Suggested Short Title For Thesis:

"A Study of the Potsdam Sandstone,

Mallet Well, Ste. Thérèse, Que."

by

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A Petrographic Study of Part of the Potsdam Sandstone Core From the Mallet Well, Ste. Thérèse, Québec

by

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INTRODUCTION

General Statement

Essentially, this work is a petrographical study of 504 feet of drill core taken from the top of the Potsdam sandstone at the Mallet well near Sainte-Thérèse, Québec. It is hoped that from this study additional information will be obtained concerning:

1) The original rock types from which the material forming this part of the Potsdam sandstone was derived.
2) The type of weathering undergone by this material and the conditions under which it was deposited.
3) The number of cycles of erosion and deposition represented by the material in the Potsdam sandstone.

The Mallet well and Sainte-Thérèse, 2 miles to the south, are located approximately 15 miles northwest from Mount Royal (Map No.2, Laval Map Sheet in Pocket, Clark, 1952), 3½ miles northwest from the Riviére des Milles Iles and 10 miles southeast from the border of the Canadian Shield (Map No.1). Although the Mallet well represents an unsuccessful attempt to find oil the information contained in the log of this well has been of much help in interpreting the stratigraphy of the area. In drilling, 10 feet of drift, 270 feet of Chazy limestone, 1060 feet of Beekmantown dolomite and 1696 feet of Potsdam sandstone were passed through, the total depth of the hole being 3036 feet (Clark, 1952, pp.142-143). At this point the drill failed and the operations were discontinued.

Sainte-Thérèse and the Mallet well are located on the north side of the St. Lawrence Lowlands. The area is flat and low lying, the elevation at the Mallet well being approximately 225 feet above sea level. A low swampy area occurs 1 mile north of the Mallet well while to the south and southwest the topography becomes slightly more irregular (Laval map sheet in pocket, Clark, 1952).

Analyses of Sediments

General:

Numerous methods and techniques have been developed for the analysis of sediments and sedimentary rocks. As it would not be feasible to discuss all of them here reference will be made to some of the better texts on the subject in which they are described, and only the procedure employed by the writer will be discussed in detail.

The different methods of analysis of sediments may be classified into three main types; chemical, mechanical and mineralogical. Also, since the close of the nineteenth century (Krumbein, 1932), much attention has been given to the statistical representation of the results obtained from analyses in order that the greatest possible information may be obtained from these results.

Chemical:

The chemical analysis of sediments involves the use of chemical methods to determine the percentage of the different elements present in the sample. The results are usually expressed as the percentage of the oxide of the element that is present. Much valuable information on the composition of rocks and rock minerals, including the results of chemical analyses is contained in a bulletin published by the United States Geological Survey (Clarke, F.W., 1924). Mineralographic and microchemical methods are given an excellent treatment in another bulletin of the same survey (Short, 1940). Other chemical methods for determining minerals have been published elsewhere (Krumbein and Pettijohn, 1938; Twenhofel and Tyler, 1941; Milner, 1952).

Mechanical:

The mechanical analysis of sediments has been defined by Krumbein and Pettijohn (op cit), as "the quantitative expression of the size frequency distribution of particles in granular, fragmental, or powdered material". They also state that it does not necessarily involve the actual separation of the substance into grade sizes, nor does it require unconsolidated material. All three works mentioned at the end of the preceding paragraph contain good treatments on the collecting of samples, their preparation for analysis, and the different methods of analysis. The first two works also give a good description of the different statistical methods employed to represent the results.

Mineralogical:

In a mineralogical analysis of sediments the different minerals present are determined as well as their relative proportions in the sediment. Several different methods are employed to separate minerals (Krumbein and Pettijohn, 1938; Twenhofel and Tyler, 1941; Milner, 1952). The separation of minerals of sediments is most commonly effected by the use of heavy liquids and this was the method employed by the writer.

The properties of sedimentary rock minerals are best treated by Milner (1952). The descriptions of the minerals are supplemented by drawings and photomicrographs of typical forms. Additional diagrams and photomicrographs which may be of help are contained in an earlier work in which Milner collaborated with Raeburn (Raeburn and Milner, 1927). Tables have also been published which are often of help in tracking down an unknown mineral (Johannsen, 1922; Cordell, 1949).

A bibliography with abstracts of publications concerning the mineralogy of sedimentary rocks is included in a work by Boswell (1933). The United States Department of

Agriculture (1950) has recently published an annotated bibliography on sedimentation.

