ENVIRONMENTAL HISTORY OF SAND AND GRAVEL DEPOSITS OF THE CHAMPLAIN SEA IN THE GATINEAU VALLEY, QUEBEC

by

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ABSTRACT

According to new radiocarbon dates, the Champlain Sea was well established in the mouth of the Gatineau River Valley and the Ottawa area by about 12,200 years B.P., which is much earlier than previously believed. An uplift curve including these dates indicates that this early and rapid melting of the ice sheet caused very rapid vertical movement of the land, much faster than the eustatic rise in sea level during the early phase of the Champlain Sea episode. Hence a transgressive phase of the sea cannot be postulated for the period from 12,200 to 10,000 years B.P. A high energy environment, probably pro-glacial, prevailed in the Gatineau River Valley during the Champlain Sea episode. Most exposures are of sediments deposited against steep valley walls, which show very poor sorting, due to the proximity of the source and narrowness of the inlet where little wave energy could be generated. Variation in sea water temperature and salinity were estimated from trends in size characteristics of fossil populations of the mollusks Macoma balthica (Linné) and Hiatella arctica (Linné). These trends indicate a cool early phase of the Champlain Sea with progressive warming of the sea water with time. Salinities remained normal to near normal throughout the episode, but were lower in proximity to the ice front where mixing with glacial melt water occurred.

ACKNOWLEDGEMENTS

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INTRODUCTION

This is a study of Quaternary sediments in the Ottawa-Hull area. These deposits belong to both the Pleistocene and Holocene (Recent) Epochs since their age varies from about 12,000 to 6,000 radio carbon years B.P.

Access

The lower reaches of the Gatineau River Valley, and most of the localities discussed in this study are situated within areas of the provinces of Quebec and Ontario bounded by 45°15' and 45°55' north latitude and 75°30' to 75°10' west longitude. The area is covered by the following topographic maps at scales of 1:50,000; 31F/16E (Kazabazua), 31G/13W (Low), 31F/9E (Quyon), 31G/12W (Wakefield) and 31G/5 (Ottawa).

A major highway on the west bank of the Gatineau River and many other paved or unpaved roads on either side of the river make the area of study easily accessible from Hull or Ottawa, see fig., 1.

Physiography

The Gatineau River flows through a narrow depression cutting across two major physiographic regions of Canada; the Laurentian Region and the Saint Lawrence Lowlands (Bostock, 1970). The main features of these regions are in many aspects different in the present area.

The rocks of the Laurentian Highlands underlying most of the drainage basin consist of highly deformed and intruded metasediments of the Grenville Series such as: marbles, quartzites, a variety of gneissic and calc-silicate rocks. Intrusive rocks include syenites, diorites, granites, anorthosites and pegmatites in all manner of occurences from dykes to sills, and stocks to plutons. The geology of the area is described in many reports; Dresser and Denis (1944), Maufette (1950), Beland (1954), Sabourin (1965), Hogarth (1962, 1970).

Paleozoic sediments, mostly limestones, shales, and dolomites, outcrop near the mouth of the river where it debouches into the Ottawa River. These flat lying and faulted Ordovician sediments are characteristic of the Central Saint Lawrence Lowlands in the Ottawa-Hull area (Wilson, 1946).

The northern boundary between the two physiographic regions is expressed topographically by a scarp which rises abruptly some 300 to 400 feet above the lowlands, which have a very subdued topography, never rising more than 400 feet in elevation. The highlands in the immediate area near the Gatineau River rise up to 1,500 feet above present sea level.

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The relief of the Gatineau River Valley is asymmetric; the valley floor rises more gently on the western side than on the eastern side, where the valley walls rise abruptly. This is reflected in the drainage pattern of the basin where most of the important rivers discharging into the Gatineau come from the western, broader side of the drainage basin.

Drift cover is concentrated in the low lying areas of the valley floor or against rocky ridges as terraces. These sediments will be discussed in more detail subsequently.

The Gatineau Valley area near Hull and Ottawa was once a very active mining district. Micas, feldspars, brucite, apatite, graphite, and iron deposits were extensively mined until recently (Hogarth 1962). In recent years the economic potential of the area has shifted from mines to the many quarries and sand pits, which are extensively exploited for the construction industry.

Concern about the environment and the rapid development of urban areas have also triggered investigations of the geotechnical characteristics of the clay deposits which are very sensitive and thus prone to frequent landslides.

Aims and Methods

The purpose of this study is to characterise the sedimentary environments prevailing in the Gatineau Valley during the Champlain Sea episode. The Champlain Sea episode is the time taken for an arm of the Atlantic Ocean to invade the continent immediately after or contemporaneous with the melting of the glaciers, and to recede following gradual uplift of the uncovered land. This time period is roughly bracketed between 12,000 and 10,000 years B.P. Such environmental characteristics as energy, temperature and salinity of sea water, and the response of the land to the unloading of the glacier ice are investigated using information about the sediments, their fossil content, and their relative age.

A method of environmental interpretation of textural features of a suite of sediments using scatter diagrams of textural parameters (Folk and Ward, 1957) was applied to the sediments of the area and the efficiency of the method in identifying environments is discussed. Temperature and salinity of the Champlain Sea waters were approximated by comparing the size characteristics of certain species of the fossil fauna with those of living representatives of the same species in recent seas. Finally a model describing postglacial uplift (Andrews, 1970 b), using the elevations of radiocarbon dated fossils, is applied to the area, and is discussed in relation to the validity of its underlying assumptions and the precision of its predictions.

Field work was started in the fall of 1970 and continued during the summers of 1971 and 1972. Because of the very irregular distribution of the sediments, it was not the aim of the author to map the surficial deposits in the area of study. Instead, the greatest number of available exposures, such as gravel and sand pits, were visited and the best exposures were sampled and described in detail (see Appendix II). The fossiliferous horizons when present in the sections were sampled and their elevation measured with an aneroid barometer on different traverses. Mechanical analysis of the sediments was done by sieving, the size parameters were calculated, and tabulated (see Appendix I). The length and height of the fossils found in the sections were measured and radiocarbon dates were obtained from two localities in the study area.

Previous work

Sedimentary deposits in the Gatineau River Valley proper have not received direct attention until very recently (Buckley (1968, 1970), Scott (1971), Gadd (1973)). In earlier times, the difficulty of access of the Gatineau Valley relative to that of the flat land in the Ottawa area, was possibly the main reason for the lateness of the investigations. Specific information on the sedimentary cover at localities in the Gatineau Valley was in most cases related to more extensive studies in the Ottawa area, or to other studies of regional interest. This is true of the Kingsmere locality first investigated by De Geer (1892) for the purpose of identifying the limit of marine submergence in north eastern America during late Glacial time. De Geer's determination of the elevation of the beach at Kingsmere (705 feet) was subsequently remeasured by many workers; Chalmers (1901), Keele and Johnston (1913) and Johnston (1916), and fixed at an elevation of 690 feet.

Johnston (1917) investigated the surficial sediments in the Ottawa area and produced a map of their distribution including portions of the present Gatineau Park and a small area at the mouth of the Gatineau River, where he mentions the occurrence of beach terraces cut in marine clay. His map and interpretation of the events that took place in the area are still accepted today, and his works are basic reading for investigators in this area.

Goldring (1922) suggested that the salinity of the sea water decreased westward, on the basis of size comparison of the Champlain Sea fossils, and the abundance of species.

However, the fossils she measured from the present area were not given any more specific location than Ottawa and vicinity. Wagner (1970), using the same approach found less variation between the size of fossils from the Ottawa and Montreal areas, and suggested that conditions were brackish throughout the major part of the Champlain Sea, with waters in the farthest extremities being the least saline.

Wilson (1924) noted that depressions in the highlands to the north of the Ottawa area (Maniwaki area) were occupied by wide flat areas underlain by stratified clay, silt, and sand, seldom rising more than 600 feet above sea level. These deposits were similar to others in the lower parts of the Gatineau Valley which contained marine fossils. The deposits in the Maniwaki area were suggested to be related to the Champlain Sea; the fact that they did not contain fossils was probably because the water in the further reaches of the sea was not favorable paleoecologically.

Wilson (1924) concluded that the maximum elevation of the sea in the area was not less than 600 feet.

Antevs (1925), from observations of sedimentary successions and well defined beach terraces at about 250 feet, both in the Ottawa area and the Gatineau Valley, attributed them to Lake Ottawa, a fresh water body held up by a dam near Hawkesbury and extending to the west and northwest. Some confusion as to a marine or fresh water origin of sets of clay beds in the same areas led him (Antevs, 1928) to suggest that Lake Ottawa was established by a transgression of the Champlain Sea from below the 250 feet level to about 340 feet a.s.l; he thus renamed the lake the Ottawa Sea. The situation was later clarified by Gadd (1961), who identified the lower clay unit, below the 250 feet level as a redeposited older marine clay.

Indications of the northerly extension of the Champlain Sea into the Gatineau River Valley were in the form of marine fossils in sediments near Venosta (Antevs, 1928), and at Farrelton in the Gatineau Valley and Val-des Bois (Maufette, 1949) in the Lièvre Valley. A more recent report describes marine fossils in bottom sediments of Manitou Lake, a few miles north of Martindale (Bickel, 1970).

With the advent of radio carbon dating, the chronology of events that had taken place in the area could be better described. Organic deposits such as peat and shelly horizons could be dated and used as time markers. Potzger and Courtemanche (1956), dated a basal layer of a peat bog on the Kazabazua sand plain at 9910 ± 200 years B.P. (G.S.C. - 680) at an elevation of 580 feet; this is a minimum date for the recession of the Champlain Sea from the Gatineau Valley.

Revision of the map of the surficial sediments of the Ottawa area (Johnston, 1917) by Gadd (1961 and 1963) did not change the general history of the area as described by Johnston (1917), but put the events that had occurred here in better perspective with information available from other surrounding areas. Radio carbon chronology helped to put some order in the general scheme of events,(see Romanelli 1975).

Sabourin (1965) published a map of the geology of the Bristol-Masham area including the sedimentary cover of parts of the Gatineau Park with information of fossil occurrences and the direction of glacial striae. The distribution of sediments in the Gatineau Park and small areas along the shores of the Gatineau River was investigated by Buckley (1968). This is the most recent published information on the surficial sediments in the Gatineau River Valley.

Studies presently under.way,(Scott (1971), Gadd (1973)),will yield much needed information on the general distribution of sediments in the valley so that more detailed work can be done in the future. These studies particularly relate to the geotechnical properties of the clay deposits, whereas, the present study is an investigation of all types of Quaternary sediments in relation to their stratigraphic occurrence.

SEDIMENTOLOGY

Stratigraphy

Many of the exposures of the Quaternary sediments in the Gatineau Valley are adjacent to steep walls of bedrock, against which rest till (rarely exposed) or beds of partly cemented gravel containing well rounded cobbles. These deposits are overlain by an unfossiliferous succession of interbedded sand and gravel, which varies greatly in thickness due to the high bedrock relief in the valley. At most exposures the sand and gravel are unconformably overlain by a relatively thin unit of grey silty clay, the lower part of which has a laminated, varve-like appearance, and contains marine fossils. Lamination gradually dies out upwards as the unit passes into faintly stratified gray silty clay, which is abundantly fossiliferous and at many localities is overlain by fossil-bearing sand and gravel. The macrofossils present are diagnostic of a marine environment and include species such as Macoma balthica (Linné), Hiatella arctica (Linné), Portlandia arctica (Gray), Mytilus edulis (Linné), Balanus balanus (Linné), and Balanus crenatus (Bruguière). The sediments also contain micro-fossils such as Ostracoda and Foraminifera. A discussion of the stratigraphy is given by Rust and Romanelli (1975), in which a mode of deposition is postulated for the non-marine massive sand and gravel unit overlying the basal till. The authors conclude that these sediments, termed subaqueous outwash, were deposited under deep water ponded in front of the retreating glaciers due to isostatic depression of the land. The relatively high position of the water plane at that time is indicated by the marine clay unit overlying the outwash.

Grain size analysis

Characterisation of sedimentary environments using grain size distribution parameters has never been attempted for surficial sediments in the Ottawa-Hull area. Previous workers limited their reports to qualitative description of the sediments.

Grain size is a very important descriptive property of a sediment, but the analysis of many samples is necessary to discuss its significance. In order to do so, the author has incorporated into the data from the present study in the Gatineau River Valley, earlier data from unpublished manuscripts dealing with specific sand and gravel pits in the Uplands area (Romanelli, 1970), and Stittsville area (Smith, 1970).

The depositional environments for the two last mentioned localities have been discussed in some detail, and a comparison of the textural features of the sediments of the Gatineau Valley with those of these areas will serve as the basis for environmental interpretation in the Gatineau Valley.

Method

Sieving was the most frequently used method of analysis because of the obvious bias of the suite studied towards the coarser grained sediments; pipetting of the finer portion (less than 4 Ø) was also performed on a smaller number of samples. Sieving was performed on an Endecott Test Sieve Shaker, for about 20-25 minutes, using U.S. Standard sieves stacked at intervals of ½ Ø units.

If the mud fraction (silt + clay) was estimated at about 5% or less by weight, the sample was dried at room temperature, disaggregated and weighed before dry sieving. If the mud content was suspected to be higher than 5% by weight, the sample was wet sieved through 4 0 sieve and the fine fraction was analysed by the pipette method (Galehouse, 1971, p. 79), and the coarse fraction was dried, weighed, and sieved. If the mud content was estimated to be more than 30 to 50% by weight, the sample was split and analysed using the moisture replicate method (Folk, 1968, p. 22). This method consists of estimating the percentage of water (by weight) in homogenous sub-samples, and finding by subtraction the amount of sand and mud in the sample.

Each sieve fraction was weighed to the nearest 0.01 gram and the weight of each pipette fraction to the nearest 0.001 gram. The basic data, weight in grams per sieve interval phi (0) units was punched on computer cards for further mechanical calculations.

Statistical Parameters used in the analysis

There are many methods of obtaining grain size parameters, which are grouped into two major categories: the mathematical methods (or moment method), and the graphical methods. A recent literature review of grain size parameters (Folk, 1966) along with investigation of the efficiency of methods (McCammon, 1962) and testing of accuracy relative to sieving (Isphording, 1972), all came to similar conclusions.

Folk (1966, p. 80) summarized these views as follows: "The author agrees with Friedman (1962) and Middleton (1962) that the method of moments measures a slightly different property than the graphic method, but that it has no specially sacred aura of fundamentality; each method has its advantages and its drawbacks, and each is equally valid for comparing a suite of samples".

In view of these conclusions, a graphical method was chosen for the analysis of the samples. The method proposed by Folk and Ward (1957) was used by previous workers (Romanelli, 1970, and Smith, 1970) and was retained so that direct comparisons could be made. The first step of this method consists of plotting a computed cumulative weight frequency distribution curve on probability paper. Secondly, phi (Ø) units measurements are taken from this curve at the following fixed percentile points: Ø5%, Ø16%, Ø25%, Ø50%, Ø75%, Ø84% and Ø95%, to calculate the four grain size distribution parameters; Graphic Mean (M_z), Inclusive Graphic Standard Deviation (σ_I), Inclusive Graphic Skewness (Sk_I), and Graphic Kurtosis (K_G), for which formulae are listed in Appendix I.

Modal Characteristics of the Sediments

The mode of a sample was chosen as the most frequently occurring grain size diameter, represented by a peak on the non-cumulative frequency distribution curve. This method of finding the mode is not as precise as others, such as finding the slope of the curve at every

½φ interval, but it nevertheless gives a good approximation of the position of the mode. The frequency of modal class occurrence (fig. 2) shows a definite bimodality in the distribution for all the samples from the Gatineau area, the Uplands area and the Stittsville area. There is a high frequency of modes in the pebble range (-2φ to -3φ), and a higher frequency of samples having a sand mode (1.5φ to 3φ). There are very few samples that have modes in the intermediate size ranges; from granules to coarse sands (-2φ to 1φ), and from coarse silts to clays (4φ to 8φ).

The type of modal class distribution observed is quite common for all suites of sediments, and was noted very early in the literature (Wentworth, 1933). The modal distribution is apparently due to the fact that nature provides clasts of three predominant size populations; gravel, sand plus coarse silt, and clay. In the present study the lack of a modal class in the clay range would be accounted for by the bias of the sample towards the coarser grain sizes as mentioned before, and is an indication of the high energy of the depositional environment in the Gatineau Valley.

However, the data on the frequency of modal class occurrence for the sediments at each area taken separately (Appendix I), shows a change in the relative abundance and position of the modal class. In the Gatineau Valley, the sediments have a modal class in the gravel range at about -2.5φ, and a large sand mode from about 1.0φ to 2.5φ with a relatively large number of samples with modes in the finer sizes up to 10φ. The sediments from the Uplands area are coarser, in that

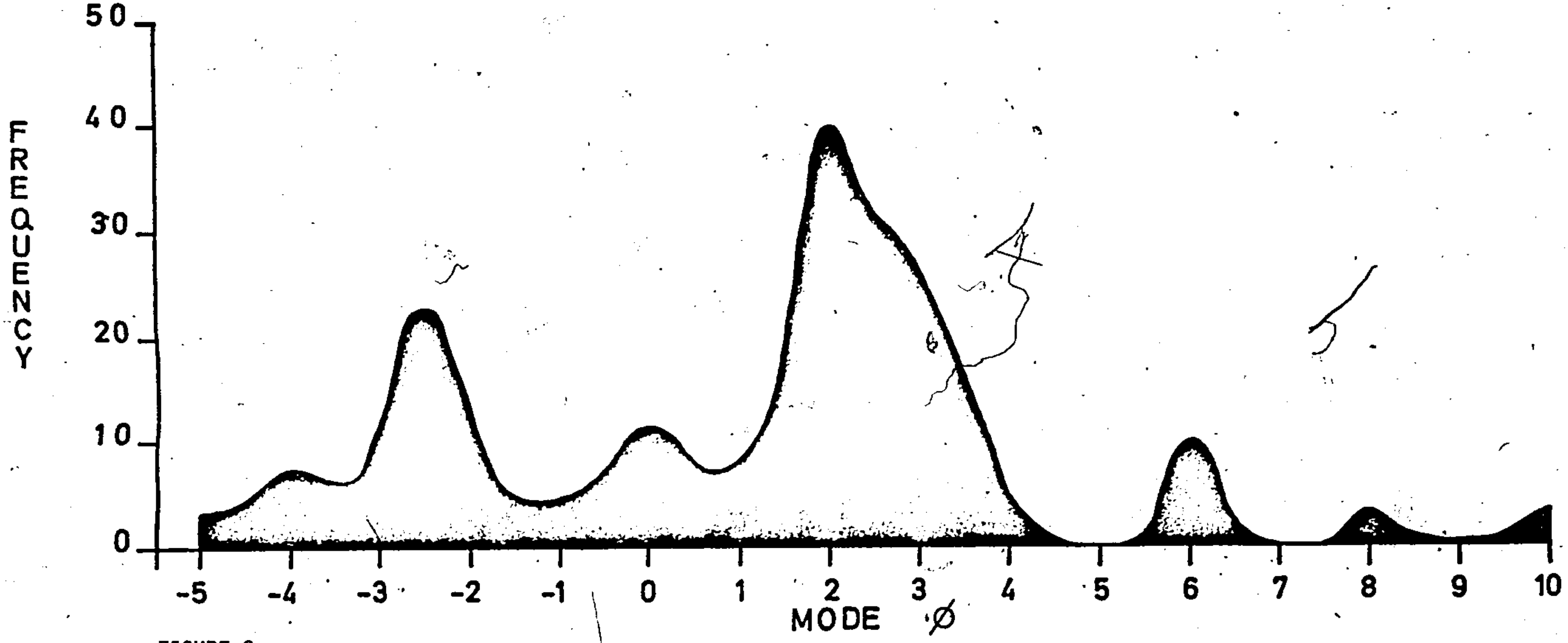


FIGURE 2.

Frequency of modal class occurrencesin samples analysed from the study area. The mode is measured in phi (Ø) units. Localities included are the Gatineau area, the Uplands and Stittsville areas.

there are relatively few samples in the finer size range, the gravel mode is well defined at -2.50 to -3.00, and the sand mode is also well defined from 2.00 to 3.00. The sediments from the Stittsville area completely lack a gravel or fine clay mode and have a sand mode in a finer size class than the other two areas; the sand mode is between 3.00 and 3.50.

Interrelationships of the four grain size parameters

The following exercise is identical to one of Folk and Ward (1957), on sand bars in the Brazos River, Texas, and part of it is also similar to the method used by Friedman (1967). It is used here in an attempt to determine which part of the Folk and Ward, and Friedman methods are most useful. The exercise consists of the interpretation of depositional environments from trends shown on a series of diagrams on which pairs of the grain size parameters have been plotted against one another. All the diagrams have been tried and a discussion of the trends on each of them is given. Some diagrams are better than others as will be seen later in the discussion. On every diagram, all samples are shown and differentiated by a different symbol, and the trends on the scatter diagrams are discussed in relation to the theoretical trends proposed by Folk and Ward (1957).

Mean size versus standard deviation

The trend on this diagram (fig. 3) approximates a sine curve, where the minima of best sorting coincide with dominant modes in the sediment suite and maxima of poor sorting occur in samples having mean sizes in the ranges between the modal sizes. Clean gravels with mean sizes (M_z) around -2.5ø have a sorting value (σ_I) of 1.25 to 2.5ø. As the pure gravel mode is mixed with a small amount of the sand mode, the mean size decreases and the degree of sorting decreases until it reaches a maximum of poor sorting when the two modes are present in about equal proportions ($M_z \cong -1ø$). As the sand mode increases in abundance, the mean size becomes finer and the sorting improves until the sediments consist of the pure sand mode where σ_I reaches a minimum between 0.3ø to 1.0ø. The sorting worsens again when small amounts of the third mode (in the clay size range) are added. A maximum of poor sorting appears to be reached at values of mean size at about 7ø to 8ø at the fine end of these analyses, although there is no indication of a downward trend on the right side of the diagram at mean size of about 7ø to 8ø. If more clayey samples had been analysed, this trend would have probably continued until it had reached a minimum of best sorting in the clay size range.

In the samples from the Uplands area the fact that mean sizes are close to the sand mode indicates that they are much better sorted than samples from the other two areas. Where sediments have a wide range of mean sizes, like the Gatineau area and the Uplands area, the trend in the diagram is more sinusoidal than that of a sediment suite from an area where the mean size is restricted to the sand range like as in the Stittsville example. The trend from such a locality has a V shape.

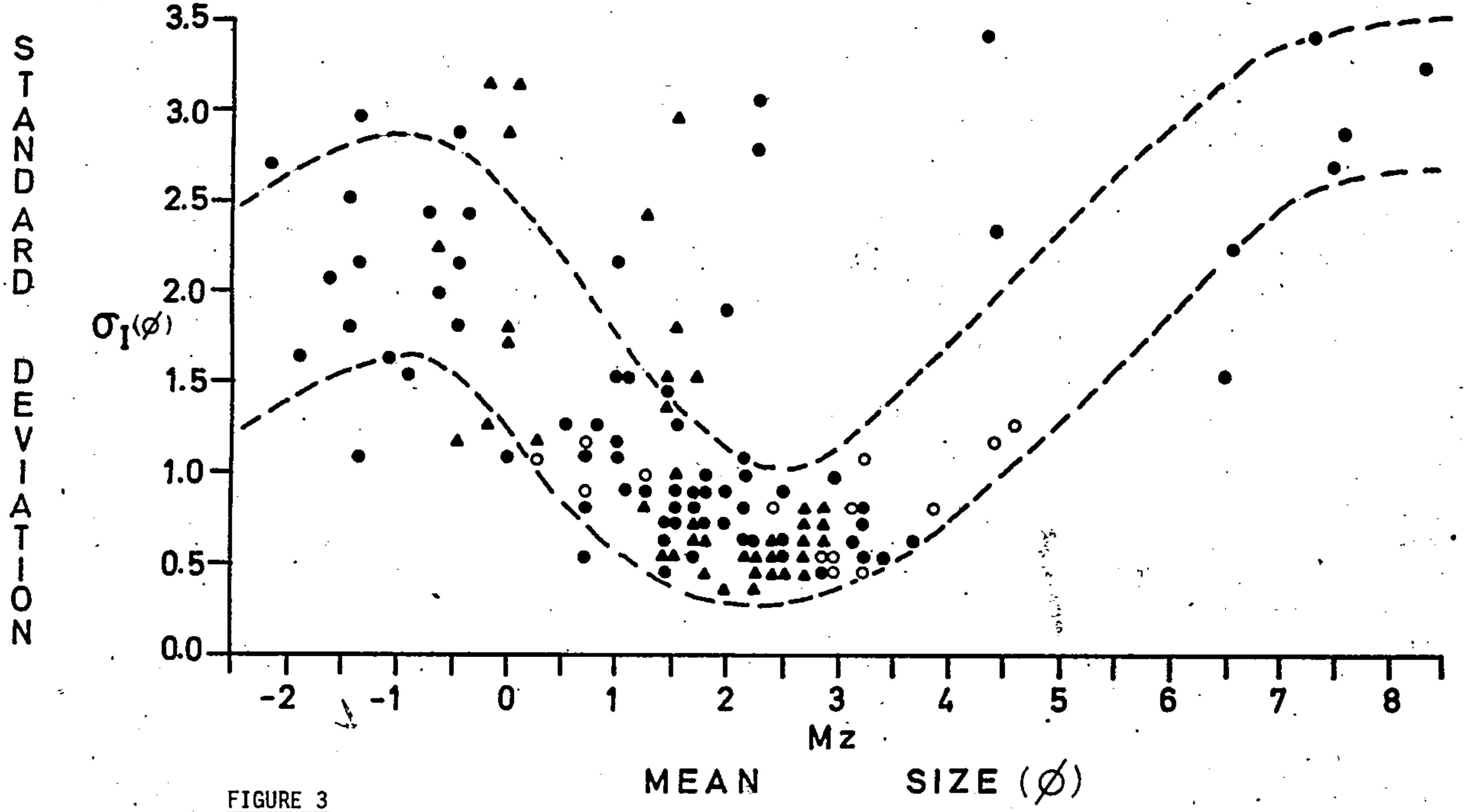


FIGURE 3

Scatter diagram of Mean Size (M_z) versus Inclusive Standard Deviation (σ_I). Samples from the Gatineau River Valley area are shown as full circles (●), samples from the Uplands area are shown as full triangles (▲), and those from the Stittsville area as open circles (○).

* Theoretical sinusoidal trend is from Folk and Ward (1957, pp. 18)

Standard Deviation versus Skewness

The distribution of points on this diagram (fig. 4) was interpreted by Folk and Ward as being almost circular, which they explained as follows. Unimodal samples with good sorting or poorly sorted samples having equal portions of two modes, have symmetrical curves and thus normal skewness values. On the other hand, sediments which are mixtures of one dominant mode and another subordinate mode give high positive or negative skewness with moderate values of sorting (σ_I). The trend on the diagram between the finer grained sediments and coarser grained ones would go from silty sands (A), to pure sands (B), to sands with a little gravel (C). The dashed line on the diagram gives the theoretical trend; the actual data depart considerably from this model.

