand.
5.2 - 5.4	Coarse sand lamina.
5.4 - 5.5	Fine granule lamina.
5.5 - 5.55	Sand lamina with granules.
5.55 - 5.8	Granules and very coarse sand lamina.
5.8 - 5.85	Dark clay, with discontinuous pebble horizon.
5.85 - 6.25	Interbedded mixed sand, with pebbles and coarse sand.

Structures:

I Bed 1.4 - 2.2 dipping 10 degrees downward to east.
II Beds 5.2 - 5.8 dipping 11 degrees downward to east.

Section 2D   Pit

0.0 - 1.5	Soil horizon.
1.5 - 2.0	Medium sand.

Section 2E   Pit

0.0 - 1.0	Soil horizon.
1.0 - 3.0	Medium and fine sand, with granules. 2.5 Y 6-2.

Section 3A — Pit

Depth (ft.)	Description
0.0 - 1.5	Soil horizon.
1.5 - 2.0	Fine sand predonimantly, with coarse and medium sand and silt.

Section 3B — Quarry perpendicular to the long axis of the ridge

Depth (ft.)	Description
0.0 - 1.4	Soil horizon.
1.4 - 1.7	Sandy soil, mixed with granules.
1.7 - 2.6	Bedded gravel horizon--coarse below and fine above.
2.6 - 2.95	Unsorted pebbles, granules and coarse sand.
2.95 - 3.0	Very coarse sand lamina.
3.0 - 3.05	Coarse granule lamina.
3.05 - 3.25	Medium sand, with coarse sand laminae.
3.25 - 3.5	Graded, coarse granules below and fine above.
3.5 - 4.25	Granules and very coarse sand, with medium sand laminae at 3.75 and 3.8.
4.25 - 4.3	Fine granule horizon.
4.3 - 4.8	Medium to fine sand--few granules.
4.8 - 5.0	Very coarse sand.
5.0 - 5.2	Predominantly coarse granules and very coarse sand.
5.2 - 5.4	Medium sand.
5.4 - 5.6	Medium and very coarse sand.
5.6 - 5.8	Granules and very coarse sand.
5.8 - 6.1	Medium sand.
6.1 - 6.3	Medium sand, very coarse sand laminae at 6.1 and 6.3.
6.3 - 6.4	Mixed granule horizon.
6.4 - 6.6	Medium sand with coarse sand laminae.
6.6 - 8.0	Fine to coarse sand, with fine granules

Structure:

I Beds 1.4 - 3.0 dipping 2.5 degrees downwards to west.

Section 3C Quarry perpendicular to the long axis of the ridge

Depth (ft.)	Description
0.0 - 1.0	Soil horizon.
1.0 - 1.7	Mixed zone disturbed by quarry working.
1.7 - 1.9	Graded--coarse sand above, granules below.
1.9 - 2.0	Medium sand, with coarse sand laminae.
2.0 - 2.2	Very coarse sand, with granule laminae.
2.2 - 2.45	Unsorted granules, very coarse and fine sand.
2.45 - 3.3	Medium sand, with very coarse sand lamina at 2.6 and 3.0. 10 YR 8-2.
3.3 - 3.7	Predominantly very coarse sand, grading into granules below.
3.7 - 4.0	Unsorted medium sand, with few granules.
4.0 - 4.1	Mixed granule horizon--few pebbles.
4.1 - 4.2	Very coarse sand lamina.
4.2 - 4.4	Coarse sand lamina.
4.4 - 4.8	Unsorted sand and granules.
4.8 - 5.0	Finely laminated sand.
5.0 - 5.1	Coarse sand lamina.
5.1 - 5.6	Mixed sand and granules.
5.6 - 6.1	Medium sand and few granules.
6.1 - 6.4	Coarse sand, with fine sand lamina at 6.3.
6.4 - 6.7	Graded bed of medium to coarse sand--granules below.
6.7 - 6.9	Medium sand.
6.9 - 6.95	Very coarse sand.
6.95 - 7.4	Medium sand.
7.4 - 8.8	Unsorted granules, coarse and medium sand.

Structures:

I	Beds	1.0 - 2.2	dipping 27 degrees downwards to east.
II	Beds	4.2 - 4.4	dipping 7 degrees downwards to west.
III	Bed	6.1 - 6.4	dipping 9 degrees downwards to west.
IV	Bed	6.9 - 6.95	dipping 7 degrees downwards to west.

Section 3D — Quarry perpendicular to the long axis of the ridge

Depth (ft.)	Description
0.0 - 0.5	Soil horizon, mixed with coarse sand and gravel.
0.5 - 0.9	Unsorted granules, very coarse and medium sand.
0.9 - 1.1	Medium sand, with coarse lamina at 1.0.
1.1 - 1.4	Graded horizon--coarse granule above and sand below.
1.4 - 1.8	Very coarse and medium sand.
1.8 - 2.0	Very coarse sand and granules.
2.0 - 2.7	Medium to fine sand, coarse grit lamina at 2.5.

Section 3E — Pit

0.0 - 0.8	Soil horizon.
0.8 - 1.0	Soil and sand.
1.0 - 2.0	Coarse sand, interbedded with pebbles and medium sand.
2.0 - 3.6	Reverse graded medium to fine sand. 2.5 YR 7-2.
3.6 - 4.0	Very coarse sand.

Section 4A — Pit

0.0 - 0.3	Soil horizon, with pebbles and coarse sand.
0.3 - 1.4	Clayey silt, with fine sand.
1.4 - 1.6	Granules, coarse sand and some silt.
1.6 - 2.3	Predominantly fine to very fine sand. Some coarse silt. 2.5 Y 7-2.

Section 4B — Pit

0.0 - 2.3	Unsorted granules and coarse sand.
2.3 - 2.7	Interbedded medium and fine sand.
2.7 - 3.05	Unsorted granules, pebbles and sand.
3.05 - 3.7	Coarse silt, with fine sand lamina at 3.4. 10 YR 7-2.
3.7 - 4.9	Mixed granules in bedded coarse and medium sand.
4.9 - 5.3	Pebble horizon.
5.3 - 6.0	Unsorted pebbles, granules and sand.

Section 4C — Pit

Depth (ft.)	Description
0.0 - 2.3	Unsorted sand with granules and pebbles. 10 YR 7-2.

Section 4D — Quarry parallel to the long axis of the ridge

Depth (ft.)	Description
0.0 - 0.9	Soil horizon.
0.9 - 1.75	Unsorted very coarse sand, granules and pebbles.
1.75 - 2.1	Coarse sand and granules, interbedded with medium sand and silt. 10 YR 3-7.
2.1 - 2.2	Very coarse sand lamina.
2.2 - 3.35	Unsorted pebbles, coarse sand and granules.
3.35 - 3.75	Medium to fine sand, few granules. 10 YR 8-2.
3.75 - 3.8	Coarse granules, interbedded with coarse and medium sand.
3.8 - 4.05	Very coarse sand lamina.
4.05 - 4.25	Pebble-granule lamina.
4.25 - 4.5	Unsorted fine and very coarse sand.
4.5 - 4.6	Coarse pebble horizon.
4.6 - 5.0	Unsorted sand and granules.
5.0 - 5.4	Medium sand, with coarse laminae.
5.4 - 5.45	Very coarse sand lamina.
5.45 - 6.1	Unsorted pebbles, granules and sand.
6.1 - 6.8	Predominantly coarse sand, with very coarse laminae below.
6.8 - 8.0	Medium to fine sand, with laminae of coarse silt. Few granules. 2.5 Y 7-2.
8.0 - 8.1	Pebble horizon.
8.1 - 9.0	Unsorted granules, pebbles and coarse sand.

Section 4E — Pit

Depth (ft.)	Description
0.0 - 0.7	Soil horizon.
0.7 - 1.1	Fine sand and soil.
1.1 - 2.2	Fine sand and coarse silt. 2.5 Y 6-2
2.2 - 3.0	Unsorted fine and medium sand. Few granules.

Section 5A Pit

Depth (ft.)	Description
0.0 - 0.6	Soil horizon.
0.6 - 1.2	Dark silty clay.
1.2 - 3.6	White clay.

Large boulders e.g. Porphyritic granite 6.0 z 3.5'.

Section 5B Pit

0.0 - 1.6	Unsorted pebbles, sand and cobbles.
1.6 - 3.0	Fine sand. 2.5 Y 2-8.
3.0 - 4.5	Silt horizon.

Section 5C Quarry parallel to long axis of ridge

0.0 - 1.0	Soil horizon.
1.0 - 1.4	Soil mixed with pebbles and cobbles.
1.4 - 2.5	Sand and cobble horizon, with calcareous accretions on underside of cobbles.
2.5 - 3.5	Medium sand, with coarse sand laminae.
3.5 - 4.0	Graded bed--coarse sand lamina above, granules below.
4.0 - 4.7	Cobble and pebble horizon--some sand.
4.7 - 5.0	Coarse sand lamina.
5.0 - 5.1	Medium-coarse sand.
5.1 - 5.22	Coarse sand lamina.
5.22 - 6.6	Medium sand with coarse lamina at 5.3, 5.4 and 5.5.
6.6 - 6.7	Lamina of coarse sand and fine granules. 10 4R 7-2.
6.7 - 6.8	Coarse granule lamina.
6.8 - 6.85	Very coarse sand lamina.
6.85 - 6.9	Granule horizon.
6.9 - 7.0	Coarse granules and sand.
7.0 - 7.1	Pebbles and very coarse sand.
7.1 - 8.4	Coarse pebbles, granules and very coarse sand.

Section 5D Pit

Depth (ft.)	Description
0.0 - 0.6	Soil horizon.
0.6 - 1.0	Mixed granule horizon, sand and soil.
1.0 - 1.3	Coarse granules and sand.
1.3 - 1.4	Very coarse sand laminae.
1.4 - 1.6	Medium sand with coarse sand laminae.
1.6 - 2.3	Unsorted granules, pebbles and sand. 2.5 Y 7-2.
2.3 - 2.9	Medium sand with coarse laminae.
2.9 - 3.15	Pebble horizon--some sand.
3.15 - 3.3	Medium sand.
3.3 - 3.5	Pebble horizon.

Section 5E Pit

0.0 - 1.0	Soil horizon.
1.0 - 1.4	Soil and fine sand.
1.4 - 2.0	Unsorted granules, very coarse and medium sand.
2.0 - 2.9	Medium to fine sand with coarse laminae. 2.5 Y 7-2.
2.9 - 3.4	Medium-coarse sand.

Section 6A Pit

0.0 - 0.4	Rotted leaf mat.
0.4 - 1.3	Dark clay.
1.3 - 2.6	White clay.

Section 6B Pit

0.0 - 0.5	Soil horizon.
0.5 - 0.7	Soil with fine sand and pebbles.
0.7 - 1.1	Very coarse sand.
1.1 - 1.5	Medium to fine sand. 2.5 Y 7-2.
1.5 - 2.3	Unsorted coarse pebbles, granules, sand and coarse silt. 10 YR 7-2.

Section 6C Quarry parallel to the long axis of the ridge

Depth (ft.)	Description
0.0 - 0.5	Soil and scattered pebbles.
0.5 - 0.8	Cobble and pebble horizon.
0.8 - 1.1	Very coarse sand.
1.1 - 1.3	Unsorted cobbles, gravel and sand.
1.3 - 1.55	Medium sand and pebbles.
1.55 - 1.65	Pebble lamina.
1.65 - 2.05	Coarse silt with fine sand lamina at 1.75, 1.85, 1.9. 10 YR 7-2.
2.05 - 2.15	Coarse pebble lamina.
2.15 - 3.6	Fine sand, with medium sand laminae at 0.2.

Section 6D Pit

0.0 - 0.5	Soil horizon.
0.5 - 0.8	Coarse sand, granules and pebples, with soil.
0.8 - 1.1	Unsorted very coarse sand, granules and pebbles.
1.1 - 1.8	Granules and coarse silt with fine sand laminae at 1.45, 1.6.
1.8 - 2.05	Medium sand and coarse silt. 10 YR 7-2.
2.05 - 3.3	Medium sand--few pebbles and granules.
3.3 - 4.0	Pebbles and very coarse sand.

Section 6E Pit

0.0 - 0.8	Soil horizon.
0.8 - 1.2	Fine sand and soil.
1.2 - 1.6	Medium sand, with granules and fine pebbles.
1.6 - 2.1	Fine sand and granules, interbedded with medium sand and coarse silt. 10 YR 7-2.
2.1 - 2.8	Graded sand--fine above becoming coarser below.

Section 7A Pit

Depth (ft.)	Description
0.0 - 1.0	Soil horizon.
1.0 - 1.5	Mixed sand and soil.
1.5 - 1.6	Fine sand.
1.6 - 3.0	Unsorted pebble, with fine and coarse sand. 2.5 Y 7-2.

Section 7B Pit

0.0 - 1.0	Soil horizon.
1.0 - 1.3	Soil, sand and fine granules.
1.3 - 1.9	Medium to fine sand, with granules. 10 YR 7-3.
1.9 - 2.0	Very coarse sand lamina.
2.0 - 2.1	Medium sand.
2.1 - 2.2	Pebble horizon.
2.2 - 2.35	Medium sand.
2.35 - 2.8	Pebbles and sand.
2.8 - 3.6	Coarse to medium sand.