METHOD OF STUDY

Megascopic Procedure

Logging of Core:

The top 504 feet of Potsdam sandstone core from the Mallet well was logged in detail with the aid of a hand lens and a binocular microscope. The core lengths had been stamped previously with arrows pointing towards the bottom of the hole, which made the logging more accurate. In addition, the footages from the top of the drill hole and from the bottom of the drill hole (base of the observed section of Potsdam sandstone), were given for the tops and bottoms of the sections of core contained in the boxes. Lengths of missing core had also been noted. In logging the core such properties as cement, colour, cross-bedding, frosting, grain size, sorting, the presence of shale laminae and inclusions, minerals, and the reaction with dilute hydrochloric acid were noted. The grain size was determined with a transparent celluloid millimeter rule.

Selection of Thin Section Specimens:

Specimens for thin section analysis were selected to represent the different facies of the Potsdam sandstone observed in the core. Some specimens were also taken where the likelihood of heavy minerals being present seemed especially good. The thin sections were cut along the axis of the core, almost perpendicular to the bedding.

Heavy Mineral Samples:

Selection. Heavy minerals generally comprise considerably less than one percent of the rock. An attempt was made therefore, to select samples that would yield as large an amount of heavy mineral concentrate as possible. Core lengths of approximately 1 inch were selected for each separation. Different grain sizes were also selected to ascertain if there was any direct relationship between the grain size and the proportion of heavy minerals present.

Crushing. Because much of the core had a siliceous cement and contained quartz grains showing secondary enlargement, it was not considered worthwhile to attempt a mechanical analysis of the grains, although such an analysis could have been made of a considerable part of the core. Therefore each sample for heavy mineral separation was crushed without attempting to preserve the original quartz grains. Different crushing devices were experimented with until a satisfactory device was found.

In the first method to be tried out, the one inch length of core was broken up by passing it once through a laboratory ¼ inch jaw crusher. The crushed rock was then ground down to the desired fineness using an iron bucking board and muller (Taggart, 1951). Although this method is quick, a large quantity of fines were produced even when much care was taken in grinding on the bucking board. A large amount of iron filings were also produced, and although these could easily be removed with a small magnet, the few magnetite and other magnetic mineral grains that were occasionally present stood a greater chance of being lost or overlooked in the iron filings.

A second method consisted in the use of a small electric hand drill fitted with a vibratory attachment with a small mortar and pestle, the pestle possessing a narrow neck over which the vibratory attachment on the drill fitted. Only a minute amount of iron filings were produced by this method; but it was still difficult to control the amount of fines that were produced.

The method finally decided upon was the use of a steel mortar and pestle, the crushing being done by hand with a heavy geological hammer (Plate I). Although this method was a little longer and more tedious than the others, iron filings were rarely produced and the proportion of fines that resulted from the crushing could be controlled to a higher degree. The control of the proportion of fines produced was effected by sifting out the undersize at frequent intervals.

<u>Screening</u>. Screening was carried out by hand on 8-inch Tyler testing sieves. It was desired to select a grade

size small enough for microscopic work, yet large enough to preserve the original shapes of the heavy mineral, or accessory grains. It was also desired not to release inclusions in detrital grains by crushing, for if they were released they might have entered the detrital suite and so lead to erroneous conclusions as to origin and distance of transportation. (Tyler, 1936). It is believed that this happened only rarely at the most, as practically all the inclusions observed were acicular inclusions in quartz grains. After several trials the following screening procedure was selected as the one giving the best results.

A nest of sieves consisting of a 100, 150 and 200 mesh screens with a pan and cover was used, and the specimen was crushed, using the method decided upon above, until all the material passed through the 100 mesh (0.147 mm.) screen. The material that was retained on the 150 mesh (0.104 mm.) screen was used for the heavy mineral separation, while the material that was retained on the 200 mesh (0.074mm.) was kept for reference if necessary. The material that passed through the 200 mesh screen was caught on the pan and discarded as fines.

It was found that the grains of the 100 - 150 mesh grade size gave high interference colours when observed through a miscroscope. This gave a little difficulty until the writer became accumstomed to the increased birefringence. It was also occasionally difficult or impossible to obtain interference figures from strongly coloured grains. On the other hand the original shapes were generally preserved and such properties as cleavage could be observed fully. Smaller grains (-150 mesh) were found to be too small generally from which to obtain interference figures. Also, the heavy mineral grains were often crushed so that the original shapes of the grains were destroyed and other properties such as cleavage were obscured.

Heavy Mineral Separations. Two methods are used to effect a separation of minerals with the use of heavy liquids; the gravity method and the centrifuge method. It has been found that the centrifuge method effects a cleaner separation than does the gravity method, although with care the gravity method can give good results. The results obtained from either of the methods are equally consistent and hence for any one method, the results obtained for different samples can be compared confidently (Rittenhouse, and Bertholf, Jr., 1942).