Friedman (1967) used the same parameters to differentiate between river sands and beach sands. The line (F-F') separating the field of beach sands and the field of river sands on a scatter diagram of the two parameters is included on figure 4. The samples from the Uplands area fall mostly into the field of beach sands and are broadly differentiated from the sediments of the two other areas. The samples from Stittsville are moderately to poorly sorted and have a high positive skewness. The samples from the Gatineau area cover a wide range of sorting and are either positively or negatively skewed.

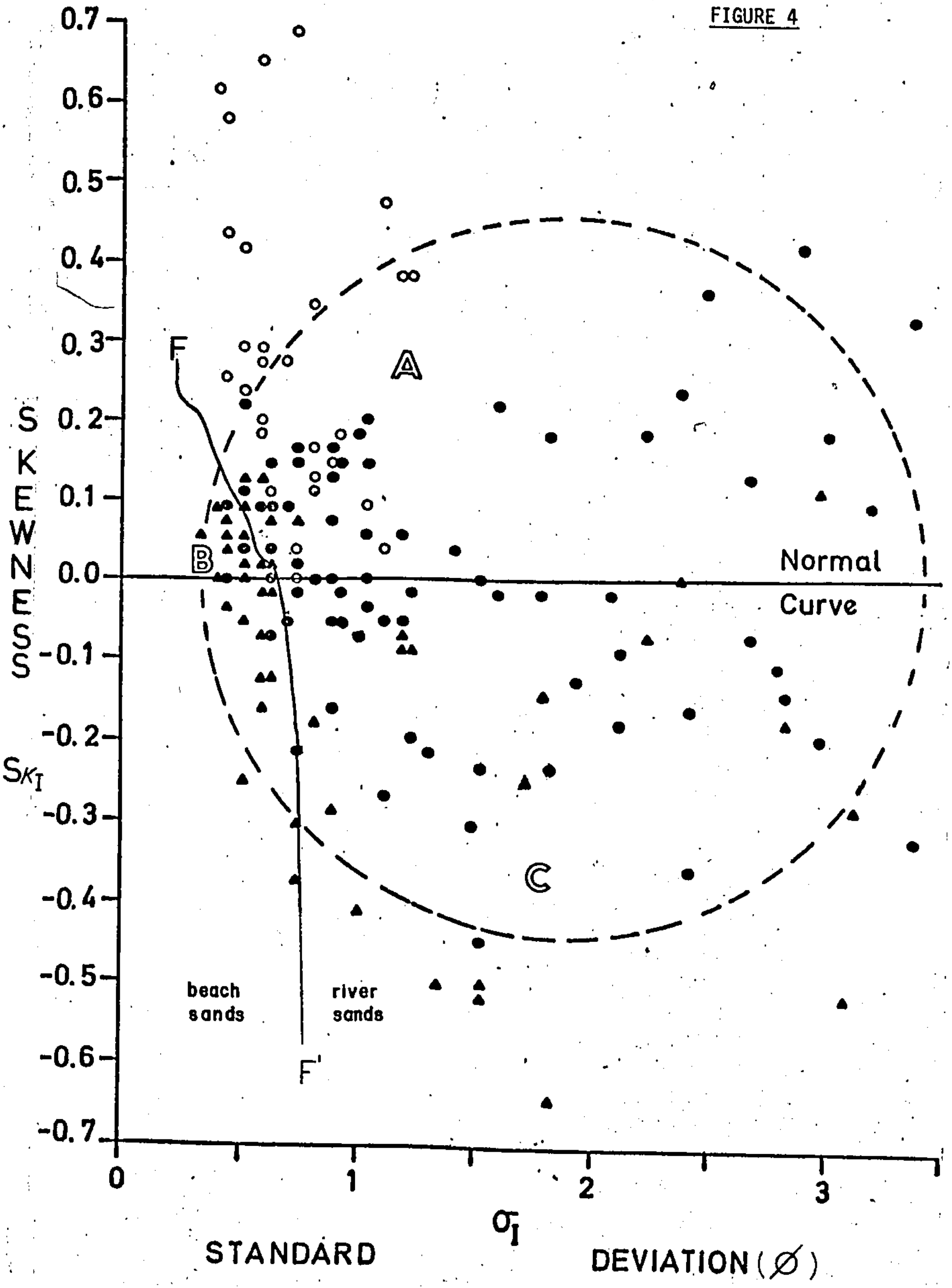
FIGURE 4

Scatter diagram of Inclusive Standard Deviation (σ_I) versus Inclusive Graphic Skewness (SK_I). The line separating the fields of beach and river sands from Friedman (1967) is indicated on the diagram by line FF'. Symbols are as in figure 3.

The dashed line on the diagram is the theoretical trend from Folk and Ward (1957, pp. 20). The generalized fields of silty sands (A), pure sands (B), and sands with a little gravel (C) are included in the diagram.

LEGEND: ● Samples from Gatineau River Valley area
▲ Samples from Uplands area
○ Samples from Stittsville area

FIGURE 4


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
SKEWNESS
S_{K_I}
F
F'
A
B
C
Normal Curve
beach sands
river sands
0
1
2
3
σ_I
STANDARD DEVIATION (Ø)

Mean Size versus Skewness

The trend on this diagram (fig. 5) is again approximated by a sine curve. The pure sand mode has a symmetrical distribution i.e. the skewness of these samples varies around 0.0. The addition of a small amount of the gravel mode imparts a negative skewness to the sediments and a maximum negative skewness of about -0.7 is attained at mean sizes (M_z) between 1 to 1.50. As more gravel is added and the two modes become about equal in proportion, the sediments have again a nearly symmetrical distribution with skewness values around 0.0. When the gravel mode becomes the dominant mode in the sediments, the skewness becomes increasingly positive until it reaches a maximum at mean sizes of about -2.00. The pure gravel mode is approximately between -2 to -2.50, and at this mean size the skewness should theoretically decrease to 0.0 (Folk and Ward, 1957, pp. 19), although samples to prove that are lacking.

If on the other hand, the sand mode is mixed with minor amounts of the finer clay size mode, the sediments become very positively skewed, like those of the Stittsville area, and the skewness reaches a maximum of about +0.7 at mean sizes around 40. The trend of the diagram should theoretically pass through values of skewness around 0.0 for sediments in which the sand and clay mode would be in equal proportions. The trend is not shown very well in this region of the diagram, again because of the bias of the sample suite towards the coarser grained sediments.

● Samples from Gatineau River Valley area

▲ Samples from Uplands area

○ Samples from Stittsville area

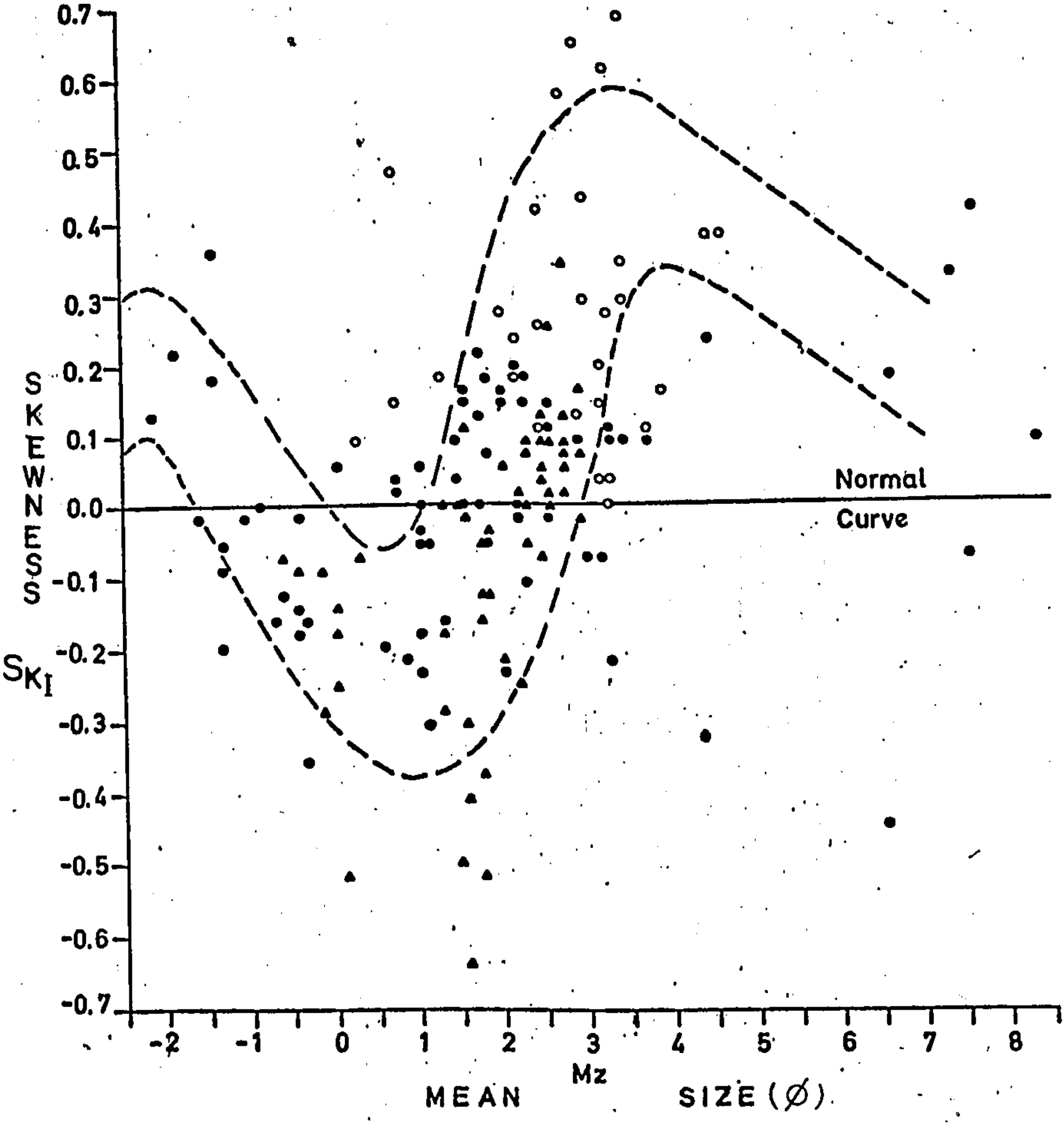


FIGURE 5

Scatter diagram of Mean Size (M_z) versus Inclusive Graphic Skewness (SK_I). Symbols are as in figure 3. Theoretical trend from Folk and Ward (1957, pp. 19).

Mean Size versus Kurtosis

The trend on this diagram (fig. 6) has been drawn largely from theoretical considerations (Folk and Ward, 1957, p. 20) because the data on hand did not give any clear indications. However the trend still appears to be oscillatory due to the relative abundance of the prominant modes in the sediments. It can be seen from the broad envelope on this diagram that these parameters are not very efficient in characterising the sediments. However, the general features of this diagram are as follows: sediments with mean sizes in the sand or gravel mode have normal kurtosis values of 1.0, while the addition of very small amounts of either a coarser or finer mode gives the sediments kurtosis values much greater than 1.0. Sediments with equal proportions of the two modes have kurtosis values smaller than one.

The kurtosis (K_G) has been modified and shown on every diagram as K_G and K'_G where necessary. This modification involves a normalisation of the kurtosis values because of the very skewed distribution of values of kurtosis in natural sediments, ranging from about 0.5 to 8.0, with normal kurtosis values of about 1.0. The normalisation gives normal kurtosis values of about 0.5 with a range from 0.3 to 0.9.

● Samples from Gatineau River Valley area

▲ Samples from Uplands area

○ Samples from Stittsville area

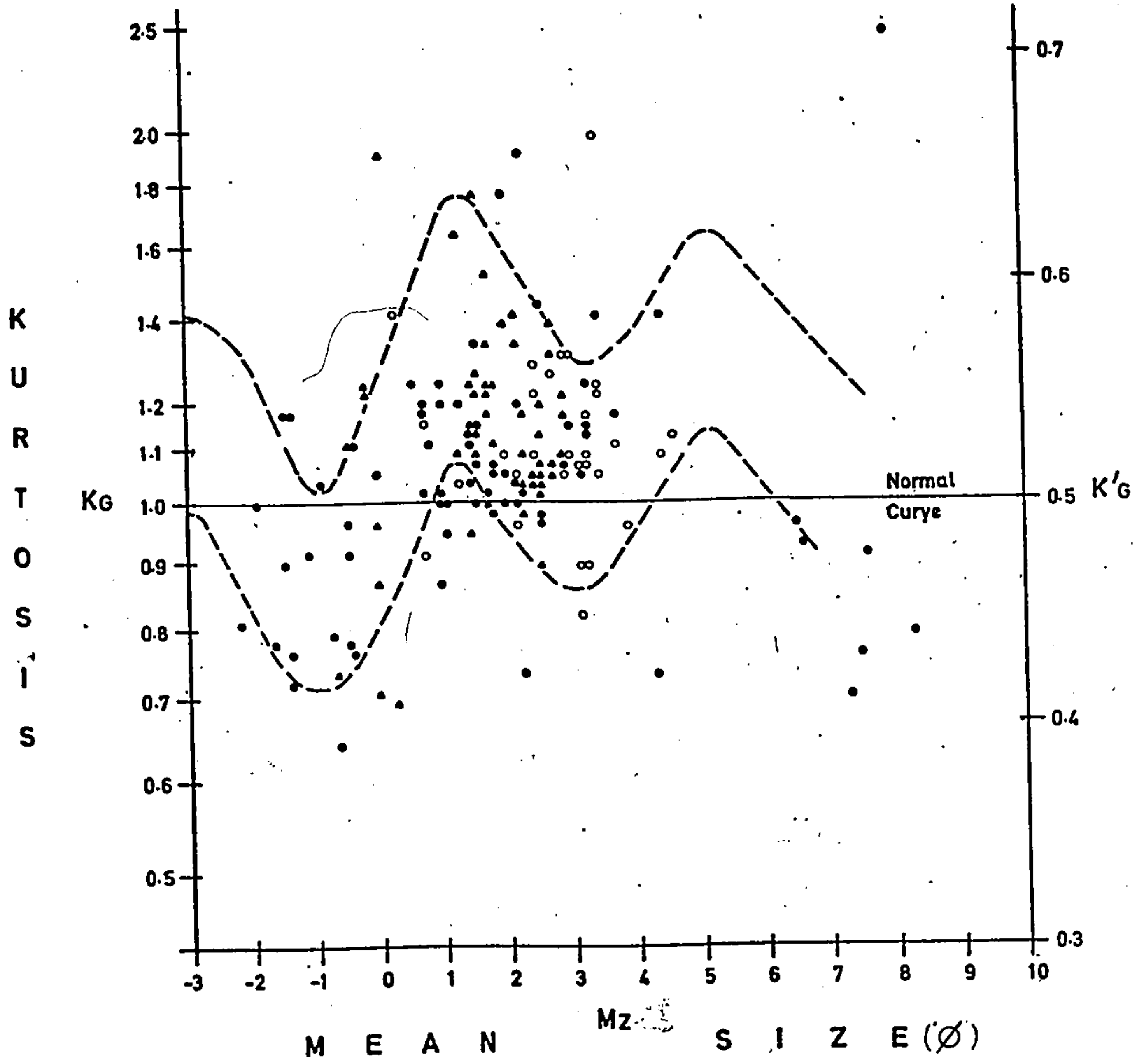


FIGURE 6

Scatter diagram of Mean Size (M_z) versus Graphic Kurtosis (K_G). The theoretical trend as suggested by Folk and Ward (1957, p. 20) is drawn on the diagram as a dashed line. Symbols are as in figure 3.

Kurtosis versus Standard Deviation

The sinusoidal trend in this diagram (fig. 7), (Folk and Ward 1957, p. 21), is easily explained when one considers that the lowest degree of sorting is found in sediments which are mixtures of two modes in equal proportions, and that these sediments also have the lowest kurtosis. The highest kurtosis values are found in sediments which are a mixture of one dominant mode and the other subordinate, these sediments also have moderate sorting. Unimodal sediments are best sorted and have normal kurtosis values about 1.0.

The path followed on the diagram, going from coarser sediments to finer ones is as follows: from the field of sandy gravel (A), to the field of pure sands (B), back to (A) which is also the field fo silty sands and finally to (C) which is the field of sediments with equal proportions of sand and clay.

Skewness versus Kurtosis

As both of these parameters are dependent on the proportions of the modes in the sediments, a regular path is followed on the diagram as the mean size changes, because of the variation in the abundance of the different modes (fig. 8). A U-shaped trend from fields A to E is displayed by plotting the skewness and kurtosis values of sediments of decreasing mean size from nearly pure gravels in field (A). These gravels usually contain a little sand, giving their distribution a positive

FIGURE 7

Scatter diagram of Inclusive Standard Deviation (σ_I) versus Graphic Kurtosis (K_G). Included in the diagram are the fields of sandy gravels (A), pure sands (B), and silty sands (C). Symbols as in figure 3. The dashed line represents the theoretical trend shown by Folk and Ward (1957, p. 21).

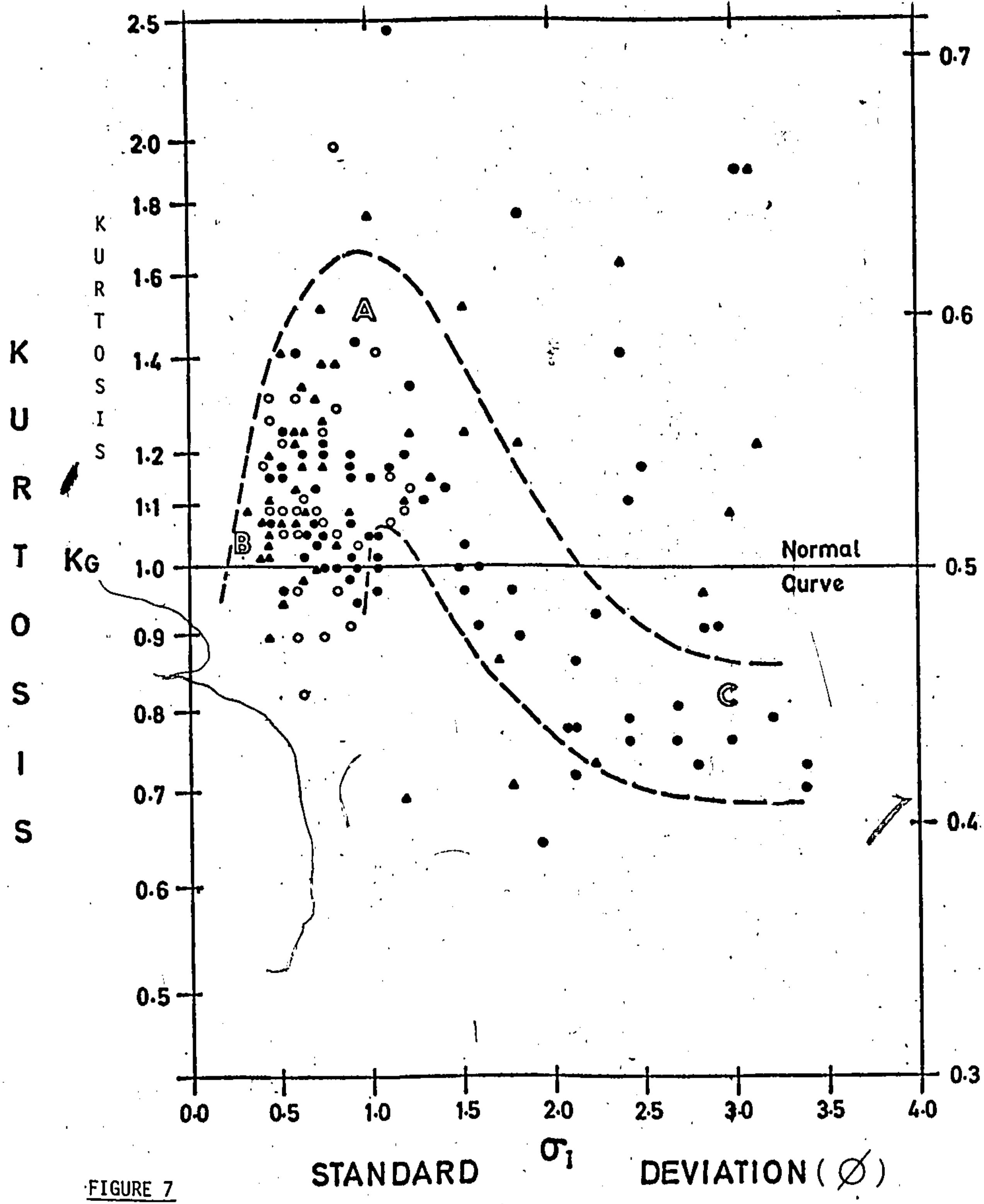


FIGURE 7

Scatter diagram of Inclusive Standard Deviation (σ_I) versus Graphic Kurtosis (K_G). Included in the diagram are the fields of sandy gravels (A), pure sands (B), and silty sands (C). Symbols as in figure 3. The dashed line represents the theoretical trend shown by Folk and Ward (1957, p. 21).

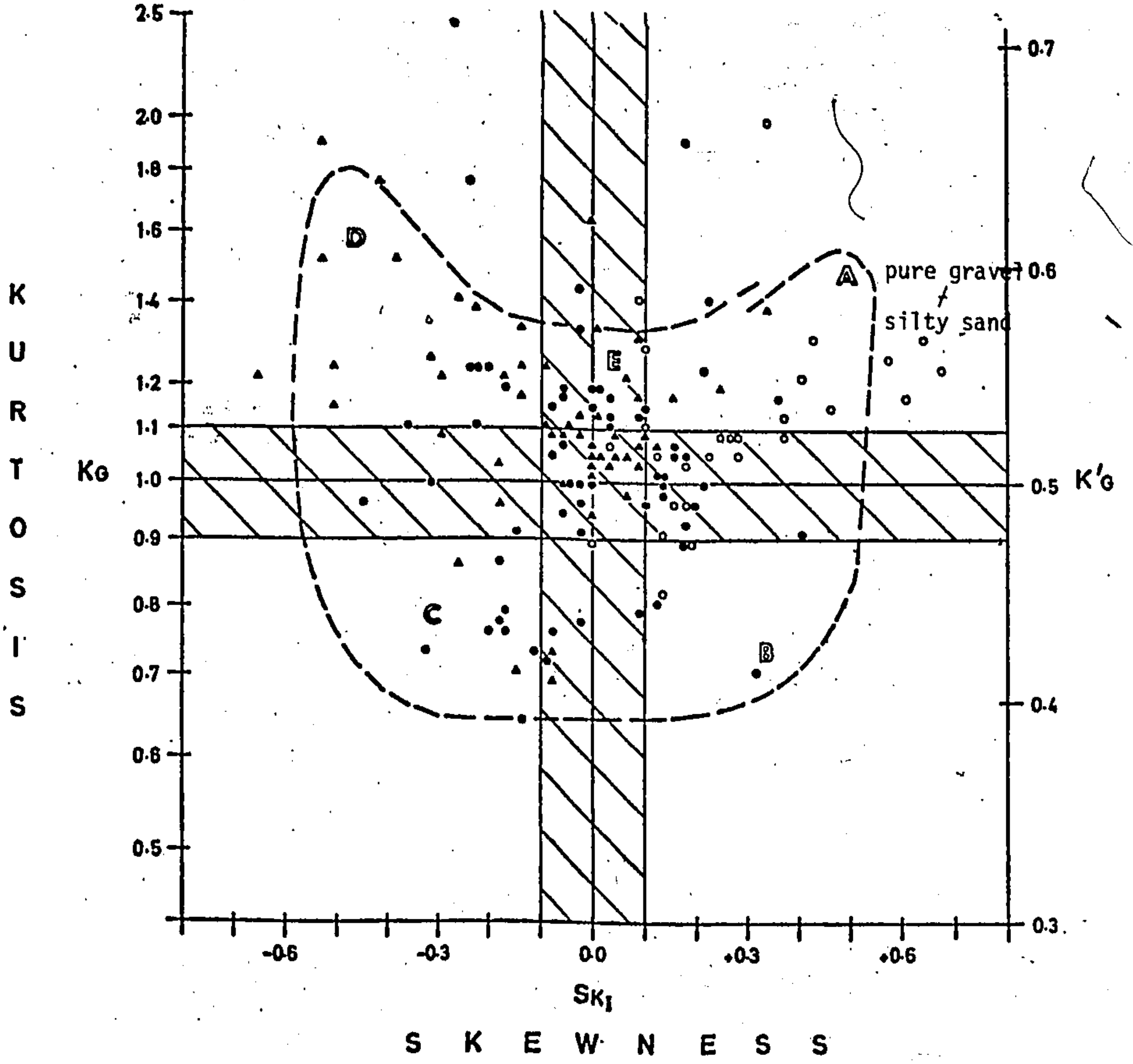


FIGURE 8

Scatter diagram of Inclusive Graphic Skewness (SK_I) versus Graphic Kurtosis (K_G). The areas defined as within the range of the normal curve ($SK_I = 0.0$ and $K_G = 1.0$) are shown by the diagonal line pattern. The fields of nearly pure gravels (A), gravelly sands (B) and (C), gravelly sands (D), and pure sands (E), are indicated on the diagram. Symbols as in figure 3. The theoretical trend (dashed line) is shown as in Folk and Ward (1957, p. 22). ● Gatineau, ▲ Uplands, o Stittsville skewness with a high kurtosis (greater than 1.0). As more and more sand is added to the sediments, the modes become equal or subequal in proportion and the kurtosis values approach 1.0, with minor change in the skewness. When the gravel mode becomes subordinate, the skewness becomes very negative with values ranging from -0.3 to -0.6, the kurtosis does not vary much, such as in field (C), gravelly sands. When only a fraction of the gravel mode is still present in the sediment, the kurtosis values are very high, with skewness values remaining negative, field (D). As the gravel mode disappears, the sediments become pure sands having normal values of kurtosis and skewness, field (E). The field of nearly pure gravel (A), would coincide with that of the silty sands, because these sediments also have high kurtosis values and positive skewness. This overlapping of the fields of silty sands and sandy gravels is shown on the diagram by the similar position of the samples from Stittsville, which are silty sands, and a few samples from Uplands and Gatineau areas which are nearly pure gravels.

Discussion

From the preceding exercise, it is seen that the sediments from the three areas chosen (Gatineau, Uplands, Stittsville), have different textural features. The sediments from the Gatineau area cover a wide range of grain sizes with mean sizes from -2φ to 8.0φ; they are moderately to poorly sorted, with values as high as 3.5φ. Skewness values vary from normal ($SK_I = 1.0$) to negative for samples with mean sizes between 0.0 and -2Ø and 6 to 8Ø; the standard deviation of these samples is usually very high from (M_z) of 2 to 3Ø units, and their kurtosis values are less than normal ($K_G = I$). Some samples with mean sizes of about 2Ø, have high kurtosis values up to 2.0.

Samples collected from the Uplands area cover a restricted size range with mean sizes from -1 to 3Ø. They are usually well to moderately well sorted, with σ_I varying from 0.35 to 1.0Ø, although some samples are also poorly sorted. Those poorly sorted samples display very negative skewness values ($SK_I = -0.7$) and high kurtosis values up to 2.0 at mean sizes of about 1.5Ø. Lower than normal values of kurtosis (0.8) are encountered in samples with mean sizes between -1.0 and 0.0Ø; these are poorly sorted with σ_I values as high as 2.0Ø.