Section 7C Pit

0.0 - 1.0	Soil horizon--coarse sand, granules and pebbles.
1.0 - 1.2	Medium sand, coarse lamina at 1.03.
1.2 - 1.3	Graded bed--very coarse sand to granules.
1.3 - 1.55	Pebbles interbedded with sand.
1.55 - 2.0	Medium to fine sand. 10 YR 7-3.
2.0 - 2.35	Coarse sand.
2.35 - 2.8	Unsorted pebbles and granules.
2.8 - 3.9	Medium sand.

Section 7D Pit

0.0 - 0.9	Soil horizon.
0.9 - 2.2	Unsorted medium sand, with pebbles and granules.
2.2 - 2.7	Reverse graded bed--medium sand and fine sand with granules. 2.5 Y 7-2.

Section 7E — Pit

Depth (ft.)	Description
0.0 - 0.6	Soil horizon.
0.6 - 1.0	Medium sand.
1.0 - 1.9	Medium to fine sand, and granules. 2.5 Y 7-2.
1.9 - 2.4	Graded bed, medium to very coarse sand.
2.4 - 3.0	Very coarse sand and granules.

Section 8A — Pit

0.0 - 1.0	Soil horizon.
1.0 - 1.65	Medium sand and granules.
1.65 - 2.2	Fine sand. 2.5 Y 8-2.
2.2 - 2.6	Coarse and medium sand.

Section 8B — Pit

0.0 - 1.6	Soil horizon.
1.6 - 2.9	Unsorted pebbles, granules, fine sand and coarse silt. 10 YR 7-2.
2.9 - 3.8	Unsorted coarse gravel and sand.

Section 8C — Quarry perpendicular to the long axis of the ridge

0.0 - 0.5	Soil horizon--some pebbles.
0.5 - 1.0	Medium sand, pebbles and soil.
1.0 - 1.2	Coarse pebbles--some soil.
1.2 - 1.7	Medium sand.
1.7 - 2.8	Unsorted medium sand and pebbles.
2.8 - 3.0	Unsorted pebbles, granules, sand and coarse silt. 2.5 Y 7-2.
3.0 - 4.6	Coarse sand, granules and pebbles.

Section 8D — Quarry perpendicular to the long axis of the ridge

0.0 - 0.6	Soil horizon, with very coarse sand and granules.
0.6 - 1.0	Pebbles with medium sand--graded to fine sand.
1.0 - 1.4	Irregular pebble horizon.
1.4 - 1.5	Fine sand, with dipping medium sand lamina.
1.5 - 1.6	Partially disintegrated pebbles, in mixed sand.

Section 8D (continued)

Depth (ft.)	Description
1.6 - 1.8	Granules and mixed sand.
1.8 - 2.0	Unsorted pebbles, granules and sand.
2.0 - 2.5	Unsorted pebbles, granules and sand. Few cobbles.
2.5 - 3.9	Fine and some medium sand, with coarse silt. 10 YR 7-2.
3.9 - 4.2	Unsorted granules and sand.

Structure:

I Beds 0.6 - 2.0 dipping 16 degrees downwards to west.

Section 8E Quarry perpendicular to the long axis of the ridge

0.0 - 0.35	Soil horizon.
0.35 - 0.65	Soil with pebbles.
0.65 - 1.05	Unsorted horizon of fine granules, medium sand and soil.
1.05 - 1.3	Unsorted bed of pebbles, granules, sand coarse silt. 10 YR 7-2.
1.3 - 2.15	Coarse sand, with medium sand laminae. 10 YR 7-2.
2.15 - 2.6	Fine pebbles interbedded with sand.
2.6 - 3.45	Predoninantly fine sand with some coarse silt. 10 YR 7-3.
3.45 - 4.0	Fine clay.
4.0 - 4.6	Medium sand.

Structure:

I Bed 1.05 - 1.3 dipping downward to east.

Section 8F Pit

0.0 - 0.5	Soil horizon.
0.5 - 2.1	Medium sand, graded coarser below.
2.1 - 3.6	Predominantly fine sand and coarse silt, with pebbles and granules. 2.5 Y 2-7.

Section 9A — Pit

Depth (ft.)	Description	
0.0 - 1.1	Soil horizon.	
1.1 - 1.7	Fine sand.	2.5 Y 6-2.

Section 9B — Pit

Depth (ft.)	Description	
0.0 - 1.0	Soil horizon.	
1.0 - 1.7	Medium sand with coarse sand laminae.	
1.7 - 2.1	Medium granules, with sand.	
2.1 - 2.6	Medium sand with granules.	2.5 Y 7-2.
2.6 - 2.8	Unsorted granules and sand.	

Section 9C — Pit

Depth (ft.)	Description	
0.0 - 0.9	Soil horizon.	
0.9 - 1.2	Medium sand and soil.	
1.2 - 2.4	Graded coarse sand and granules.	
2.4 - 3.0	Fine sand	2.5 Y 8-2.

Section 9D — Quarry parallel to the long axis of the ridge

Depth (ft.)	Description	
0.0 - 0.55	Soil horizon.	
0.55 - 1.5	Unsorted soil, fine sand and granules.	2.5 Y 7-2.
1.5 - 4.3	Fine to medium, with irregular dark streaks. (Fe?)	
4.3 - 5.0	Medium sand.	

Section 9E — Pit

Depth (ft.)	Description	
0.0 - 1.5	Soil horizon.	
1.5 - 2.7	Medium to fine sand.	2.5 Y 6-2.

Section 10A — Pit

Depth (ft.)	Description
0.0 - 0.2	Soil horizon.
0.2 - 0.8	Soil, with granules and pebbles.
0.8 - 1.8	Medium sand, grey clay and fine pebbles.
1.8 - 2.0	Medium sand and fine pebbles.

Section 10A (continued)

Depth (ft.)	Description
2.0 - 2.2	Fine sand.
2.2 - 2.5	Fine sand, some staining. (Fe?)
2.5 - 3.0	White clay, irregular pebbles.

Section 10B Pit

0.0 - 0.7	Leached coarse and gravel.
0.7 - 1.4	Soil horizon and fine pebbles.
1.4 - 2.1	Medium sand, granules and coarse silt. 2.5 Y 7-2.
2.1 - 3.1	Unsorted sand and pebbles.
3.1 - 3.8	Graded bed--medium to coarse sand.
3.8 - 5.1	Graded bed--fine to medium sand.

Section 10C Quarry perpendicular to the long axis of the ridge

0.0 - 0.5	Soil horizon.
0.5 - 1.7	Soil and fine pebbles.
1.7 - 2.1	Unsorted coarse pebbles, granules and sand.
2.1 - 2.5	Fine granules.
2.5 - 3.0	Medium sand and coarse silt. 2.5 Y 7-2.
3.0 - 3.2	Unsorted pebbles, granules and coarse sand.
3.2 - 3.5	Coarse pebble horizon.
3.5 - 4.33	Medium sand and granules.
4.33 - 4.38	Coarse granules.
4.38 - 4.6	Coarse sand.
4.6 - 5.05	Coarse, medium and fine sand. 2.5 Y 7-2.
5.05 - 5.28	Medium to coarse sand.
5.28 - 5.32	Clay band and coarse granules.
5.32 - 7.00	Medium sand containing very coarse sand.

Structures:

I Bed 1.7 - 2.1 dipping 10 degrees downwards to east.
II Bed 2.5 - 3.0 dipping 20 degrees downward to east.

Section 10D — Pit

Depth (ft.)	Description
0.0 - 1.0	Very coarse sand.
1.0 - 2.4	Soil, with fine granules and pebbles.
2.4 - 3.6	Medium sand, coarse silt with few granules. (Fe?) 2.5 Y 7-4.

Section 10E — Pit

0.0 - 1.3	Soil horizon.
1.3 - 2.0	Soil with medium sand.
2.0 - 3.8	Coarse silt, with fine to coarse sand. 2.5 Y 5-2.

Section 11A — Pit

0.0 - 0.5	Soil horizon.
0.5 - 0.7	Soil with some silt.
0.7 - 1.1	Very coarse sand.
1.1 - 1.2	Light clay.
1.2 - 3.6	Dark clay.

Section 11B — Pit

0.0 - 1.7	Soil horizon.
1.7 - 2.1	Very coarse sand and coarse granules.
2.1 - 3.2	Intermixed coarse and very coarse sand, with granules. 2.5 Y 7-2.

Section 11C — Pit

0.0 - 0.7	Soil horizon.
0.7 - 1.1	Very coarse sand, with granule laminations.
1.1 - 4.0	Medium and coarse sand, with very coarse laminations. 2.5 Y 7-2.

Section 11D Pit

Depth (ft.)	Description
0.0 - 0.9	Soil horizon.
0.9 - 2.2	Graded fine granules and coarse grit.
2.2 - 3.6	Coarse to medium sand. 2.5 Y 8-4.

Section 11E Pit

0.0 - 0.7	Soil horizon.
0.7 - 1.6	Soil with silt and pebbles.
1.6 - 3.4	Silt with coarse to medium sand. 2.5 Y 6-2.

Section 12A Pit

0.0 - 1.1	Soil horizon.
1.1 - 2.0	Unsorted granules, sands and silt. 10 YR 6-2.
2.0 - 3.9	Silty clay.

Section 12B Pit

0.0 - 0.8	Soil horizon.
0.8 - 2.9	Unsorted granules, pebbles, sand and silt. 10 YR 7-2.
2.0 - 4.0	Medium sand.

Section 12C Pit

0.0 - 0.4	Soil horizon.
0.4 - 0.85	Very coarse sand and granules.
0.85 - 2.0	Unsorted fine to very coarse sand with granules. 10 YR 6-3.
2.0 - 3.6	Pebbles with medium sand.

Section 12D Pit

0.0 - 0.55	Soil horizon
0.55 - 0.9	Soil, with granules and very coarse sand.
0.9 - 2.0	Unsorted pebbles, coarse and medium sand.

Section 12D (continued)

Depth (ft.)	Description
2.0 - 2.1	Pebble horizon, some sand.
2.1 - 2.6	Graded medium sand and granules. 10 YR 7-3.
2.6 - 2.8	Pebble horizon.
2.8 - 3.4	Very coarse sand.

Structure:
I Bed 0.9 - 2.1 dipping 7 degrees downward to east.

Section 12E Pit

0.0 - 1.0	Soil horizon.
1.0 - 2.4	Unsorted granules and coarse silt, with irregular pebbles. 2.5 Y 7-2.
2.4 - 3.6	Clay. 2.5 Y 8-2.

Section 13A Pit

0.0 - 0.9	Soil horizon with some granules.
0.9 - 1.3	Gravel horizon.
1.3 - 3.4	Pebbles, granules and coarse sand. 2.5 Y 7-2.

Section 13B Pit

0.0 - 0.8	Soil horizon.
0.8 - 1.4	Soil with gravel.
1.4 - 1.65	Coarse sand interbedded with medium sand.
1.65 - 2.4	Unsorted granules, with coarse and very coarse sand. 2.5 Y 6-2.
2.4 - 3.8	Silty sand.

Section 13C Pit

0.0 - 0.5	Soil horizon.
0.5 - 1.3	Soil with pebbles.
1.3 - 1.5	Very coarse sand and granules.
1.5 - 3.0	Predominantly very coarse sand, with granules and coarse sand. 10 YR 6-2.

Section 13D Pit

Depth (ft.)	Description
0.0 - 0.7	Soil horizon.
0.7 - 0.9	Pebbles and granules.
0.9 - 1.8	Predominantly very coarse sand, with some medium sand and granules.
1.8 - 3.8	Coarse sand, with very coarse sand, granules and irregular pebbles. 10 YR 6-2.
3.8 - 4.0	Silty sand.

No 13E position was sampled because the ridge narrows at this point.

Section 14A Pit

0.0 - 1.0	Soil with coarse pebbles.
1.0 - 1.6	Very coarse and medium sand.
1.6 - 1.8	Clay, with some medium sand.
1.8 - 3.8	Clay horizon. 2.5 Y 8-2.

Section 14B Quarry parallel to the transverse axis of the ridge

0.0 - 0.9	Soil with coarse pebbles.
0.9 - 1.15	Very coarse sand lamina.
1.15 - 1.25	Medium sand, with very coarse sand laminae.
1.25 - 1.4	Very coarse sand lamina, with irregular pebbles.
1.4 - 1.55	Graded coarse to medium sand lamina.
1.55 - 1.6	Pebble horizon.
1.6 - 1.85	Graded bed--coarse sand to medium granules.
1.85 - 2.1	Coarse and medium sand--pebble horizon at 2.1.
2.1 - 2.5	Graded very coarse to medium sand.
2.5 - 3.3	Graded coarse to fine sand. 10 YR 7-3.
3.3 - 3.8	Mixed sand horizon with irregular granules.
3.8 - 3.83	Clay horizon.
3.83 - 5.3	Boulders, with unsorted pebbles and mixed sand.

Section 14B (continued)

Structures:

I	Bed	1.6 - 1.85	dipping 4	degrees downward to west.
II	Bed	1.85 - 2.1	dipping 4.5	degrees downward to west.

Section 14C Quarry parallel to the transverse axis of the ridge

Depth (ft.)	Description
0.0 - 1.2	Soil with pebbles and very coarse sand.
1.2 - 1.65	Medium sand.
1.65 - 2.25	Silty clay horizon.
2.25 - 2.8	Medium sand graded, coarser below with irregular pebbles.
2.8 - 2.9	Very coarse sand and pebble lamina.
2.9 - 3.1	Medium sand with irregular pebbles.
3.1 - 3.2	Clay horizon.
3.2 - 3.25	Coarse granules.
3.25 - 3.8	Very coarse pebble horizon, some medium sand.
3.8 - 4.8	Predominantly coarse sand, with medium sand, coarse pebbles, granules and boulders. 2.5 Y 7-2.