The gravity method was employed by the writer and the apparatus that was used is shown in Plate I. The separatory funnel was of a simple design with straight sides which made an angle of approximately 13° with the vertical. Bromoform with a specific gravity of 2.87 was used as the heavy liquid medium and benzene was used to wash the heavy and light residues.

Plate I

A - Separatory funnel containing bromoform and sample.
B - Funnel with filter paper for catching heavy residue.
C - Funnel with filter paper for catching light residue.
D - Bottles for catching used bromoform.
E - Used bromoform bottle.
F - Fresh bromoform bottle.
G - Benzene.
H - Tyler screens and brush.
I - Steel mortar and pestle.

A suitable amount of bromoform was placed in the separatory funnel. Because the sample mineral grains were only rarely slightly stained, it was not necessary to treat them before placing them in the heavy liquid. The grains were added to the bromoform in such a way that they were kept away from the sides of the funnel as much as possible.

Care was taken also not to place too large an amount of crushed material in the bromoform, two separations per sample being done if necessary. The grains were stirred frequently, care being taken not to send the light grains too close to the bottom of the funnel and so possibly contaminate the heavy residue. Approximately ½ hour was allowed for the heavy grains to settle to ensure a good separation. The separatory funnel was kept covered to prevent evaporation and the formation of convection currents (Milner, 1952). When the separation was complete the heavy and light residues were drawn off, filtered, washed with benzene and dried. No attempt was made to recover the bromoform from the benzene washings, as the samples were small and only two or three samples were separated at a time. The used bromoform was reused and replenished with fresh bromoform whenever necessary. Cohee (1937) describes a simple, inexpensive method for reclaiming heavy liquids.

In the present case it was not necessary to sample the heavy residues as most, if not all, of each residue was employed in microscopic analysis. Also, as the light residues were generally composed mainly of quartz it was not considered necessary to obtain a representative sample. Errors occur, however, if only a small part of a residue is taken at random for quantitative analysis and several good methods have been put forward to eliminate these errors. One is the microsplit which is a modified form of the Jones ore sample splitter

(Otto, 1933). Another is the rotary microsplitter, in which 16 small glass vials are rotated in a horizontal plane under a steady stream of mineral grains. (Wentworth, Wilgus and Koch, 1934). A third method which takes considerably longer than the above two methods, but requires only four rectangular pieces of smooth paper, each twice as long as they are wide has also been described. (Pettijohn, 1931).

Microscopic Procedure

General:

Microscopic analyses of the thin sections and heavy residues were carried out to determine the minerals present, their characteristic physical and optical properties and the amounts of these minerals present. The results of these analyses are given in subsequent sections.

The methods that were used to determine the mineral frequencies, and the physical properties such as grain size, roundness and sphericity which are due mainly to weathering processes, will now be discussed together with the methods used to tabulate the results. Because some of the methods were used only for one or the other, it is stated whether the method was used for thin sections, heavy residues, or both.

Grain Counts:

The percentages of the different minerals present were determined for each thin section, and for each light and heavy residue that was examined, by the areal method. In this method the percentages are determined by counting the grains of each mineral present in several microscopic fields, making allowances for differences in grain size if necessary. The figures for each mineral are then converted to a percentage of the total number of grains counted of all the minerals. These percentage figures refer only to the relative amounts of heavy minerals that are present in a particular heavy residue and do not refer to the amounts of these heavy minerals present in the original sample. The percentages may be taken as corresponding to percentages by volume, which is not strictly true,for in working with loose grains, the grains tend to lie on a slide with their largest dimensions in a plane approximately parallel to the slide. Thus thin platy mineral grains might appear to occur in larger amounts than a mineral whose grains are more or less equidimensional, although the reverse might actually be true. Also, in thin sections, only two dimensions are seen. Therefore, in making grain counts, allowances were made for these factors. It has been shown that the areal method is very nearly as accurate as the lineal method by Rosiwal, (Thomson, 1930) which is capable of an accuracy of within 1 - 2 percent. The percentages by volume may be converted to percentages by weight if so desired, although it was not considered necessary in the present work.

In examining the thin sections several fields were counted, and as in some cases grain sizes were quite irregular, circular cross section grids were used as aids in determining the percentages of the different minerals present (Thomson, 1930). These grids were drawn so that they appeared to be the same size as the microscopic field and were divided into radial segments. The individual grains were drawn to scale on the grid and the percentages of the minerals present were then determined. As there is a possibility of considerable error in this method, several determinations were made for each slide for which this method was used.