Lastly, the samples from the Stittsville area cover a very restricted size range, with mean sizes from 0.0 to 4.0Ø. They are moderately to poorly sorted (σ_I values from 0.5 to 1.5Ø) and display very high positive skewness ($SK_I = 0.7$), and high kurtosis values ($K_G = 1.4$), especially at mean sizes between 3 and 4.Ø.

The variation in the textural parameters has been discussed in terms of the mixing of the modes in a suite of samples, but this mixing of the modes is firstly a function of the source area and the efficiency of the processes active in the depositional environment, at separating these modes.

The sedimentary environment in which the sediments at Uplands were deposited was investigated earlier (Gadd, 1963 and Romanelli 1970), and it was proposed that the origin of the sediments be attributed to the reworking of morainic ridges by shore currents of the Champlain Sea. The wide areal extent of the sea at that time provided suitable conditions for high wave energy and steady bottom currents near the shores. This is reflected in the textural features of the sediments from the area; they are well sorted and the high negative skewness is due to the presence of a minor amount of gravel in the samples, probably transported by rolling on the sea floor. The source of the gravel is the polymodal sediment of the morainic ridge; the proximity of the source causes an excess of sand, and thus the high kurtosis values observed (Folk and Ward 1957, p. 26).

The sediments from the Stittsville area (Smith, 1970), although lacking fossils, are thought to have a submarine origin, but in close proximity to the ice front (Rust and Romanelli, 1975). The sediments, which contain a great variety of structures, could have been deposited by streams flowing from englacial tunnels down from a ridge under deep, probably marine water, as in turbidity currents. This mode of deposition would account for the moderate to poor sorting and kurtosis values of these sediments, and is a reflection of the inefficiency of the environment at separating the modes (sand and silt), either because of the poor winnowing capacity of the current, or the proximity of the source.

The depositional environment in the Gatineau Valley cannot be postulated from the textural characteristics of the sediments alone. This is because, contrary to the suite of sediments from the Uplands and Stittsville areas, the one from the Gatineau area shows the widest range in grain size modes.

In view of the above difficulty, an important part of the environmental interpretation should be based on the stratigraphic succession. The thick sand and gravel unit found adjacent to bedrock ridges in the Gatineau Valley area contains sediments sometimes structureless, with very poor sorting values. Their position, underlying marine clays and sands, suggests a deposition in a glacial or pro-glacial environment of very high energy. The very poor sorting of these sediments in this high energy environment is probably due to the close proximity of the source and an excessive rate of supply, as in the Stittsville area. The depositional process active in such an environment , under these conditions could be of the same type as mentionned for the Stittsville area; meltwaters issuing from tunnels in the glacier and flowing over bedrock ridges under deep water conditions, as indicated by the overlying marine clays and sand.

The marine sands found at the top of the succession in the Gatineau Valley area show similar textural characteristics to those found in the marine beaches in the Uplands area, but to a lesser degree. As shown on figures 3 and 4, the marine sands from the Gatineau Valley area show poorer sorting and lesser skewness values than the sands from Uplands.

Considering that the major sorting agent acting on marine beaches is wave action, it could be postulated that the marine sands from the Gatineau Valley beaches were subjected to a weaker wave energy than those from the Uplands area. The narrowness of the Champlain Sea in the Gatineau Valley area could be the reason for this diminished wave energy, due to the lesser fetch of the waves, as compared to the nearly open sea conditions prevailing in the Uplands area during the Champlain Sea episode.

For comparison of the textural features of sediments from the three areas chosen, it would appear that the most useful diagrams are those shown in figures 3, 4 and 5. The reason for this is that the processes active in the glacial or near glacial environments usually do not separate the modes in the sediments efficiently enough to permit the use of diagrams with very sensitive parameters like skewness and especially kurtosis. The mean size, standard deviation and skewness are the most useful parameters of a distribution for broad environmental investigations. This is shown by the simpler and clearer trends on figures 3, 4 and 5.

The continuation of the method in the manner of Folk and Ward (1957) and others (see Folk 1966), into a three dimensional relationship in the form of a helicoidal trend between the four grain size parameters seems unnecessary in this study. This is due to the reasons previously mentioned, i.e., the bias of the sampling, and the great sensitivity of kurtosis to errors due to the method of analysis and treatment of data.

FOSSILS AND PALEOENVIRONMENT

Introduction

Pleistocene and Holocene fossils from the Ottawa area, especially those of the Champlain Sea, have stirred continuous attention amongst the scientific community for more than a century. A list of published references on Champlain Sea fossils (Wagner, 1967), indicates that Lyell (1845) commented on a concretion from near Bytown (Ottawa) Canada, containing the fish Mallotus villosus (Muller). The very first workers observed that some fossils found in Champlain Sea sediments were the same species as those living in northern parts of the Gulf of Saint Lawrence, and that the climate at that time was generally colder than at present, probably subarctic.

Because of the above mentioned fact, the fossils of the Champlain Sea were subsequently used as paleoclimatic indicators. Goldring (1922) suggested that the salinity of the Champlain Sea waters decreased southwestward, from Montreal to the Champlain Valley of New York and Vermont, and Ottawa. Her conclusion was based on the decrease in size of certain mollusks and also a decrease in the species density westward within these regions. Elson (1960, 1969 a) suggested that as the Champlain Sea withdrew from the continent, because of land uplift, the salinity decreased and the temperature increased. The indication of such changes is from trends in size characteristics of the mollusks

Macoma balthica (Linné) and Hiatella arctica (Linné), with decreasing elevation. Elson found that the modal length of Macoma increases while the modal length of Hiatella decreases with decreasing elevation.

Vertebrate fossils of the Champlain Sea have also yielded broad indications of climatic conditions. Remains of cold-adapted marine mammals which are still living today, such as the white whale (Beluga), the humpback whale, and the harp seal, are found fossilized in sediments around Ottawa, suggesting an early cool (subarctic) phase of the Champlain Sea (Harrington, 1971 and 1972).

The following study is an attempt to approximate the temperature and salinity of the Champlain Sea waters from comparison of size characteristics of fossil populations of mollusks.

Method

Fossil horizons from different elevations in the Gatineau Valley and Ottawa area were sampled, and size characteristics of populations of Macoma and Hiatella were measured, namely the length of the shell, and the height of the shell. The length is taken as the maximum distance measured between the posterior and anterior edges of the shell; the height of the shell is measured from the umbo to the middle of the shell edge. The tabulation of the measurements is given in table I and in figure 9 and 10, in the form of histograms. All the measurements were made on the left valve of the shell because in most cases the fossils were found very well preserved, with both valves present, hinged and in growth position. A growth curve was drawn for three populations of Macoma balthica where preservation was good and a sufficient number of non-eroded shells were available for determining the ages of individuals using the growth ring interpretation method (Sergerstrale, 1960), figure 12. Comparison of the size characteristics of the fossil populations of Macoma with those of living populations in the Gulf of Saint-Lawrence, the Baltic Sea, and the Wadden Sea, was made to approximate the salinity and temperature at which these fossil populations lived.

Hardy (1970) has employed the same method as the one used here with fossil populations of Macoma from the Laflamme Sea (Elson, 1969 b, and Laverdière, 1967), in the Lac Saint Jean area.

Results and Discussion

The comparison of modal length of fossil mollusks is not necessarily a direct measure of the effects of salinity and temperature. It is the combined effect of the growth rate of a fossil population and its time of exposure, i.e. the life duration of the population. Consequently, a trend of size versus elevation such as that in figure 11, for populations of Macoma found in the study area, cannot be directly interpreted in terms of paleotemperature or paleosalinity, as done by Elson (1960). This is because some of these populations could have different growth rates, and the life duration of the population could affect the modal size.

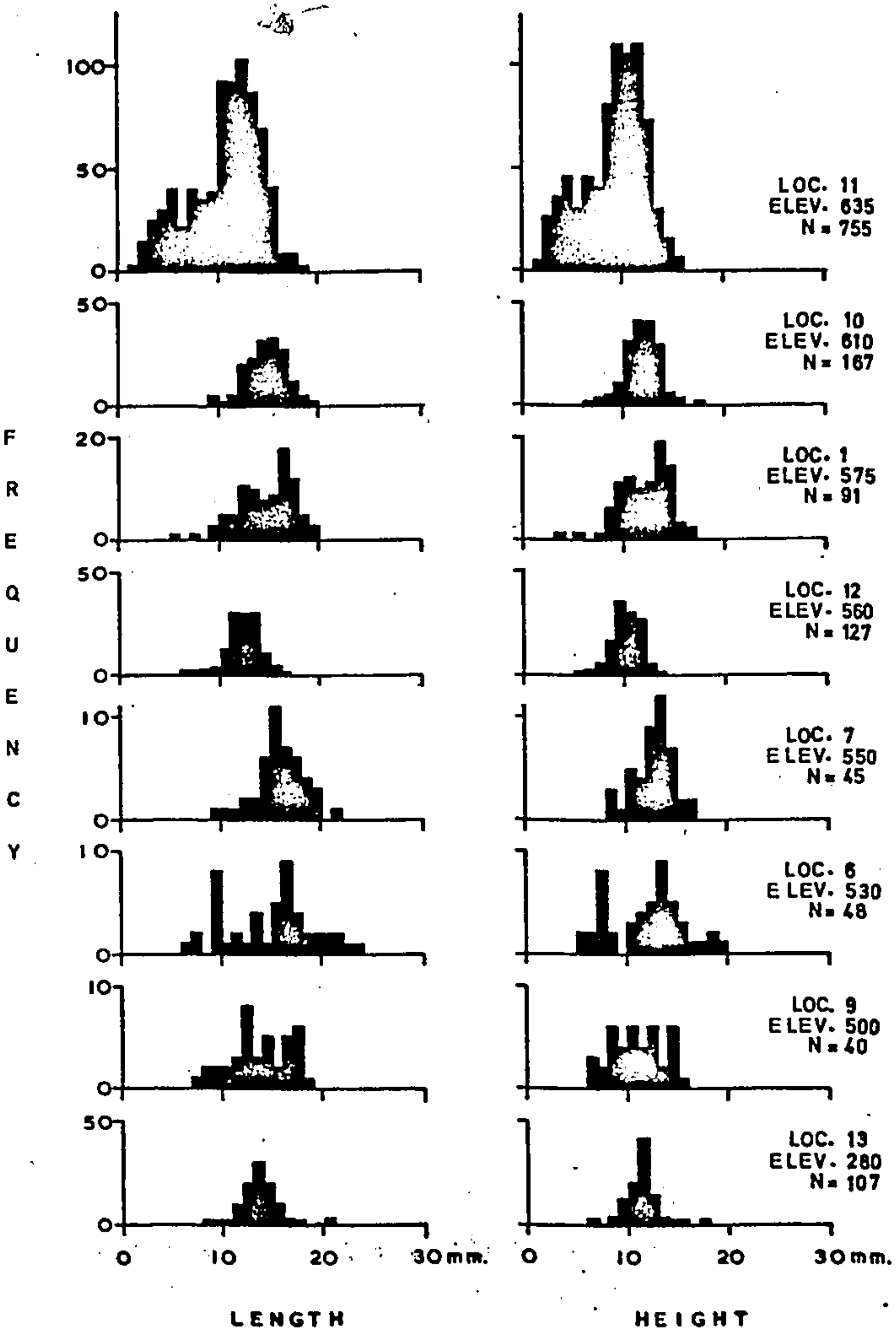


FIG. 9 — FREQUENCY HISTOGRAMS OF LENGTH AND HEIGHT FROM POPULATIONS OF *Macoma balthica* TAKEN AT DIFFERENT ELEVATIONS. N IS THE NUMBER OF LEFT VALVES MEASURED AT EACH LOCALITY.

Locality numbers (i.e. loc. 9) are listed in Appendix II, as shown on Fig. 1

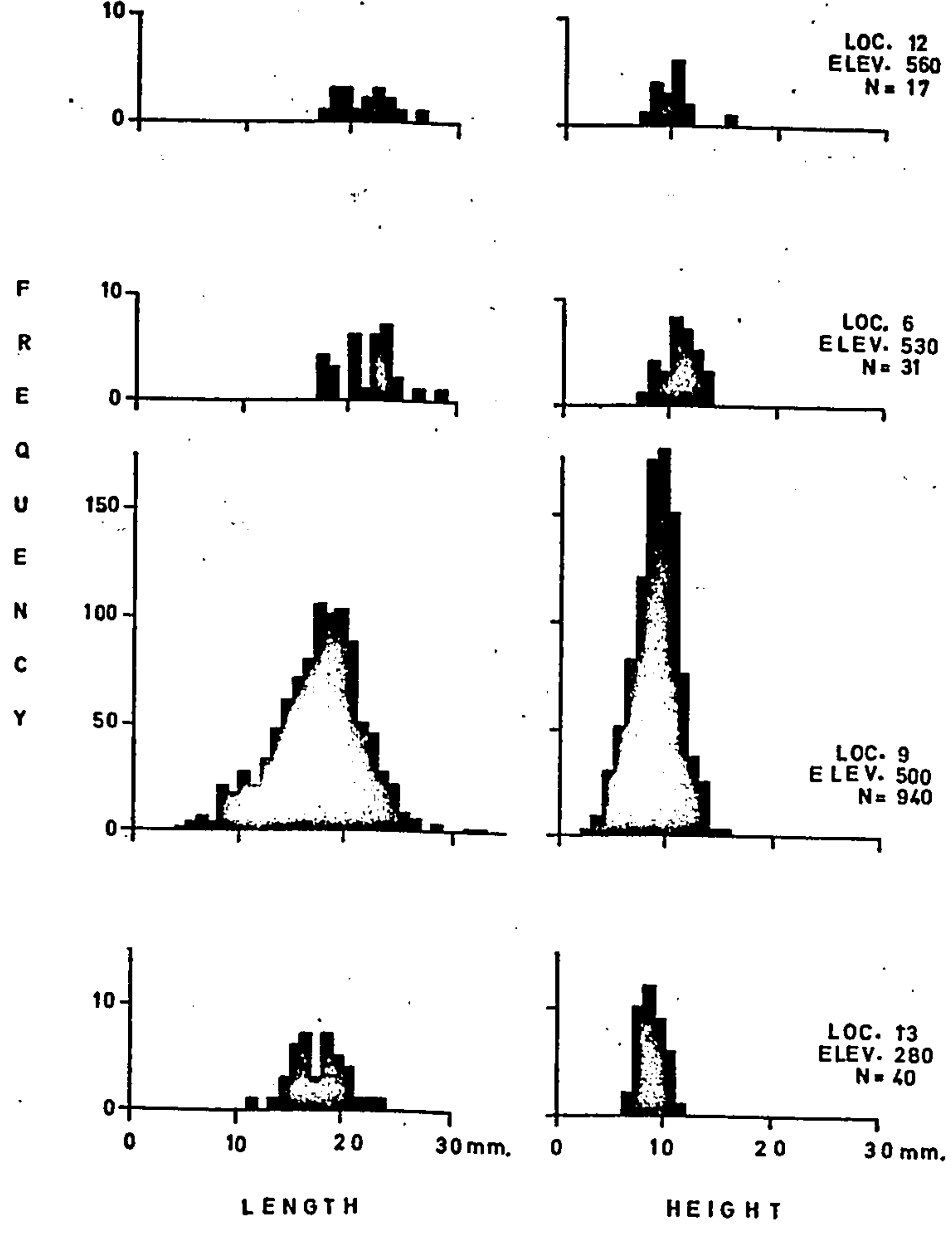


FIG.10— FREQUENCY HISTOGRAMS OF LENGTH AND HEIGHT FROM POPULATIONS OF *Hiatella arctica* TAKEN AT DIFFERENT ELEVATIONS. N IS THE NUMBER OF LEFT VALVES MEASURED AT EACH LOCALITY.

Locality numbers (i.e. loc. 9) are listed in Appendix II, as shown on Fig. 1

TABLE I: SIZE CHARACTERISTICS OF FOSSIL POPULATIONS OF *Macoma balthica* AND *Hiatella arctica* FROM THE STUDY AREA.

LOCALITY NUMBER	SPECIES (general name)	ELEVATION m (ft.)	LENGTH (mm.)			HEIGHT (mm.)		
			Minimum	Mean ± 1σ	Maximum	Minimum	Mean ± 1σ	Maximum
11	*Macoma*	193.5 (635)	1.5	10.75 ± 0.8	18.5	1.5	9.10 ± 0.6	15.5
10	*Macoma*	186.0 (610)	7.5	14.70 ± 1.1	19.5	6.5	11.77 ± 0.9	17.5
1	*Macoma*	176.2 (578)	5.5	14.69 ± 2.0	19.5	3.5	11.97 ± 1.8	16.5
12	*Macoma*	170.5 (560)	6.5	12.38 ± 1.0	16.5	5.5	10.03 ± 0.7	13.5
12	*Hiatella*	170.5 (560)	17.5	21.20 ± 2.3	26.5	7.5	10.08 ± 2.1	15.5
7	*Macoma*	167.5 (550)	9.5	15.93 ± 2.0	21.5	8.5	12.74 ± 1.1	16.5
6	*Macoma*	161.5 (530)	6.5	14.87 ± 3.2	23.5	5.5	11.91 ± 2.4	19.5
6	*Hiatella*	161.5 (530)	17.5	21.72 ± 2.3	28.5	7.5	10.88 ± 1.0	13.5
9	*Macoma*	152.5 (500)	7.5	13.72 ± 2.0	18.5	6.5	10.92 ± 1.4	15.5
9	*Hiatella*	152.5 (500)	4.5	17.45 ± 1.5	32.5	2.5	8.75 ± 0.5	15.5
13	*Macoma*	85.0 (280)	8.5	13.70 ± 1.3	20.5	6.5	11.25 ± 1.2	17.5
13	*Hiatella*	85.0 (280)	11.5	17.65 ± 2.1	23.5	6.5	8.75 ± 0.7	11.5

To test this, growth curves were drawn (figure 12) for three populations, one from the Cantley area (loc. 11), another from Meach Lake (loc. 12), and the third from the Uplands area (loc. 13).

It can be seen that the population at Meach Lake had a slower growth rate than the population at Uplands, but that they have roughly the same mean size. This means that the Meach Lake population lived longer than the population at Uplands, which is not apparent on graphs of size versus elevation, fig. 11 . For this reason, the method of comparing different modal length of mean size (Elson, 1960) of a particular species at different elevations is not reliable as a paleoclimatic indication.

The comparison of growth rates of fossil populations with recent ones, seems a more reliable approach to the question. This has been done for the three populations at Cantley, Meach Lake and Uplands, where 63, 81 and 41 measurements of age (growth rings) have been made, respectively. The average age, length, and growth rate of these three populations are shown in table II.

The environmental conditions and size characteristics of six recent populations of <u>Macoma balthica</u> are given in table III, and the growth curves for these populations as given in figure 13. The growth curve for the population from the Wadden Sea (1), (Lammens, 1967) has been drawn from the information given by the author since he measured growth in terms of height and projection area. The other curves all

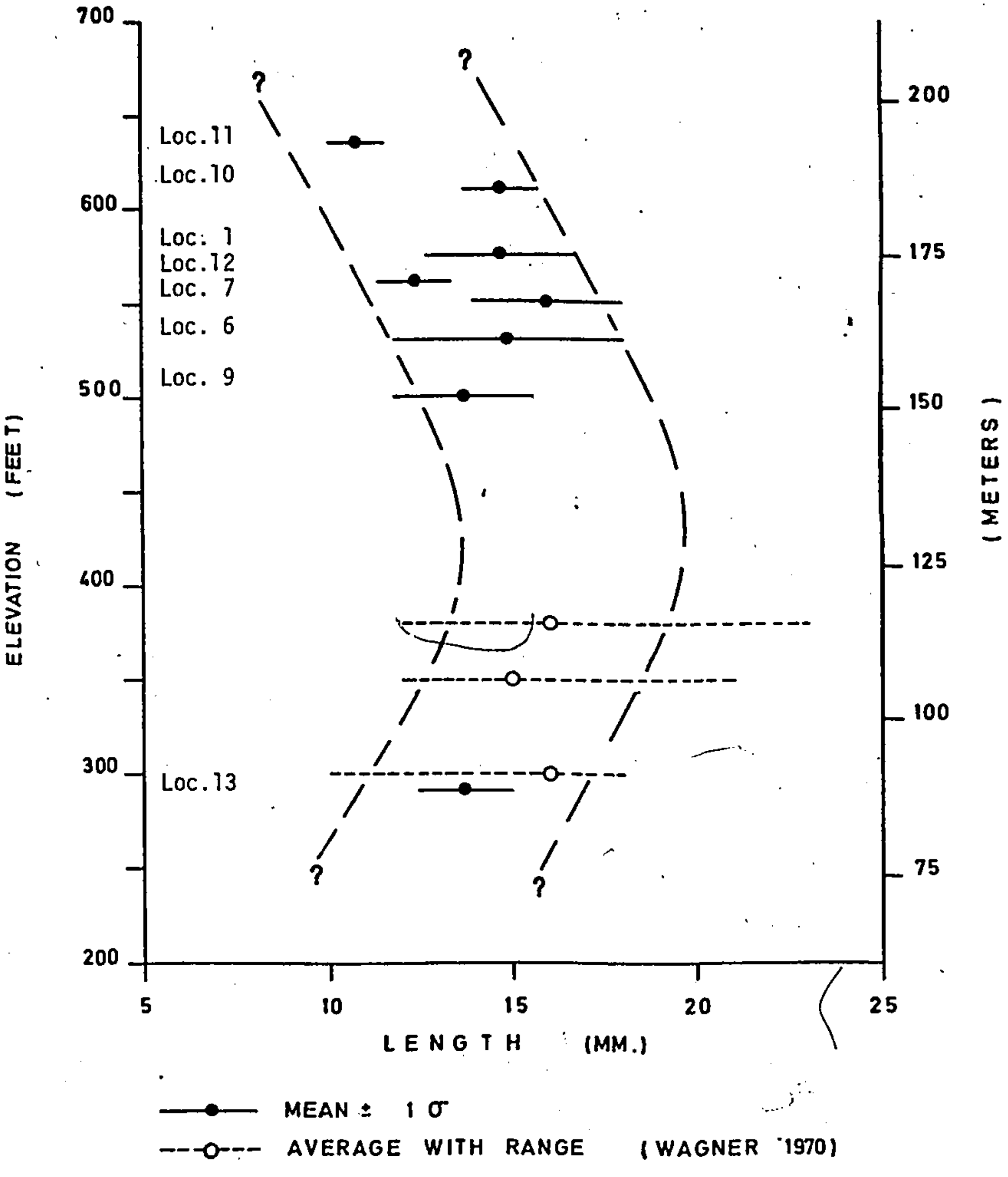


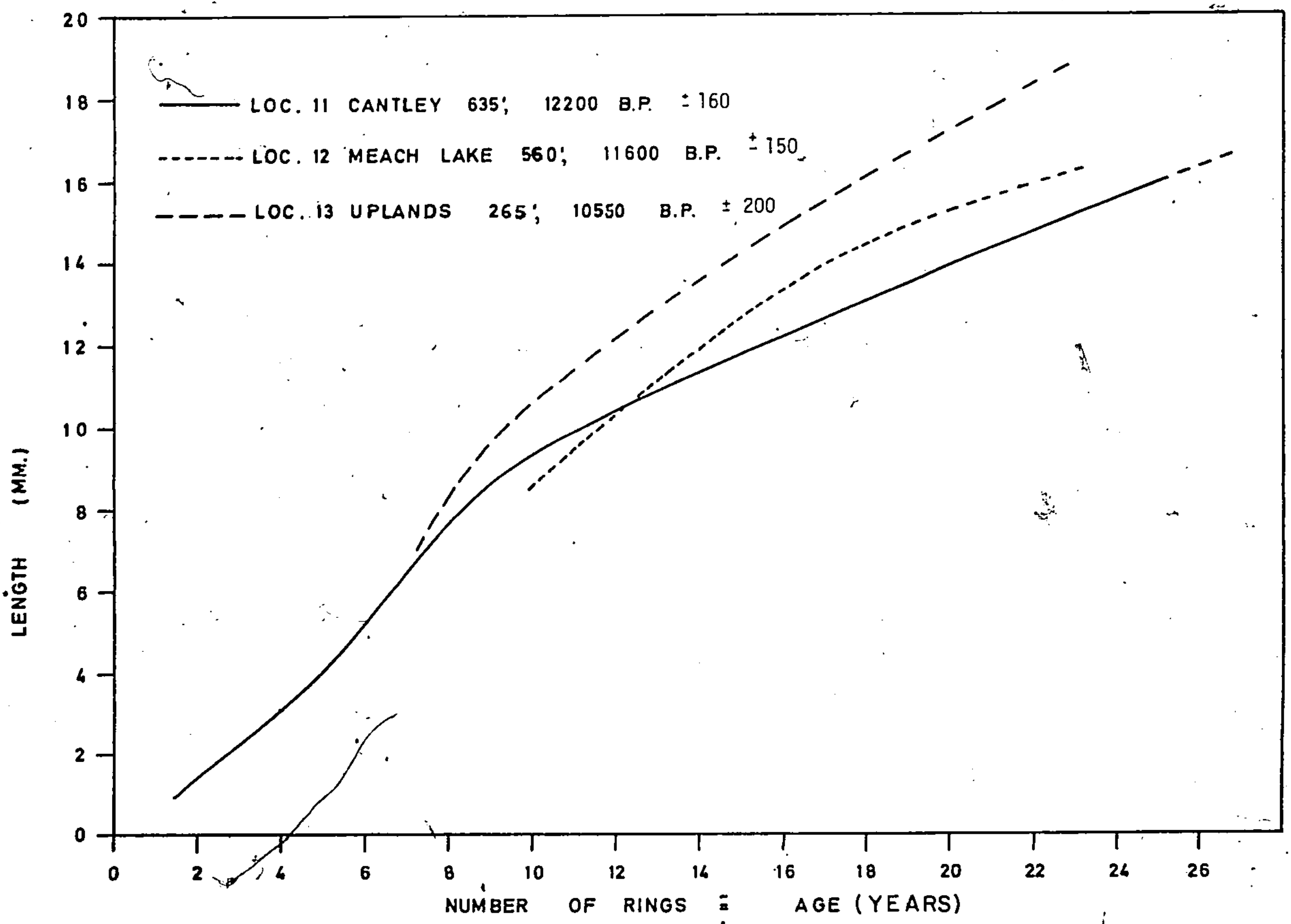
FIGURE 11: Variation in the mean length of Macoma balthica (Linné) with elevation in the Ottawa-Hull area. A tentative trend is drawn through the data points. Data are from table I unless otherwise noted.

TABLE II: GROWTH CHARACTERISTICS OF THREE POPULATIONS of <u>Macoma Balthica</u> FROM THE OTTAWA-HULL AREA

DATA	LOC. 11 CANTLEY	LOC. 12 MEACH LAKE	LOC. 13 UPLANDS
Number of measurements	63	81	41
Average length (mm)	10.75	12.38	13.70
Average age (years)	12.7	14.5	14.2
Average growth rate (mm/year)	0.83	0.85	0.96

FIGURE 12

Growth curves of three fossil populations of <u>Macoma</u> <u>balthica</u>(Linné), of different ages and elevations from the Ottawa-Hull area. (Data from Table II).


