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THE WHIRLPOOL SANDSTONE

by

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Scope and contents of this thesis

A review of the history of the nomenclature of the Medina Formation and of the previous studies of its members, particularly those studies dealing with the source of the Whirlpool sandstone. This is an attempt to show the direction of origin of the detrital materials of the Whirlpool sandstone by a study of the lateral variation of its grain size along the Niagara Escarpment. It is illustrated with maps and with photographs taken by the writer.

This thesis has been read and approved by:

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PART I

PART I

INTRODUCTION

The Silurian rocks of the Ontario Peninsula and the adjacent State of New York have been extensively studied in the past. As well as forming the basis of this research, they will doubtless continue to be of interest to geologists in the future. Although it is not essential to this study, a review of the nomenclature of the Lower Silurian Medina formation is here included, together with an outline of previous detailed investigations of its members, by other workers. Primary interest lies in the work done upon the Whirlpool sandstone, particularly with regard to its origin, a subject which is dealt with in the present research.

HISTORY

Nomenclature

The history of the Medina formation has been well summarized by H. Johnson (1934), and with some revision, his work is reproduced here.

The basal Silurian rocks of New York were first studied by Professor Amos Eaton in 1824. He introduced the terms Saliferous, Grey band, Grey Feke, and Millstone Grit. Of these, Grey band is the only term in use at the present time, but it is being rapidly replaced in the literature by the local term, Thorold sandstone.

In 1837, T. A. Conrad, in the First Annual Report of the New York State Geological Survey, called the rocks of the Lower Silurian "the red or variegated sandstone of the Niagara

River", and discarded Eaton's earlier terms as not being descriptive. Conrad referred to the rocks in question as "Red sandstones".

L. Vanuxem, in 1839, proposed the name "Medina" for the sandstone which formerly had been known as 'the red sandstone of Oswego'. He described a generalised section which includes, at the top, Eaton's 'Grey band', now known as the Thorold sandstone; the main red sandstone mass, equivalent to the Grimsby shales; the grey quartzose sandstone "distinct from the Grey band," called the Whirlpool sandstone. These members constituted the Upper Medina, and are underlain by a 'Red Marl', which Vanuxem termed the Lower Medina.

The first description of Silurian rocks in Ontario was by the Rogers brothers, who, working with Alexander Murray in 1843, traced the Silurian rocks of western New York into southwestern Ontario. (Johnson, 1934). In 1863, Sir Wm. Logan stated that the Medina is best exposed in the Niagara region. In southern Ontario some confusion arose concerning the position of the Thorold sandstone, known as the Grey band, and that of the Whirlpool sandstone. North and west of Dundas the basal sandstones were described as the Grey band. Actually the true Grey band does not appear this far north. The limestones and green and red shales overlying the sandstone were referred to the Clinton, instead of to the Medina. The error was continued when H. A. Nicholson and G. J. Hinde, (Johnson, 1934) listed and described species of Cataract and Medina fossils as belonging to the Clinton.

A. W. Grabau, in 1901, (Johnson, 1934) described as Silurian the section exposed in the Niagara gorge, including the Oswego sandstone, which underlies the Queenston shales, with the Medina shales and sandstones. He later divided the Medina into a Lower Medina or Red Marl and an Upper Medina or Whirlpool sandstone (Grabau, 1905).

This usage was followed by C. A. Hartnagel in 1907, (Johnson, 1934) who divided the Medina into lower shales and upper sandstones. He recorded a uniform band of sandstone, 25 feet thick, and traced it into the vicinity of the Niagara River.

In 1908 Grabau redefined the Medina, restricting it to what was formerly known as the Upper Medina sandstones, which he correlated with the Oneida conglomerate of New York (Grabau, 1905). The lower shales he named the Queenston formation, and showed that they represented the continental deposits of Richmond time, thus placing them in the Ordovician system.

Continued investigation of these strata brought forth increasing amounts of information and in 1910 the interpretation of the Lower Silurian beds of Ontario was questioned. Papers by Charles Schuchert, W. A. Parks and M. Y. Williams (Johnson, 1934) showed that the Clinton of southwest Ontario was not the Clinton of New York State, but a new horizon which lay directly beneath the fossiliferous Medina and was known as the Cataract formation, from the locality at Cataract, Ontario.

Williams, in 1919, used the term'Medina-Cataract' in describing the Lower Silurian rocks of Ontario. He justified the use of the hyphenated term on the basis of the lateral variation of the formation. The name 'Medina' as used by Grabau, was applied to the strata extending from Niagara Falls to the vicinity of Hamilton. The term 'Cataract', as proposed by Schuchert (1914), was used to describe the rocks northward from Hamilton and Dundas.

H. Johnson (1934), objected to the use of the term 'Medina-Cataract' on the ground that it was misleading and preferred to retain the single term 'Cataract'. The Cataract formation was defined as consisting of the following members:

Cabot Head shale

Manitoulin dolomite

Whirlpool sandstone

In 1940, J. F. Caley reverted to the terminology advanced by Grabau, in referring to the Medina formation. He included in the Medina all the strata between the Queenston shales below, and the Clinton formation above. The difference in the faunas of the two phases, Medina and Cataract, which had been partly responsible for the use of the two different terms applied to these rocks, he attributed to a difference in habitat, rather than to separate faunal invasions. The Cataract he considered to be a facies of the Medina, which, traced westward and northward, grades from an almost purely clastic assemblage to one composed largely of limestone.

In all reports, the upper contact of the Whirlpool sandstone with the overlying Manitoulin member is described as transitional. The upper beds of the Whirlpool sandstone are interbedded with shales, and are sparingly fossiliferous.

T. E. Bolton (1949), in describing the Silurian section at De Cew Falls, drew the upper boundary of the Whirlpool sandstone at the top of the massive sandstone beds. The overlying interbedded shales and sandstones he included in his Power Glen member, a new stratigraphic unit which he considered to be, in part, a facies equivalent of the Manitoulin member.

This division had been suggested by Johnson in 1934, who observed that the zone of fossiliferous sandstone and shale should be included in the Manitoulin member, or its equivalent. The Power Glen member, as proposed by Bolton at De Cew Falls, is the equivalent of the Manitoulin and the Cabot Head members to the north.

Bolton 1949		Caley 1940
Thorold sandstone	....	Thorold sandstone
Grimsby shales	....	Grimsby shales
	....	Cabot Head shales
Power Glen shales	....	
	....	Manitoulin dolomite
Whirlpool sandstone	....	Whirlpool sandstone

In view of the fact that, in the southern and eastern extensions of the Silurian rocks of Ontario, the upper boundary of the Manitoulin member is very difficult to define (Caley, 1940), the suggestion that the Power Glen member is the equivalent of the Manitoulin member and the Cabot Head member, may be regarded as reasonable. Caley (1940) states that, "The Manitoulin member and the overlying Cabot Head strata cannot be separated on the Niarara River on lithological evidence". Only in the northern localities of their occurrence, where the Manitoulin member is typically developed as an argillaceous magnesian or dolomitic limestone, can it be easily separated from the overlying Cabot Head shales. Toward the south and east it becomes increasingly shaly, until, in the Niagara River, the Manitoulin horizon is occupied by strata that are dominantly shale.

In this study, the usage proposed by Bolton is followed. The Whirlpool sandstone is understood to consist of the massive sandstones, the upper boundary being placed at the first appearance of the shales of the overlying Power Glen member.

Previous Work

A considerable amount of detailed petrographic work has been done on the Whirlpool sandstone by various workers. One of the earliest of these was H. L. Alling (1929), who referred to the sandstone as a felspathic sandstone, and listed the following heavy minerals: garnet, chlorite, leucoxene, magnetite, phosphate pebbles, apatite, tourmaline and zircon, as well as perthite, microcline and plagioclase. He observed that many of the quartz grains were secondarily enlarged, and that chlorite, clay and silica materials acted as cement to the particles. The size grades of the quartz grains placed it in the fine to medium sand size range. He suggested, on the basis of double peaks of the size frequency distribution curves of the quartz grains, that the sandstone showed the effects of two different transporting and sorting agents: aeolian and aqueous.

One of the most comprehensive studies of the heavy minerals of the sandstone has been made by A. Holstein (1934).

He directed his attention chiefly to their variations, both laterally and vertically. Unlike Alling, who was interested in the sandstone with regard to the stage of metamorphism represented, Holstein attempted to derive conclusions as to the origin of the sandstone. He was able to show a remarkable constancy of some of the heavy minerals, and a noteworthy variation in others. In addition to those heavy minerals mentioned by Alling, Holstein reported the presence of rutile, ilmenite, pyrite and glauconite. He observed that there appeared to be an inverse relationship between zircon and collophane and that leucoxene became less abundant toward the upper contact of the sandstone. The remaining mineral species appeared to be more or less constant in number. He states that "the presence of physically and chemically stable minerals in quantity, to the exclusion of less stable ones, constitutes likely evidence of repeated working of older sediments" (Holstein, 1934). The restricted variety of minerals present also indicates a source in pre-existing sediments. The thinning of the Whirlpool sandstone to the west and north also indicates a source area to the south and east of its present position. Holstein concluded that "....sediments of the Appalachians, as well as rocks of the Adirondacks, were responsible for the material composing the Whirlpool sandstone".