Several fields were examined, and 400 to 600 grains were counted for most of the heavy residue samples. Some of the samples, however, contained fewer than 400 grains and in these cases all the grains were counted. Not quite one-half of the light residues were also examined in this manner.

The technique developed by the writer for counting grains is similar to the method described by Carroll (1941), the differences being largely matters of personal preference. It was found more convenient by the writer to begin the examination of a slide in its northwest corner and then to proceed in approximately straight lines down and up. The examination of each field was begun on the north-south lines of the northwest quadrant and continued around anticlockwise to the same position in the northeast quadrant. The mineral grains were counted in the following order; opaques (ilmenite, leucoxene, limonite, magnetite, pyrite), zircon, tourmaline, and the minor constituents. Reflected light was used for the opaque grains and also for rutile as the physical properties of rutile, such as colour and cleavage, are often more clearly shown in reflected light. Tourmaline also has a characteristic appearance when observed with reflected light, which may be of help in identifying this mineral. Polarized light was used for the other minerals. When the determination of a mineral was in doubt, the refractive indices were determined with the use of refractive index oils. In examining some of the light residues it was occasionally rather difficult to distinguish between quartz and feldspar, so that it was necessary to search for interference figures and perhaps to determine the refractive indices. The use of a staining method, such as the one suggested by Russell (1935), in which malachite green is used might have been more accurate, less tiresome, and perhaps just as quick.

Occasionally, there was insufficient grains of a mineral in a heavy residue to allow the determination of refractive indices without using the same grains repeatedly. The writer used gelatinous slides in a few cases; but these soon became cloudy and it was found to be rather difficult to move grains around on them as desired. Another method that was used was to clean off the slide with benzene so that the grains were caught in a filter paper held in a funnel.

The filter paper was then dried and the grains replaced on the slide. With care a few grains can be used over again several times; however, the method is quite slow and some of the grains are usually lost with each operation. Howard (1932) describes a simple, ingenious device which is essentially a pair of tweezers which have to be forced open instead of shut.

Grain Size:

A micrometer eyepiece, calibrated for each objective of the microscope with the aid of a stage micrometer (Rogers and Kerr, 1942), was used to determine the arithmetical average of the diameters of the grains in each thin section. Each thin section was moved across the field of vision in a direction perpendicular to the bedding, and the long and short diameters of each grain passing along the centre line were noted. The arithmetical average obtained was taken as a measure of the grain size, and the grains were then classed in the corresponding division of Wentworth's size classification, which is reproduced in part in Table I, together with the corresponding symbols that were used in Tables VII and IX. Grain sizes noted in the log of the core also refer to Wentworth's size classification.

There are serious objections to the use of the arithmetical average of the diameters of particles as a measure of grain size (Krumbein and Pettijohn, 1938). As the main purpose in using the arithmetical average was to determine qualitatively whether any relationship exists in the present case between grain size, roundness and sphericity, this method was considered to be adequate for the purpose.

Table I - Wentworth's Size Classification

Name of Particles	Diameter (mm.)	Symbol Used
Pebble	64-4	
Granule	4-2	
Very coarse sand	2-1	
Coarse sand	1-½	a
Medium sand	½-¼	b
Fine sand	¼-1/8	c
Very fine sand	1/8 - 1/16	d
Silt	1/16 - 1/256	e

Abundance of Heavy Residues:

The relative amount of any one mineral that is found to be present in a sample is the frequency of that mineral, and is also referred to as the abundance. For present purposes, however, "abundance" is used to refer to the amount of heavy residue that is obtained from a certain sample. In the present work the samples were not weighed; but a rough estimate was made, of the relative amount of volume, of heavy residue that was obtained from each sample. It is believed that the largest heavy residues that were obtained were not quite 1 percent by volume of the original sample. The estimates were made as follows: Assuming the original core sample was 1 inch in length, 1 percent by volume of this sample would be represented by a slice of core of the same diameter 1/100 of an inch thick; which converted to millimeters is 0.254 mm. As the 100 - 150 mesh grade size, which was used for microscopic work has a mid-point of 0.124 mm. (Pettijohn, 1949), this slice of core, if it were composed of heavy residue minerals would be 2 grains thick. Similarly a slice one grain thick would be 0.5 percent, half of this slice would be 0.25 percent, and so on. A circle was drawn with the same diameter as the core and divided into six radial sectors. The amount of heavy residue was compared with this diagram and the percent was estimated. This was not done with the idea that the value obtained would be even a good approximation to the correct value for it does not account for the heavy mineral grains in the finer grade sizes; but it does provide a quick way of comparing the relative amounts of heavy residues that were obtained from the samples. With this idea in mind an abundance scale was set up as used in Table V and is given below in Table II. Letters were used instead of figures, which are generally employed, in order to avoid confusion with percentage figures.