LOC. 11 CANTLEY 635', 12200 B.P. ± 160
LOC. 12 MEACH LAKE 560', 11600 B.P. ± 150
LOC. 13 UPLANDS 265', 10550 B.P. ± 200
LENGTH (MM.)
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
NUMBER OF RINGS = AGE (YEARS)

measure growth in terms of length. By comparing the shape of the growth curves for the three fossil populations to those of the recent populations it is seen that the population from Cantley has similar characteristics to the one from the Tvarminne area (5) (Sergerstrale, 1960), while the growth curve from Uplands is more similar to that of populations (3) and (4) from the Gulf of Saint Lawrence and the Tvarminne areas respectively. The growth curve from the Meach Lake area is intermediate between these two examples. From this comparison it is suggested that the fossils at Uplands lived in waters with a temperature range from winter to summer of about 4°C to 15°C, and that the salinity, although uncertain was probably higher than at Cantley. The population from Cantley lived in much colder waters, with temperatures from 2°C in winter months to 8°C during the summer months, with a salinity of about 8 parts per thousand (8⁰/oo).

The indication that the temperature and salinity of the Champlain Sea waters were both low during the very early stage of the sea (12,200 B.P.), is supported by the fact that the fossil assemblage at Cantley contains Hiatella, which is slightly less tolerant to reduced salinity than Macoma (Zenkevitch, 1963) but also needs temperature lower than 11°C during the summer months to reproduce (Hunter, 1949). These conditions indicate proximity to the ice front, which would influence the temperature and salinity of the waters by the volume of glacial melt-waters flowing into the sea. The salinity of the sea water was probably higher than 8⁰/oo, in areas further from the ice front.

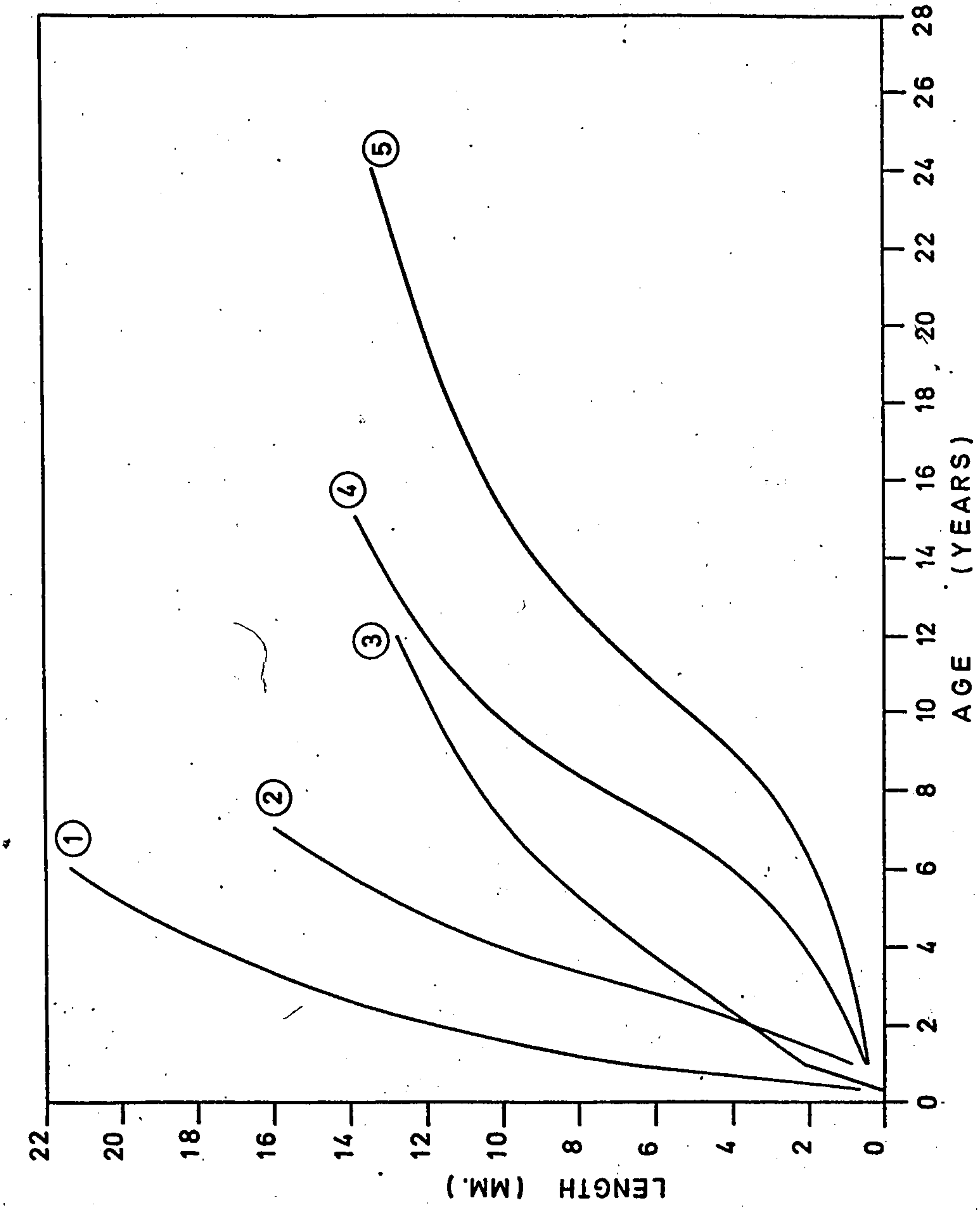
The increase in growth rate of Macoma from Cantley to Uplands

TABLE III: SIZE CHARACTERISTICS AND LIFE CONDITIONS OF LIVING POPULATIONS OF <u>Macoma balthica</u>

	Lammens (1967) Den Helder, Wadden Sea	Lavoie *et al.* (1968) Lavoie *et al.* (1969) Cacouna-est and Pointe-à-Boisvert Gulf of Saint Lawrence	Sergerstrale (1960) Tvarminne Gulf of Finland		
Curve number (See fig. 13)	1	3	2	4	5
Depth of population	tidal flats	intertidal	3m.	20m	35m
Temperature (winter-summer)	10-18°C	4-20°C	10-19°C	-5-14°C	2-8°C
Salinity	near normal 34 - 36°/oo	22-26°/oo	7°/oo	8°/oo	8°/oo
Average age at death (years)	2	8	7	15	25
Average length at death (mm.)	12.1	10.6	16	13.8	13.6
Average growth rate (mm/year)	6.5	1.3	2.2	0.9	0.5

FIGURE 13

Growth curves from five recent populations of <u>Macoma balthica</u> (Linné). The population numbers correspond to those described in Table III.


LENGTH (MM.)
0
2
4
6
8
10
12
14
16
18
20
22
AGE (YEARS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
①
②
③
④
⑤

can be correlated with an increase in the temperature of the sea water, on the basis of the growth curves from the Tvarminne area. The temperature range at Uplands from winter to summer months was probably from 4° to about 15°C and probably higher in very shallow regions of the sea during the summer months. The contradictory evidence from both curves (3 & 4, figure 13) is an indication that the species is very tolerant to changes in salinity.

Indications of the salinity conditions at Uplands can also come from the fossil assemblages contemporaneous with Macoma populations. Illman et al. (1970) commented on the marine algal deposit dated at 10,800 ± 150 B.P. (G.S.C. -570), reported by Mott (1968). The alga was identified as Laminaria, which is indicative of waters of normal or near normal salinities and a cold-water environment similar to present day conditions along the eastern coast of Canada. Since this algal material comes from a nearby locality and the age of the material is roughly that of the deposits at Uplands, this would seem to indicate that the sea water in which the fossil population of Macoma from the Uplands area lived was approximately of normal salinity, from 26 to 34°/oo.

Similar comparisons of growth or size characteristics of fossil populations of marine mollusks of the Champlain Sea with growth conditions of recent populations of the same species have yielded similar conclusions about the salinity and temperature conditions of the fossil populations. Hillaire-Marcel (1972) has concluded from the study of a Mya arenaria (Linné) population from the St-Joseph-du-Lac area that the salinity and temperature of the Champlain Sea during the Mya arenaria phase (Elson and Elson, 1959), were from 20 to $6^{o}/oo$ and from 12 to $15^{o}C$. Since the fossils from this locality have been dated at about 10,200 years B.P.; GrN-2035, 10,330 ± 100, Elson (1969b), and GIF-2107, 9950 ± 185 B.P., Gangloff and Moign (1972), and are therefore younger than the fossil populations from the Ottawa area, the trend is one of increase in sea water temperature and a decrease in salinity with the withdrawal of the Champlain Sea.

CHRONOLOGY AND POSTGLACIAL UPLIFT

Introduction

During the course of this study, a sample of marine shells from Cantley, P. Q. was submitted to the Geological Survey of Canada for radiocarbon-dating. The results came as a surprise since the age of these shells was much older than any other previously obtained from the same area; G.S.C. - 1646, 12,200 ± 160 years B.P. To check this presumably anomalous date a second sample of marine shells was collected near Martindale P.Q., some 20 miles (32 km) north of the Cantley locality. The result of this second radiocarbon dating; G.S.C. - 1772, 11,900 ± 160 years B.P., corroborated the previous date and thus gave it a certain reliability.

Before the publication of the second date (G.S.C. - 1772), Romanelli (1975) emphasized the good agreement between G.S.C. - 1646, 12,200 ± 160 and others obtained from the early phase of the Champlain Sea from the Drummondville and Brockville areas, G.S.C. - 396, 12,000 ± 320 and G.S.C. - 1013, 11,800 ± 210 (Lowdon et, al.,1968); and suggested an earlier invasion of the St.Lawrence Lowlands by the Champlain Sea than was previously assumed (Prest 1970).

These old dates from the Ottawa-Hull area indicate that the invasion of sea water and the colonization by marine mollusks is synchronous with the withdrawal of the glaciers from the area. Considering that the immediate response of the land to this rapid unloading is a very rapid rebound, the possibility of a true transgression by the Champlain Sea is remote.

These recent additions to the list of radiocarbon dates from this area have prompted an attempt to illustrate the chronology and approximate relative movement of the land and sea level during the Champlain Sea episode or early postglacial time. With the results of such an investigation, the possibility of a marine transgression or multiple deep water stages of the Champlain Sea in the Ottawa-Hull area can be examined more critically.

Previous work

Johnston (1916, p. 14) stated, "It seems improbable that depression of the land took place in the Ottawa Valley during the time of the retreat of the ice-sheet from this region, for the results of investigations by numerous geologists of raised beaches of the Great Lakes region, has shown that differential uplift took place almost continuously as the ice withdrew,...".

Antevs (1928, 1939) introduced the concept of the Ottawa Sea, based on the stratigraphic position of two units of clay below the 240 foot level in the Ottawa area. The upper clay unit below that level was presumed to have been deposited in a deep water stage of the Champlain Sea established by a transgression. This upper clay was later shown to be a redeposited older marine clay (Gadd, 1961).

Kenney (1964) published a diagram showing sea level and postglacial crustal movements at Ottawa. A eustatic sea level curve was constructed from world wide data, but the information (radiocarbon dates), used in constructing the uplift curve was not abundant or reliable. Kenny nevertheless concluded that there had been only one period of submergence during which the land was at all times rising with respect to the sea level.

Elson (1969a) postulated a deepening of the Champlain Sea partly on the evidence of three pairs of radiocarbon dates. At each locality the lower shells dated were consistently older than the higher shells. Elson (1969b) suggested that the probability of a transgression would be increased if major oscillations are shown on the eustatic sea level curve from Curray (1965). This need of confirmation arises because of the unreliable nature of the data from the radiocarbon dates, in terms of counting errors inherent to the method and also the error in the inference of actual sea level position from the living depth of the fossils dated.

It can be seen from this brief review that the knowledge of past sea levels and a quantification of the process of postglacial uplift are necessary pre-requisites to a valid discussion of the relative movement of land and sea level. The present state of the research in those fields only permits approximations of the movement.

Method

Andrews (1968) proposed that uplift in Arctic Canada could be predicted from the elevation of the marine limit and the date of deglaciation of a specific area. The establishment of the marine limit is assumed to be synchronous with deglaciation at a particular point.

Assuming that: (1) the phenomenon of uplift is sufficiently well understood to permit simplifications such as expressing it as a simple exponential decay function; (2) the eustatic sea level curve for the past 13,000 years B.P. is precisely known; and (3) the uplift remaining at the present day is negligible in terms of total uplift accomplished, the amount of uplift remaining at a time t (expressed in thousands of years) after deglaciation, at any locality, can be expressed as follows:

$$U = U_0 e^{-kt} \qquad \text{......(1)}$$

where U is uplift remaining at time t after deglaciation, which is the sum of the inferred sea level position and the eustatic correction at that time, and U_0 represents the amount of uplift remaining at the time of deglaciation (or t = 0.0). The decay constant k (independent of time) is variable within regions such as North America, Fennoscandia; but it is constant at a fixed locality and can be estimated by a single observation of the elevation and age of a past sea level, preferably the marine limit.

These, briefly summarized are the basic assumptions of the model subsequently used by Andrews (1970a, 1970b) for the interpretation of uplift and rates of uplift in glaciated areas of eastern North America.

Grant and Walcott (1971) strongly criticized this model and attacked the basis of the previously stated assumptions. They suggested firstly that uplift is not well enough understood to warrant any simplifications, and secondly that the eustatic sea level curve is less precisely known for the period from 13,000 to 6,000 years B.P., which is a critical period for the model. Furthermore, they pointed out that according to Andrews' own data (Andrews, 196 , table I, pp. 40), the decay constant, k, was not constant and varied within a specific region by a factor of almost two. This last observation led Walcott (1970) to suggest that the shape of the uplift curve was best approximated by a function which is the sum of two exponential terms. This type of function agrees well with what is known about uplift; that a fast rate of uplift is observed immediately after deglaciation, and is followed by a slower rate of uplift to the present day. However, the constants of such an equation are not yet known reliably, although the form of the proposed equation is similar to other types of equations used in geophysical earth models, to study the elastic effects of the lithosphere on the shape of an isostatic depression produced by an ice sheet.

Considering the limitations of the previously mentioned model (Andrews, 1968), an application of it is made for the available data from this area and a discussion of the results are made in view of the critical remarks discussed above.

Uplift in the Ottawa-Hull area

Table IV lists 25 radiocarbon dates from the area, from which a selection of six (table V) was made on the basis of reliability. The dates chosen are those that provide a good estimate of sea level position, because they come from fossil horizons in beach sediments. The eustatic correction (column 5, table V), is obtained from the following equation:

$$y = 0.0506t - 0.0023t^2 - 0.000012t^3 \quad ....(2)$$

which is similar to that of Andrews (1970b, p. 24), where y is the sea level position (Shepard, 1963) in meters at time t, expressed in hundreds of years B.P.. The equation describes a sea level rise from -70m, 14,000 years B.P., to 0m at the present day. Postglacial uplift remaining (column 6, table V, is obtained in the following manner; if a past sea level is recorded at 122m above present sea level, and is dated at 10,000 years B.P., the sea level has risen some 30m since that time (eq. 2) and it follows that the amount of uplift remaining at that locality 10,000 years B.P. is the sum of the inferred sea level (122m) and the eustatic correction (30m), about 152m (498 ft).

The marine limit in the Ottawa-Hull area is assumed fixed by a radiocarbon date from Cantley, Quebec, at 12,200±160 years B.P. (G.S.C.-1646, Lowdon & Blake, 1973) at an elevation of 198m (650 ft), because this date is until now the highest and oldest recorded for the Champlain Sea episode in this area. Furthermore, the position of the fossil horizon(see p.118), suggests an even higher marine limit.

The data in table V, columns 6 and 7, plot as a straight line on semi-logarithmic paper, fig. 14. They are therefore assumed to obey a simple exponential decay function, the equation of the line having the form of :

$$\mathrm{Ln}\ y = \mathrm{Ln}\ 828 - 0.425t \quad \ldots\ldots\ (3)$$

where y is the ordinate and represents the amount of uplift remaining (feet) at time t, after deglaciation; -0.425 is the slope of the line, and 828 is the intercept of the line with the ordinate axis. Since, nearly all of the elevations of the radiocarbon dates have been reported in feet, the unit used for the manipulation and analysis of the data is in feet, and equivalents are given in brackets.

This equation represents the best fit as determined by least square method with an error of estimation of the slope of 0.01 and a correlation coefficient between y and t of -0.998.

The equation of the best fit of the data of table V is of similar form to equation (1) since :

$$\mathrm{Ln}\ U = \mathrm{Ln}U_0 - kt \quad \ldots\ldots\ (4)$$

The small difference (15 feet) between the data, i.e. the amount of uplift remaining at time t = 0 after deglaciation, 248m (813.6 ft) (column 6, table V) and the calculated value from the least square fit on semi-logarithmic paper (i.e. 828 ft) is considered negligible in terms of total uplift accomplished.

The reasons for this discrepancy are due firstly to the simplification of the uplift process and also to the fact that U_o represents the sum of total uplift accomplished to the present day, and the future uplift

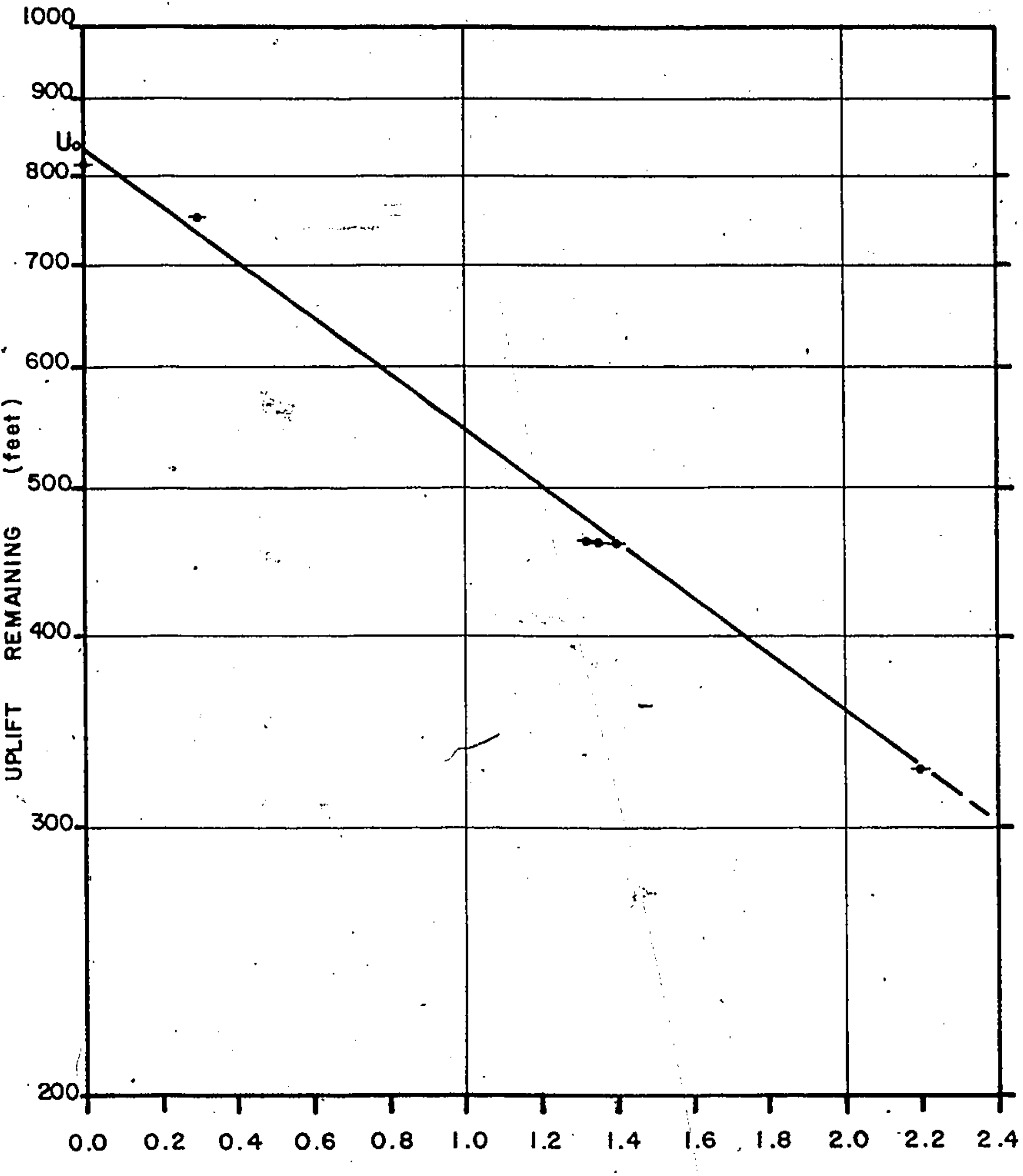


FIGURE 14. Best fit of postglacial uplift data on table V columns 6 and 7, using least square method on semi-logarithmic paper. The ordinate intercept U_o = 828 ft and the slope of the line K = -0.425.

TABLE IV: LIST OF RADIOCARBON DATES FROM THE OTTAWA/HULL AREA

DATE NUMBER	LOCALITY	^{14}C AGE YEARS B.P.	MATERIAL DATED	ELEVATION m(ft.)	REFERENCE
G.S.C. - 1646	Cantley, Qué.	12,200±160	shells	193.5 (635)	Lowdon & Blake 1973.
G.S.C. - 1772	Martindale, Qué.	11,900±160	shells	176.2 (578)	Lowdon & Blake 1973.
G.S.C. - 842	Meach Lake, Qué.	11,600±150	shells	169.8 (557)	Lowdon & Blake 1968.
G.S.C. - 1612	Masham Nord, Qué.	11,500±150	shells	166.1 (545)	Gadd, pers.comm 1972.
L-639-B	Old Chelsea, Qué.	11,320±200	shells	152.4 (500)	Gadd, 1964.
G.S.C. - 982	Mahon lake, Qué.	11,300±180	shells	157.0 (515)	Lowdon & Blake 1968.
G.S.C. - 1672	Almonte, Ont.	11,200±160	shells	153.9 (505)	Scott, 1973.
G.S.C. - 587	Ottawa, Ont.	10,620±200	shells	103.6 (340)	Mott, 1968.
G.S.C. - 570	Ottawa, Ont.	10,800±150	seaweed	97.8 (321)	Mott, 1968.
G.S.C. - 588	Ottawa, Ont.	10,880±160	shells	96.9 (318)	Mott, 1968.
Y-216	Ottawa, Ont.	10,850±330	shells	98.5 (323)	Preston <u>et</u>. <u>al</u>., 1955.
Y-215	Hull, Qué.	10,630±330	shells	119.5 (392)	Preston <u>et</u>. <u>al</u>., 1955.
L-604A	Ottawa, Ont.	10,700±200	shells	79.2 (260)	Olsen & Broecke 1961.
G.S.C. - 623	Ottawa, Ont.	10,720±150	shells	64.0 (210)	Lowdon <u>et</u>. <u>al</u>., 1967.
L-604B	Ottawa, Ont.	10,550±200	shells	80.8 (265)	Olsen & Broecke 1961.
G.S.C. - 454	Ottawa, Ont.	10,420±150	whale bone	91.4 (300)	Dyck <u>et</u>. <u>al</u>., 1
L-604D	Ottawa, Ont.	10,200±200	shells	106.7 (350)	Dyck & Fyles, 1962.
G.S.C. - 1553	Russell, Ont.	10,000±320	shells	70.1 (230)	Scott, 1972.
G.S.C. - 680	Kazabazua, Qué.	9,910±200	gytja	176.8 (580)	Lowdon & Blake 1968.
G.S.C. - 546	Ottawa, Ont.	8,830±190	gytja	61.0 (200)	Lowdon <u>et</u>. <u>al</u>., 1967.

TABLE IV: LIST OF RADIOCARBON DATES FROM THE OTTAWA/HULL AREA

DATE NUMBER	LOCALITY	^{14}C AGE YEARS B.P.	MATERIAL DATED	ELEVATION m(ft.)	REFERENCE
G.S.C. - 547	Ottawa, Ont.	8,220-150	woody peat	71.6(235)	Lowdon *et. al*., 1967.
G.S.C. - 621	Ottawa, Ont.	8,010-180	gytja	30.0(98)	Lowdon *et. al*., 1971.
G.S.C. - 628	Ottawa, Ont.	7,870-160	gytja	67.1(220)	Lowdon *et. al*., 1967.
G.S.C. - 681	Ottawa, Ont.	7,650-210	gytja	64.0(210)	Lowdon & Blake 1968.
G.S.C. - 548	Ottawa, Ont.	6,750-150	peat	67.1(220)	Lowdon *et. al*., 1967.

Uplift curve

Uplift can also be described in terms of uplift accomplished in feet or meters at a time t, expressed in thousands of years after deglaciation, such as in the following equation:

$$U' = U'_0 (1 - e^{-kt}) \quad \ldots\ldots\ldots (5)$$

where U' is the uplift accomplished at time t after deglaciation and U'_0 is the total amount of uplift accomplished since deglaciation and is constant. Using the same parameters as those defined in equation (3) and using the data on table V, an uplift curve was calculated and plotted as curve A, on figure 15. On the same figure, an emergence curve was also drafted (curve B) along with actual data points. The emergence curve is obtained by correcting the uplift remaining for eustatic sea level variations.

Rate of uplift

The rate of uplift at a time t after deglaciation can be estimated by the first derivative of equation (5):

$$\frac{dU'}{dt} = -k\,U'_0 \times e^{-kt} \quad \ldots\ldots\ldots (6)$$

Similarly, the rate of sea level rise can be obtained from the first

TABLE V: SELECTED RADIOCARBON DATES FROM THE OTTAWA-HULL AREA, FOR THE CONSTRUCTION OF THE UPLIFT CURVE

DATE NUMBER	^{14}C AGE YEARS B.P.	ELEVATION m(ft.)	INFERRED SEA LEVEL m(ft.)	EUSTATIC CORRECTION m(ft.)	UPLIFT REMAINING m(ft.)	TIME AFTER DEGLACIATION X 10^3 YEARS
G.S.C. - 1646	12,200±160	193,5(635)	198.1(650)	49.9(163.6)	248.0(813.6)	0.00
G.S.C. - 1772	11,900±160	176.2(578)	182.9(600)	46.8(153.4)	229.7(753.4)	0.30
G.S.C. - 588	10,880±160	96.9(318)	103.6(340)	37.2(122.0)	140.8(462.0)	1.32
G.S.C. - 570	10,800±150	97.8(321)	103.6(340)	36.5(119.7)	140.1(459.7)	1.40
Y-216	10,850±320	98.5(323)	103.6(340)	36.9(121.1)	140.5(461.1)	1.35
G.S.C. - 1553	10,000±320	70.1(230)	70.1(230)	29.9(98.2)	100.0(328.2)	2.20

FIGURE 15

Postglacial uplift curve (A) calculated from equation 5 for the Ottawa-Hull area. The emergence curve (B) is obtained from the uplift curve by correcting the amount of uplift remaining for eustatic sea level. The actual radiocarbon dates used to calculate the curve are shown with their standard deviations.