In 1949, T. E. Bolton, describing the Silurian section at De Cew Falls, briefly mentioned the Whirlpool sandstone, and noted the presence of zircon and rutile as inclusions in the quartz. He commented on the well rounded and well sorted nature of the detrital material making up the sandstone and stated that no definite crystals were observed. Bolton concluded, on the basis of its regional extent together with petrological and lithological evidence, that the Whirlpool sandstone is a marginal deposit, the materials of which have been derived from the elevated Appalachian province and distributed by wind and water over the mud-cracked Queenston surface, and reworked by the shallow waters of the advancing Silurian sea.

ECONOMIC VALUE

Building Stone

The Whirlpool sandstone first became known to the early settlers of Ontario as a source of excellent building stone. At present it is not used for this purpose nearly as much as it has been in the past; other structural materials having taken its place.

W. A. Parks (1912) reports that three types of building stone were quarried from the sandstone:

1. Light grey sandstone.
2. Chocolate colored sandstone.
3. Mottled brown and grey sandstone.

Quarrying is limited by the cross-bedded nature of the sandstone, which often makes impossible the removal of large blocks. The best grade of sandstone is usually found where it is most difficult to remove.

Gas

In Ontario the Whirlpool sandstone, known as the 'White Medina' by drillers, is rated next to the Clinton formation as a producer of gas. The counties of Welland and Moulton Twp? have been the most productive from this horizon. (See map, fig. 1) (Harkness, 1927)

Oil

In 1903, six wells were drilled in Onandaga township, east of Brantford, with producing gas horizons in the Whirlpool sandstone (Corkill,1905). As the gas was used, the gas pressure dropped and investigation revealed that oil had oozed into two of the wells. Production was small, for the year 1904, it averaged only eighteen barrels per month and the field soon ceased to exist as an oil producing area.

ORIGIN OF THE WHIRLPOOL SANDSTONE

A review of the literature concerning the Whirlpool sandstone reveals that the problem of its origin has received a great deal of attention.

In 1903, A. W. G. Wilson (Williams, 1919) attributed it to the reworking of a sand dune area by an advancing sea. This interpretation is favored by the character of the grains composing this rock and by its distribution.

Grabau, in 1913, (Williams, 1919), suggested that the 'Medina red sands' and the 'Thorold quartzite' were produced by the erosion of the folded Juniata beds and the Bald Eagle quartzite of the Appalachian region. He observed that "the Whirlpool quartzite is not known at Rochester.....(it) is thus seen to be a local formation, apparently unconnected with any direct eastern source". (Williams, 1919).

Williams (1919) suggested that the shales and sandstones of the Queenston and Medina formations were derived in general from the Appalachian region. The Queenston shales, of late Ordovician time, become more arenaceous toward the east, where they were probably characterised by sand bars of river origin and flood plain deposits of gravel and sand. Sands were deposited in a shallow littoral zone, the shales of the Queenston and finer materials were carried farther out into the shallow Richmond sea. With the retreat of the Ordovician sea to the west (Weller, 1898), shallow water conditions again returned, indicated by the mud-cracked surface of the Queenston shales. The sands from the eastern extensions of the deposits were distributed over the surface of the Queenston shales by winds and gentle currents and reworked by the initial advance of the Silurian sea. Williams (1919) states that "the difficulty in determining the boundary between the Queenston and Medina sandstones eastward from Rochester may be attributed to the poor sorting of the red sandstone of contemporaneous age with the Whirlpool sandstone". According to Williams, the evidence for the reworking of the Whirlpool sandstone consists of:

1. Its comparatively uniform thickness.
2. Cross bedding in part of the beds only, is more regular than that which would be produced by wind deposition.
3. The thin upper beds are interbedded with shales.

4. The sparingly fossiliferous upper beds contain a fauna characteristic of the marine littoral zone.

It is to be noted that the thin upper beds have been included by Bolton (1949) in the base of the Power Glen member and are regarded by him as representing the beginning of a different phase of sedimentation than that which was responsible for the deposition of the Whirlpool sandstone.

In 1929, following a petrographic study of the sediments of the Niagara gorge, H. L. Alling suggested that the sandstone had been derived from a pre-existing sediment, possibly the reworked Juniata-Tuscarora beds of Pennsylvania, as had been postulated by Grabau in 1913.

H. Johnson (1934) recognised the Whirlpool sandstone as a marginal deposit laid down by an encroaching Silurian sea. The materials of the formation he suggested as having been derived from an emergent Appalachian province, probably after Queenston time.

A. Holstein (1934), on the basis of the heavy mineral content, suggested a source for the Whirlpool sandstone in a pre-existing sediment to the south or east of its present location. The qualitative nature of the heavy mineral suite precludes Precambrian terrains as source areas.

In 1940, J. F. Caley, in describing the Whirlpool sandstone, agreed with the conclusions regarding its origin, as reached by Grabau (1913) and Alling (1929).

T. E. Bolton (1949), after reviewing the lithological and petrographic evidence; and the regional distribution of the sandstone, regarded it as "a marginal deposit laid down by the encroaching shallow seas on the undulating and mud-cracked Queenston surface". The material of this deposit was transported by wind and water from the elevated Appalachian province.

The present research is an attempt to show, on the basis of lateral variation of grain size and sorting, that the Whirlpool sandstone has its source to the south and east of its present location. The writer is thus in agreement with the majority of workers who have studied the problem of its origin, and it is hoped that the evidence presented will be such as to uphold their conclusions. That the sandstone has been derived, at least in part, from the erosion of the folded and uplifted Juniata beds of the Appalachian regions appears to be reasonable.

The heavy mineral suite, which would be most likely to provide a clue as to the provenance of a sediment (Dryden, 1946) has been intensively studied by Holstein (1934), who concluded that the heavy minerals present indicate a source in a pre-existing sediment. In this connection, it would be interesting to compare the heavy mineral suite of the Juniata formation to that of the Whirlpool sandstone. Some differences could be expected, especially with regard to the more unstable heavy mineral species and the comparison could probably not be made quantitatively, but if the conclusion that the Juniata beds of the Appalachian region are source beds of the Whirlpool sandstone is correct, the suites of the stable detrital heavy minerals should be very similar.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge the kindness of Mr. A. S. Robertson of the Hydro Electric Power Commission of Ontario, in allowing him access to the excellent exposure of the Whirlpool sandstone at De Cew Falls. He is also indebted to Mr. T. E. Bolton of Toronto University and to Mr. J. J. Crabb of McMaster University, for advice and suggestions in various phases of the work. The assistance of Mr. H. S. Scott of McMaster University, in taking photomicrographs, is also appreciated. The writer would also like to acknowledge the help and interest of Dr. H. S. Armstrong, Head of the Department of Geology at McMaster University, who suggested the problem and under whose supervision this research was carried out.