Table II - Abundance Scale

Symbol	Term	Percent
A	Rare	0 - 0.08
B	Occasional	0.08 - 0.25
C	Common	0.25 - 0.50
D	Abundant	0.50 - 1.0

Roundness:

Roundness has been defined as the ratio of the average radius of curvature of the several corners and edges to the radius of the maximum inscribed circle (Wadell, 1932). As the actual determination of the roundness of the different mineral grains would have been too lengthy, the different mineral grains in the thin sections and heavy residues were compared with a chart given by Pettijohn (1949, p.52)which shows five principal roundness classes. This chart is a modification of a more detailed chart prepared by Krumbein (1941). The values given by Pettijohn to his roundness classes are reproduced below in Table III.

Table III - Roundness Grades

Grade Term	Class Limits
Angular	0 - 0.15
Subangular	0.15 - 0.25
Subrounded	0.25 - 0.40
Rounded	0.40 - 0.60
Well Rounded	0.60 - 1.00

Sphericity:

"The relation of the particle intercepts to each other may be expressed as the sphericity of the particle" (Krumbein and Sloss, 1951, p. 78). It was originally defined by Wadell (1932) as the ratio of the surface area of a sphere of the same volume as the particle to the actual surface area of the particle, which did not prove to be practical. It has been shown also that the sphericity is simply the ratio of the nominal diameter of the particle to the maximum intercept through the particle (Krumbein and Sloss, 1951, p. 79).

True sphericity was not determined; but two dimensional sphericity was determined in the thin section analyses by comparing the grains with a chart (Rittenhouse, 1943 a). The grains were then divided into three sphericity classes which are given in Table IV.

Table IV - Sphericity Grades

Grade Term	Class Limits
Low sphericity	0.45 - 0.65
Moderate sphericity	0.65 - 0.81
High sphericity	0.81 - 0.97

Tabulations of Results:

The results of the analyses are given in tabular form and graphically. Three tables have been set up, one each for the heavy residue, light residue and the thin section analyses. In these tables (Table VII, Table IX, Table XI), the minerals have been listed vertically together with the percentages present in each residue and thin section, whereas the sample number and the horizon at which the samples were taken are listed horizontally. A fourth table (Table XII) was drawn up giving the roundness values of the minerals examined in the heavy residue analyses. Two small tables have been drawn up; one (Table X), to show the general relationship of the abundance of heavy residues to the grain size of the sample, and the other (Table VIII), to show the relationship of roundness and sphericity to grain size.

Several graphs (Graphs I, II, III, IV and V), have been constructed in which the vertical elevation from the bottom of the drill hole is plotted as abscissae and percentage figures are plotted as ordinates. These graphs are based on the information given in the above tables with the exception of the one for quartz. In this case the graph was corrected by examining the drill core in conjunction with the results of the analyses.

Sources of Error

Selection of Samples:

The results obtained for the relative amounts of minerals present in heavy residues and the amounts of heavy residues obtained from the samples would probably have been more representative if larger lengths of core had been selected for analysis. However, as the determinations of the abundance of heavy residues obtained was mainly relative and as certain minerals have a greater tendency to produce fines than others, the samples were sufficiently large for the desired purpose. In selecting the samples an attempt was made to choose those that were believed to contain the greatest amounts of heavy minerals. Therefore, the amounts of the heavy residues obtained from them is probably higher than the average heavy residue content.

Crushing:

A considerable amount of fines was generally produced in crushing. As certain minerals are more easily crushed than others, their relative amounts in the fines would be greater than in the original sample, and their relative amounts in the larger grade sizes (100 - 150 mesh) would be less than in the original sample. Because of this the more resistant minerals would have their relative proportions increased in the 100 - 150 mesh grade scale. It is not known to what extent this latter occurred; but it is doubtful whether the general picture of any of the analyses was changed to any extent.

Heavy Mineral Separations, Grain Counts, Grain Size:

The accuracy of these methods has already been discussed. It should also be mentioned that a few grains of quartz or feldspar were often present in the heavy residues and that a few grains of heavy minerals were usually present in the light residues. The amount of these contaminating grains was never greater than 1 percent and in most cases represented only a trace of all the grains present.

Roundness and Sphericity:

The roundness of pebbles may be determined within approximately 2 percent by using the method of visual comparison (Krumbein, 1941). The same order of error would probably exist in working with grains of microscopic size.

Two-dimensional sphericity values may be estimated by the method of visual comparison to within 0.07 of the values obtained using Wadell's method (Rittenhouse, 1943a). The accuracy of sphericity and roundness determinations was lessened in some cases by authigenic enlargement of the grains.