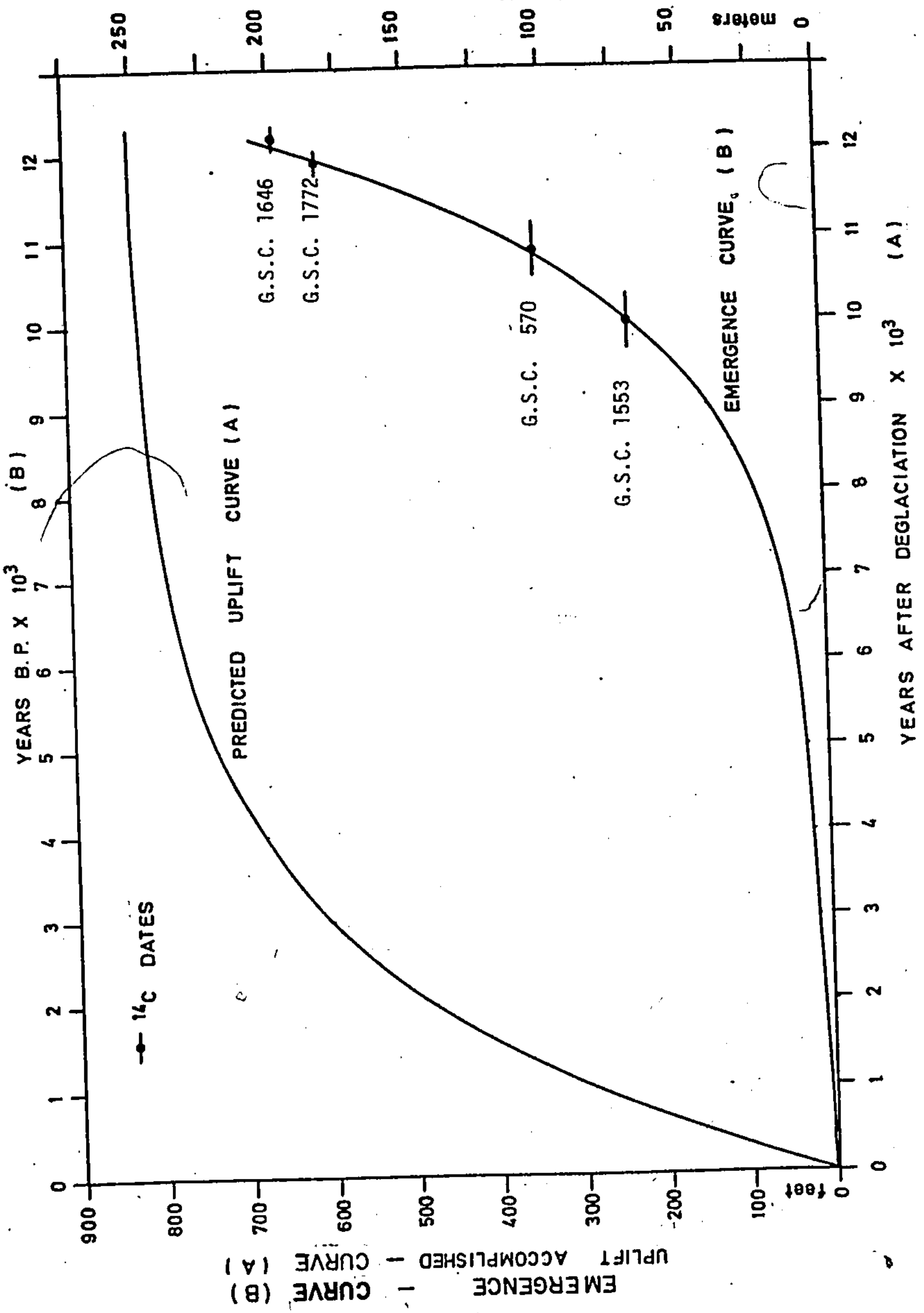
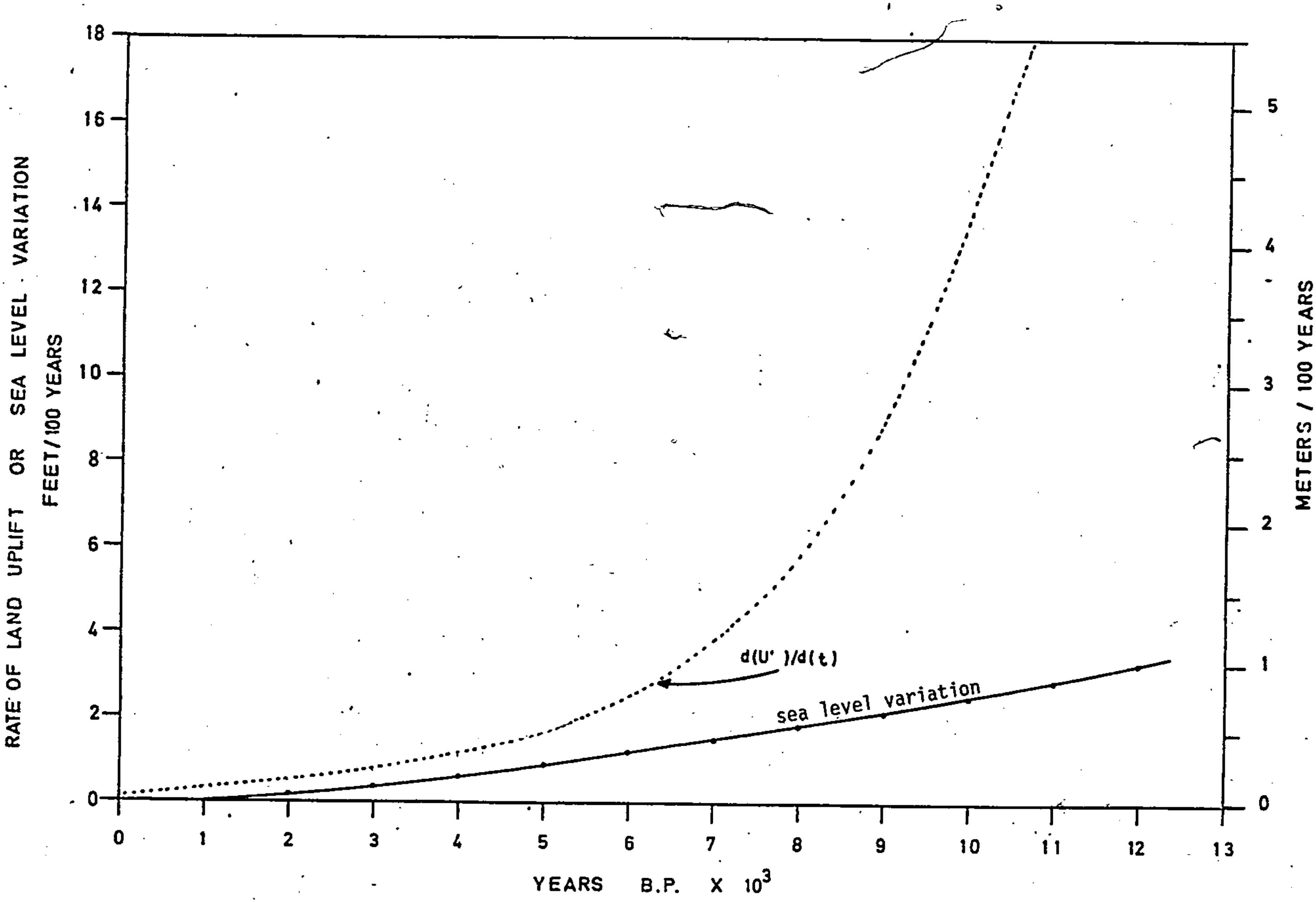

YEARS B.P. X 10^3
0
1
2
3
4
5
6
7
8
9
10
11
12
(B)
250
200
150
100
50
0
meters
^{14}C DATES
PREDICTED UPLIFT CURVE (A)
G.S.C. 1646
G.S.C. 1772
G.S.C. 570
G.S.C. 1553
EMERGENCE CURVE (B)
YEARS AFTER DEGLACIATION X 10^3
(A)
900
800
700
600
500
400
300
200
100
0
feet
UPLIFT ACCOMPLISHED — CURVE (A)
EMERGENCE — CURVE (B)

FIGURE 16

Rates of land uplift and sea level rise for the Ottawa-Hull area, calculated fron the derivative of equation 5; $\frac{d\,U'}{dt}$ and from the first derivative of equation 2, (eustatic curve from Shepard 1963).


RATE OF LAND UPLIFT OR SEA LEVEL VARIATION
FEET/100 YEARS
18
16
14
12
10
8
6
4
2
0
METERS / 100 YEARS
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
YEARS B.P. X 10^3
d(U')/d(t)
sea level variation

derivative of equation 2. The comparison of the rate of uplift and sea level rise is given in figure 16.

It is observed that the rates of land uplift in the first few thousands of years after deglaciation in the Ottawa-Hull area were from 2 to 10 times greater than the rates of eustatic rise in sea level calculated from Shepard's (1963) curve. The general similarities of the eustatic curves of Milliman and Emery (1968), Curray (1965)and that of Shepard (1963) for the time period 13,000 to 6,000 years B.P., strongly suggest that similar differences in the order of magnitude of the rates of land uplift and sea level variation would be observed if either of these other curves were used in Andrews' model. The possibility of oscillations on Curray's curve remains doubtful and is not proven.

As shown in figure 15, the present rate of land uplift is estimated at about 0.1m/100 years. However, Clark and Persoage (1970) show a rate of present uplift for the northern portion of the Great Lakes region of about 0.45 to 0.5m/100 years based on water level measurements, and Gale (1970) shows a present rate of uplift of 0.4 to 0.8m/100 years based on geodetic relevelling for the Lac Saint-Jean area, more specifically the Saint-Félicien area.

Discussion

The author agrees with the conclusions of Walcott (1972) concerning Andrews' model (1970 b) for the interpretation of rebound data. The generalization is not a totally adequate description of glacio-eustatic rebound, but the method appears to have a definite use which in this case is the study of a specific problem, i.e. the possibility of a marine transgression between 11,000 and 10,000 years B.P. Furthermore, the use of any model is strongly affected by the amount of data and the very narrow period into which reliable radiocarbon dates are clustered, from 12,000 to 10,000 years B.P.

However, the use of Andrews' (1970 b) model, even if it is somewhat inadequate, shows that for a period of 2,000 years immediately after deglaciation in the Hull-Ottawa area, the amount of land uplift accomplished was about 150 m (495'). The first derivative of the proposed uplift equation shows that the rate of land uplift during that time exceeded the rate of sea level rise.

Thus the critical period, from 11,000 to 10,000 years B.P., for which a rise of sea level or transgressive phase of the Champlain Sea is postulated by Elson (1969 a) seems to be a period of rapid land uplift at least in the area studied. Similar conclusions have been reached by Hillaire-Marcel _et_. _al_. (1974) in the Oka area, where it is concluded that for a period extending from 12,000 to 9,800 years B.P., sediments were deposited by stages during slow regressive phases separated by periods of faster regression of the sea. At no time is there any evidence of a faster rise of sea level than that of land uplift.

A readvance of the Laurentide ice sheet contemporaneous with the Champlain Sea at about 10,500 years B.P. is suggested for the formation of the Saint Narcisse moraine in the area north of Trois Rivières. Such a phenomenon in the context of a rising sea level would produce a transgression because of the inherent land subsidence due to ice loading. However, Gadd (1971) suggests that the moraine was deposited from ice centered in the Laurentian Highlands, extending only a short distance into the Champlain Sea basin, and because of insufficient evidence the moraine should be considered as recessionnal rather than terminal. Thus, the magnitude of this readvance is not considered high enough to cause overall land subsidence in the Champlain Sea basin and is at best only a local phenomenon.

Lastly, the rate of land uplift depends on the rate of retreat of the ice sheet, and it is inferred that where the rate of retreat is rapid, very rapid vertical movement would occur (Walcott, 1972). The two dates G.S.C.-1646 and G.S.C.-1772 (table IV) show that the ice had retreated very rapidly from the Ottawa-Hull area to permit inundation by the Champlain Sea. It is inferred from these observations that the response of the earth to this unloading gave way to very rapid vertical movement, thus preventing any real transgression of the sea.

CONCLUSIONS

From the discussion and comparison of the textural features of suites of sediments from three areas, it is suggested that a high energy environment prevailed in the Gatineau River Valley during the early phase of the Champlain Sea episode.

The depositional environment of the sediments in the Gatineau Valley area is deduced from their textural parameters, stratigraphic succession and origin. The textural features of the marine sands in the Gatineau Valley area suggest that the wave energy dissipated on these beaches was much lower and less efficient than in the Uplands area, where open sea conditions prevailed. This lesser wave energy was a result of the narrowness of the inlet during the Champlain Sea episode in the Gatineau Valley area. The non-marine sediments found in thick successions near bedrock ridges are thought to have been deposited by turbidity currents issuing from glaciers under standing water conditions. This depositional process, along with a close proximity to the ice front and an excessive rate of supply account for the poorly sorted, polymodal, sometimes structureless outwash deposits in the area.

The macrofossils found in the Gatineau River Valley, especially the mollusks, indicate a cool subarctic climate at the beginning of the

Champlain Sea episode. The temperature and salinity of the sea water at that time, approximated from the living conditions of present day populations of <u>Macoma</u> <u>balthica</u>, were from 2^{0} to 8^{0}C and normal salinities respectively. The low salinity (8^{0}/oo) estimated for a population at Cantley is probably due to the mixing of large volumes of glacial meltwater into the sea. The temperature of the sea water increased and the salinity remained approximately the same as the sea withdrew. During the latter phase of the Champlain Sea episode in the area, the temperature had risen to a range of 4^{0} to 15^{0}C, which is indicated by an increase in the growth rates of <u>Macoma</u> <u>balthica</u> from older to younger populations in the area. Comparable estimates of temperature for the younger <u>Mya</u> <u>arenaria</u> phase of the Champlain Sea (Hillaire-Marcel, 1972) have been made.

The withdrawal of the Champlain Sea from the Gatineau and Ottawa Valleys is attributed to the rebound of the land due to unloading as a result of the melting ice sheets. Eustatic sea level was rising during the Champlain Sea episode, but the uplift of the land took place at a much faster rate so that the resulting movement was one of apparent fall in sea level, or withdrawal. The possibility of a transgression during the Champlain Sea episode cannot be substantiated with certainty because of the imprecisions in elevation and age of the radiocarbon dates. On the other hand, a subsidence of the land permitting marine waters to transgress over the area, would need a major readvance of the ice sheets.

At the present time there is no evidence for such a readvance in the Gatineau Valley and Ottawa area; uplift is thought to have proceeded smoothly and continuously since the time of deglaciation. The approximation of the phenomenon of uplift as a simple exponential decay is not mathematically sound and should be avoided if rigourous studies of uplift are attempted. Nonetheless, the results in terms of uplift and rates of uplift are broadly similar to those obtained from non-manipulated data, and thus should be used within the limitations and aims of the model from which they are obtained.

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APPENDIX I

GRAIN SIZE DISTRIBUTION PARAMETERS OF SAMPLES FROM:

I-A) Uplands area (Romanelli, 1970)

I-B) Stittsville area (Smith, 1970)

I-C) Gatineau River Valley area (Romanelli, present study)

The parameters listed in the following appendix are derived from the cumulative frequency distribution curves using the percentile method (Folk and Ward, 1957). They are calculated using the following formulas:

Graphic Mean (M_z) or mean size:

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Inclusive Graphic Standard Deviation (O_I) or sorting:

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

Inclusive Graphic Skewness (SK_I) or skewness:

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

Graphic Kurtosis (K_G) or kurtosis *:

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

* The normalized kurtosis K'_G is expressed as:

$$K'_G = \frac{K_G}{K_G + 1}$$

Grain size is measured in Ø (phi) units, which is a logarithmic transformation of the millimiter grain size scale,

$$\phi = -\lg_2 \text{ diameter (mm.)}$$

APPENDIX 1A-GRAIN SIZE DISTRIBUTION PARAMETERS OBTAINED FROM MECHANICAL ANALYSIS OF SAMPLES FROM THE UPLANDS AREA (ROMANELLI,1970).

NUMBER	MEAN	SORTING	SKEWNESS	KURTOSIS	K'G
1.00	1.70	0.70	-0.12	1.22	0.55
2.00	1.98	0.50	-0.05	1.10	0.52
3.00	2.32	0.57	-0.06	1.09	0.52
4.00	1.72	0.70	-0.06	1.00	0.50
5.00	1.42	1.55	-0.51	1.23	0.55
6.00	0.11	1.77	-0.14	0.71	0.41
7.00	1.70	0.61	-0.17	1.21	0.55
8.00	2.12	0.40	0.06	1.08	0.52
9.00	1.64	1.01	-0.41	1.73	0.63
10.00	2.15	0.56	-0.25	1.40	0.58
11.00	1.80	1.52	-0.51	1.52	0.60
12.00	1.53	0.56	0.00	0.93	0.48
13.00	1.31	0.84	-0.18	1.02	0.50
14.00	0.02	1.69	-0.25	0.86	0.46
15.00	1.57	1.82	-0.64	1.20	0.55
16.00	1.70	0.69	-0.12	1.17	0.54
17.00	1.53	1.38	-0.49	1.15	0.54
18.00	2.03	0.78	-0.21	1.36	0.58
19.00	1.62	0.81	-0.31	1.25	0.56

20.00	2.34	0.51	-0.01	1.02	0.50
21.00	1.78	0.64	-0.14	1.32	0.57
22.00	1.41	0.86	-0.29	1.08	0.52
23.00	2.50	0.52	0.04	1.02	0.51
24.00	1.64	0.60	-0.03	1.12	0.53
25.00	2.54	0.51	0.06	1.04	0.51
26.00	2.65	0.52	0.01	1.05	0.51
27.00	1.77	0.80	-0.38	1.51	0.60
28.00	2.59	0.45	-0.01	1.01	0.50
29.00	2.56	0.59	0.03	1.11	0.53
30.00	2.73	0.63	0.12	1.06	0.51
31.00	2.58	0.56	0.10	1.06	0.51
32.00	2.46	0.63	-0.07	1.07	0.52
33.00	2.52	0.48	0.09	1.02	0.51
34.00	2.48	0.56	0.12	1.04	0.51
35.00	2.62	0.48	0.00	1.00	0.50
36.00	2.55	0.46	0.02	1.06	0.51
37.00	2.74	0.53	0.02	1.05	0.51
38.00	2.72	0.50	0.09	1.04	0.51
39.00	2.59	0.52	-0.00	0.89	0.47
40.00	2.58	0.50	0.01	1.02	0.51
41.00	2.63	0.50	0.25	1.18	0.54
42.00	2.81	0.56	0.06	1.05	0.51

```
     43.00      2.79      0.71      0.10      1.29      0.56
     44.00      2.85      0.81      0.08      1.20      0.55
     45.00      2.92      0.64     -0.03      1.08      0.52
     46.00      2.97      0.78      0.17      1.17      0.54
     54.00     -0.07      2.84     -0.18      0.96      0.49
     55.00      2.72      0.84      0.33      1.36      0.58
     59.00      0.15      3.08     -0.51      1.91      0.66
     60.00      1.63      2.94      0.12      1.08      0.52
     61.00     -0.23      1.23     -0.10      1.22      0.55
     62.00     -0.43      1.21     -0.10      1.11      0.53
     63.00      2.25      0.65      0.03      1.32      0.57
     66.00     -0.20      3.13     -0.29      1.22      0.55
     67.00      1.30      2.38      0.02      1.62      0.62
     68.00      2.31      0.67      0.08      0.98      0.49
     70.00      2.38      0.41      0.10      1.17      0.54
     72.00     -0.63      2.23     -0.07      0.73      0.42
     73.00      1.88      0.64     -0.13      1.23      0.55
     74.00      0.42      1.20     -0.07      0.69      0.41

 FREQUENCY OF MODAL CLASSES, SIZE IS IN PHI UNITS
 SIZE-5.0-4.5-4.0-3.5-3.0-2.5-2.0-1.5-1.0-0.5 0.0 0.5 1.0 1.5
       1.  0.  3.  0.  7.  7.  0.  3.  0.  3.  6.  0.  3.  5.
 SIZE 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5
      15. 17. 18.  0.  0.  0.  0.  0.  4.  3.  0.  0.  0.  0.


 SIZE 9.0 9.510.0
       0.  0.  0.
```

APPENDIX 1B-GRAIN SIZE DISTRIBUTION PARAMETERS OBTAINED FROM MECHANICAL ANALYSIS OF SAMPLES FROM THE STITSVILLE AREA (SMITH,1970).

NUMBER	MEAN	SORTING	SKEWNESS	KURTOSIS	K'G
1.00	0.42	1.06	0.10	1.38	0.58
2.00	3.17	0.62	0.19	0.89	0.47
3.00	3.70	0.69	0.12	1.11	0.53
4.00	2.98	0.54	0.29	1.08	0.52
5.00	4.57	1.24	0.37	1.13	0.53
6.00	2.77	0.52	0.57	1.24	0.55
7.00	2.42	0.47	0.25	1.09	0.52
8.00	2.91	0.60	0.64	1.30	0.56
9.00	3.45	0.61	0.28	1.05	0.51
10.00	3.33	0.45	0.60	1.15	0.54
11.00	3.13	0.70	0.15	0.82	0.45
12.00	4.52	1.17	0.37	1.08	0.52
13.00	2.49	0.58	0.41	1.20	0.55
14.00	3.29	0.76	-0.01	0.89	0.47
15.00	3.87	0.86	0.17	0.96	0.49
16.00	3.17	0.80	0.04	1.07	0.52
17.00	3.37	1.12	0.05	1.07	0.52
18.00	2.90	0.84	0.13	1.04	0.51
19.00	2.24	0.62	0.19	0.96	0.49

```
    20.00        0.80      1.17      0.46      1.13      0.53
    21.00        2.16      0.58      0.24      1.04      0.51
    22.00        3.52      0.85      0.35      1.96      0.66
    23.00        0.80      0.88      0.14      0.90      0.47
    23.00(1)     2.53      0.86      0.11      1.27      0.56
    24.00        3.44      0.80      0.67      1.23      0.55
    25.00        3.02      0.50      0.42      1.30      0.57
    26.00        2.07      0.70      0.28      1.09      0.52
    27.00        1.40      0.97      0.18      1.02      0.51
    28.00        3.30      0.60      0.28      1.09      0.52

FREQUENCY OF MODAL CLASSES, SIZE IS IN PHI UNITS
SIZE-5.0-4.5-4.0-3.5-3.0-2.5-2.0-1.5-1.0-0.5 0.0 0.5 1.0 1.5
     0.  0.  0.  0.  0.  0.  0.  0.  1.  0.  2.  0.  3.  0.
SIZE 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5
     3.  3.  8.  8.  3.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SIZE 9.0 9.510.0
     0.  0.  0.
```

APPENDIX 1C-GRAIN SIZE DISTRIBUTION PARAMETERS OBTAINED FROM MECHANICAL ANALYSIS OF SAMPLES FROM THE GATINEAU VALLEY AREA (ROMANELLI,1973)

NUMBER	MEAN	SORTING	SKEWNESS	KURTOSIS	K'G
1.00	2.99	1.04	-0.08	1.15	0.54
2.00	3.71	0.69	0.10	1.16	0.54
4.00	7.87	1.15	-0.27	2.44	0.71
5.00	2.21	0.83	-0.02	1.03	0.51
5.00A	2.15	1.06	0.20	0.96	0.49
6.00	-1.85	1.62	0.21	0.99	0.50
7.00	8.35	3.17	0.10	0.79	0.44
8.00	2.22	0.98	-0.03	0.99	0.50
9.00	-1.45	1.83	0.19	0.89	0.47
10.00	2.58	0.57	0.10	0.96	0.49
11.00	2.38	3.02	0.19	1.89	0.65
12.00	3.40	0.53	0.12	1.14	0.53
13.00	1.63	1.27	-0.02	1.32	0.57
15.00	1.98	0.77	0.17	1.05	0.51
16.00	1.90	0.75	-0.06	1.06	0.52
17.00	0.60	1.24	-0.20	1.22	0.55
19.00	-0.52	2.81	-0.14	0.90	0.47
20.00	2.09	1.86	-0.23	1.73	0.63
21.00	1.00	2.11	-0.18	0.86	0.46

22.00	0.93	1.29	-0.21	1.11	0.53
23.00	3.18	0.69	-0.08	1.05	0.51
231.00	3.42	0.61	0.09	1.41	0.58
24.00	7.58	2.86	0.40	0.90	0.47
25.00	3.27	0.81	-0.22	1.23	0.55
26.00	2.37	2.79	-0.12	0.73	0.42
27.00	6.55	2.25	0.19	0.92	0.48
28.00	2.14	0.67	-0.02	1.19	0.54
29.00	1.58	0.80	-0.03	1.00	0.50
31.00	1.55	0.71	0.10	1.02	0.51
33.00	1.15	1.49	-0.31	1.00	0.50
34.00	-0.37	2.41	-0.35	1.10	0.52
35.00	-0.81	2.40	-0.17	0.78	0.44
935.00	-2.15	2.67	0.12	0.80	0.44
363.00	7.38	2.67	-0.08	0.75	0.43
361.00	4.47	2.36	0.24	1.40	0.58
37.00	2.07	0.95	0.16	0.99	0.50
837.00	1.92	1.02	0.18	1.05	0.51
937.00	1.51	0.69	0.05	1.10	0.52
38.00	-0.42	2.40	-0.16	0.75	0.43
39.00	2.58	0.68	0.15	0.97	0.49
40.00	-0.43	1.79	-0.03	0.96	0.49
41.00	3.29	0.71	0.09	1.13	0.53

42.00	2.65	0.94	-0.02	1.42	0.59
43.00	2.39	0.69	0.15	1.01	0.50
44.00	6.50	1.57	-0.44	0.95	0.49
45.00	1.06	1.06	-0.05	0.99	0.50
46.00	-1.52	2.47	0.35	1.17	0.54
47.00	-1.04	1.61	-0.02	0.91	0.48
48.00	0.80	-0.80	0.02	1.18	0.54
49.00	0.81	0.57	0.04	1.17	0.54
50.00	0.75	1.11	0.14	1.01	0.50
51.00	1.57	0.78	0.14	1.00	0.50
53.00	1.64	0.89	0.16	1.07	0.52
54.00	-1.61	2.05	-0.03	0.78	0.44
55.00	7.35	3.34	0.32	0.70	0.41
56.00	-1.37	2.95	-0.20	0.76	0.43
57.00	-1.32	2.14	-0.10	0.72	0.42
58.00	1.42	1.43	0.05	1.13	0.53
59.00	-1.28	1.12	-0.07	1.17	0.54
60.00	1.47	0.47	0.01	1.13	0.53
61.00	1.19	0.95	-0.07	0.94	0.48
62.00	1.33	0.93	-0.16	1.18	0.54
63.00	1.08	1.10	-0.01	1.00	0.50
64.00	1.76	0.88	0.13	1.01	0.50
65.00	-0.58	1.93	-0.13	0.65	0.39

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 66.00      1.07      1.18     -0.06      1.19      0.54
 67.00     -0.97      1.54     -0.00      1.02      0.50
 68.00      1.59      0.91      0.00      1.14      0.53
 69.00      1.84      0.93      0.08      0.98      0.49
 70.00     -0.52      2.14     -0.18      0.78      0.44
 71.00      1.76      0.87      0.01      1.00      0.50
 72.00      2.95      0.50      0.09      1.06      0.52
 73.00      0.05      1.11      0.07      1.05      0.51
 74.00      1.71      0.57      0.22      1.22      0.55
 75.00      1.07      1.52     -0.24      1.23      0.55
 76.00      1.74      0.90     -0.06      1.16      0.54
 77.00      4.28      3.35     -0.31      0.73      0.42