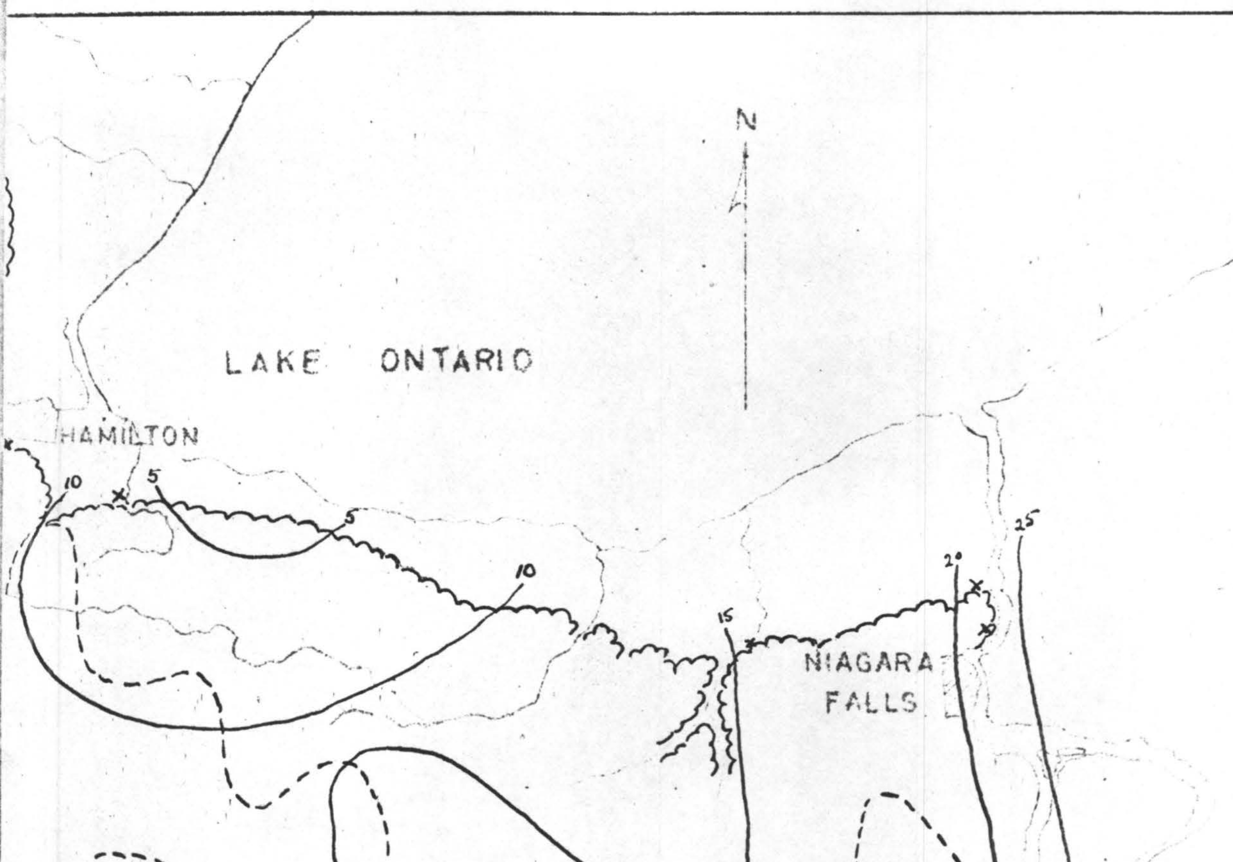
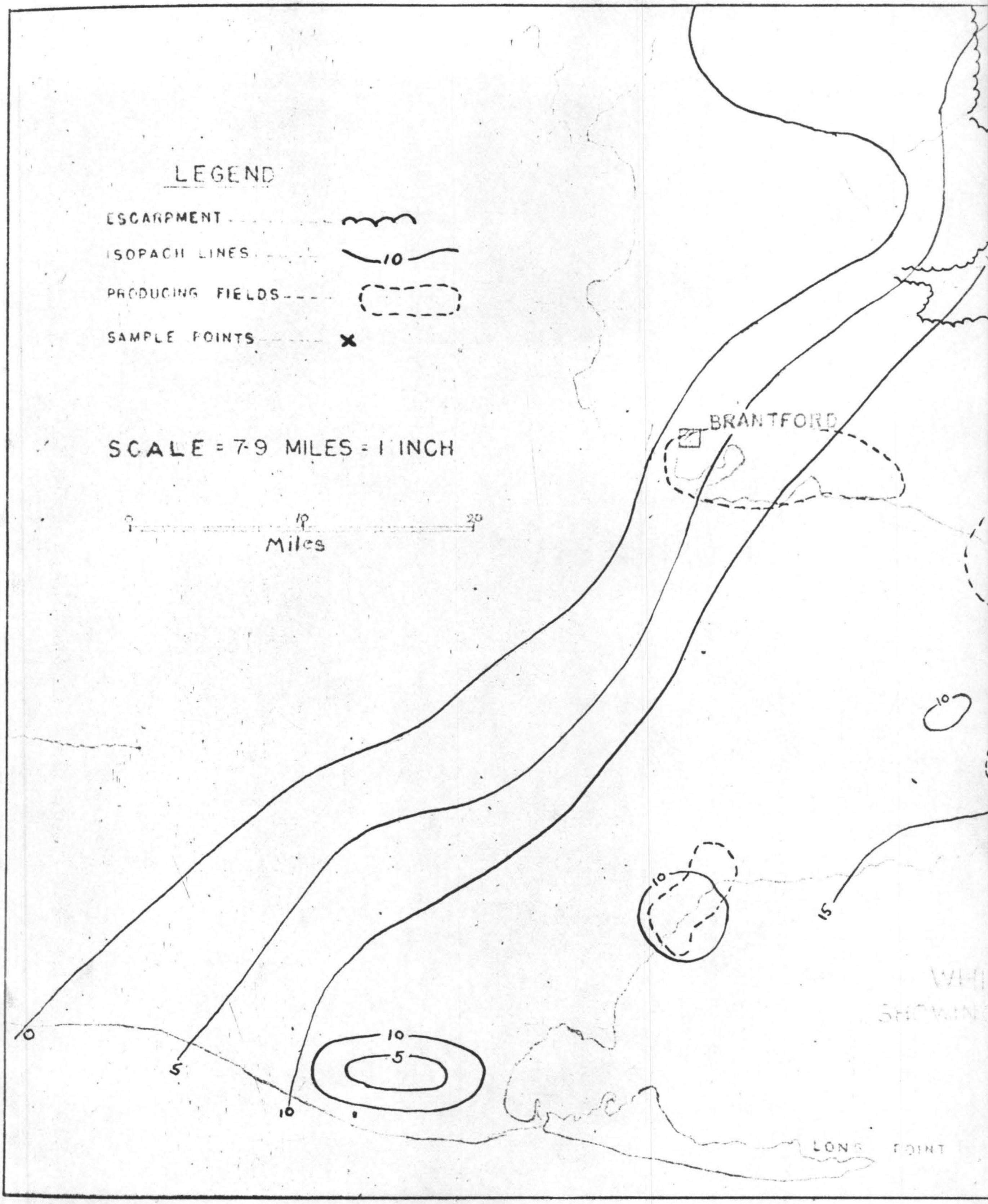


Figure I.

(After Harkness, 1928)



LEGEND
ESCARPMENT
ISOPACH LINES
10
PRODUCING FIELDS
SAMPLE POINTS
SCALE = 7·9 MILES = 1 INCH
0
10
20
Miles
BRANTFORD
LONG POINT
0
5
10
15

PART II

RESEARCH WORK

Field Description

The Whirlpool sandstone is a massive, thick-bedded, light grey, buff-to grey-weathering quartzitic sandstone, locally variable in thickness, resting on the mud-cracked surface of the Queenston shales. It is overlain by the shaly and sandy beds of the Power Glen member in the southeast and by the Manitoulin member toward the north. In the vicinity of Niagara Falls it has a thickness of 25 feet and thins gradually to the north and west, being 12 feet thick at De Cew Falls, 10 feet at Stoney Creek and Hamilton, and in its most northerly extent near Duntroon, it has a thickness of from 4 to 6 feet (Williams, 1919). The thicknesses as given include the interbedded shales and sandstones which Bolton (1949) later included in his Power Glen member.

At all the localities the writer visited, the rocks are irregularly cross-bedded in at least part of their thickness. The presence of thin zones of rolled clay pebbles or mud galls was noted throughout the thickness of the sandstone, both along horizontal bedding planes and along the inclined foresets of the cross bedded phases. (Plate I) H. L. Fairchild (1901), who clearly shows that the sandstone has the characteristics of a beach deposit, states that the clay galls and pebbles are the result of the deposition of fine material by still waters in troughs formed between successive sand ridges. Subsequent erosion and transportation resulted in a certain amount of abrasion and rounding of the aggregates of fine material prior to their redeposition within the sandstone. Alling (1929) observed that this fine material was similar to that of the Queenston shales. The finding of this material near the top of the Whirlpool sandstone presents a problem, particularly because of the extremely friable nature of the clay galls. The suggestion by Alling, that the rolled clay pebbles were derived from the underlying Queenston shale, could possibly apply to those found very near the lower contact of the Whirlpool sandstone. For the presence of rolled clay pebbles higher in the sandstone, the explanation advanced by Fairchild is favored.

Throughout their known extent, the Whirlpool sandstone overlies the Queenston shales with a marked disconformity. The break in sedimentation, together with the faunal differences in the associated fossiliferous strata, have lead geologists in the past to place the Ordovician-Silurian boundary at this disconformity (Kindle, 1914). The lower surface of sandstone everywhere is irregular in its contact with the underlying Queenston shales. (Plate II) This irregular contact may be due partly to the deposition of the sandstones on the mud-cracked surface of the shales and partly to the differential compaction of the shale beneath the weight of the overlying rock, producing what is referred to by Shrock (1948) as 'trail' and 'underplight'.

Sampling Procedure

The purpose of a rock sample must be considered when sampling is undertaken. Different methods of sampling are followed according to the kind of information to be derived from the specimen. In this case the lateral variation of the Whirlpool sandstone with regard to grain size and sorting was to be studied. Specimens were therefore collected from the lower, intermediate and upper beds of the sandstone member, at the following localities: Queenston, Niagara Glen, De Cew Falls, Stoney Creek and Hamilton. While these localities do not provide a general sample of the entire known outcrop of the Whirlpool sandstone, it was felt that they would provide sufficient data to indicate a direction for further research. Specimens were taken only of the massive sandstone. The overlying interbedded sandstones and shales, referred to the base of the Power Glen member, were not sampled for this study.