Structures:

I	Bed	1.2 - 1.65	dipping 7	degrees downward to east.
II	Bed	1.65 - 2.15	dipping 4	degrees downward to east.
III	Bed	2.15 - 2.25	dipping 5	degrees downward to east.
IV	Bed	2.8 - 2.9	dipping 17	degrees downward to east.

Section 14D Pit

0.0 - 0.8	Soil horizon with fine granules and pebbles.
0.8 - 1.7	Horizon of very fine granules graded to pebbles below.
1.7 - 2.5	Coarse to medium sand and irregular pebbles. 10 YR 7-2.
2.5 - 2.7	Very coarse sand lamina.
2.7 - 3.4	Unsorted horizon of very coarse sand, and pebbles.

Section 14E Pit

Depth (ft.)	Description
0.0 - 0.8	Soil horizon.
0.8 - 3.0	Soil with coarse sand and irregular pebbles.
3.0 - 3.5	Unsorted granules with fine sand, silt and clay. 2.5 Y 7-4.

Section 15A Pit

0.0 - 0.6	Soil horizon.
0.6 - 0.8	Pebble lamina.
0.8 - 2.0	Coarse sand and pebbles. 2.5 Y 7-2.
2.0 - ?	Boulders.

Section 15B Pit

0.0 - 1.1	Soil horizon, with pebbles.
1.1 - 1.4	Coarse sand, graded, coarser below.
1.4 - 1.6	Clay horizon, with some granules.
1.6 - 1.8	Coarse gravel horizon.
1.8 - 2.8	Coarse sand, graded, very coarse below, with some granules. 2.5 y 7-2.
2.8 - 3.4	Silt horizon, with irregular pebbles.

Section 15C Pit

0.0 - 0.6	Soil horizon.
0.6 - 1.0	Soil with irregular pebbles.
1.0 - 2.5	Very coarse sand and pebbles.
2.5 - 3.5	Unsorted coarse to medium sand, some granules. 2.5 Y 7-2.

Section 15D Pit

0.0 - 0.9	Soil horizon.
0.9 - 1.4	Coarse sand.
1.4 - 1.5	Coarse granule horizon, reverse grading into coarse sand below.
1.5 - 1.8	Very coarse sand, with medium sand laminae.

Section 15D (continued)

	Depth (ft.)	Description
	1.8 - 1.9	Very coarse sand lamina.
	1.9 - 2.2	Unsorted very coarse to medium sand. Some granules and pebbles. 2.5 Y 7-2.
	2.2 - 3.0	Boulders and cobbles in clay matrix.

Section 15E Pit

0.0 - 0.1	Soil horizon.
0.1 - 1.6	Fine silty clay, with irregular granules.
1.6 - 2.0	Clay, with few granules.
2.0 - 3.6	White clay.

Section 16A Pit

0.0 - 1.2	Soil horizon.
1.2 - 2.0	Clay with irregular pebbles.
2.0 - 3.5	Clay.

Section 16B East Quarry parallel to the transverse axis of the ridge
Top soil removed by quarry workings.

0.0 - 0.8	Disturbed horizon due to quarrying.
0.8 - 0.85	Very coarse sand lamina.
0.85 - 0.95	Pebble horizon, with coarse sand.
0.95 - 1.3	Very coarse sand lamina.
1.3 - 1.9	Pebble horizon with coarse and very coarse sand. 10 YR 6-1.
1.9 - 2.2	Very coarse sand, graded with granules below.
2.2 - 2.5	Medium sand.
2.5 - 2.55	Coarse sand lamina.
2.55 - 2.75	Coarse and medium sand, with some clay. 10 YR 7-2.
2.75 - 2.95	Unsorted pebbles, coarse sand and silt. 2.5 Y 7-2.
2.95 - 3.0	Coarse granules with very coarse sand.
3.0 - 3.1	Clay horizon.
3.1 - 3.3	Medium sand, graded below into granules.
3.3 - 3.35	Medium and very coarse sand.

Section 16B East (continued)

Depth (ft.)	Description
3.35 - 3.45	Very coarse sand lamina.
3.45 - 3.55	Medium sand.
3.55 - 3.65	Very coarse sand and granules. 10 YR 7-3.
3.65 - 3.8	Unsorted pebbles and coarse sand.
3.8 - 3.9	Coarse granula lamina.
3.9 - 4.35	Unsorted sand and gravel.
4.35 - 4.45	Pebbles with very coarse sand.
4.45 - 4.9	Medium sand and granules.
4.9 - 5.1	Unsorted horizon of granules and coarse sand.

Structures:

I	Bed	0.95 - 1.3	dipping 11	degrees downward to west	
II	Bed	2.5 - 2.55	dipping 10	degrees downward to west	
III	Bed	2.75 - 2.95	dipping 2	degrees downward to west	
IV	Bed	3.1 - 3.3	dipping 15	degrees downward to east	
V	Bed	3.55 - 3.65	dipping 4.5	degrees downward to east	
VI	Bed	4.35 - 4.45	dipping 16	degrees downward to east.	

Section 16B West   Quarry parallel to the transverse axis of the ridge

0.0 - 1.75	Disturbed horizon due to quarrying.
1.75 - 1.85	Very coarse sand and granule lamina.
1.85 - 2.0	Coarse sand lamina.
2.0 - 2.1	Pebble horizon.
2.1 - 2.8	Granules, pebbles and coarse sand. 2.5 Y 7-2.
2.8 - 2.9	Clay horizon.
2.9 - 3.2	Coarse and fine granules and mixed sand.
3.2 - 3.4	Sand lamina with irregular granules--reverse graded.
3.4 - 3.45	Medium granule horizon.
3.45 - 3.7	Coarse sand and granules.
3.7 - 3.9	Pebbles, very coarse sand with some fine sand and silt. 2.5 Y 6-2.
3.9 - 4.4	Unsorted pebbles, coarse and very coarse sand.

Section 16B West (continued)

Structures:

I	Bed	2.1 - 2.8	dipping 15 degrees downward to west
II	Bed	3.9 - 4.4	dipping 4 degrees downward to east

Section 16C Pit

Depth (ft.)	Description
0.0 - 0.6	Disturbed horizon due to quarrying.
0.6 - 1.6	Coarse granules with very coarse sand.
1.6 - 2.1	Unsorted coarse sand to coarse silt with granules and pebbles. 2.5 Y 7-2.
2.1 - 2.2	Very coarse sand lamina.
2.2 - 2.6	Coarse granule horizon.
2.6 - 3.3	Unosrted coarse sand and pebbles.

Structures:

I Bed 1.6 - 2.2 dipping 3 degrees downward to east.

Section 16D Pit

0.0 - 1.0	Soil with coarse granules and very coarse sand.
1.0 - 1.4	Very fine sand graded into fine granules. 2.5 Y 7-2.
1.4 - 2.3	Pebble horizon with coarse sand.

Section 16E Pit

0.0 - 0.8	Soil horizon.
0.8 - 1.2	Dark clay.
1.2 - 2.0	Very coarse to fine sand with some granules and light clay. 2.5 Y 8-2.

Section 17A   Pit

Depth (ft.)	Description
0.0 - 0.8	Soil horizon, with large boulders on surface.
0.8 - 1.6	Very coarse sand and pebbles. 2.5 Y 5-2.
1.6 - 3.5	Silty sand and irregular pebbles.

Section 17B   Pit

0.0 - 1.0	Soil horizon.
1.0 - 1.5	Predominantly soil with very coarse sand and irregular granules.
1.5 - 2.6	Very coarse sand and coarse granules.
2.6 - 3.7	Medium sand with granules and pebbles. 2.5 Y 7-2.

Section 17C   Pit

0.0 - 0.6	Soil horizon.
0.6 - 2.2	Mixed horizon of granules, very coarse and medium sand.
2.2 - 2.4	Medium sand.
2.4 - 3.0	Medium sand, with coarse sand laminae and irregular pebbles.
3.0 - 3.4	Very coarse sand and granules.
3.4 - 3.65	Medium sand lamina. 2.5 Y 7-2.
3.65 - 3.85	Unsorted sand and granules.
3.85 - 3.95	Coarse granule horizon.
3.95 - 5.3	Unsorted coarse and very coarse sand, and granules.

Structure:

I Bed 3.0 - 3.4 dipping 27 degrees downward to east.

Section 17D   Pit

0.0 - 0.6	Soil horizon.
0.6 - 1.55	Soil, with granules.
1.55 - 2.0	Coarse granules and very coarse sand.
2.0 - 2.9	Medium sand and irregular granules.

Section 17D (continued)

Depth (ft.)	Description
2.9 - 2.95	Coarse granule horizon.
2.95 - 3.8	Unsorted very coarse to fine sand some granules. 2.5 Y 7-2.
3.8 - 4.6	Very coarse sand and granules.

Section 17E Pit

0.0 - 1.4	Soil horizon.
1.4 - 2.0	Medium to fine sand, some coarse silt. 10 YR 5-2.
2.0 - 3.6	Dark clay.

Section 18A Pit

0.0 - 0.6	Soil horizon.
0.6 - 1.1	Soil, pebbles, very coarse sand and boulders.
1.1 - 1.6	Granules, pebbles and coarse sand. 2.5 Y 6-2.
1.6 - 3.4	Silty sand.

Section 18B Pit

0.0 - 0.5	Soil horizon
0.5 - 1.2	Soil with very coarse sand and granules.
1.2 - 2.0	Coarse sand with pebbles, granules and silt. 10 YR 7-2.
2.0 - 3.4	Granules, with coarse silt.

Section 18C Quarry parallel to the transverse axis of the ridge

0.0 - 0.5	Disturbed due to quarrying.
0.5 - 1.1	Unsorted granules in clay.
1.1 - 1.2	Silt, with coarse sand and granules.
1.2 - 1.35	Unsorted gravel and sand.
1.35 - 1.75	Medium sand, with very coarse sand laminae, some pebbles and silt. 2.5 Y 7-2.
1.75 - 1.9	Coarse sand, grading into fine granules.
1.9 - 2.05	Unsorted coarse granules and sand.

Section 18C (continued)

Depth (ft.)	Description
2.05 - 3.0	Pebble horizons in mixed sand.
3.0 - 4.7	Unsorted granules, pebbles, very coarse sand and silt. 2.5 Y 7-2.

Structures:

I Bed 1.75 - 1.9 dipping 1 degree downward to west
II Bed 2.05 - 3.0 dipping 5 degrees downward to east.

Section 18D Pit

0.0 - 0.5	Soil horizon
0.5 - 1.0	Soil with fine pebbles.
1.0 - 1.5	Predominantly medium sand, with very coarse sand and granules.
1.5 - 2.2	Pebble horizon.
2.2 - 3.4	Coarse pebbles.
3.4 - 4.0	Silty sand.

Section 18E Pit

0.0 - 1.6	Soil horizon.
1.6 - 1.8	Silty sand.
1.8 - 2.3	Silty clay.

Section 19A Pit

0.0 - 0.9	Soil horizon.
0.9 - 1.3	Clay with irregular granules.
1.3 - 3.0	Clay. 2.5 Y 6-2.

Section 19B Pit

0.0 - 0.5	Soil horizon.
0.5 - 1.0	Granules and soil.
1.0 - 1.2	Unsorted coarse and medium sand.
1.2 - 1.5	Very coarse sand lamina and irregular granules.
1.5 - 2.3	Unsorted sand with irregular granules, pebbles and coarse laminae. 2.5 Y 7-2.

Section 19C Quarry perpendicular to the long axis of the ridge.

Depth (ft.)	Description
0.0 - 0.6	Soil horizon.
0.6 - 1.2	Soil, with very coarse sand and granules.
1.2 - 2.3	Coarse sand and irregular granules.
2.3 - 3.9	Very coarse sand with discontinuous gravel laminae. 2.5 Y 6-2.
3.9 - 4.6	Pebble horizons, with medium and very coarse sand.

Structure:

I Bed 2.3 - 3.9 dipping 10 degrees downward to west

Section 19D Pit

0.0 - 0.8	Soil horizon.
0.8 - 1.3	Granules and very coarse sand.
1.3 - 1.5	Silty clay, with irregular granules.
1.5 - 3.6	Unsorted cobbles, pebbles and granules.

Section 19E Pit

0.0 - 0.6	Soil horizon.
0.6 - 2.6	Light clay, with some silt.

Appendix 2

THE PONTON RIDGES

Transect -400.

Section -400A Pit

Depth (ft.)	Description
0.0 - 2.3	Silty sand, clay and granules. 2.5 Y 7-2.
2.3 - 2.5	Ash grey fine soil horizon.
2.5 - 4.0	Orange sand horizon.

Section -400B Pit

0.0 - 2.3	Clay.

Section -400C Pit

0.0 - 2.0	Clay.

Section -400D Pit

0.0 - 2.4	Clay.

Section -400E Pit.

0.0 - 2.1	Fine silty sand.
2.1 - 3.7	Clay horizon.

Sections - 400F and G.

Pit.

0.0 - 0.3	Silty sand.
0.3 - 0.6	Ash grey fine soil horizon.
0.6 - 4.0	Unsorted coarse to fine orange sand, with some coarse silt. 2.5 Y 7-4.

Section -400H Pit

Depth (ft.)	Description
0.0 - 2.5	Clay.

Section -400 I and J.