FREQUENCY OF MODAL CLASSES, SIZE IS IN PHI UNITS
SIZE-5.0-4.5-4.0-3.5-3.0-2.5-2.0-1.5-1.0-0.5 0.0 0.5 1.0 1.5
      4.  0.  6.  1.  1. 17.  0.  4.  3.  5.  4.  1. 10.  6.
SIZE 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5
    22. 12.  1.  8.  3.  2.  1.  0.  7.  0.  0.  0.  4.  1.
SIZE 9.0 9.510.0
      2.  0.  5.
```

APPENDIX II

Columnar sections of exposures at localities #1 to #14, from the study area.

Figures 17 a, b, c and d.

Locality List

Locality 1a, 1b	Martindale
Locality 2	Martindale area
Locality 3	Martindale area
Locality 4	Farrellton
Locality 5	Alcove area
Locality 6	Wilson Brook area
Locality 7	Wilson Brook area
Locality 8	Edelweiss area
Locality 9	Wakefield area
Locality 10	Wilsons Corners area
Locality 11a, b,	Cantley area
Locality 12	Meach Lake area
Locality 14	Tenaga

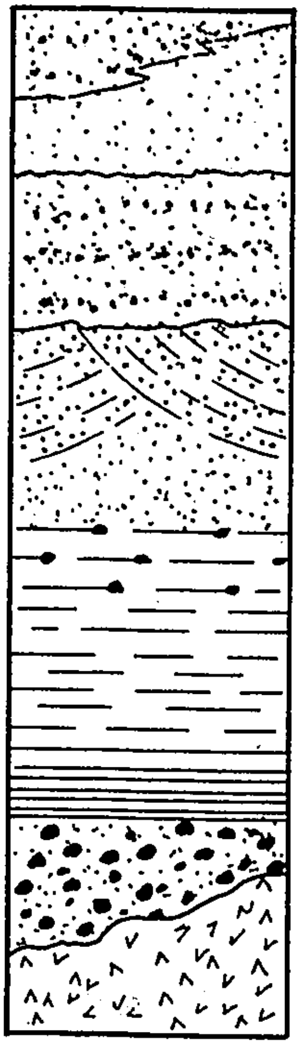
NOTE: Locality 13 (Uplands) is described in detail in Romanelli (1970), and is not shown in Appendix II.

NOTES

- Localities are situated to the nearest 100 meters, within a map area using the military grid reference (easting and northing) with the one thousand meter universal transverse Mercator grid.

- Stratigraphic sections were measured in feet and inches, and elevations are shown in feet and meters above sea level. Elevations were measured from barometric traverses from bench marks.

LEGEND



Wedge shaped sand units.

Ⓕ Fossil horizon

Gravelly sand units.

Crossbedded sand units.

Massive sand units.

Gravelly clay units.

Blocky clay units.

Laminated silty clay units.

Coarse gravel units.

Exposed bedrock.

FIGURE 17a : COLUMNAR SECTIONS OF EXPOSURES AT LOCALITIES
1a, 1b, 2 and 3

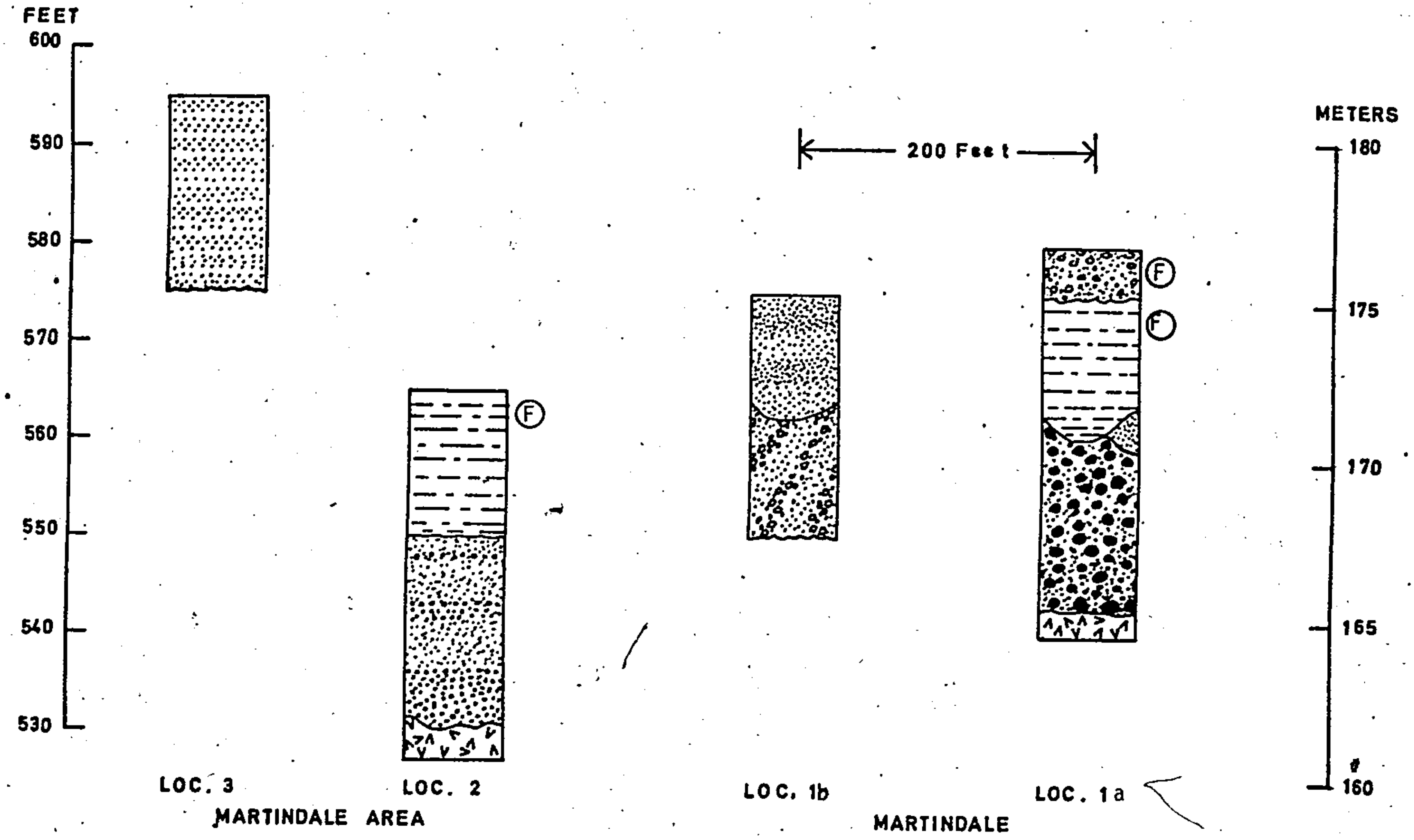
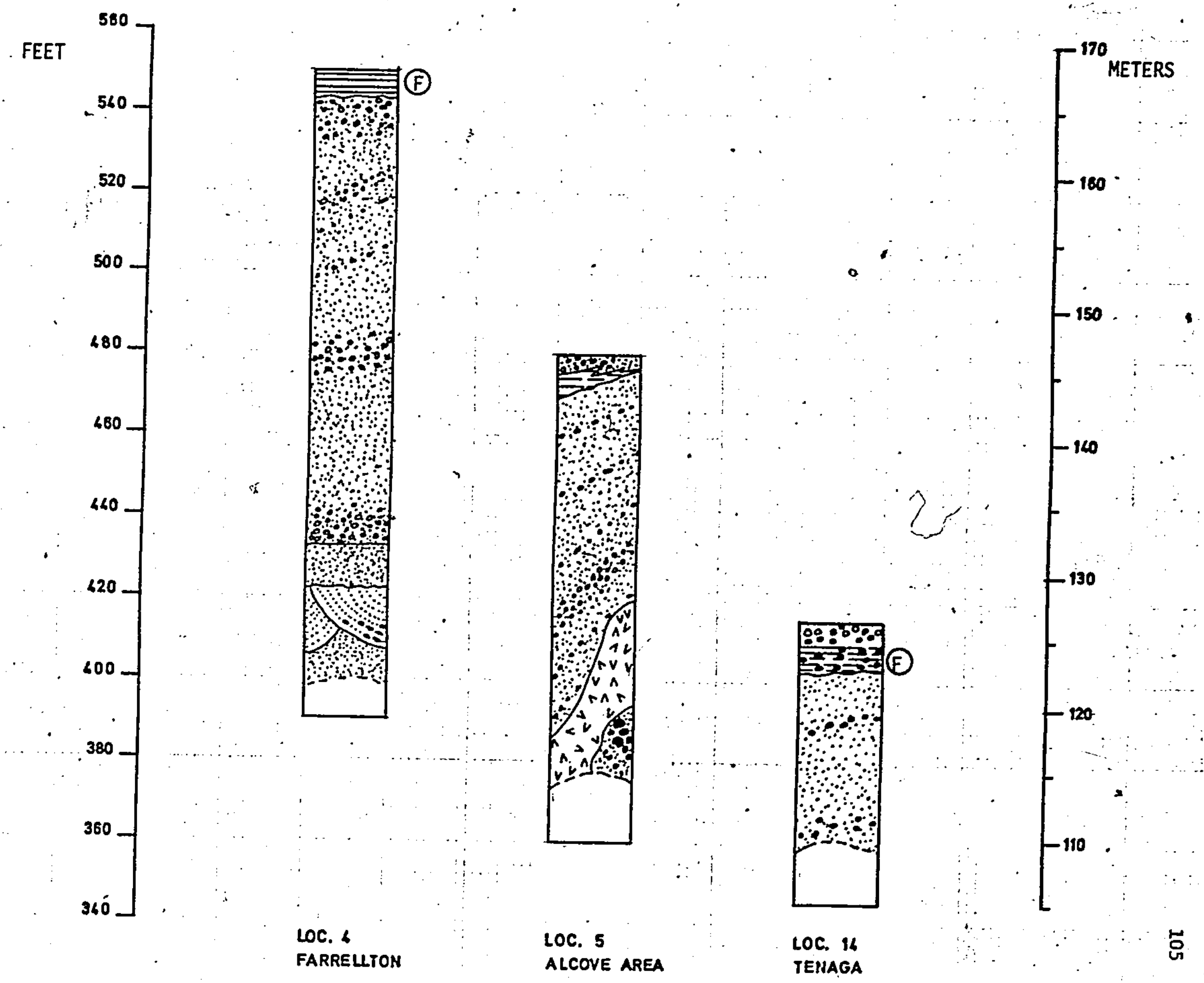


FIGURE 17a - Columnar sections of exposures at localities 1a, 1b, 2 and 3.

FIGURE 17b: Columnar sections from localities 4, 5 and 14.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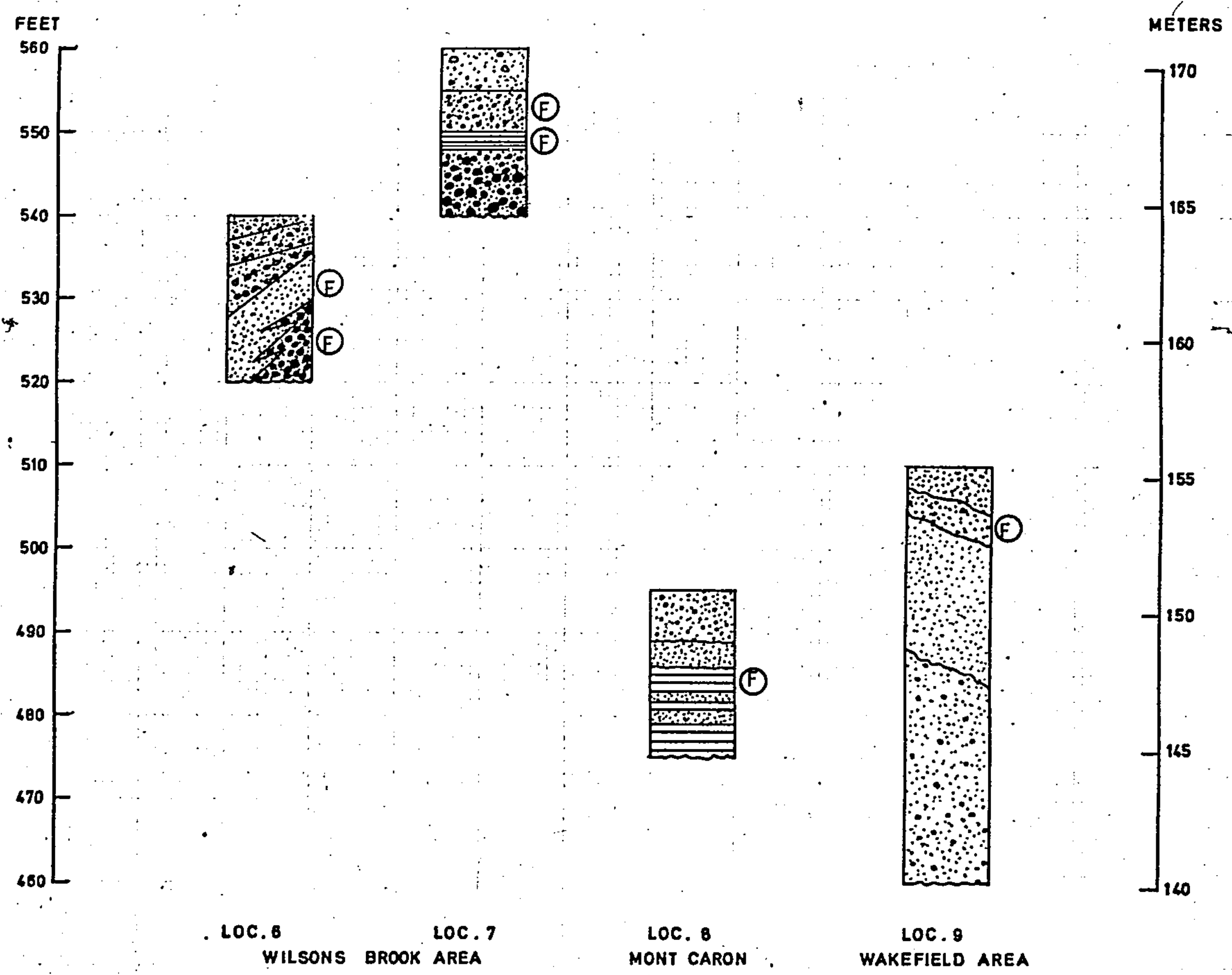
460
440
420
400
380
360
340
F
F
170
METERS
160
150
140
130
120
110
LOC. 4
FARRELLTON
LOC. 5
ALCOVE AREA
LOC. 14
TENAGA

FIGURE 17 c: Columnar sections from localities 6,7,8 and 9.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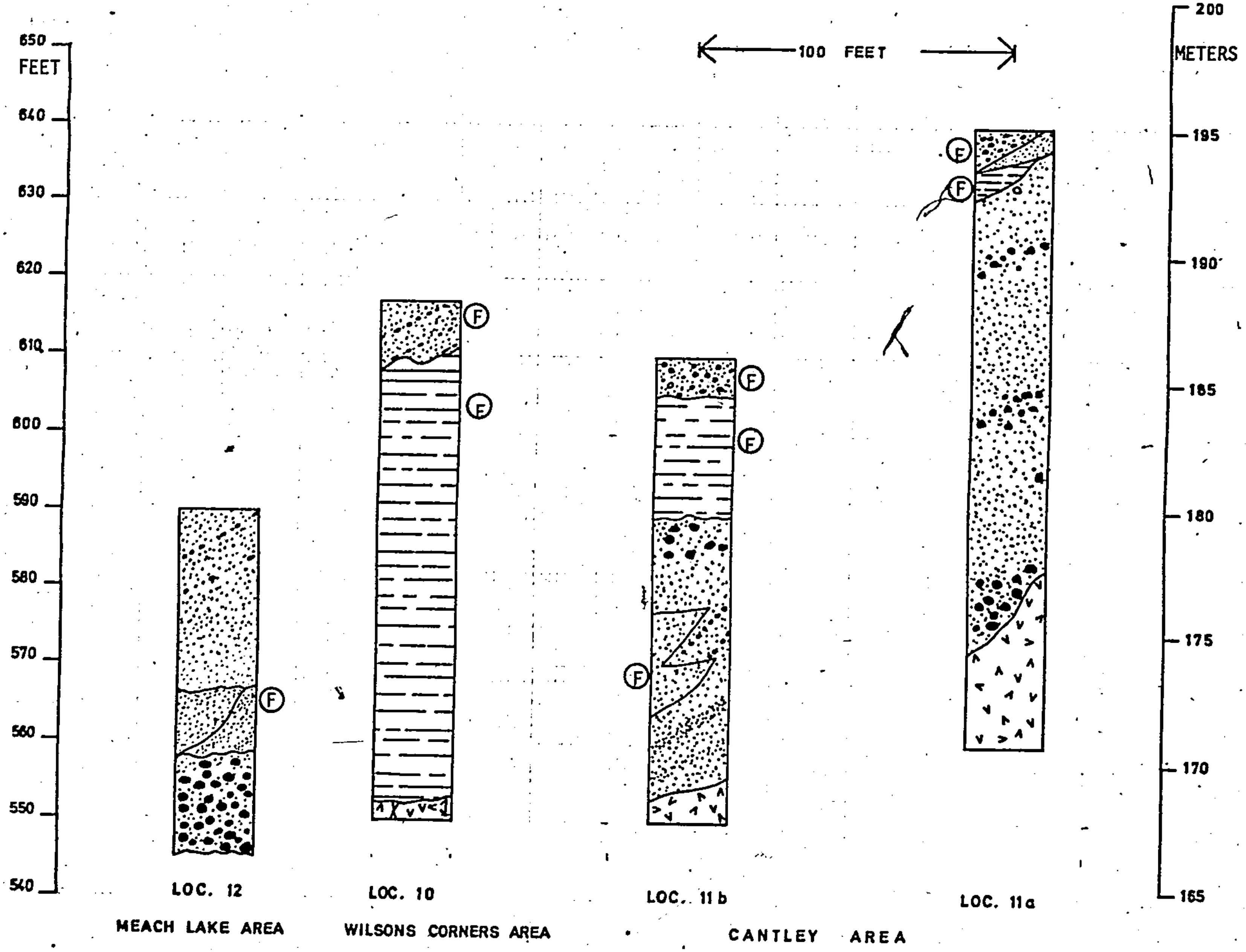
F
LOC. 6
LOC. 7
WILSONS BROOK AREA
LOC. 8
MONT CARON
LOC. 9
WAKEFIELD AREA

FIGURE 17d: Columnar sections from localities 10, 11a and 11b, and 12.


650
FEET
640
630
620
610
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590
580
570
560
550
540
100 FEET
200
METERS
195
190
185
180
175
170
165
F
LOC. 12
LOC. 10
LOC. 11 b
LOC. 11 a
MEACH LAKE AREA
WILSONS CORNERS AREA
CANTLEY AREA

Descriptions of stratigraphy at localities studied.

- Position of some samples are indicated.
- When dip of foresets is indicated, it is usually an average measurement for this unit, in the exposure.
- Where glacial striae are identified, the direction is an average of measurements on exposed outcrops.

Locality 1a (Martindale)

Location: 31G/13W Low, west bank of Gatineau River (266766), elevation ± 580 feet (bar.).

Thickness	Lithology	Cumulative Thickness *
(4)	Buff fossiliferous (<u>Macoma balthica</u>), gravelly sand, overlain by a thin soil horizon. Fossils in growth position at the lower contact (Radiocarbon date G.S.C. - 1772, 11,900 ± 160 years B.P.).	(4)
(12)	Grey mud with blocky fracture, contains large boulders. Lower portion is laminated, fossiliferous (<u>Macoma</u>) and also microfossils, sample 4.	(16)
(4)	Fine grained sand in a lens shaped unit, sample 5.	(20)
(20)	Very coarse, bouldery gravel with grey, muddy sand matrix; the boulders are very well rounded. Striated marble bedrock, striae 165°.	(40)

Locality 1b (Martindale)

Location: approximately 200 feet south of locality 1a.

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* Measured from the top of the section

Thickness	Lithology	Cumulative Thickness *
(10)	Buff colored fine grained sand. Bedding is shown by alternating fine and coarse sand layers, sample 5A.	(10)
(15)	Truncated, cross-bedded sandy gravel unit, foresets dip. 30° towards 130°.	(25)

Locality 2 (Martindale area)

Location: 31G313W Low, west bank of Gatineau River (251747), elevation ± 565 feet (bar.).

Thickness	Lithology	Cumulative Thickness *
(15)	Blocky grey colored mud, laminated in lower portion of unit. Fossiliferous, contains pelecypod shell fragments, sample 7.	(15)