LABORATORY PROCEDURE

Disaggregation

When dealing with clastic rocks in the laboratory, the worker faces the problem of disaggregation of the indurated rock, should a study of its properties relative to the characters of the individual grains be undertaken. Certain types of sedimentary rocks are more easily dealt with than others, depending upon their composition, the cementing materials, and the degree of induration of the rock.

The Whirlpool sandstone presents particular problems in that it consists of fine-to medium-sized quartz grains with a predominantly siliceous cement. Disaggregation by chemical means was out of the question, since any chemical which would act upon the siliceous cement would also affect the quartz grains themselves. Crushing the rock and screening the crushed material also proved unsatisfactory. The fragments were crushed in a mortar, the grains so produced were sieved and the coarser fractions again crushed until they would pass a 0.991 millimetre screen. Inspection showed that several single grains remained on this sieve, hence it was assumed that this size closely approximated the larger size limit of the individual grains. Continued sieving and separation of the size fractions revealed that a large number of the coarse grains were cemented aggregates of finer grains. This would have had the effect of increasing the proportion of the coarse grains and decreasing the proportion of the finer grains. Further, the crushing was found to produce a large amount of extremely fine material, which either has been cement or has been produced by the crushing and grinding of the grains during the disaggregation. The silica cement adhering to the grains would also have the effect of generally increasing the size of the quartz grains.

An attempt at disaggregation of the sample by heating the rock fragments to glowing and plunging them into cold water to bring about fracturing of the cementing material through differential contraction and expansion, had results similar to those produced by crushing. It was therefore decided that statistics based upon data derived from such disaggregated material would not be reliable. It would prove an interesting research to attempt to discover a method of disaggregating a rock of this nature in such a manner as to reproduce the characteristics of the individual grains as they were prior to cementation. The problem lies in the removal of a cement of the same composition as the constituent detrital material, without affecting the detrital grains.

Because of the uncertainties connected with the breaking down of the rock into material which could be analysed according to grain size, observations were confined to thin section studies with the aid of camera lucida drawings. A method of statistical analysis of thin sections, developed by Krumbein (1935) was followed.

Thin Section Studies

The microscopic examination of specimens of the Whirlpool sandstone reveals a mosaic of interlocking, randomly oriented grains, predominantly of quartz, with some feldspar and a fairly constant suite of heavy minerals. The spaces between the rounded outlines of many of the grains are filled by silica cement, often deposited in optical continuity with the grain itself. Crystal faces are frequently developed by the deposition of secondary silica on the quartz particles, particularly where the rock is porous or where it is cemented by calcite (Plate III). The outlines of the original grains are often marked by rounded, dusty-appearing rims within the outlines of the crystal faces.

The cementing material is composed chiefly of silica, with some carbonate and chloritic material being present.

A specimen from the locality at Queenston showed the presence of biotite, together with glauconite showing quartz inclusions (Plate IV) (Cayeux, Plate 12, fig. 16).

Chert pebbles are fairly common and are generally well rounded. The even grained nature of the specimens indicates excellent sorting of the detrital materials, and the limited nature of the suite of minerals present, as has been determined by previous workers (Alling, 1929; Holstein, 1934; Bolton, 1949), together with the presence of chert pebbles of apparently secondary origin, appears to indicate a source of material in a pre-existing sediment.

Camera Lucida Method

A random section cut through an indurated sandstone will not cut all the grains at their largest dimensions and will result in an apparent average grain size which is less than the true average grain size of the particles. Experimental work with thin sections of the St. Peter sandstone, which is only slightly cemented, together with mechanical analysis of loose grains from the same specimen, showed that the average radius of the grains in the thin section was 0.763 times the average radius of the loose grains. The size of the grains in thin section is taken as the maximum horizontal intercept, a measure which is convenient to apply. More rigorous definitions of grain size, such as the nominal sectional diameter, advanced by Wadell(1935), may be applied when dealing with irregular grains and yield less erratic results. When dealing with the average grain size or with spherical grains, the simple measurement of the maximum horizontal intercept is satisfactory. It is easily seen, however, that this method is difficult to apply to very fine sediments or to sediments which consist largely of particles such as flakes or laths, which depart too widely from sphericity.

In order to measure the grains in the thin sections, camera lucida drawings of known magnification are made of the particles. The data derived from the measurements is presented graphically to show the grain size distribution according to the numberor percentage of the grains. The moments of the distribution of the grain sizes in thin section may be calculated from the tabulated data. These moments can then be converted to the corresponding values of the grain distribution by means of correction factors. The correction factors which are derived by Krumbein (1935), are readily applied to the first and second moments of the grain sizes.

Thus: if Vx_1 = first moment of the thin section
and Vr_1 = first moment of the grains,

then $Vr_1 = \frac{4}{\pi} Vx_1 = 1.27\ Vx_1$

Similarly, if Vx_2 = second moment of the thin section,
and Vr_2 = second moment of the grains,

then $Vr_2 = \frac{3}{2} Vx_2 = 1.50\ Vx_2$

Similar equations have been worked out for the third and fourth moments but they are no longer sufficiently accurate, as they are based on higher powers of the median grain sizes.

The results of this method, which was used with the

St. Peter sandstone, compared well with the results of the mechanical analysis of the same sandstone.

The mechanical analyses of the thin sections of specimens of the Whirlpool sandstone were done by means of camera lucida drawings, with a magnification of fifty-two. The magnification was determined by means of a calibrating micrometer slide. The rounded outlines of the grains were drawn, wherever possible excluding the interstitial cementing material. Crossed nicols were used in order to determine the shape and size of the particles and to facilitate drawing. The outlines of the grains on the camera lucida drawings were measured along their maximum horizontal intercept with a millimetre scale. The number of grains of each size were counted and totalled for each locality. The actual intercepts of the grains were derived by dividing the magnified intercepts by the magnification used. These were then divided into convenient equal intervals for graphical representation. The arithmetic mean diameters of the grains at each locality were also calculated from the tabulated data.

PART III

SUMMARY OF DATA

Size Distribution Curves

The following size distribution curves were drawn up on the basis of the percentage frequency of the grains, relative to the grain sizes present. It may be noted that the actual intercepts of the grains in thin section are used. Plotting the actual grain sizes would not change the shape of the curve to any extent but would result in a slight shift of the entire curve toward the larger grain sizes. The curves may be compared with each other because the data upon which they are based were derived in the same manner for each of them.

An inspection of the curves reveals that, with increasing distance from Niagara Glen, there is a definite change in the degree of sorting and the modal size of the sand grains. This change is mostreadily observed when comparing the curves for Queenston or Niagara Glen to those of Stoney Creek and Hamilton. There is a shift of the maximum frequency toward the finer grain sizes and the spread of grain sizes present becomes more limited as the distance from the Niagara Glen toward the west increases.

These size frequency curves are shown in the following figures 2 to 6.

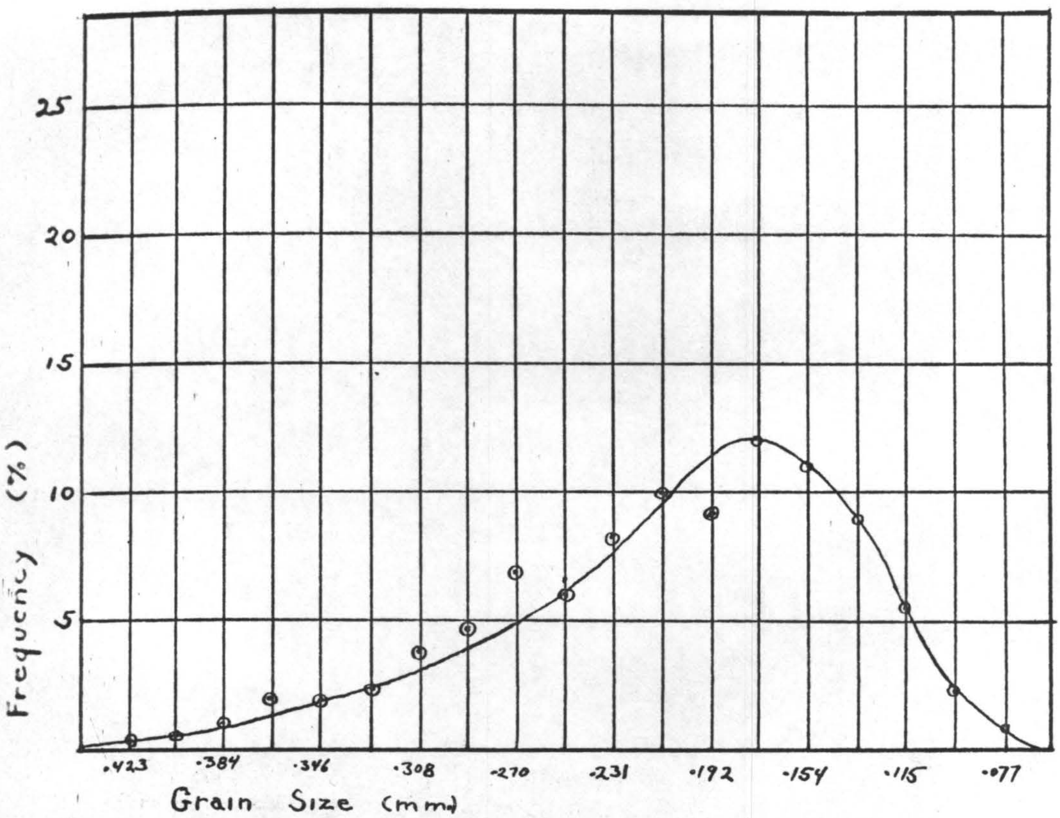


Figure 2

Grain size distribution curve, Niagara Glen locality.