Pit

0.0 - 0.6	Soil horizon.
0.6 - 0.8	Silty sand.
0.8 - 1.9	Clay

Section -400K Pit

0.0 - 6.6	Fine sand and some coarse silt. 2.5 Y 7-2.
6.6 - 7.2	Clay horizon.

Section -400L Pit

0.0 - 0.6	Medium to fine sand, some coarse silt. 2.5 Y 6-4.
0.6 - 0.9	Ash grey horizon.
0.9 - 2.8	Orange sand horizon.
2.8 - 4.1	Fine sand.

Section -400M contains the same sedimentological differentiation as -400L.

Section -400N. Pit

0.0 - 3.2	Very fine sand.
3.2 - 3.9	Clay horizon.

Section -400(0) Pit

Wet peat swamp.

Transect 000.

Section 000A Pit

0.0 - 0.6	Silty sand.
0.6 - 0.7	Organic horizon.

Section 000A (continued)

Depth (ft.)	Description
0.7 - 0.9	Ash grey fine soil horizon.
0.9 - 3.0	Fine to very fine sand. 10YR 6-6.

Section 000B and C

Pit

0.0 - 0.7	Organic horizon.
0.7 - 3.0	Clay. 2.5 Y 8-2.

Section 000D Pit

0.0 - 3.6	Fine to very fine sand, some coarse silt. 10 YR 7-2.

Section 000E Pit

0.0 - 1.0	Fine sand and silt. 2.5 Y 7-2.
1.0 - 3.7	Silty clay.

Section 000F Pit

0.0 - 0.8	Coarse sand to silt. 2.5 Y 7-4.
0.8 - 2.6	Clay.

Section 000G Pit

0.0 - 4.0	Fine sand, and some coarse silt. 2.5 Y 6-4.

Sections 000H and 000I disturbed by the road. Silty sand above and clay beneath. Some granules evident.

Section 000K Pit.

0.0 - 0.3	Organic horizon--peat.
0.3 - 0.6	Silty sand.
0.6 - 3.4	Coarse to fine sand, some coarse silt and granules. 2.5 Y 5-2.

Section 000L Pit

Depth (ft.)	Description
0.0 - 4.0	Fine sand.

Section 000M Pit

0.0 - 1.0	Silty sand.
1.0 - 2.3	Very coarse sand and granules.

Section 000N Pit

0.0 - 2.0	Very coarse sand.

Section 000(0) Pit

0.0 - 4.0	Fine sand with irregular pebples. 2.5 Y 7-2

Section 000P Pit

0.0 - 2.6	Silty sand, and irregular pebbles

Section 000Q Pit

0.0 - 1.0	Fine sand and irregular pebbles.
1.0 - 1.6	Ash grey fine soil horizon.
1.6 - 2.6	Orange sand horizon.
2.6 - 4.4	Medium to fine sand. 2.5 Y 7-4.

Section 000R Impenetrable vegetative mat and peat.

Transect 200

Section 200A Pit

0.0 - 1.0	Silty sand with some clay. 2.5 Y 7-2.
1.0 - 1.2	Dark organic soil horizon.
1.2 - 1.4	Ash grey fine soil horizon.
1.4 - 1.6	Orange sand horizon.
1.6 - 3.6	Very fine and medium sand. 2.5 Y 6-4.
3.6 - 5.0	Clay.

Section 200B Pit

Depth (ft.)	Description	
0.0 - 0.6	Fine silty sand.	2.5 Y 7-2.
0.6 - 3.0	Clay.	2.5 Y 7-2.

Sections 200C, D and E

Pit

0.0 - 0.5	Fine sand.	
0.5 - 2.3	Clay.	2.5 Y 8-2.

Section 200F Pit

0.0 - 2.6	Silty clay.
2.6 - 3.3	Silty sand.

Section 200G Pit

0.0 - 1.6	Medium to fine sand--some silt. 2.5 Y 7-2.

Section 200H Pit

0.0 - 4.0	Medium and fine sand. 2.5 Y 7-4.

Section 200I Pit

0.0 - 0.8	Fine silty sand.
0.8 - 3.2	Clay.

Section 200J Pit

0.0 - 0.6	Fine orange sand horizon.
0.6 - 2.3	White/light grey clay horizon.

Section 200K Pit

0.0 - 0.4	Silty sand.
0.4 - 2.3	Coarse to medium sand. No one color.

Section 200L Pit

Depth (ft.)	Description
0.0 - 1.0	Medium to silty sand. 2.5 Y 6-2.
1.0 - 2.3	Very fine sand. 2.5 Y 7-2.
2.3 - 2.7	Very coarse sand with irregular pebbles and clay lenticles.

Section 200M Pit

0.0 - 1.1	Silty fine to very fine sand.
1.1 - 1.3	Clay horizon with irregular pebbles.
1.3 - 2.6	Silty sand.

Section 200N Pit

0.0 - 4.0	Very fine sand with medium lamina, at 2.0'. 2.5 Y 8-4.

Section 200(0) Pit

0.0 - 1.0	Fine orange sand.
1.0 - 3.6	Fine sand. 2.5 Y 6-4.

Transect 400

Section 400A Pit

0.0 - 2.0	Fine to very fine orange sand. 2.5 Y 7-4.
2.0 - 4.0	Medium sand.

Section 400B Pit

0.0 - 2.0	Fine to very fine sand.
2.0 - 3.6	Clay, and some silt. 2.5 Y 7-4.

Section 400C Pit

0.0 - 4.0	Fine textured silty sand.

Section 400D Pit

Depth (ft.)	Description	
0.0 - 0.8	Silty sand.	
0.8 - 1.0	Clay horizon.	

Section 400E Pit

0.0 - 0.9	Medium to fine sand.	2.5 Y 7-2.
0.9 - 2.4	Clay.	2.5 Y 7-2.

Section 400F Pit

0.0 - 5.0	Fine to very fine sand.	2.5 Y 7-4.

Section 400G Pit

0.0 - 3.2	Medium to fine sand.

No clay at base but few clay lenticles in the section.

Section 400H Pit

0.0 - 1.6	Medium sand.	
1.6 - 1.8	Pebble horizon.	
1.8 - 3.6	Fine to very fine silty sand.	2.5 Y 7-2.

Section 400I Pit

0.0 - 1.0	Fine orange sand.	
1.0 - 4.6	Fine sand.	2.5 Y 7-4.

Section 400J Pit

0.0 - 4.0	Orange medium sand.

Section 400K Pit

0.0 - 1.0	Orange sand.
1.0 - 2.0	Medium sand.
2.0 - 2.1	Pebble layer (disintegrating) with white clay.

Section 400K (continued)

Depth (ft.)	Description	
2.1 - 4.2	Fine to very fine silty sand.	2.5 Y 7-2.

Boulders on the crest of the ridge.

Transect 600

Section 600A Pit

0.0 - 0.4	Ash grey fine soil horizon.	
0.4 - 3.7	Orange sand.	
3.7 - 4.2	Clay.	2.5 Y 7-2.

Section 600B Pit

0.0 - 0.1	Scattered pebbles.
0.1 - 2.6	Silty clay.
2.6 - 2.7	Organic horizons.
2.7 - 2.9	Orange sand horizon.
2.9 - 3.2	Ash grey soil horizon.
3.2 - 4.6	Orange sand horizon.

Section 600C Pit

0.0 - 4.0	Clay.	2.5 Y 7-2.

Section 600D Pit

0.0 - 3.6	Silty clay.

Section 600E Pit

0.0 - 2.0	Orange sand horizon.	
2.0 - 4.0	Fine to very fine sand.	2.5 Y 7-4.

Section 600F Pit

0.0 - 0.2	Medium sand.	
0.2 - 1.0	Very coarse sand.	
1.0 - 3.6	Fine, silty sand.	2.5 Y 7-2.

Section 600G Pit

Depth (ft.)	Description
0.0 - 4.0	Medium sand.

Section 600H Pit

0.0 - 0.6	Ash grey fine soil horizon.
0.6 - 2.6	Orange medium sand.
2.6 - 3.7	Fine to very fine sand. 2.5 Y 7-4.

Section 600I Pit

0.0 - 1.0	Medium sand.
1.0 - 2.6	Sand faintly laminated with silty horizons.
2.6 - 3.9	Sandy silt.

Transect 700

Section 700A Pit

0.0 - 0.2	Ash grey soil horizon.
0.2 - 0.6	Pebble horizon.
0.6 - 1.6	Fine to very fine sand. 2.5 Y 6-4.
1.6 - 1.8	Clay.

Clay extends to about 12 feet in depth--seen in ditch exposure.

Section 700B Pit

0.0 - 12	Clay--in roadside ditch.

Section 700C Pit

0.0 - 2.0	Orange fine to medium sand horizon. 2.5 Y 7-4.
2.0 - 5.0	Medium sand.

Section 700D Pit

0.0 - 0.6	Fine sand.
0.6 - 1.0	Clay.

Section 700E Pit

Depth (ft.)	Description
0.0 - 1.0	Fine sand. 2.5 Y 7-2.
1.0 - 3.9	Clayey sand--frozen ground.

Section 700F Pit

0.0 - 1.0	Fine sand. 2.5 Y 7-2.
1.0 and surrounding and below	--tabular boulders encountered.

Section 700G. Pit

0.0 - 4.8	Predominantly fine to very fine orange sand. 2.5 Y 7-4.

Section 700H Pit

0.0 - 2.0	Medium sand.

Transect 900

Section 900A Pit

0.0 - 3.0	Fine sand and some coarse silt.
3.0 - 4.0	Clay.

Section 900B Pit

0.0 - 4.0	Clay.

Section 900C Pit

0.0 - 3.0	Very fine sand and coarse silt. 2.5 Y 6-2.

Section 900D Pit

0.0 - 3.0	Silty sand with clay below.

Section 900E Pit

0.0 - 2.0	Fine to very fine sand 2.5 Y 7-2.
2.0 - 3.7	Clay.

Section 900F Pit

Depth (ft.)	Description
0.0 - 4.0	Fine sand.

Section 900G Pit

0.0 - 4.5	Fine sand with faint, very fine sand laminations. 2.5 Y 7-4.

Section 900H Pit

0.0 - 1.1	Fine to very fine silty sand. 2.5 Y 7-2.
1.1 - 2.3	Silty clay--frozen ground. 2.5 Y 7-2.

Section 900I Pit

0.0 - 3.0	Very fine sand.

Section 900J Pit

0.0 - 3.0	Fine sand.

Section 900K Pit

0.0 - 1.0	Silty sand.
1.0 - 2.3	Fine sand--frozen ground.

Section 900L Pit

0.0 - 0.3	Silty sand.
0.3 - 1.6	Ash grey soil horizon, with some sand.
1.6 - 3.4	Very fine sand and coarse silt. 2.5 Y 6-4.

Section 900M Pit

0.0 - 1.0	Ash grey soil horizon.
1.0 - 4.6	Medium sand predominantly with some fine sand.
4.6 - 5.3	Clay. 2.5 Y 7-2.

Transect 1100

Section 1100A Pit

Depth (ft.)	Description
0.0 - 0.4	Ash grey soil horizon.
0.4 - 4.0	Predominantly coarse to medium sand, with some fine sand. 10 YR 4-4.

Section 1100B Pit

Depth (ft.)	Description
0.0 - 1.0	Orange sand horizon.
1.0 - 3.8	Medium to fine sand with some indications of laminations. 2.5 Y 7-4.

Section 1100C Pit

Depth (ft.)	Description
0.0 - 0.6	Peat.
0.6 - 3.6	Fine silty sand.

Section 1100D Pit

Depth (ft.)	Description
0.0 - 3.0	Medium to fine silty sand. 2.5 Y 7-2.
3.0 - 3.6	Clay.

Section 1100E Pit

Water table at the surface penetration beneath indicated that the prevalent deposit was the same fine silty sand as found at 1100D.

Section 1100F Pit

F G H I in the 1100 sections have boulders, platy in type, lying horizontally at the surface.

Section 1100J Pit

Depth (ft.)	Description
0.0 - 0.3	Peat soil.
0.3 - 1.5	Silty sand with grit laminae. 2.5 Y 7-2.
1.5 - 1.55	Pebble layer.
1.55 - 2.5	Clay.

Section 1100 K Pit

Depth (ft.)	Description
0.0 - 4.0	Fine sand.

Section 1100L and M.

Pit

0.0 - 4.0	Fine to very fine sand. 2.5 Y 7-4.

Section 1100N Pit

0.0 - 0.2	Peat horizon.
0.2 - 0.6	Ash grey soil horizon.
0.6 - 1.2	Orange medium sand.
1.2 - 2.3	Fine to very fine sand. 2.5 Y 7-4.
2.3 - 3.5	Clay.

Transect 1300

Section 1300A Pit

0.0 - 0.9	Peat horizon.
0.9 - 1.8	Ash grey soil horizon.
1.8 - 2.7	Fine sand. 2.5 Y 6-2.
2.7 - 2.8	Black ? horizon.
2.8 - 3.8	Fine sand.

Section 1300B Pit

0.0 - 0.7	Fine sand.
0.7 - 1.3	Ash grey soil horizon.
1.3 - 4.6	Fine to very fine sand. 2.5 Y 7-4.

Section 1300C Pit

0.0 - 0.8	Silty sand.
0.8 - 1.0	Hard indurated sand horizon, consisting of fine to very fine sand. 2.5 Y 6-4.

Section 1300D   Pit

Depth (ft.)	Description
0.0 - 1.3	Medium to fine sand--some accretions of Fe, and laminar development
1.3 - 4.0	Orange medium sand.
4.0 - 4.1	Clay horizon.
4.1 - 4.5	Silty clay.