(20)	Buff colored fine grained sand with interbedded thin gravel beds, (sample 8), bottom 5 feet are sandy gravel, sample 9. Bedrock: marble	(35)

Locality 3 (Martindale area)

Location: 31G/13W Low, west bank of Gatineau River (261749), elevation ± 600 feet approximately.

Thickness	Lithology	Cumulative Thickness *
(20)	Very fine grained cross-bedded silty sand, foresets dip 15° towards 090°.	(20)

Locality 4 (Farrellton)

Location: 31G/12W Wakefield, west bank of Gatineau River (291653), elevation ± 545 feet (bar.).

(5)	Grey laminated, varve-like fossiliferous (Macoma) silty mud, sample 55.	(5)
(100)	Sandy gravel and gravelly sand, beds inclined and dipping 14° towards 282°, samples 56, 57, 58, 67.	(105)
(10)	Sandy gravel, sample 54	(115)
(10)	Buff colored rippled medium grained sand unit dipping 15° towards 219°, samples 53, 60, 66	(125)
(15)	Apparently massive channel fill of medium grained sand becoming coarser at the base, samples 61 to 65. Channel axis plunging 18° towards 230°.	(140)
(10)	Massive faintly-bedded medium grained sand, samples 51 to 53	(150)

Thickness	Lithology	Cumulative Thickness *
	<u>Locality 5 (Alcove area)</u>	
	Location: 31G/12W Wakefield, west bank of Gatineau River (281617), elevation ± 480 feet (bar.).	
(10)	Sandy gravel, sample 46 and 44	(10)
(50)	Medium grained cross-bedded gravelly sand, foresets dip 20° towards 155°, sample 45.	(60)
(30)	Coarse grained sandy gravel, sample 47, and gravelly sand, sample 48, units, dipping 25° and 29° towards 250° and 270°, respectively. Bedrock outcrop (marble)	(90)
(20)	Horizontally bedded bouldery gravel with a coarse well rounded gravelly sand matrix, sample 49.	(110)
	Talus underlain by marble bedrock, glacial striae 170°.	
	<u>Locality 6 (Wilson Brook area)</u>	
	Location: 31G/12W Wakefield, east bank of Gatineau River (307589) elevation ± 540 feet (bar.).	
(3)	Gravelly sand overlain by a thin soil horizon	(3)

Thickness	Lithology	Cumulative Thickness *
(3)	Steeply dipping very coarse gravelly sand, dip is 25° towards 200°, sample 21.	(6)
(6)	Steeply dipping, buff colored coarse gravelly sand wedge fossiliferous (*Macoma* and microfossils), dip is 22° towards 220°, sample 22.	(12)
(8)	Gravelly muddy fine sand with interbedded thin gravel strings, the fine sand is highly fossiliferous (*Macoma*, *Hiatella*, and microfossils), sample 20. Beds dipping 24° towards 240°.	(20)

Locality 7 (Wilson Brook area)

Location: 31G/12W Wakefield, east bank of Gatineau River (310586), elevation ± 560 feet (bar.).

(5)	Gravelly sand unit overlain by a thin soil horizon.	(5)
(5)	Sandy gravel with *Macoma* in growth position, sample 19	(10)
(2)	Laminated (¼ to ½ inch laminae) grey mud, fossiliferous (*Hiatella* and microfossils), steeply dipping 19° towards 253°, sample 18.	(12)
(8)	Partly cemented coarse gravelly sand passing downwards into a well rounded cobble gravel, sample 17.	(20)

Thickness	Lithology	Cumulative Thickness *
	<u>Locality 8 (Edelweiss)</u>	
	Location: 31G/12W Wakefield, Edelweiss ski area (337551), elevation ± 495 feet (bar.).	
(6)	Gravelly muddy fine grained sand, the gravel size clasts are well rounded mud fragments, sample 23 and 23_I	(6)
(3)	Silty sand.	(9)
(10)	Laminated and contorted silty mud and sand beds (1 to ½ inches) interbedded with thicker (6-8 inches) mud and sand layers, the sandy bed are fossiliferous and contain <u>Macoma</u> and microfossils.	(19)
	<u>Locality 9 (Wakefield area)</u>	
	Location: 31G/12W Wakefield, west bank of Gatineau River (276523), elevation ± 510 feet (bar.).	
(3)	Buff colored fine grained rippled sand, sample 10	(3)
(4)	Highly fossiliferous gravelly muddy fine grained sand, fossil assemblage is 95% <u>Hiatella</u>, 5% <u>Portlandia</u> and <u>Macoma</u> and microfossils, sample 11	(7)
(15)	Contorted grey silty sand, sample 12. The three units	(22)

Thickness	Lithology	Cumulative Thickness *
	described are dipping towards the slope of the hill against which they rest; they have probably slumped down.	
(28)	Slightly gravelly sand, with a few thin gravel beds near the base, sample 13.	(50)

Locality 10 (Wilson Corner area)

Location: 31G/12W Wakefield, Wilsons Corners area west bank of Gatineau River (386487), elevation ± 617 feet (bar.).

Thickness	Lithology	Cumulative Thickness *