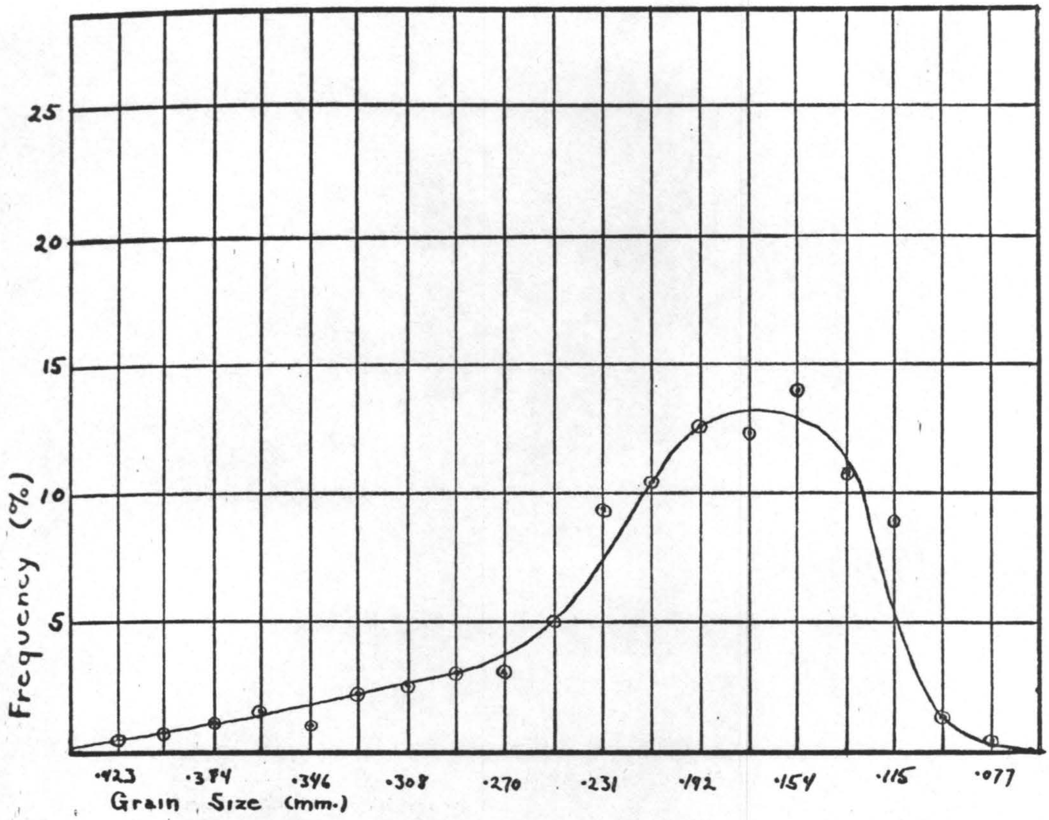


Figure 3

Grain size distribution curve, Queenston Locality.

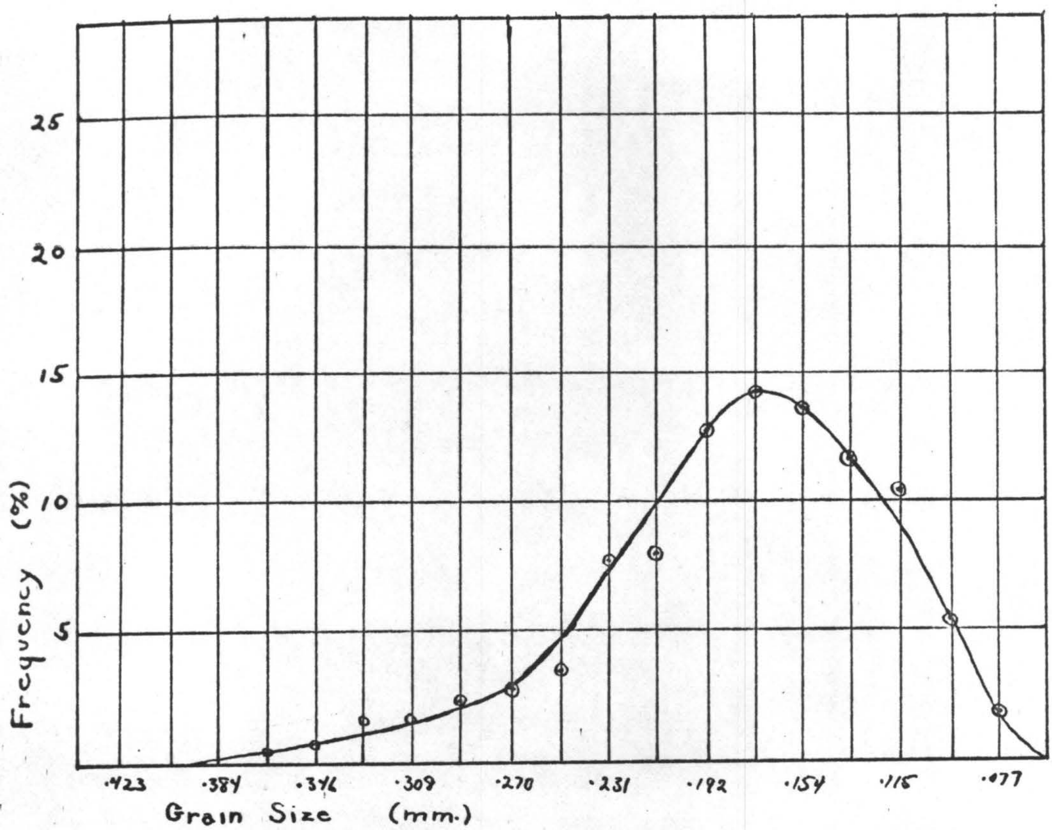


Figure 4

Grain size distribution curve,

De Cew Fall locality.

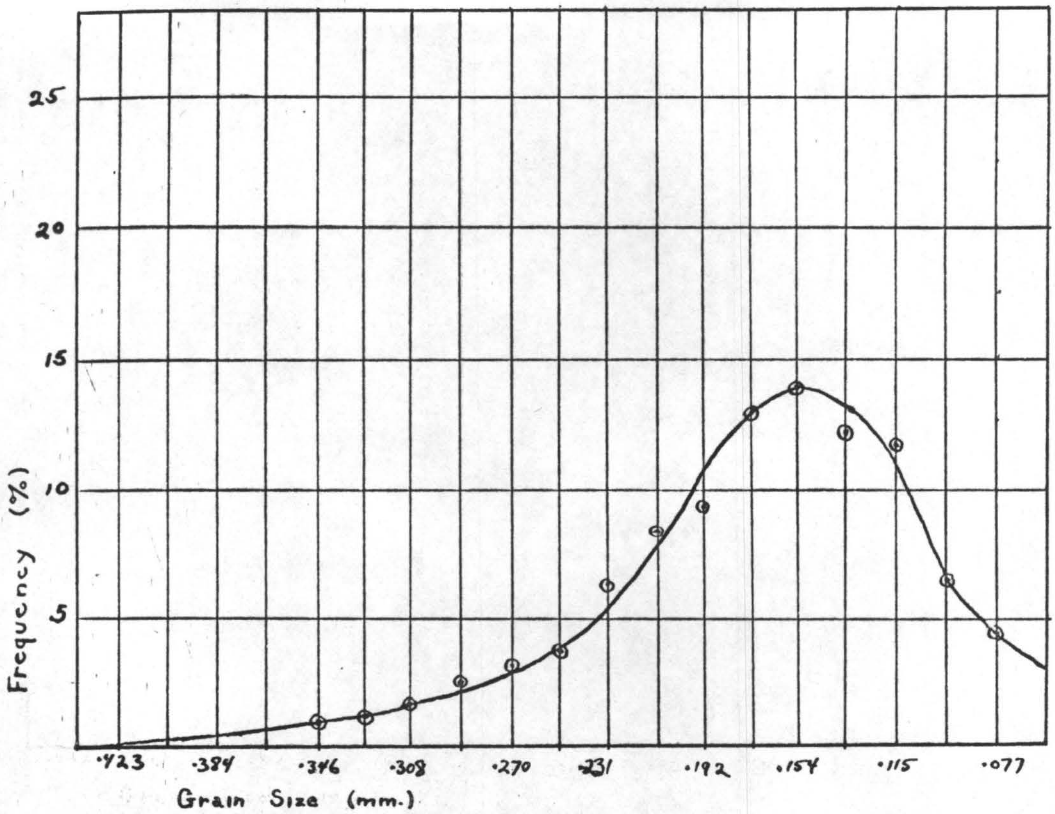


Figure 5

Grain size distribution curve,

Stoney Creek locality.