Mineral Frequencies:

It is known generally that the amount of heavy minerals in sanding stones varies for different grade sizes and that heavy minerals tend to be concentrated within the finer-grained portions. The relative amounts of the minerals present also varies for different grade sizes.

Another factor which must not be forgotten is that a mineral may be removed from or altered in a sediment after the deposition of the sediment. This factor tends to be overlooked or not fully considered in many cases.

Several methods have been suggested to compensate for these and other difficulties. One suggestion is that two grade sizes of each sample be examined. One of these should represent the same limits for all the samples and the second should represent either the same relative grade size within the distribution curves of the different samples (Rubey, 1933), or should occupy a definite position with respect to the size frequency distribution of the sample (Russel, 1936).

As 2/5 of the samples were either finer-grained or only slightly coarser-grained than the 100 - 150 mesh grade size (Table X), the heavy residues from these samples may not have contained the same proportion of heavy minerals as was present in the original sample; although all the heavy minerals were probably represented. A more accurate result for these samples might have been obtained by following either one of the methods mentioned above. The remaining 3/5 of the samples were coarser-grained (medium - very coarse) and the heavy residues probably contained about the same relative proportion of heavy minerals as the original sample.

It must be remembered in representing the heavy minerals as percentages of a heavy residue that an increase in the percentage of any one mineral does not necessarily mean a real increase in the quantity of that mineral. Some idea as to whether a real increase in the quantity of the mineral is indicated may be obtained by comparing the abundance values of the heavy residues involved. If the percentage of one mineral increases at the same time as the abundance value of the heavy residue increases a real increase in the quantity of that mineral is indicated. If the percentages of all the minerals remain practically the same while the abundance of heavy residue increases or decreases, then a real increase or decrease of the quantities of all the minerals is indicated. This method is made much more accurate by weighing the grade size or sizes involved before separation and then weighing the heavy residue obtained from the grade size. By converting the percentages of the minerals present in the heavy residue from volume to weight percentages the amount, by weight, of each mineral in the grade size involved may be easily obtained. The ideal would be to examine

POTSDAM SANDSTONE

General

Previous Work:

The Potsdam sandstone was named by Emmons in 1838 after its occurrence at Potsdam in New York State. Sir William Logan applied the same name to the extension of this formation northward into Canada and also discovered fossil tracks in the Potsdam at several localities (1849, 1851, 1852a, 1852b, 1854, 1860). Some of these fossils were described in detail by R. Owen (1851, 1852) and Billings (1856). In 1863 Logan published his Geology of Canada in which he consolidated his previous works.

Several years later Ells (1895, 1896a, 1896b, 1900, 1901, 1904; Ells and Barlow, 1895), re-surveyed the St. Lawrence Lowlands. He accepted Logan's boundary lines in the Montreal area, but modified the boundaries of the Potsdam sandstone in southeastern Ontario (1904). Ells also accepted Logan's description of the Potsdam and agreed with him on the absence of a break between this formation and the overlying Calciferous sandrock or Beekmantown dolomite (1895). Ami (1896a, 1896b), described some of the fossils collected by Ells.