(9)	Crossbedded fossiliferous (<u>Macoma</u>), buff colored sand. Foresets dip 8° towards 300°. Fossils are found in growth position	(9)
(65)	Grey blocky fossiliferous sandy silt. Fossils are <u>Portlandia</u> and microfossils, sample 27. Striated marble bedrock, striae 150°.	(74)

Locality 11a (Cantley area)

Location: 31G/12W Wakefield, west bank of Gatineau River (393459), elevation ± 640 feet (bar.).

Thickness	Lithology	Cumulative Thickness *
(3)	Gravelly sand, fossiliferous (<u>Macoma</u>), sample 40	(3)

Thickness	Lithology	Cumulative Thickness *
(4)	Wedge shaped fine grained to silty sand unit, samples 41,42, 43, dip is 20° towards 350°.	(7)
(3)	Grey mud, highly fossiliferous, fossil assemblage consists of 95% <u>Macoma</u>, and 5% <u>Balanus</u>, <u>Mytilus</u>, <u>Portlandia</u>, and microfossils, sample 361 (Radiocarbon date G.S.C. - 1646, 12,200 ± 160 years B.P., is from top of mud unit.	(10)
(60)	Coarse grained sands interbedded with well rounded gravel units. Marble bedrock. Glacial striae, 174° and 186°.	(70)

<u>Locality 11b (Cantley area)</u>

Location: 100 feet west of section 11a, elevation ± 610 feet (bar.).

(5)	Fossiliferous (<u>Macoma</u>) gravelly sand, samples 35 & 935	(5)
(15)	Grey mud, highly fossiliferous (same assemblage as in sample 361); slump probably occurred between locality 11a & 11b, sample 363.	(20)
(15)	Fine-grained sand and gravelly sand (sample 37, 837 and 937) becoming more gravelly near the bottom, sample 38	(35)
(15)	Interfingering sand (sample 29, 30, 39) and silty sand units with clayey lenses, samples 30 and 32. This unit also contains pockets of fossiliferous <u>Macoma</u> sand and gravel (samples 33 & 34). Beds are inclined 12° towards 330°.	(50)

Thickness	Lithology	Cumulative Thickness *
	<u>Locality 12 (Meach Lake area)</u>	
	Location: 31G/12W Wakefield, Meach Lake area (328415), elevation 590 feet approximately.	
(25)	Coarse grained crossbedded sands (sample 17) becoming silty near the base, dip of foresets is 20° towards 250°.	(25)
(5)	Buff colored, fossiliferous (<u>Macoma</u>) medium grained sand lens (sample 16). This lens changes laterally with a sharp contact to a disturbed unit of laminated (1 to 2 inches) sand and silty sand layers, containing <u>Hiatella</u>	(30)
(15)	Gravelly sand grading into a cobble gravel	(45)
	<u>Locality 14 (Tenaga area)</u>	
	Location: 31G/12W Wakefield, Tebaga area (383413), elevation 415 feet approximately.	
(10)	Fossiliferous (fragments of <u>Hiatella</u>), gravelly mud unit containing cobbles up to 8 inches long, sample 77.	(10)
(40)	Medium grained sand interbedded with units of fine and gravelly sand, samples 69 to 76. Striated marble bedrock striae 149°.	(50)

1 of


Venosta
Venosta Lake
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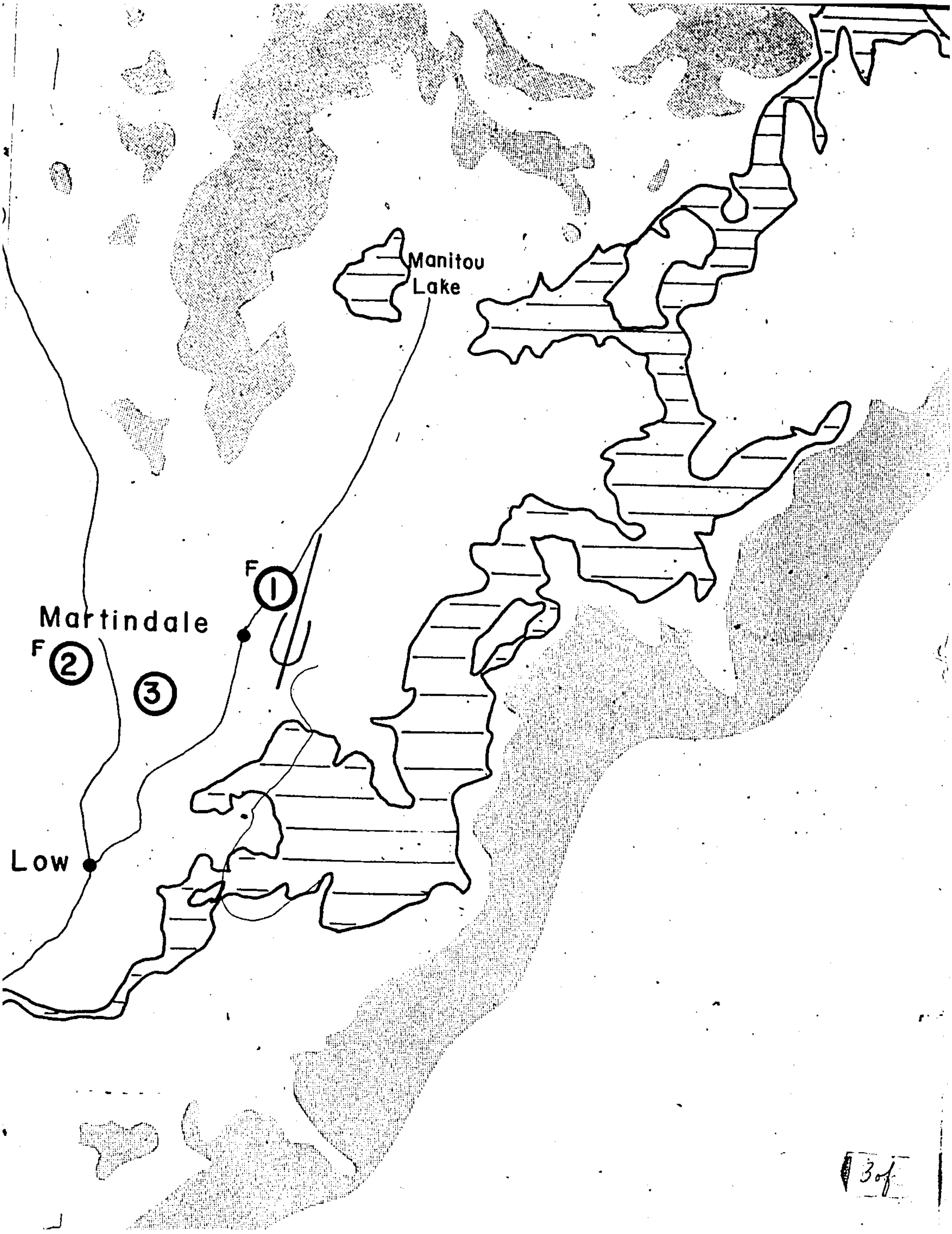
2a
Lac Bernard
Lac



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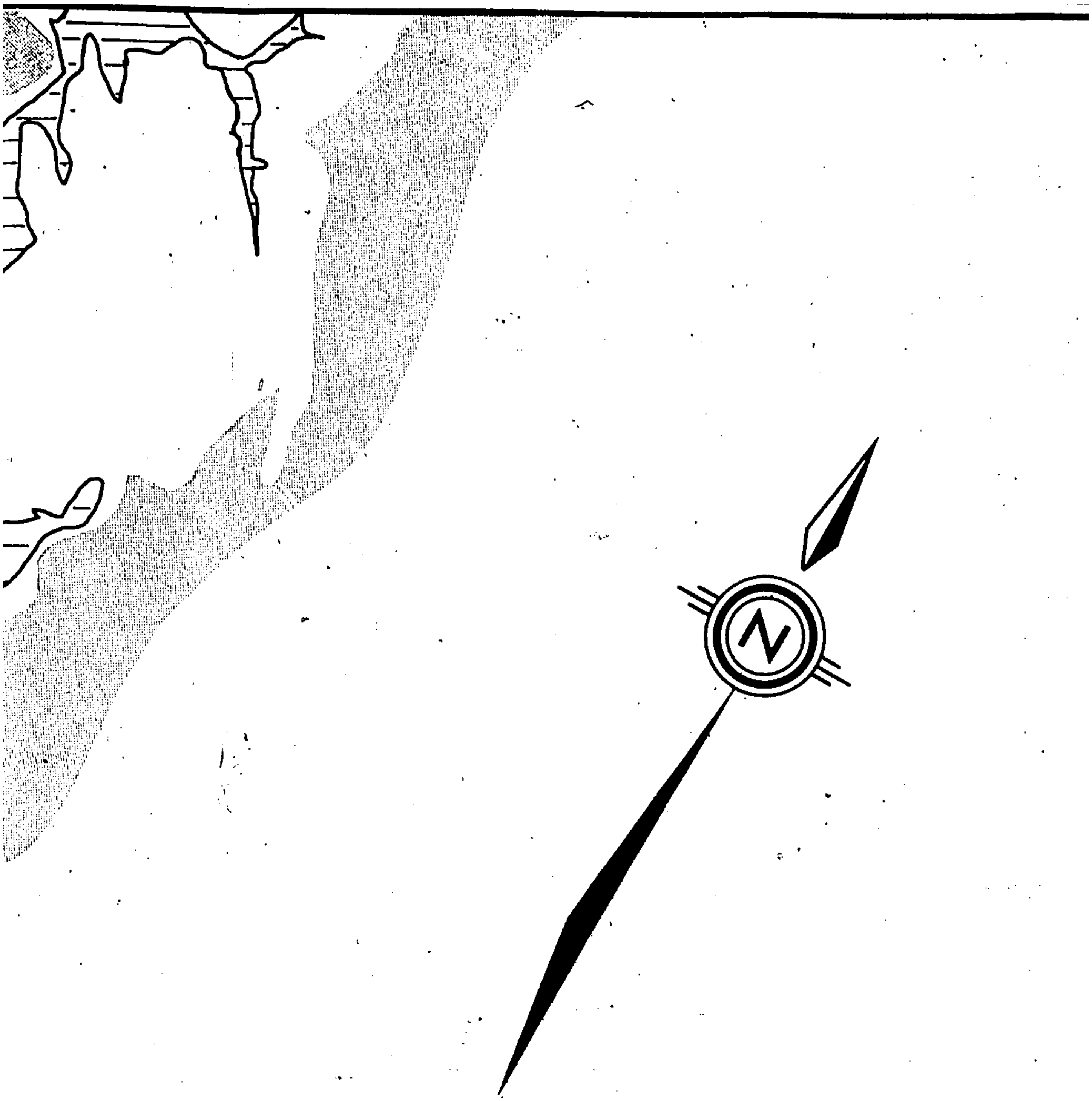

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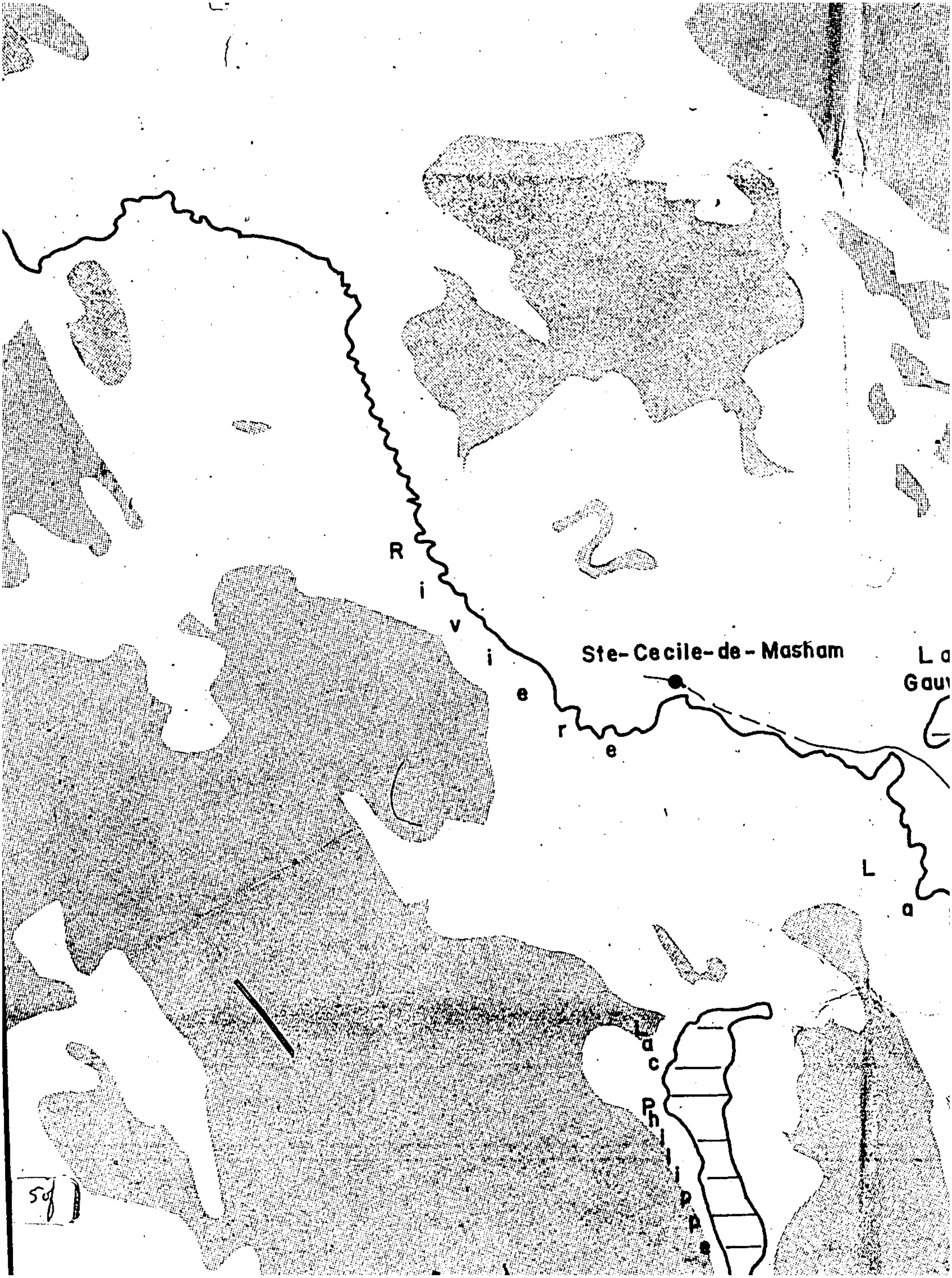
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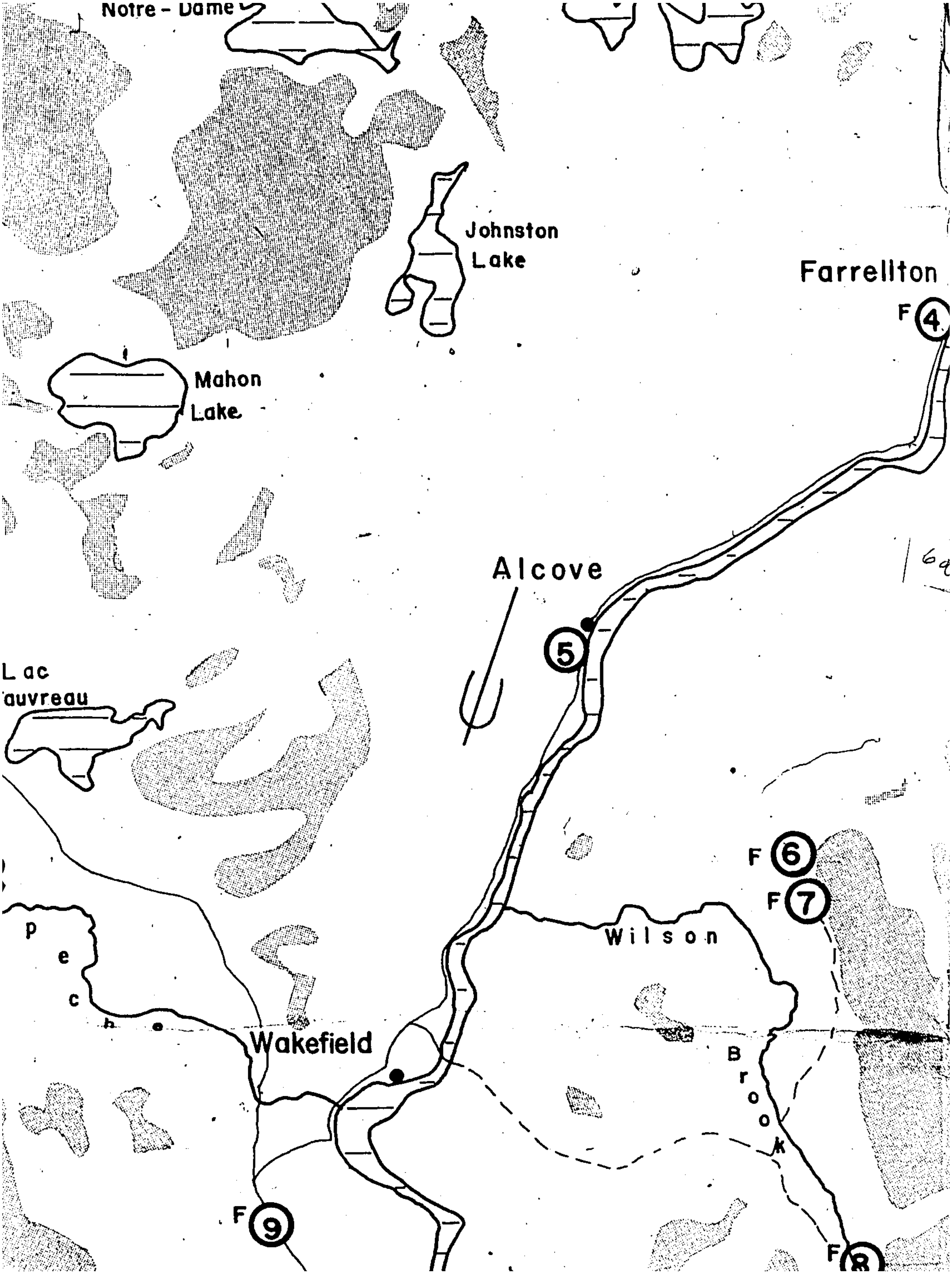
Ste-Cecile-de-Masham
La
Gauv
La
Lac Philippe


Notre - Dame
Johnston
Lake
Farrellton
F 4
Mahon
Lake
Alcove
5
Lac
auvreau
6a
F 6
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Wilson
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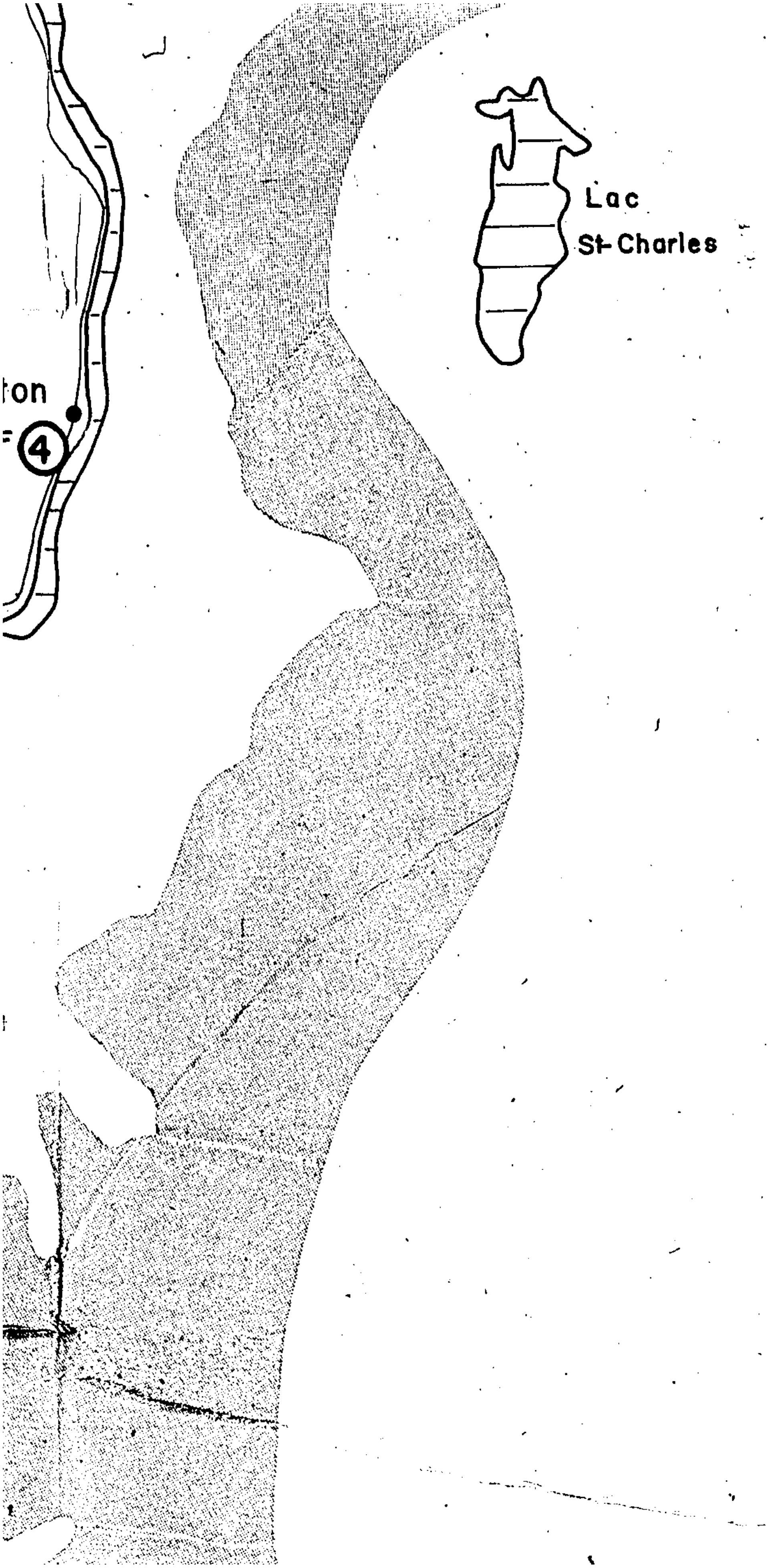
F 8



7 of 8


Lac Mousseau
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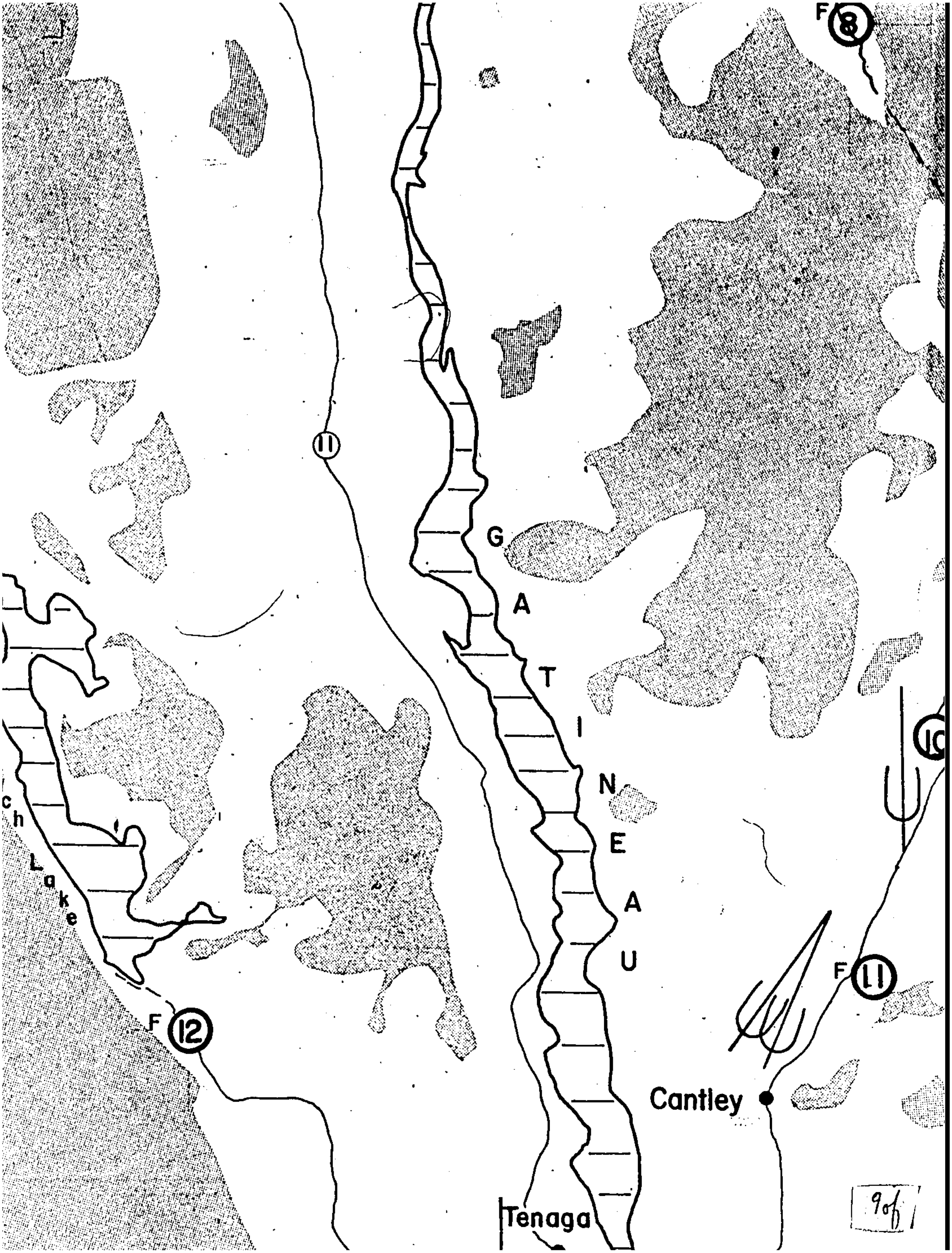
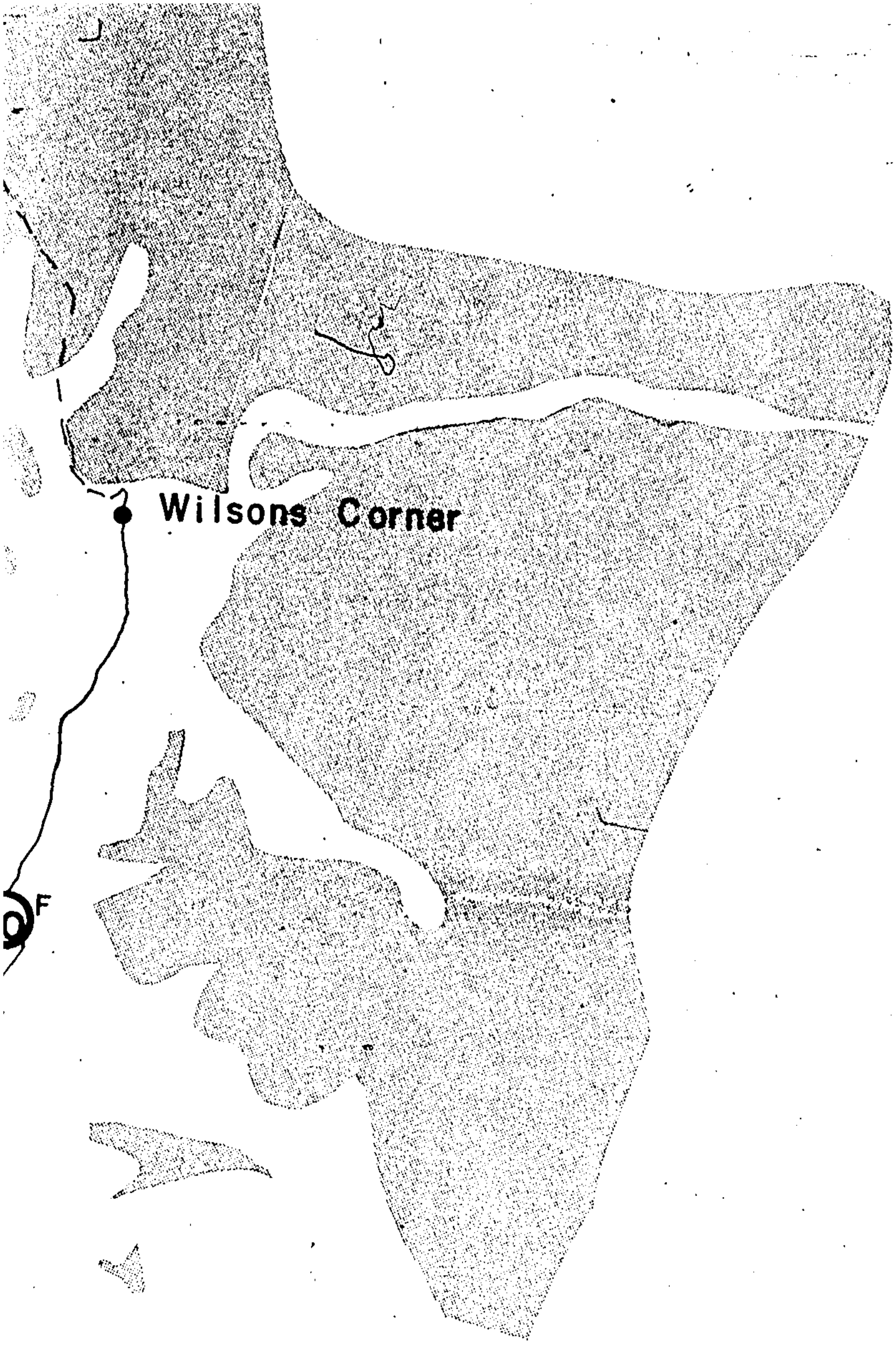
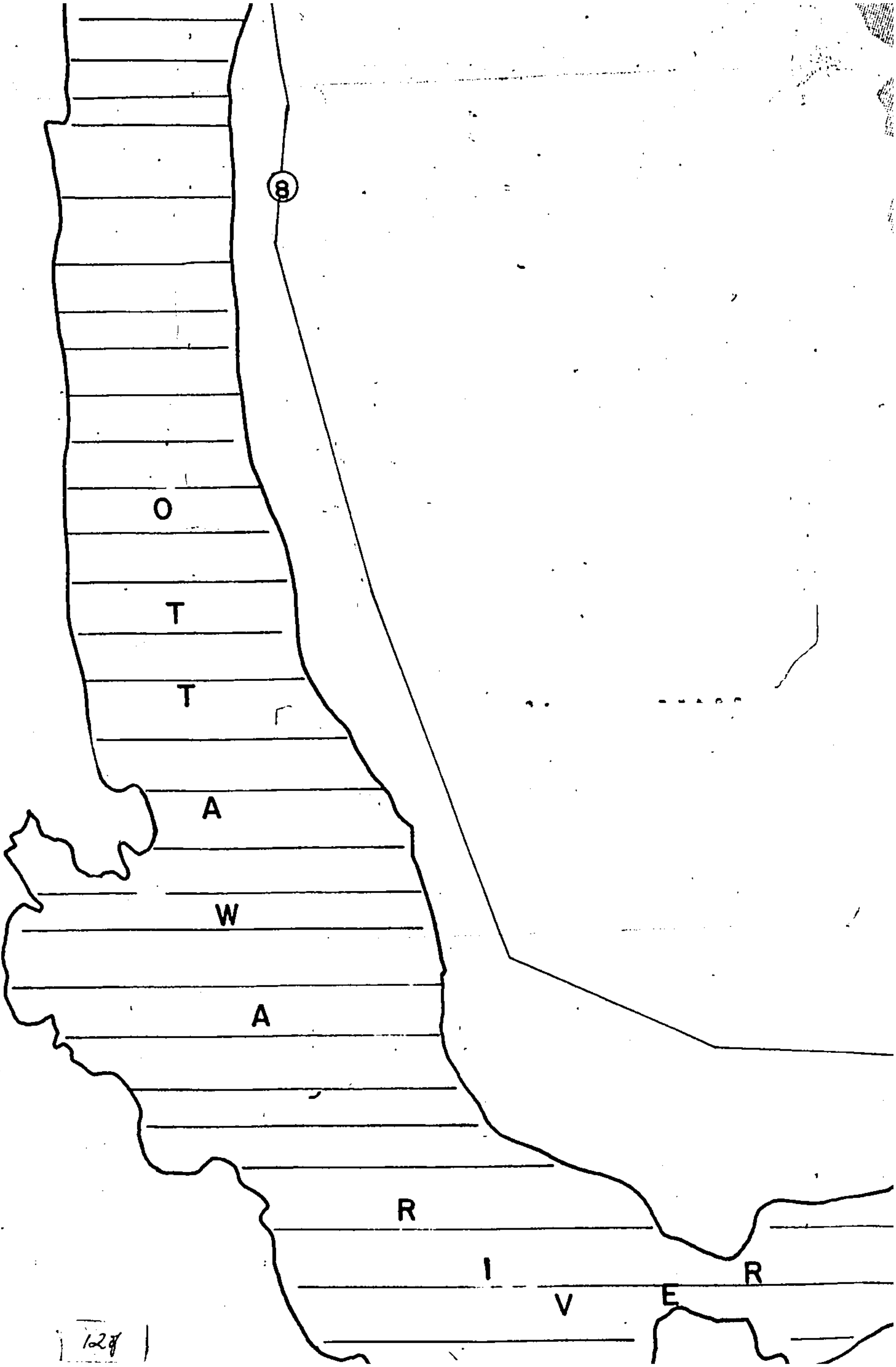
8af

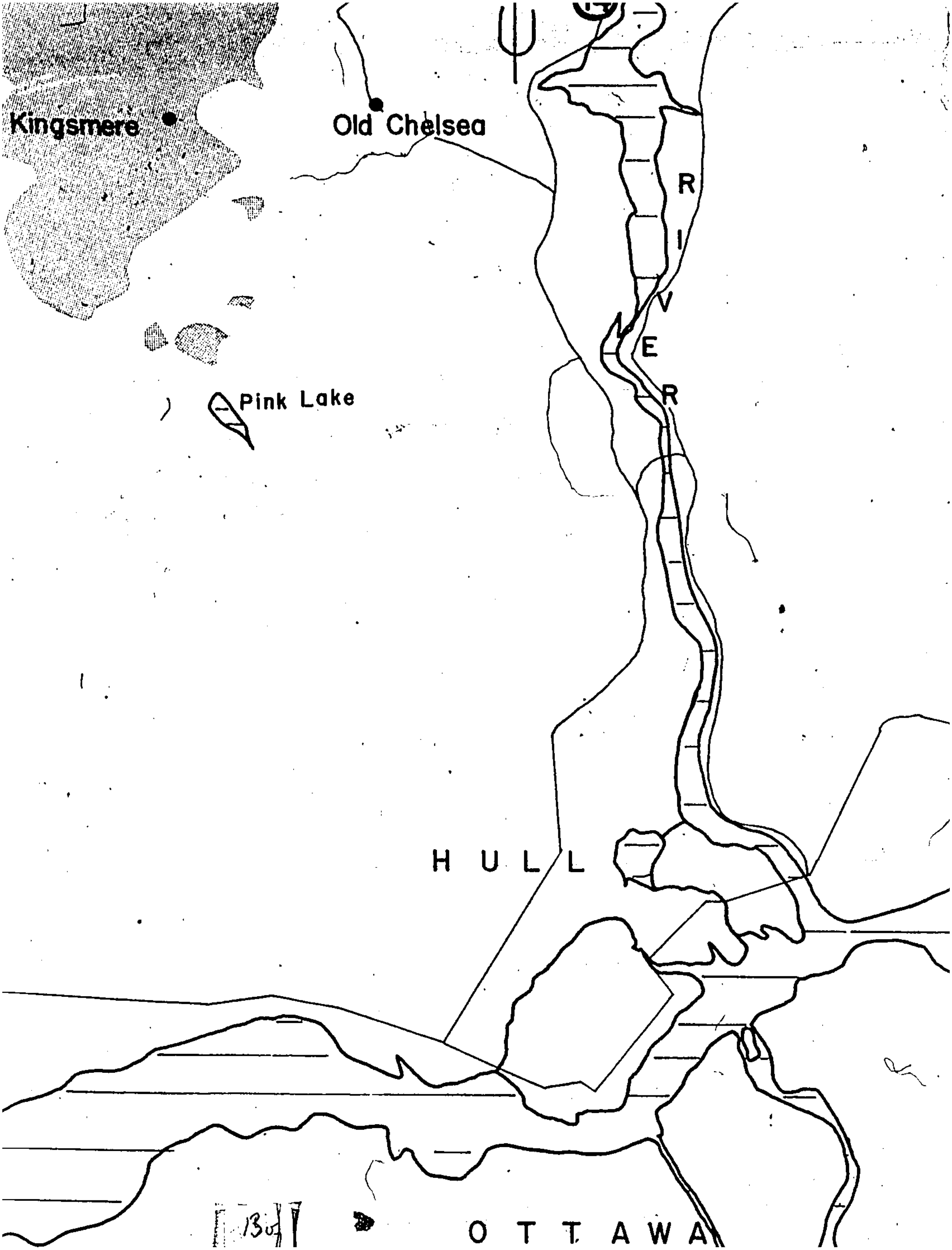


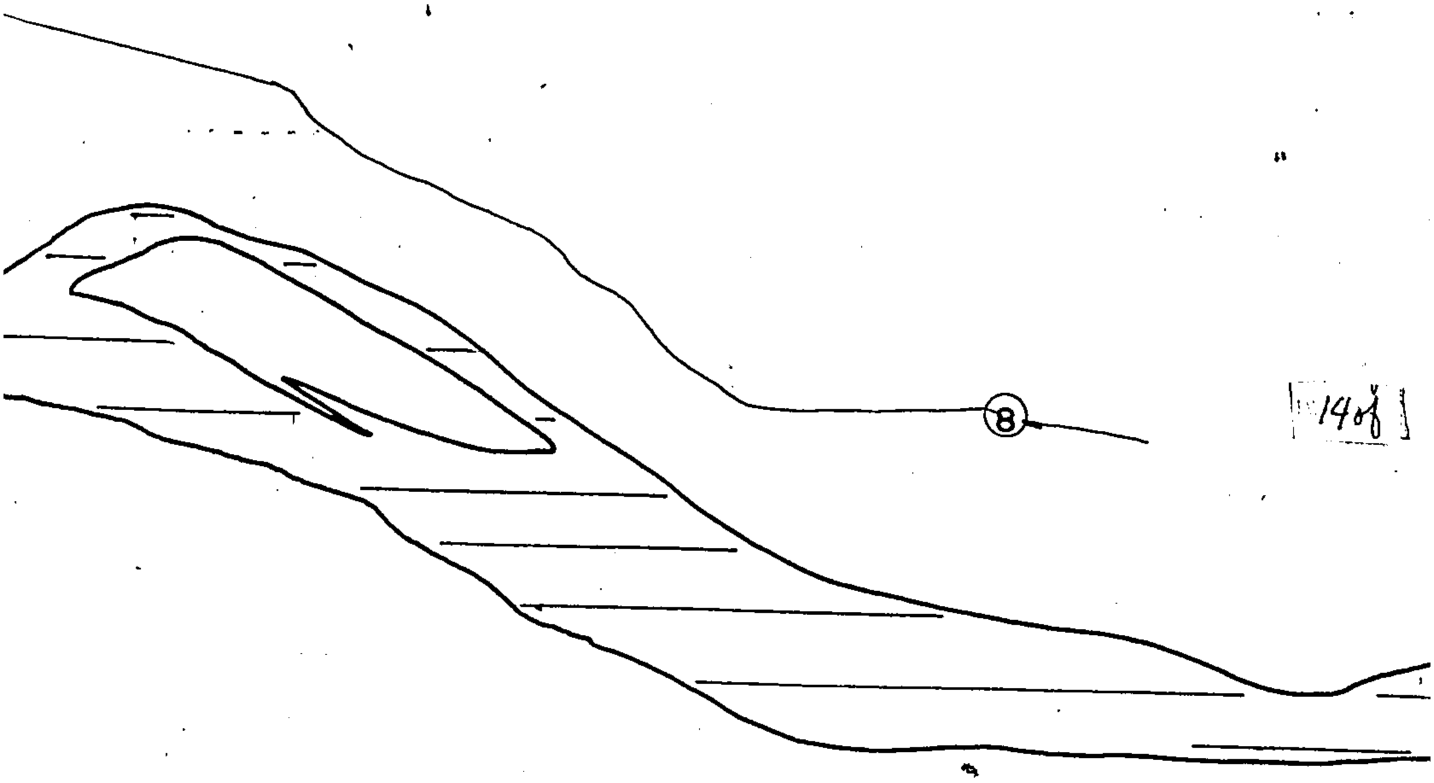
9of


Wilsons Corner
F

LEGEND


8
OTTAWA
RIVER


Kingsmere
Old Chelsea
RIVER
Pink Lake
HULL
OTTAWA


⑧
14of

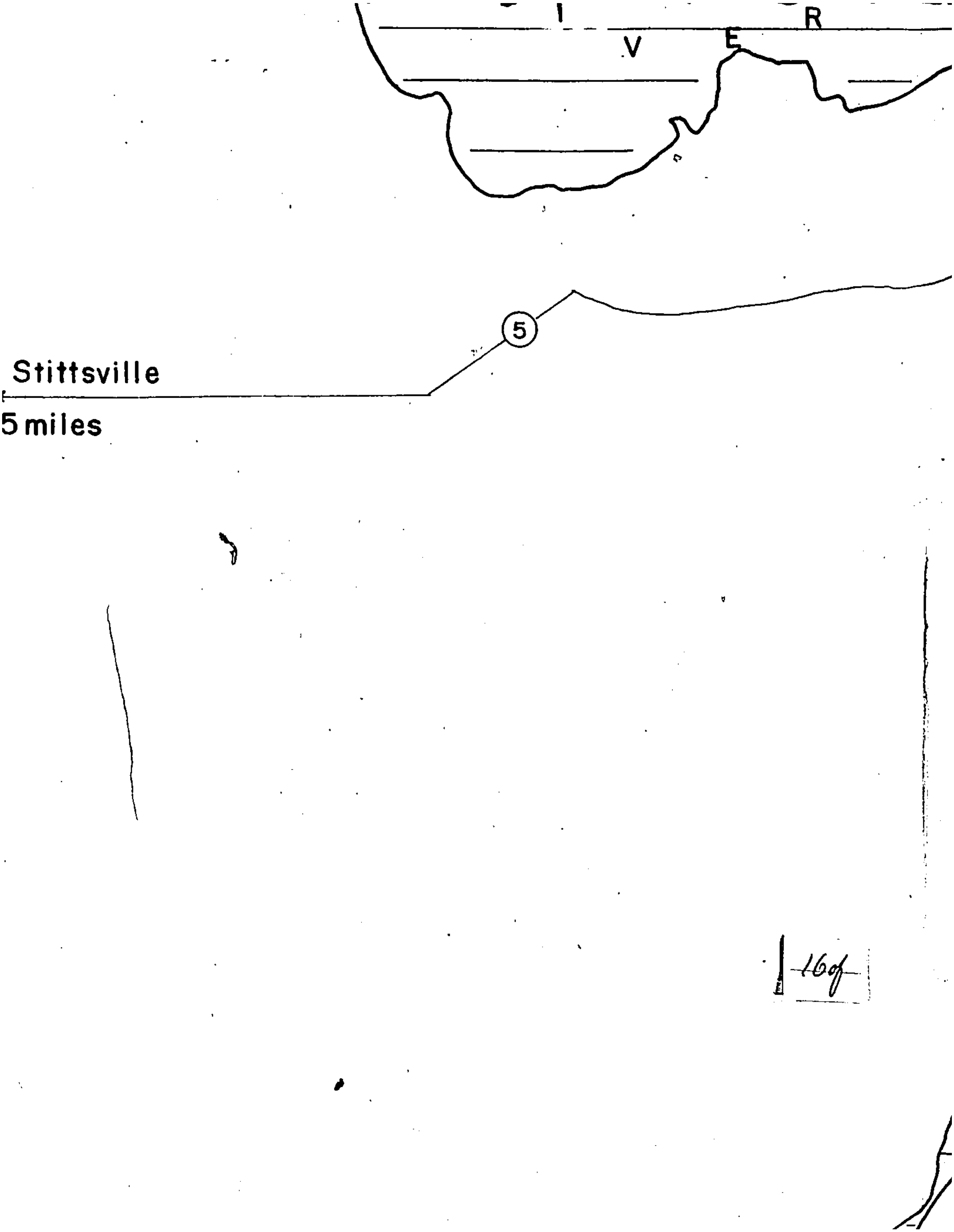
⑨	Locality number
F	Fossil locality
▨	Highlands, over 650' above sea level
≋	Lakes, rivers...
↘	Glacial striae
—⑰—	Highway

NOTES

150F

Base-maps by the SURVEYS AND MAPPING BRANCH, DEPARTMENT OF ENERGY, MINES AND RESOURCES.

Approximate magnetic declination, 14° 00' West, decreasing 0.6' annually.



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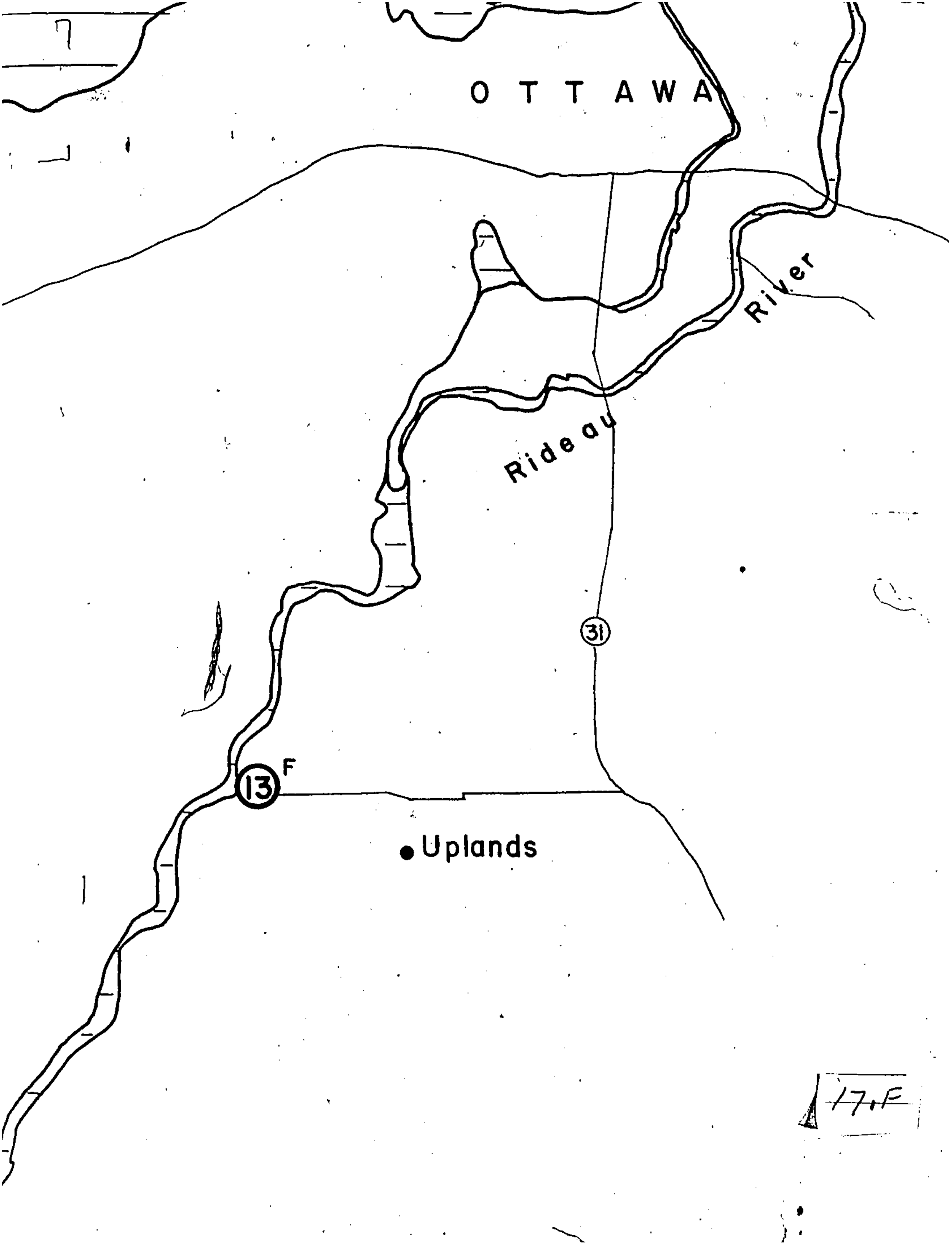
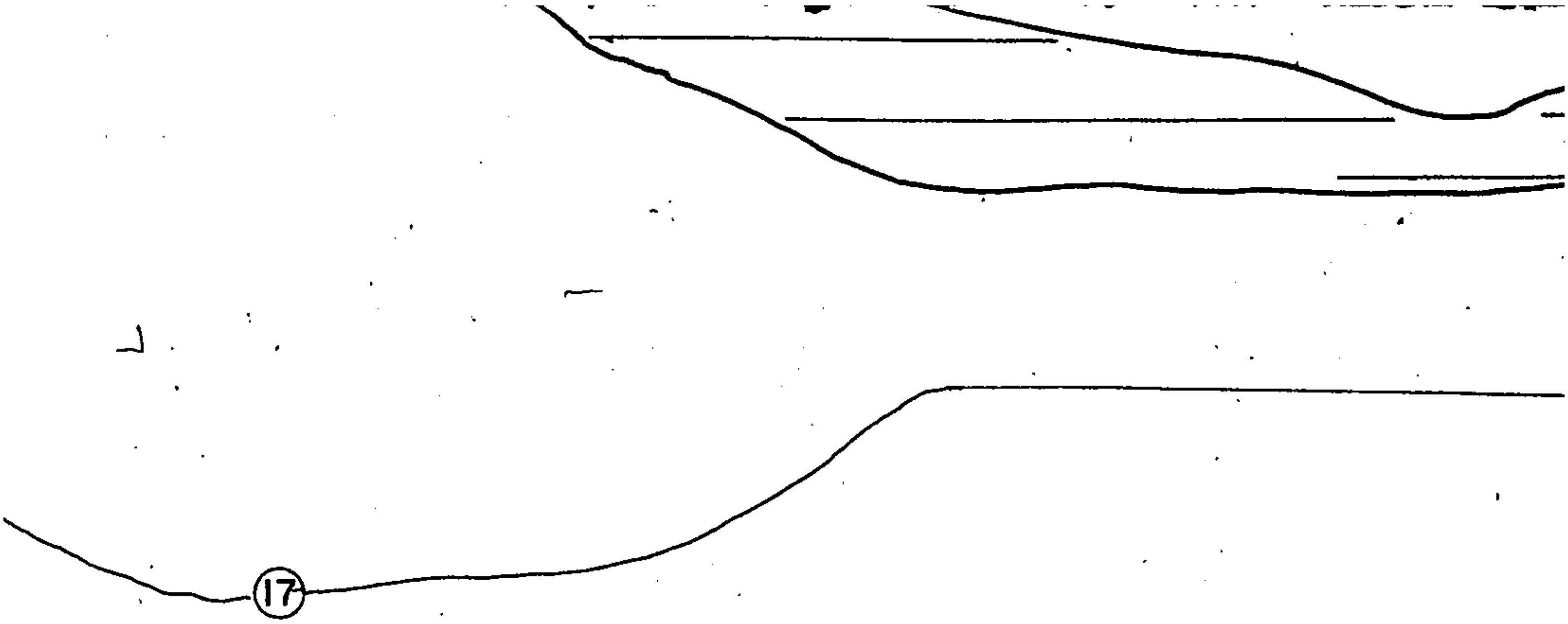

OTTAWA
Rideau River
31
13 F
Uplands
17.F


17

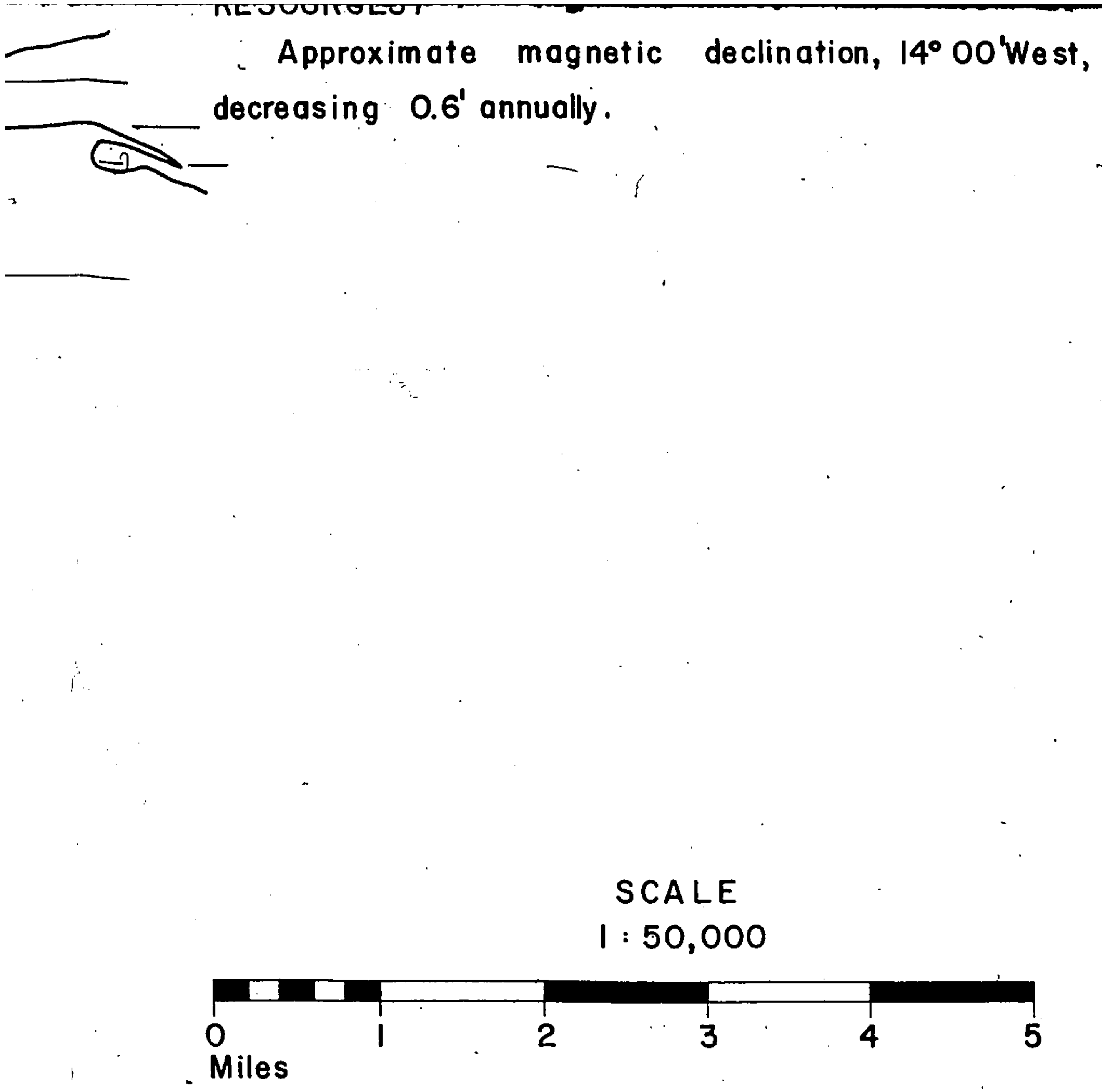


Figure 1. LOCATION MAP