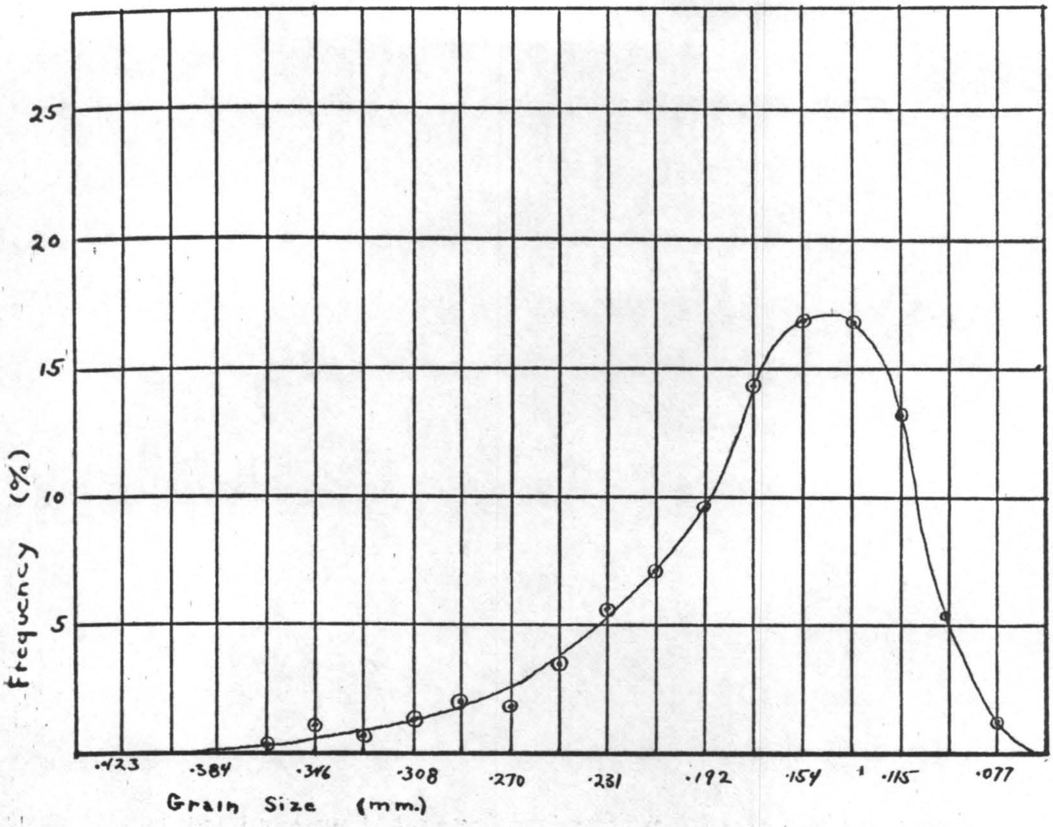


Figure 6

Grain size distribution curve,

Hamilton locality.

Moments of Size Distribution

In order to calculate the median grain size, the data were summarised as in the tables which follow. It is to be noted that the size grades are treated as discreet intervals. For example, the grains were measured as 7 mm. or 8 mm. and these measurements were then reduced to 0.135 mm. and 0.154 mm. respectively. The idea of the continuity of the grain distribution is not conveyed by the data as it is presented. This device was necessary, however, since the data are based on measurements as described above, but it is not to be inferred that grade sizes between 0.135 mm. and 0.154 mm. are not present. The usual method of using weight percentage frequency is not used in the tables. Instead of weight percentage frequency, the number frequency of the grains is used in calculating the median grain size from the data for the various localities.

The following tables show the method of calculation of the first moment of the grain-size distribution:

Niagara Glen

Size Grade	Frequency (f)	Mid-point(m)	f.m
.077 -- .115	83	.096	7.97
.135 -- .172	299	.154	46.05
.192 -- .231	258	.211	54.44
.250 -- .289	166	.270	44.82
.308 -- .346	75	.321	24.07
.365 -- .403	26	.384	9.98
.423 --	11	.455	5.00
	918		192.33

$$\text{The first moment} = \frac{192.33}{918} \times 1.27 = .2654$$

The median grain size at Niagara Glen, on the basis of measurement of 918 grains, is .2654 mm.

Queenston

Size Grade	Frequency (f)	Mid-point (m)	f.m.
.077 -- .115	114	.096	10.94
.135 -- .172	412	.154	63.45
.192 -- .231	359	.211	76.05
.250 -- .289	125	.270	33.75
.308 -- .346	64	.321	20.54
.365 -- .403	35	.384	12.39
.423 --	10	.455	4.45
	1119		221.57

$$m_1 = \frac{221.57}{1119} \times 1.27 = .251$$

The median grain size at Queenston from the measurement of 1119 grains is .251 mm.

De Cew Falls

Size Grade	Frequency (f)	Mid-point (m)	f.m.
.077 -- .115	269	.096	25.82
.135 -- .172	614	.154	94.56
.192 -- .231	431	.211	90.94
.250 -- .289	134	.270	36.18
.308 -- .346	36	.321	11.56
.365 -- .403	15	.384	5.76
.423 --	6	.455	2.73
	1505		267.55

$$m_1 = \frac{267.55}{1505} \times 1.27 = .224$$

The median grain size at De Cew Falls, based on the measurement of 1505 grains, is .224 mm.

Stoney Creek

Size Grade	Frequency (f)	Mid-point (m)	f.m.
.077 -- .115	183	.096	17.57
.135 -- .172	323	.154	48.74
.192 -- .231	198	.211	41.78
.250 -- .289	78	.270	21.06
.308 -- .346	30	.321	9.63
.365 -- .403	5	.384	1.92
	807		139.70

$$m_1 = \frac{139.70}{807} \times 1.27 = .219$$

Median grain size at Stoney Creek, based on the measurement of 807 grains, is .219 mm.

Hamilton

Size Grade	Frequency (f)	Mid-point (m)	f.m.
.077 -- .115	221	.096	21.21
.135 -- .172	519	.154	79.93
.192 -- .231	243	.211	51.27
.250 -- .289	77	.270	20.79
.308 -- .346	22	.321	7.06
.365 -- .403	9	.384	3.45
	1091		183.71

$$m_1 = \frac{183.71}{1091} \times 1.27 = .213$$

The median grain size of the Whirlpool sandstone at Hamilton, based on the measurement of 1091 grains, is 0.213 mm.

The data derived in this manner shows a consistent decrease in the average size of the grains along the Niagara escarpment, from Niagara Glen toward the west, and from Niagara Glen north toward Queenston. The variation along the escarpment, from east to west as far as Hamilton, is presented graphically (fig. 7) to show the decrease in grain size with increase in distance westward from Niagara Glen.