Section 1300E   Pit

0.0 - 3.8	Predominantly fine sand, with some medium sand. 2.5 Y 7-4.

Section 1300F   Pit

0.0 - 1.0	Silty sand.
1.0 - 1.1	Hard indurated sand horizon--frozen ground.

Section 1300G   Pit

0.0 - 3.0	Fine to very fine silty sand. 2.5 Y 6-4.

Section 1300H   Pit

0.0 - 3.8	Silty sand.
3.8 and below	Indurated sand--frozen ground.

Section 1300I   Pit

0.0 - 3.0	Silty sand.

Impenetrable below 3.0 feet because of frozen ground.

Section 1300J   Pit

0.0 - 1.2	Silty sand.

Section 1300K   Pit

Depth (ft.)	Description
0.0 - 1.0	Medium sand.
1.0 - 1.8	Ash grey soil horizon, with some sand.
1.8 - 4.4	Orange medium sand with some coarse and fine sand. 2.5 Y 7-4.

Section 1300L   Pit

0.0 - 0.3	Ash grey soil horizon.
0.3 - 1.6	Orange medium sand.
1.6 - 4.0	Coarse to medium sand. 215 Y 7-4.

Transect 1500

Section 1500A   Pit

0.0 - 0.9	Ash grey soil horizon.
0.9 - 1.4	Orange sand horizon.
1.4 and below	Impenetrable frozen ground.

Section 1500B   Pit

0.0 - 1.0	Dark orange sand horizon.
1.0 - 4.0	Light orange sand.

Section 1500C   Pit

0.0 - 1.3	Fine sand. 2.5 Y 7-4.
1.3 and below	Impenetrable frozen ground.

Section 1500D   Pit

0.0 - 4.0	Medium sand.

Section 1500E   Pit

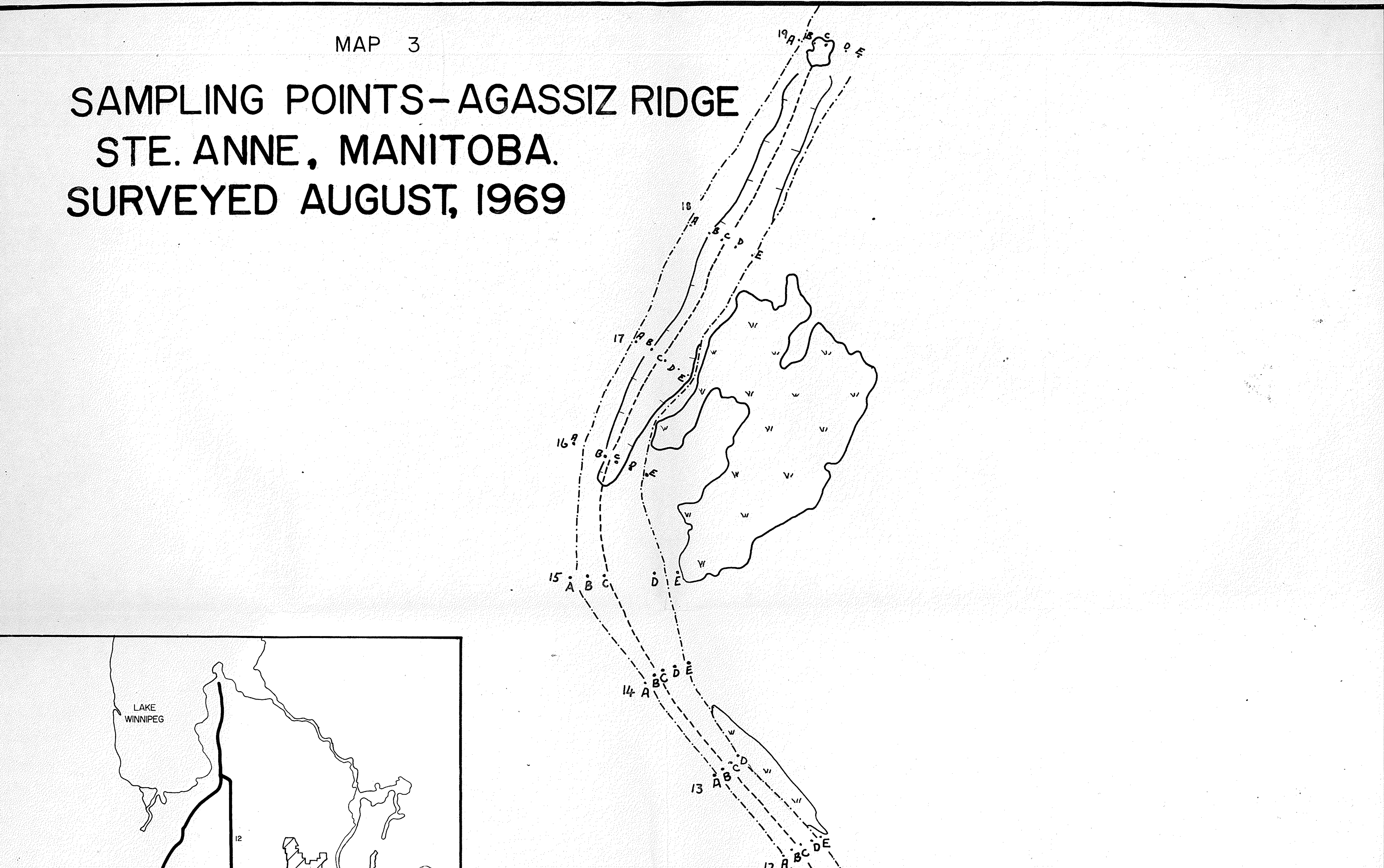
0.0 - 1.0	Orange sandy soil.
1.0 - 4.0	Medium sand.

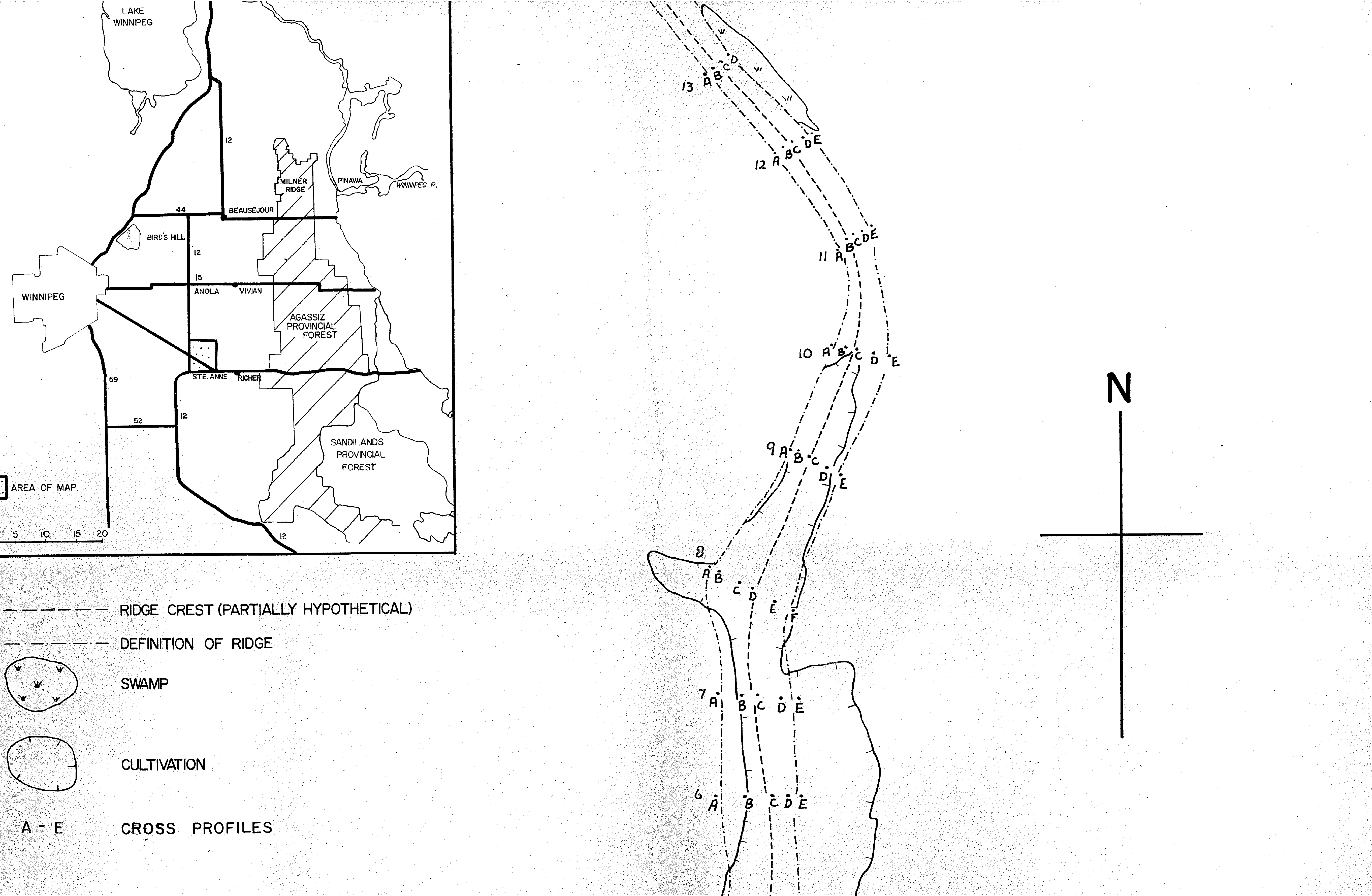
Section 1500F Pit

Depth (ft.)	Description
0.0 - 4.0	Medium to fine sand. 2.5 Y 7-2.