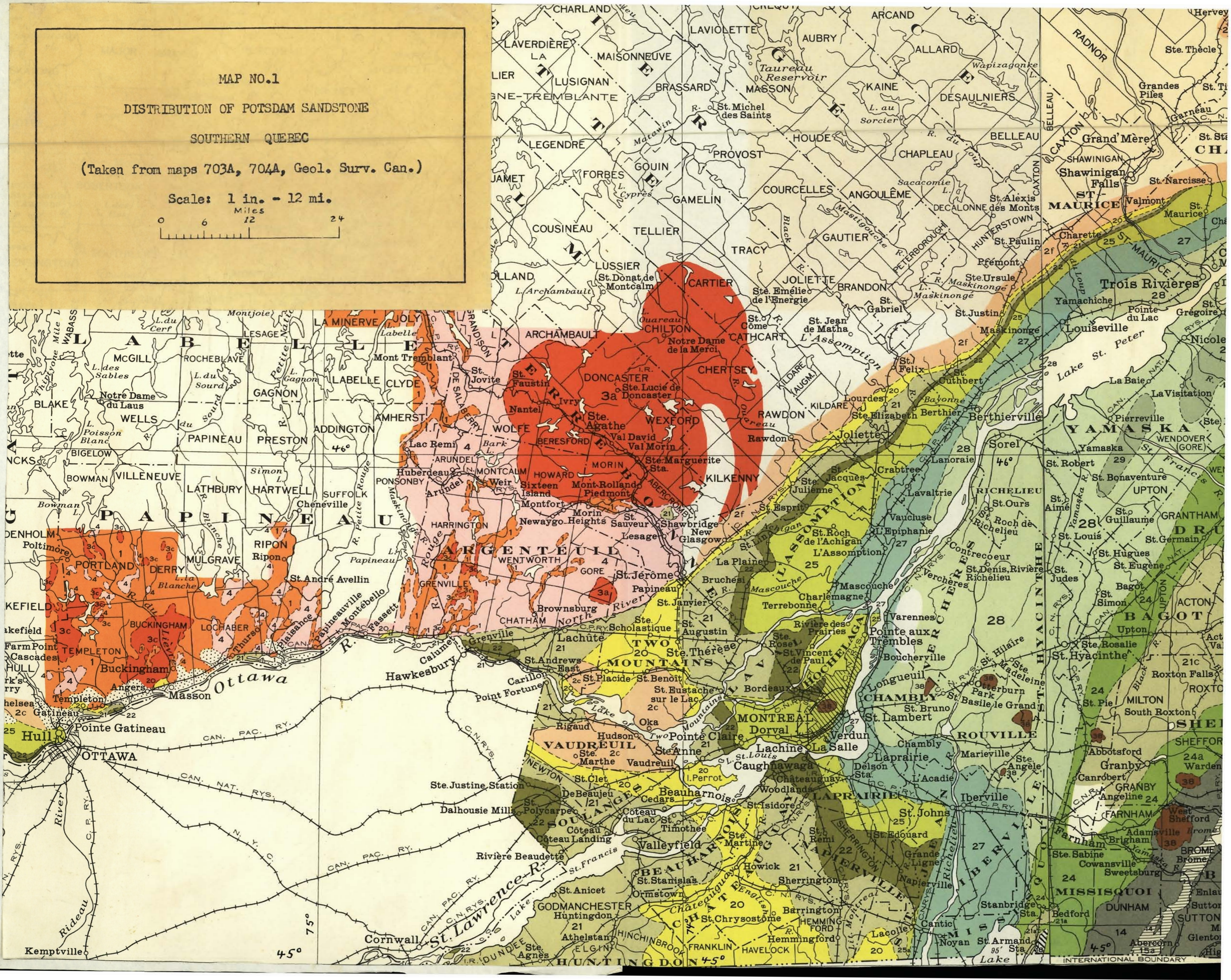
During the next few years several reports were published which added nothing of importance to the information on the Potsdam. Those by Ami (1900a, 1900b), Dresser (1897), Adams and Le Roy (1904), Valiquet (1912), and Raymond (1913) are mentioned for completeness.

The properties of different rock types used for building and ornamental purposes in Quebec and southern Ontario have been discussed by Parks (1912, 1914). Good descriptions of the Potsdam sandstone are given as it occurs at different localities.

Kindle and Burling (1915) have discussed the structural relations of the Precambrian and Paleozoic rocks north of the Ottawa and St. Lawrence river valleys. The use of the Potsdam sandstone as a road building material was referred to by Gauthier (1917, 1919)and Picher (1917) who concluded that it was in general a poor material for such purposes. Several years later Harding (1931) studied the relations of the Grenville sediments and the Potsdam sandstone in eastern Ontario. Parks (1931) stated that the Potsdam sandstone would be an effective reservoir for gas and oil, the drawback being that it lies below any oil forming strata. The origin of the basin in which the Paleozoic sediments were laid down has been discussed also by Osborne (1938). In part II of the same report McGerrigle states that the Beauharnois (Beekmantown group) formation rests disconformably on the Potsdam sandstone. Resser (1938) examined the Potsdam in Quebec and New York State, and in his report discussed briefly the structural relations of the Potsdam to the Precambrian.

Logan's interpretations of the positions of the boundaries separating the different formations remained the standard for the Montreal area until Clark (1939a, 1939b, 1940, 1941, 1944a, 1944b, 1952) began a systematic survey of the area. Clark changed several of the boundary lines and mapped numerous faults trending east-west to southeast - northwest. Logan had recognized the possibility of faults existing in this area although none was mapped by him. Good descriptions of the Potsdam sandstone have been given by Clark in two of his reports (1944b, pp 252 - 255, 1952, pp 17 - 25), and in these reports mention is made of heavy minerals occurring within the Potsdam. Clark and Usher (1948) published a report on the indicated direction of movement of the animal responsible for the fossil tracks occurring within the Potsdam sandstone and known as Climactichnites.