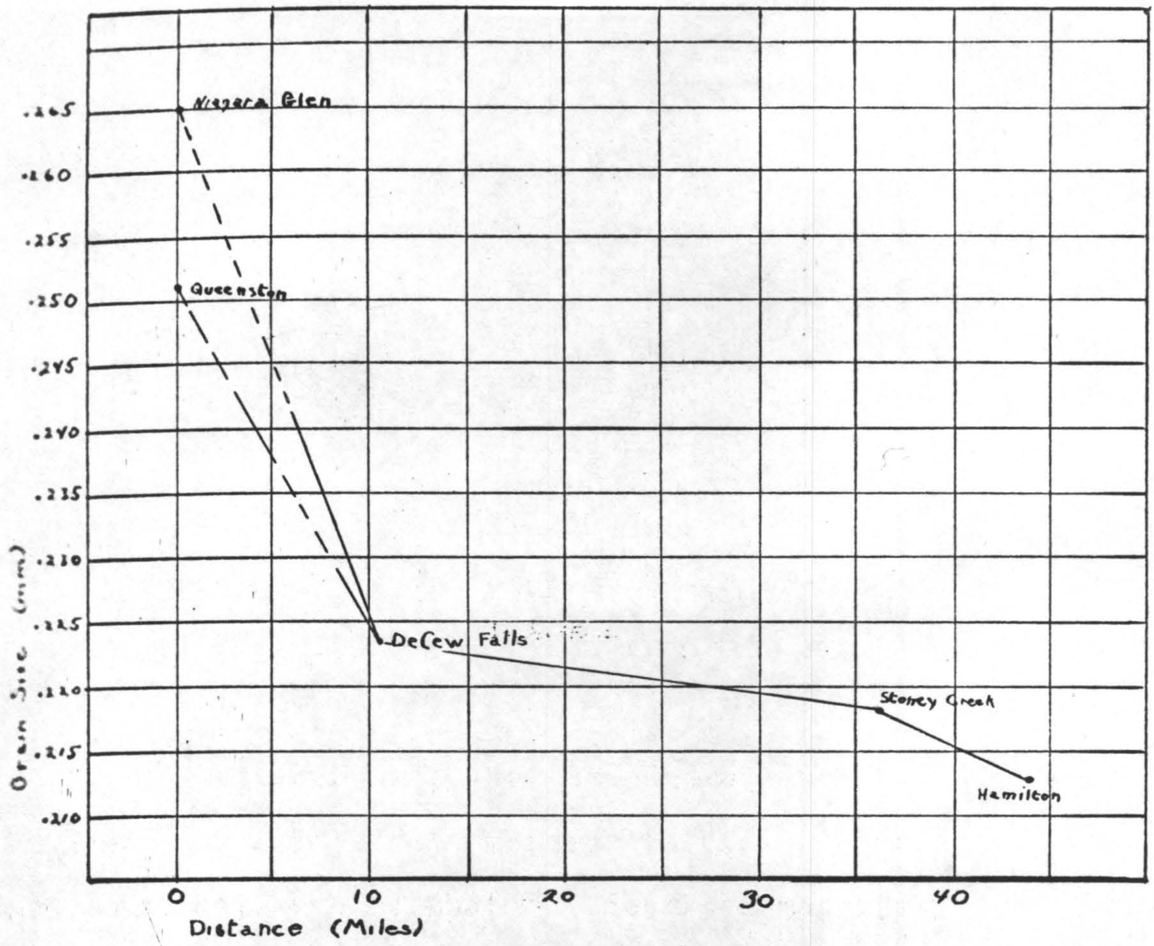


Figure 7

Graph illustrating the decrease in average grain size, as distance west of Niagara Glen increases.

PART IV

CONCLUSIONS

Grain Size

The results of the correlation of the grain size with the distance from Niagara Glen indicates a constant decrease of the average grain size of the Whirlpool sandstone with increased distance westward from Niagara Glen and a decrease in average grain size from Niagara Glen to Queenston in a northerly direction. On the basis of the gradation of sediments from coarse to fine, in a direction away from their source, the evidence shows that the direction of transport of the detrital material of the Whirlpool sandstone has been from the south and the east.

Sorting

Inspection of the curves drawn up for the size frequency distribution of the particles composing the sandstone, reveals that the detrital material is better sorted as the distance from Niagara Glen westward increases.

On the basis of the data which has been summarised above, it appears that the materials of the Whirlpool sandstone have been transported from a source to the south and east of its present location. The coarser materials were deposited nearer their source; the finer materials were carried farther out toward the north and the west. Winds probably played a large part in the distribution and sorting of the detrital materials of the sandstone, as is shown by the frequency of frosted sand grains and the even-grained nature of the sandstone itself. Reworking of the deposit by the waters of the advancing Lower Silurian sea obliterated most of the original features of the deposit and left the sandstone with features definitely suggestive of beach origin (Fairchild, 1901).

The foregoing research and conclusions are based largely on samples taken in an east-west line. The only third dimension included in the sampling was the north-south component from Niagara Glen to Queenston and even this short distance showed a significant change in the median grain size of the sandstone. It would be of interest to secure samples of the Whirlpool sandstone from drill cores taken at varying distances to the south of the Niagara escarpment and plotting the results, either by using "iso" lines on a map, or by representation on a three-dimensional graph. It is the writer's opinion that such a research, employing the same methods as used in the present work, would corroborate the evidence presented here and would even more definitely, show the direction of origin of the detrital material composing the Whirlpool sandstone.

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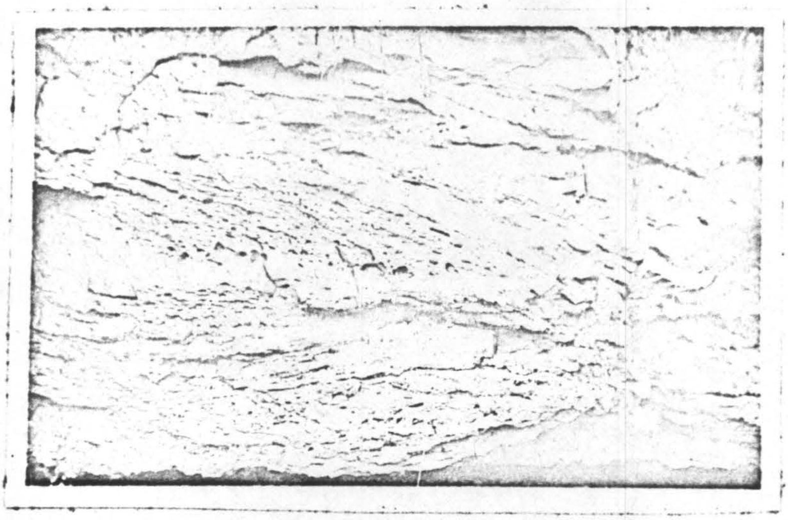
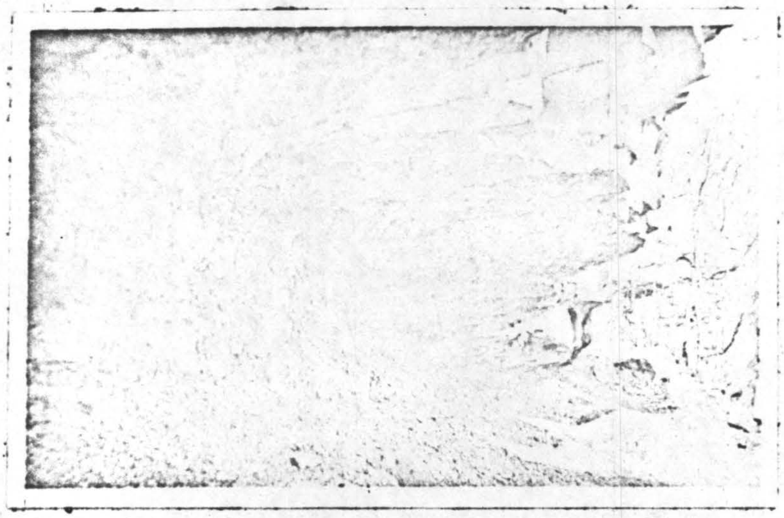
PLATE I



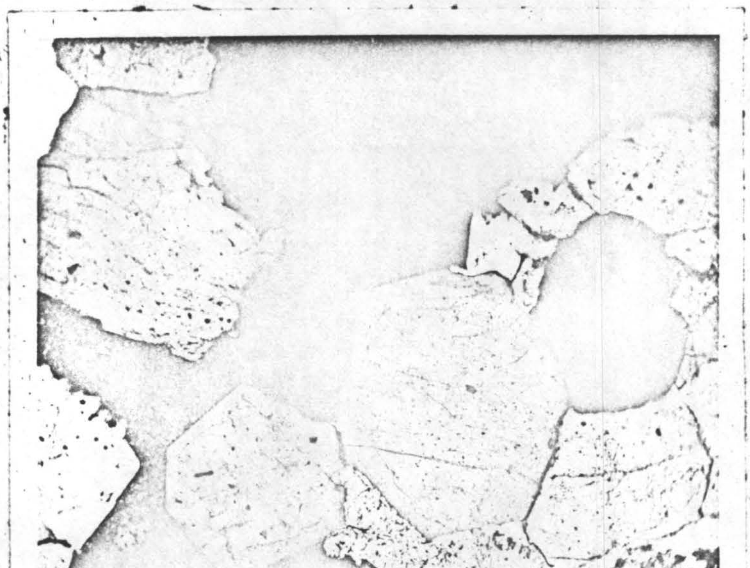
Cross bedding of the Whirlpool sandstone, showing mud galls on the foreset beds. Hamilton locality.