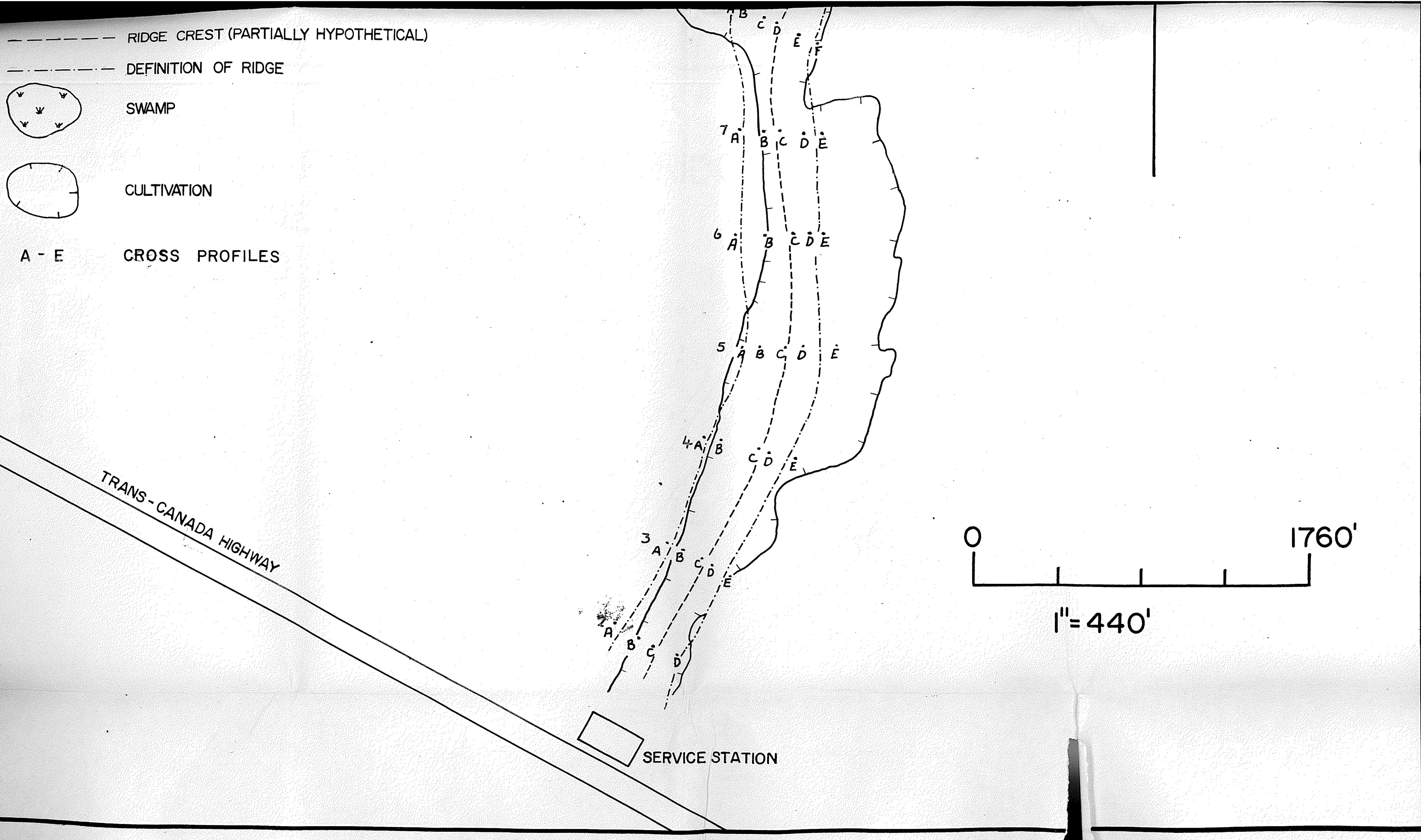
MAP 3

SAMPLING POINTS - AGASSIZ RIDGE
STE. ANNE, MANITOBA.
SURVEYED AUGUST, 1969





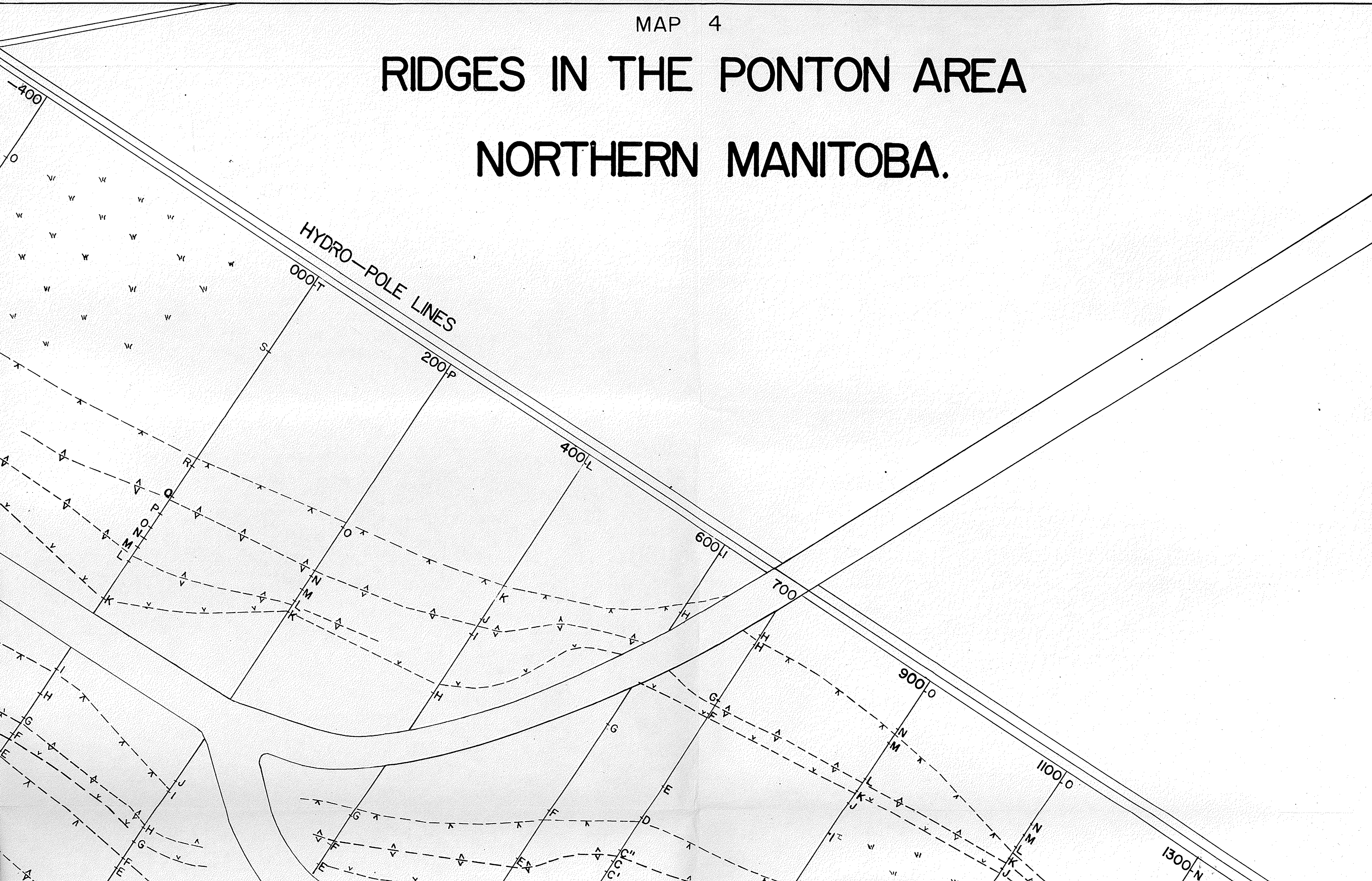
LAKE WINNIPEG
12
MILNER RIDGE
PINAWA
WINNIPEG R.
44
BEAUSEJOUR
BIRD'S HILL
12
15
ANOLA
VIVIAN
WINNIPEG
AGASSIZ PROVINCIAL FOREST
STE. ANNE
RICHER
59
52
12
SANDILANDS PROVINCIAL FOREST
AREA OF MAP
5 10 15 20
12
RIDGE CREST (PARTIALLY HYPOTHETICAL)
DEFINITION OF RIDGE
SWAMP
CULTIVATION
A - E
CROSS PROFILES
13 A B C D
12 A B C D E
11 A B C D E
10 A B C D E
9 A B C D E
8 A B C D E F
7 A B C D E
6 A B C D E
N

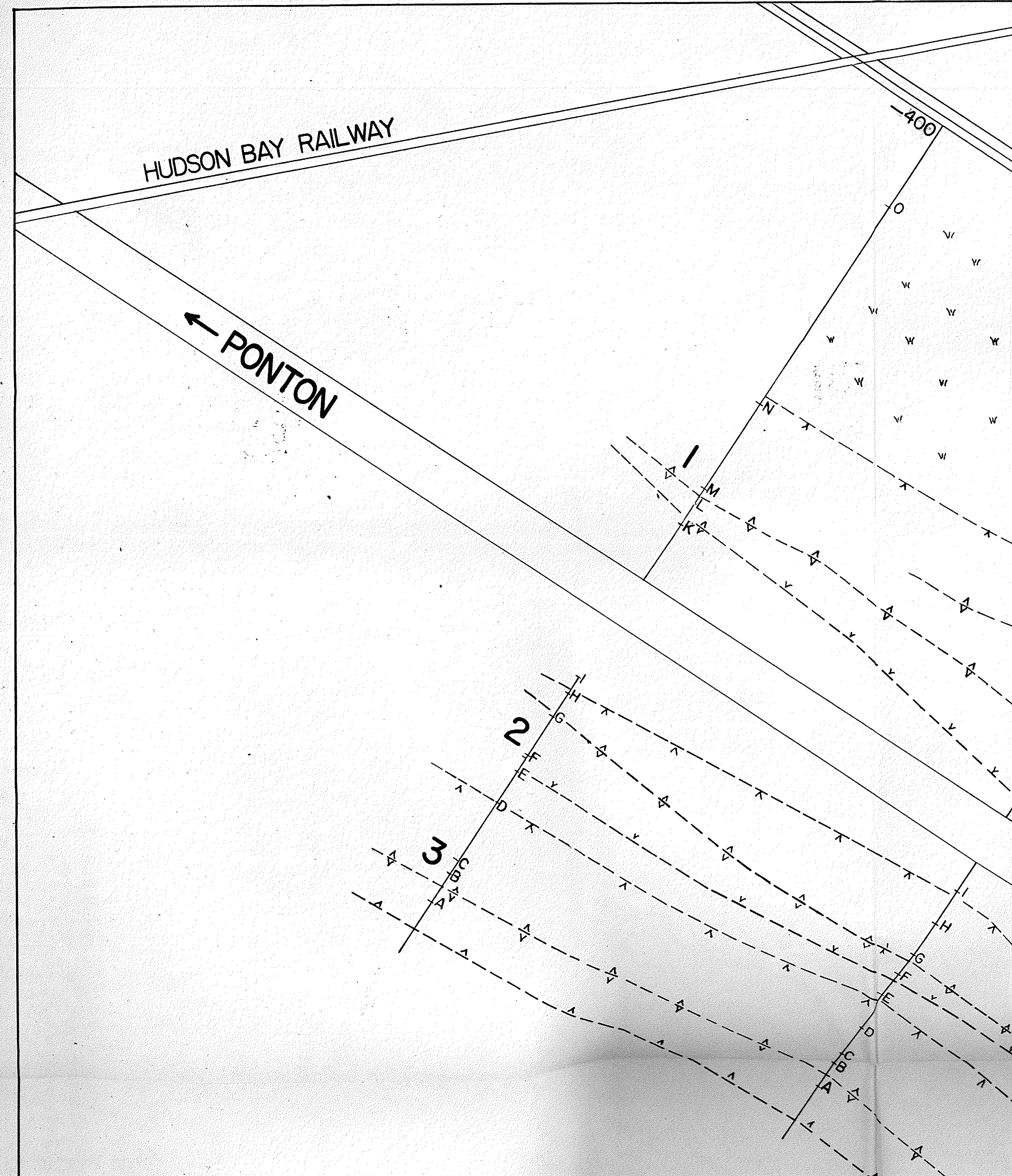

RIDGE CREST (PARTIALLY HYPOTHETICAL)
DEFINITION OF RIDGE
SWAMP
CULTIVATION
A - E CROSS PROFILES
TRANS-CANADA HIGHWAY
SERVICE STATION
0
1760'
1" = 440'

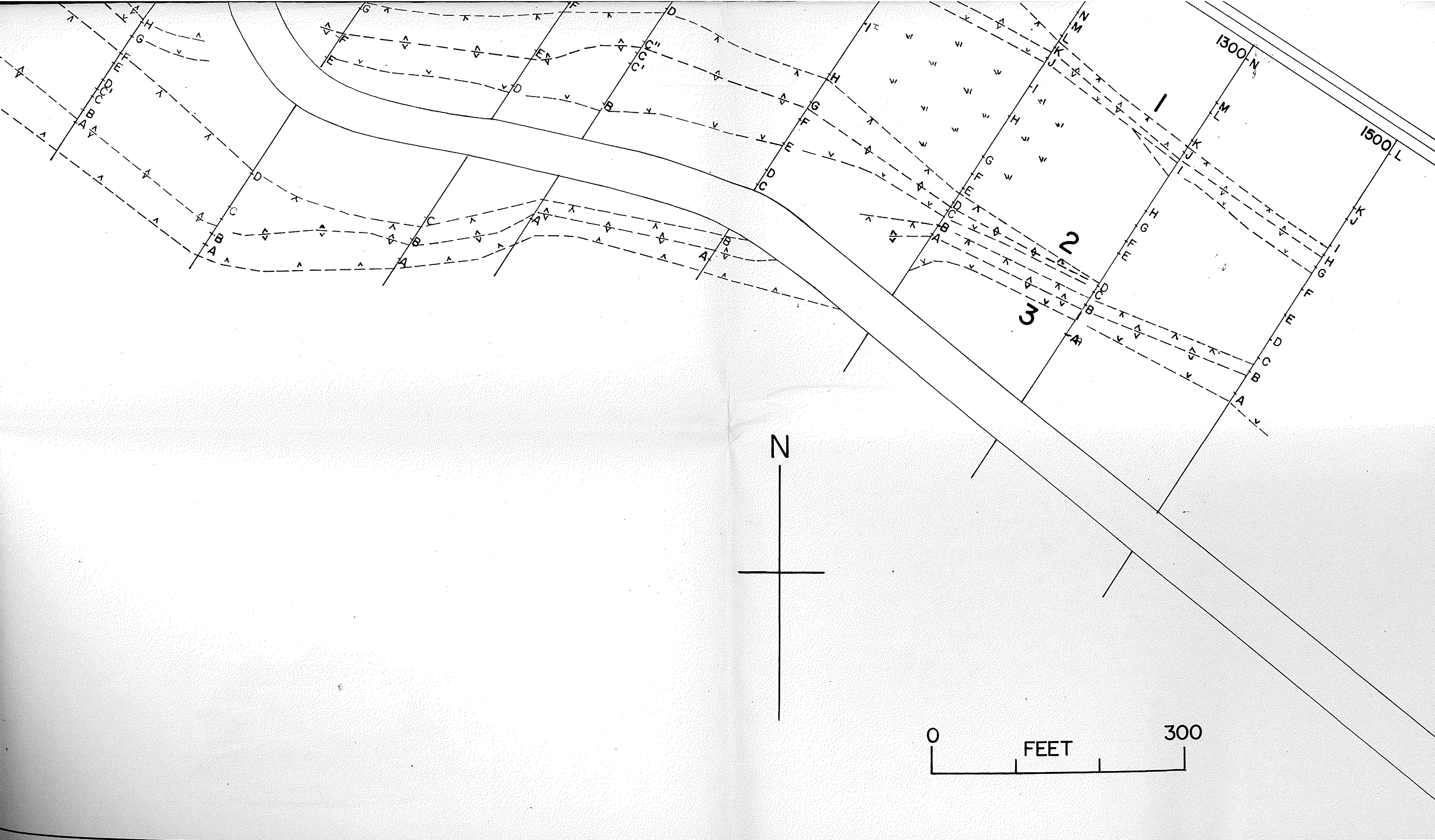
MAP 4

RIDGES IN THE PONTON AREA

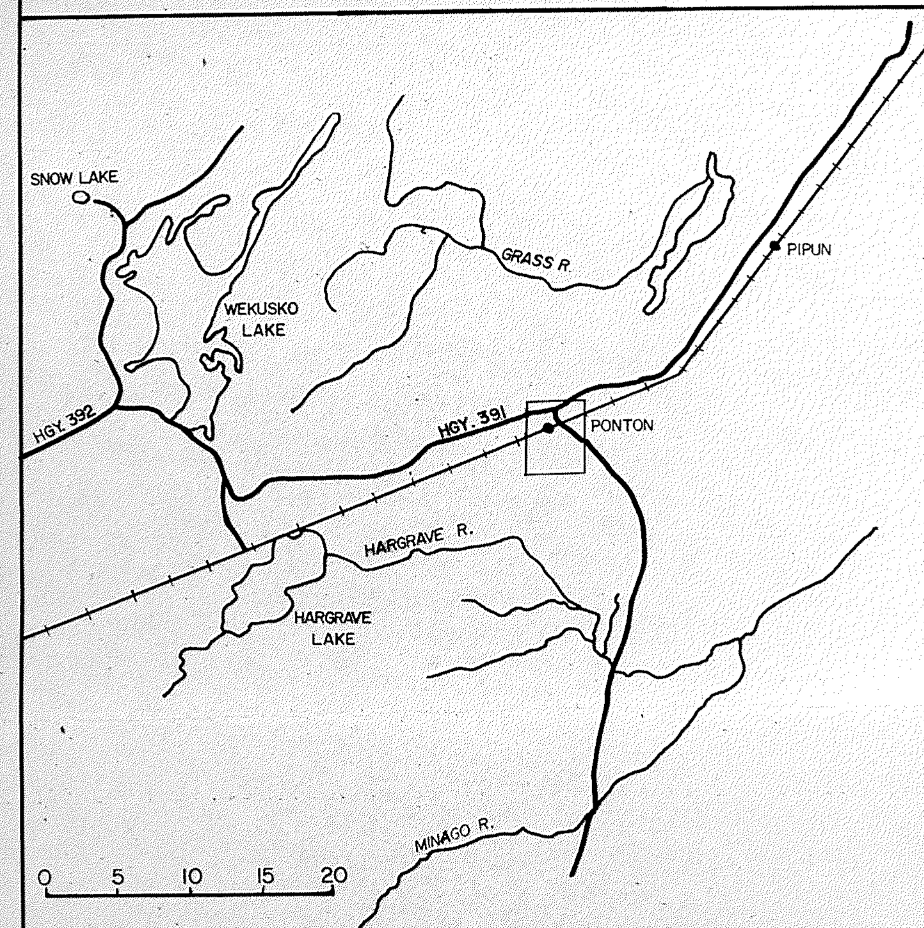
NORTHERN MANITOBA.




HUDSON BAY RAILWAY
← PONTON
400
1
2
3



1300 N
1500 L
1
2
3
N
0
FEET
300



CONVEX SLOPES

CONCAVE SLOPES

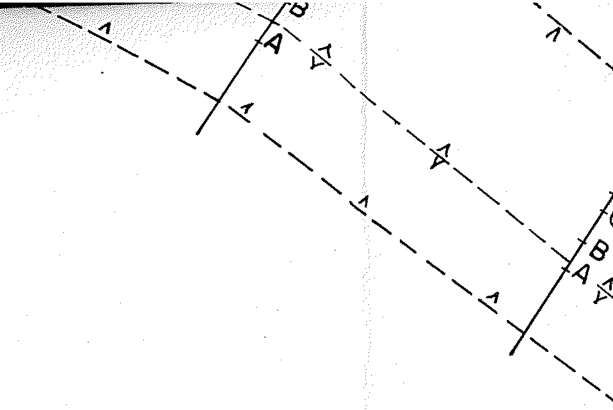
SWAMP

UNMETALLED ROAD

1—3 RIDGE NUMBERS

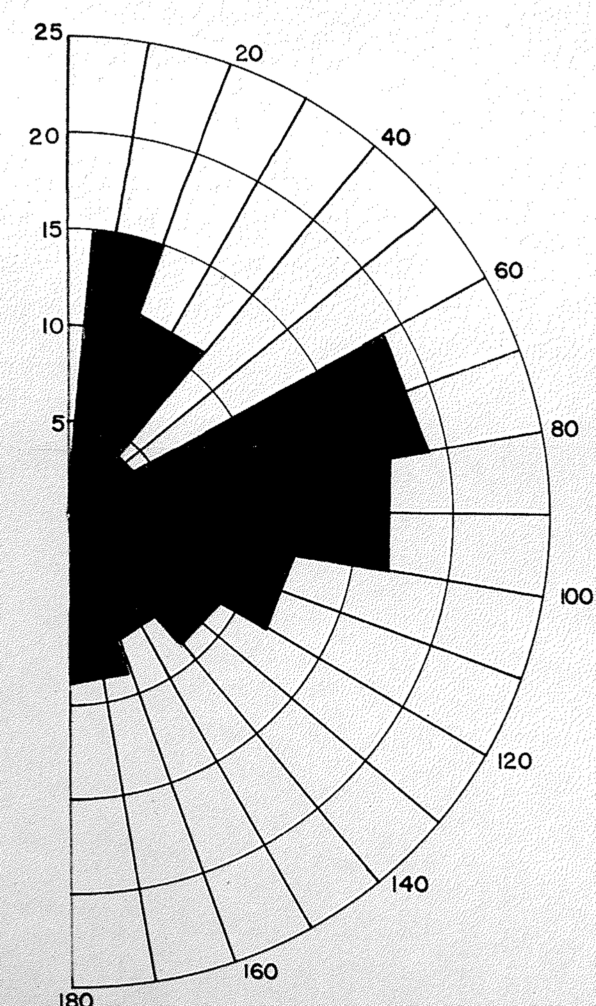
-400—1500 TRAVERSES

A—P SAMPLING POINTS

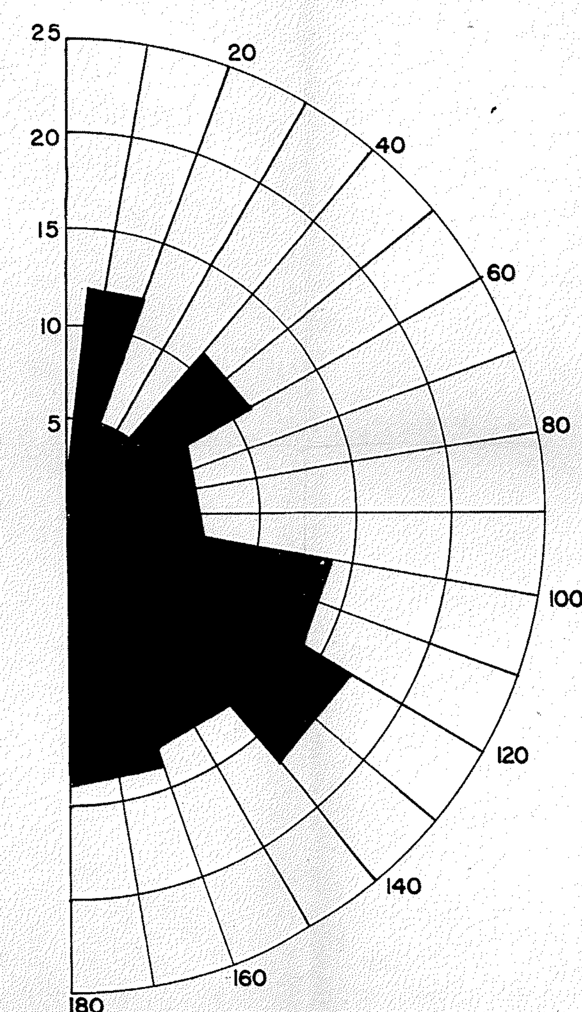


FABRIC ANALYSIS OF STE. ANNE PEBBLES.