PLATE II



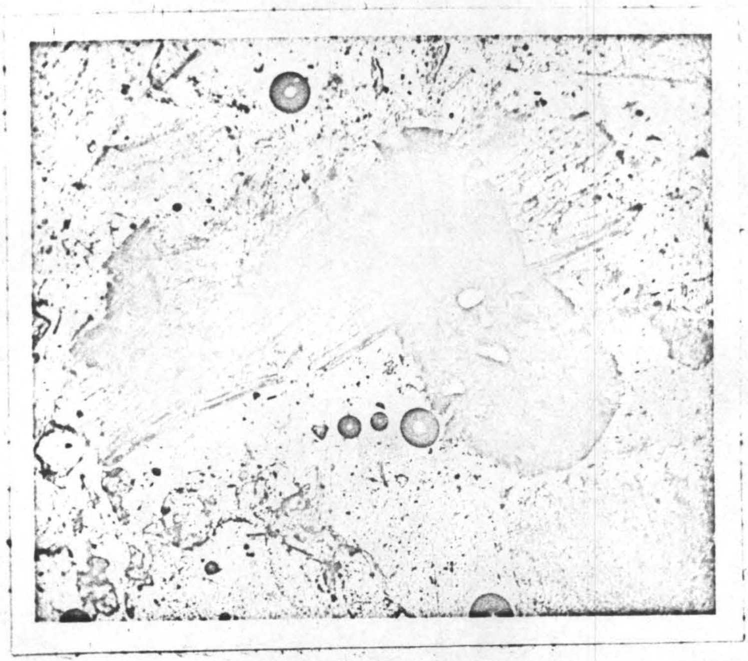
The irregular under surface of the Whirlpool sandstone, resting on the Queenston shales. Niagara Glen locality.

PLATE III



Photomicrograph showing euhedral outlines of quartz grains, caused by deposition of secondary silica. (Crossed nicols; x 52)

PLATE IV



Photomicrograph showing biotite and elongate, rounded grain of glauconite with quartz inclusions. (Plane polarised light; x 52)

PLATE V

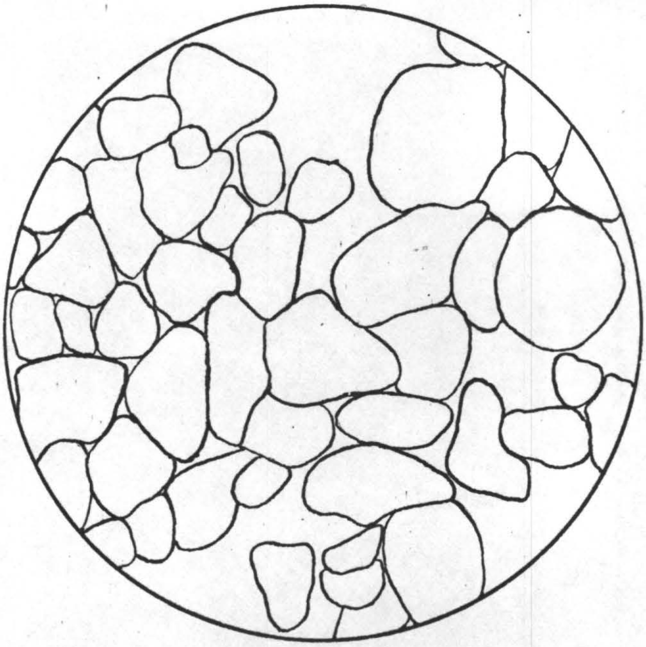


Fig. 1

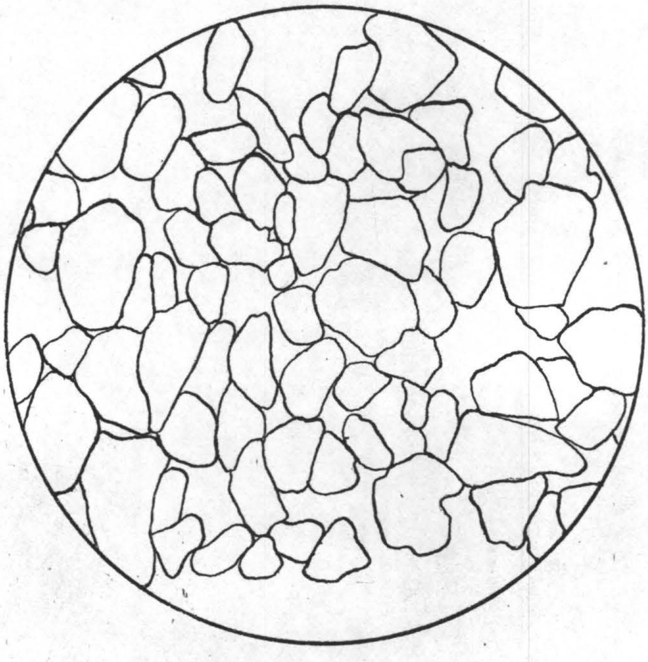


Fig. 2

PLATE VI

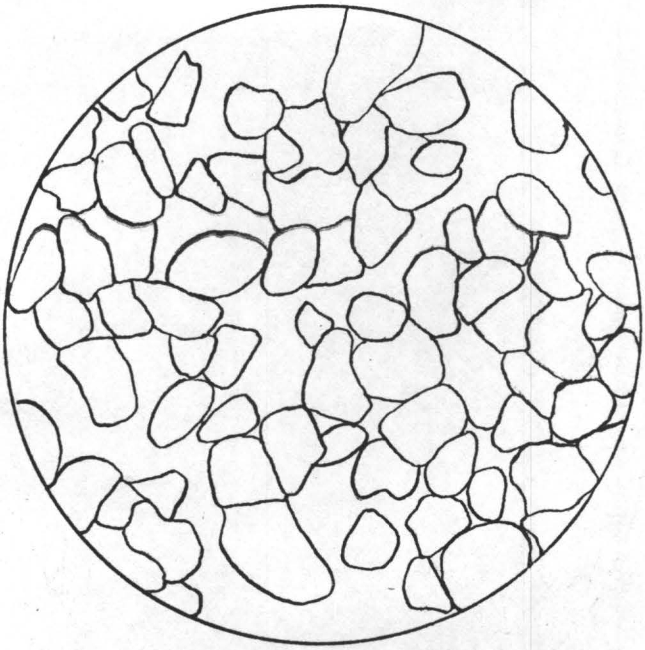


Fig. 1

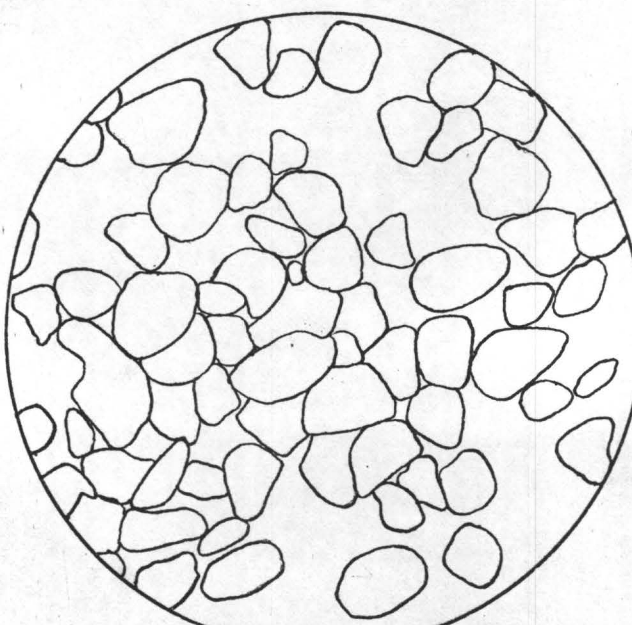


Fig. 2

PLATE VII

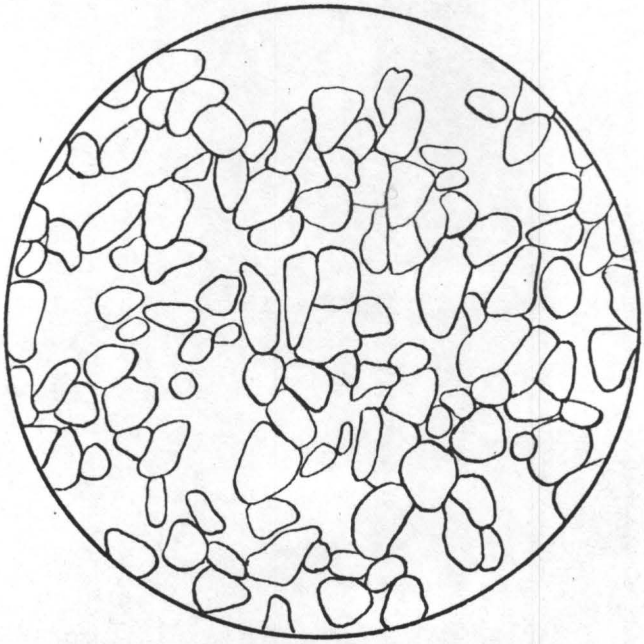


Fig. 1

CAMERA LUCIDA DRAWINGS