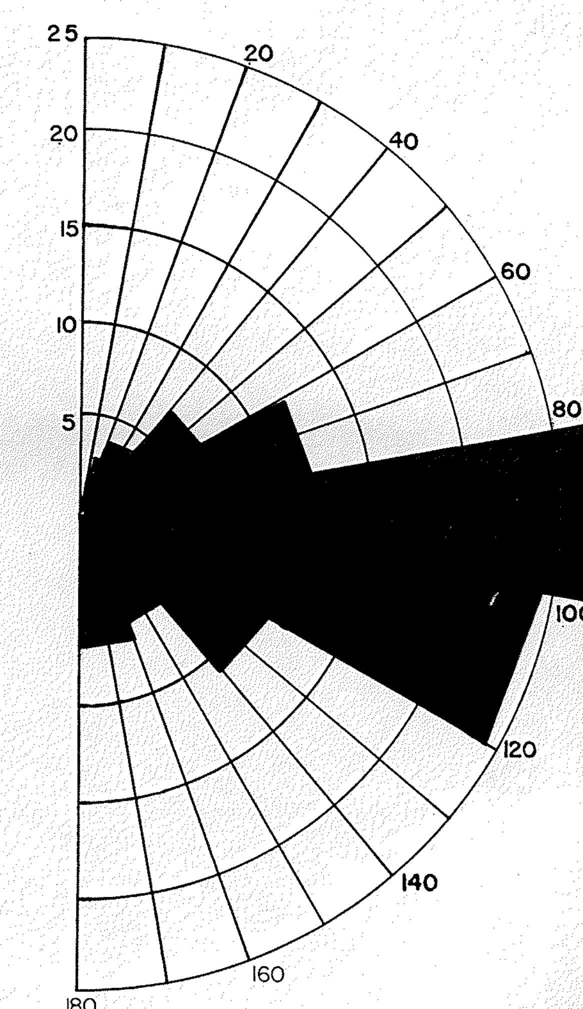
SECT 2b 3c — 103 pebbles



SECT 4d — 100 pebbles

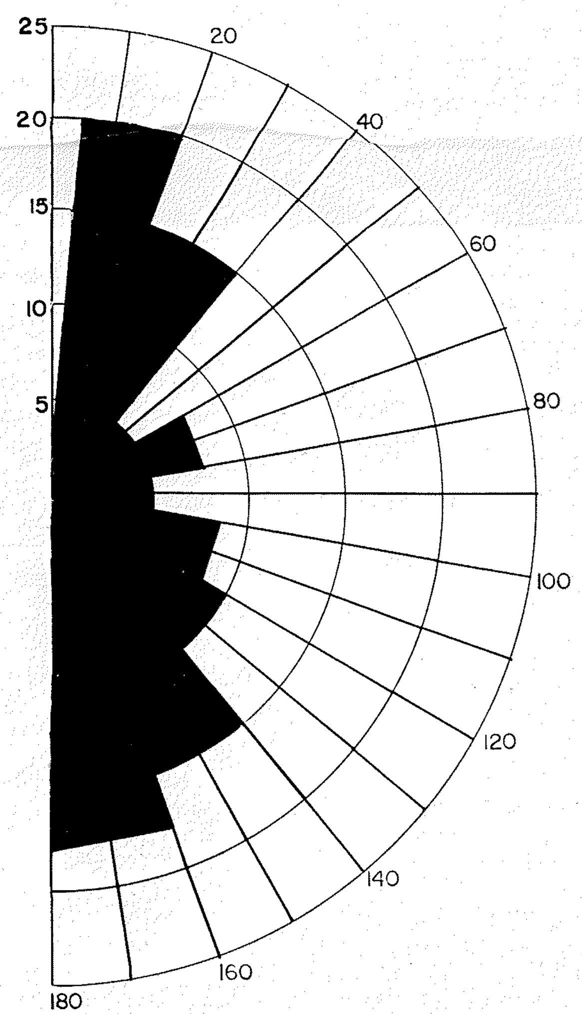


SECT 10c — 102 pebbles



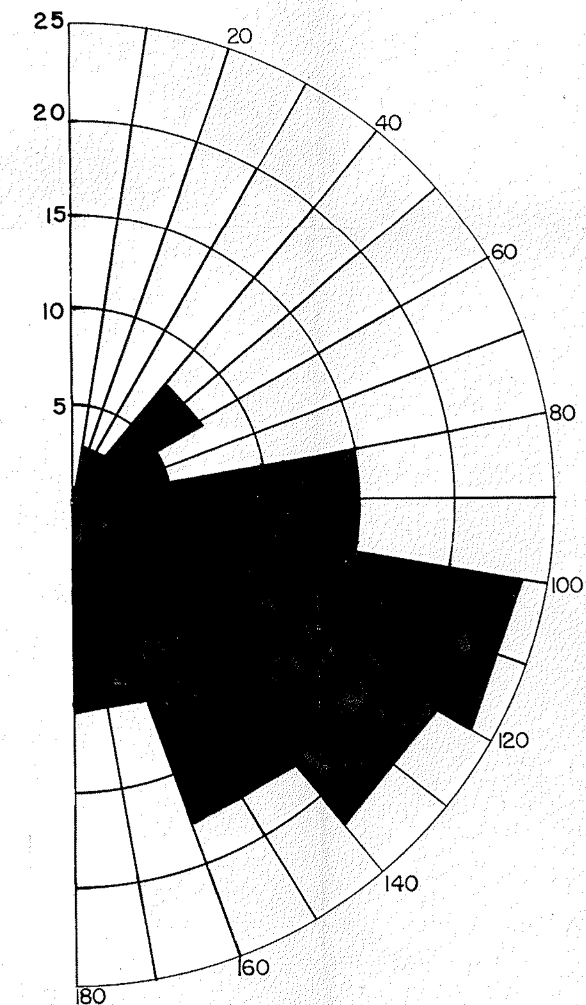
SECT 14b

104 pebbles



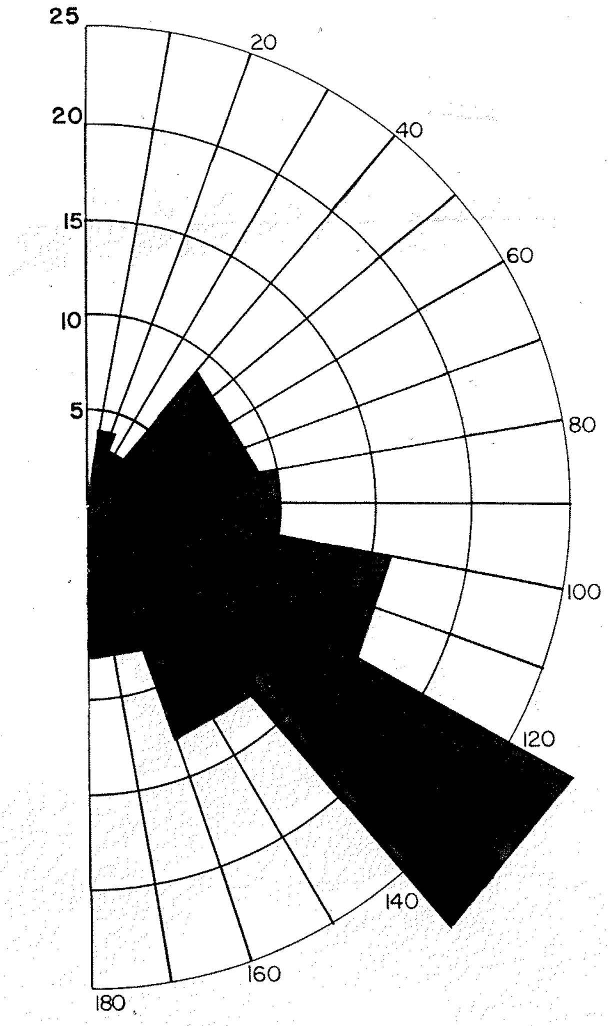
SECT 16b

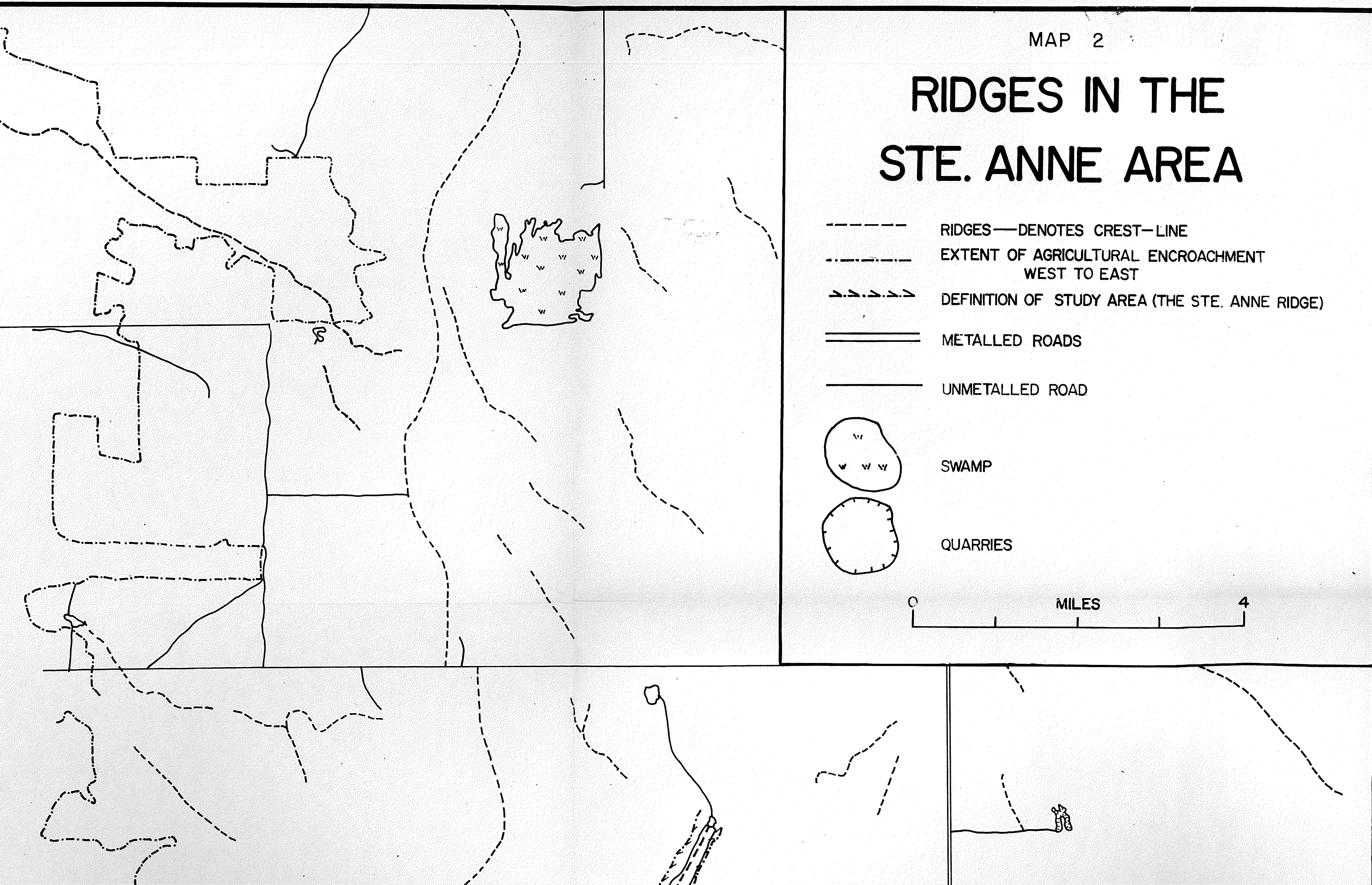
106 pebbles

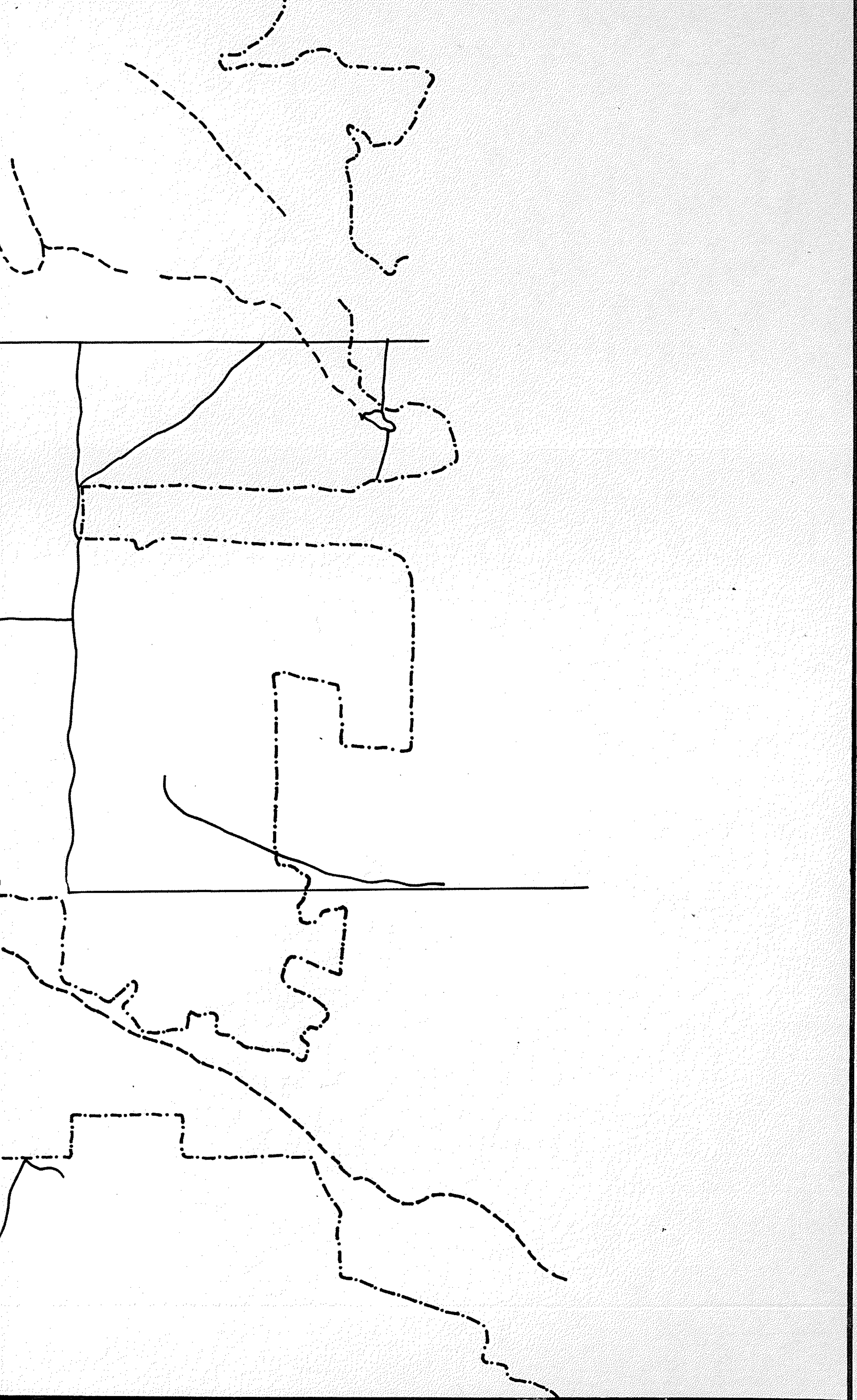


SECT 18d

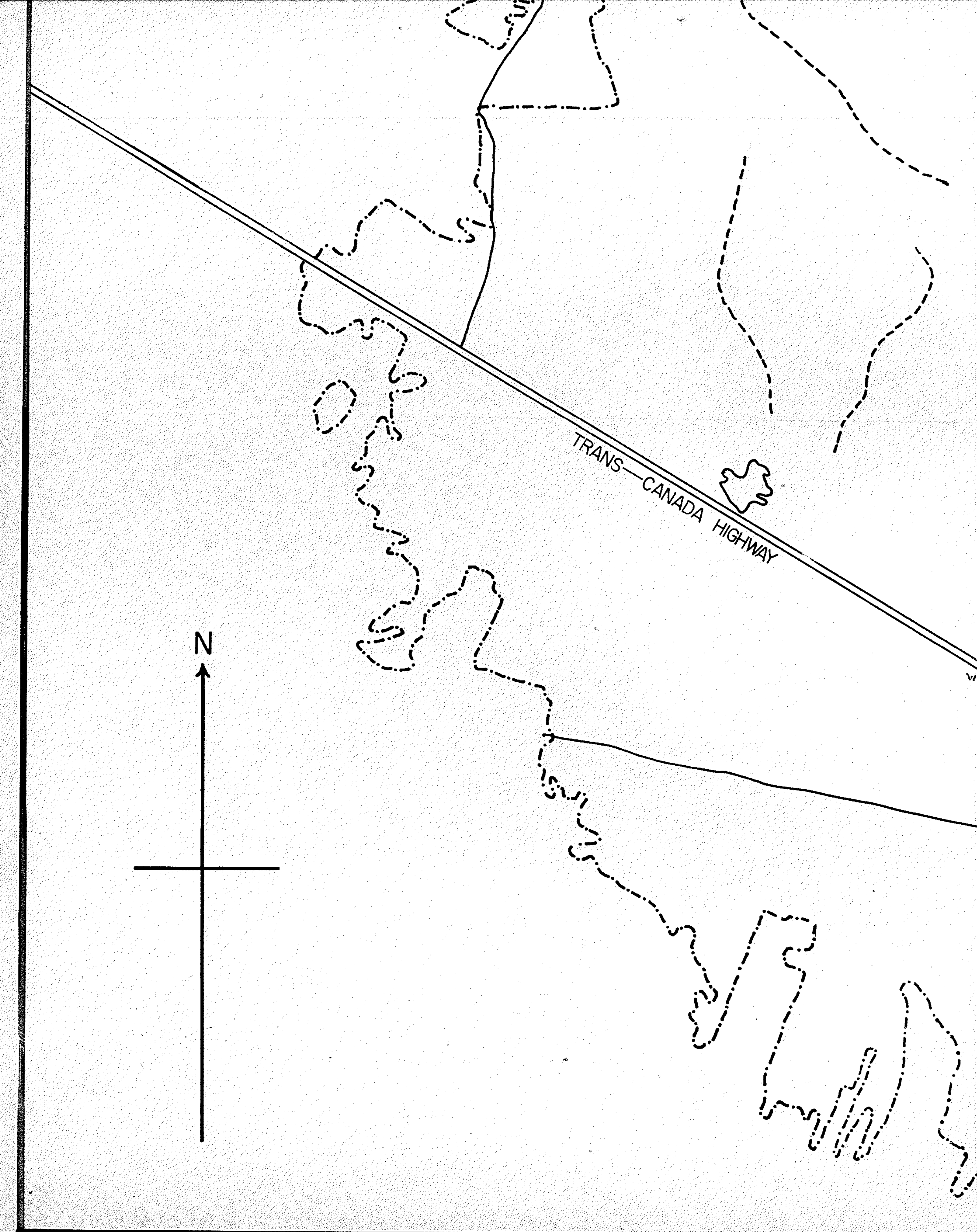
100 pebbles




MAP 2
RIDGES IN THE
STE. ANNE AREA
RIDGES—DENOTES CREST-LINE
EXTENT OF AGRICULTURAL ENCROACHMENT
WEST TO EAST
DEFINITION OF STUDY AREA (THE STE. ANNE RIDGE)
METALLED ROADS
UNMETALLED ROAD
SWAMP
QUARRIES
0
MILES
4




TRANS—CANADA HIGHWAY



N
TRANS—CANADA HIGHWAY