In recent years Wilson (1937, 1941a, 1941b, 1946a, 1946b) has re-mapped the Ottawa - St. Lawrence Lowland, "a well-defined basin within the greater physiographic province of the St. Lawrence Lowlands." (Wilson, 1946b, p. 1). Wilson (1946b, p. 10) has defined the Nepean formation to include all the sandstone in the Ottawa - St. Lawrence basin formerly known as Potsdam, and the overlying Theresa formation as well.



MAP NO.1

DISTRIBUTION OF POTSDAM SANDSTONE

SOUTHERN QUEBEC

(Taken from maps 703A, 704A, Geol. Surv. Can.)

Scale: 1 in. - 12 mi.

Miles

0 6 12 24

LEGEND

(To Accompany Map No. I)

PALÆOZOIC OR LATER

DEVONIAN OR LATER

- **38** — *Nepheline syenite, essexite, related alkaline rocks*

PALÆOZOIC

DEVONIAN

MIDDLE DEVONIAN

- **35** — *Sandstone, shale;* **35**a, *limestone, shale, conglomerate (may be, in part, Silurian)*

LOWER OR MIDDLE DEVONIAN

- **34** — *Granite, syenite*

LOWER DEVONIAN

- **32** — *Shale, limestone; conglomerate*

SILURIAN

MIDDLE SILURIAN

- **31** — *Shale, sandstone, limestone, limestone-conglomerate*

ORDOVICIAN

UPPER ORDOVICIAN

- **29** — QUEENSTON FORMATION: *reddish sandy shale and sandstone*
- **28** — LORRAINE AND RICHMOND: *shale, sandy shale, dolomitic limestone;* **28**a, LORRAINE AND UTICA: *shale, impure limestone, etc.;* **28**b, *mainly Lorraine, but includes some Trenton and probably some Collingwood and Utica*
- **27** — COLLINGWOOD AND UTICA: *impure limestone, shale*

MIDDLE AND UPPER ORDOVICIAN

- **26** — *Slate, quartzite, limestone*

MIDDLE ORDOVICIAN

- **25** — BLACK RIVER AND TRENTON: *limestone;* **25**b, *Black River not known to be present: limestone;* **25**c, *Trenton: limestone, shale, limestone-conglomerate;* **25**d, *limestone, shale, etc. (may include earlier Ordovician)*

LOWER AND MIDDLE ORDOVICIAN

- **24** — *Shale, slate;* **24**a, *includes some earlier Ordovician strata*

LOWER ORDOVICIAN

- **22** — CHAZY: *limestone*
- **21** — BEEKMANTOWN: **21**, *dolomite, some limestone and shale;* **21**a, *limestone, some dolomite, a little shale;* **21**b, *shale, limestone, limestone-conglomerate;* **21**c, *slate, sandstone, quartzite, limestone-conglomerate, and, in places, younger Ordovician strata*

CAMBRIAN OR ORDOVICIAN

- **20** — *Sandstone*

PRECAMBRIAN (?) AND PALÆOZOIC

- **17** — *Ordovician or younger: peridotite, pyroxenite, basalt, etc.;* **17**a, *porphyry, quartz porphyry, diorite, etc. in part schistose; and sedimentary rocks*
- **16** — *Ordovician (?) and, in places, Cambrian (?): slate, calcareous slate, greywacke, sandstone, quartzite, conglomerate*
- **15** — *Ordovician (?) or older: lava, tuff, clastic sedimentary rocks;* **15**a, *lava, tuff, possibly Precambrian*
- **14** — *Ordovician, Cambrian, and, possibly in part, Precambrian: slate, sandstone, dolomite, quartzite, sericite schist, mica schist, chlorite schist, lava*

PRECAMBRIAN

- **4** — *Granite, syenite, granodiorite; granite-gneiss. May not all be younger than* **3**
- **3** — **3**f, *anorthosite, gabbro. May not all be older than* **4** *nor younger than* **2**
- **2** — **2**b, *garnetiferous gneiss, schist, granite, granite-gneiss (sedimentary gneiss predominating);* **2**f, *undivided Precambrian rocks*
- **1** — GRENVILLE SERIES: *crystalline limestone, quartzite, quartz-biotite schist, gneiss; minor granite, granite-gneiss, and basic intrusions*

Drift-covered area ....

Distribution and Structure:

The exposures of Potsdam sandstone in Ontario and Quebec have been described by Logan (1852a, 1863, pp.87-96),Ells (1895, 1901, 1904), Parks (1912, pp.121-139; 1914, pp.117 - 123), Wilson (1946b, pp. 11 - 12), and Clark (1952,pp.18 - 19). It has been noted that its occurrence is discontinuous, as in some localities younger Paleizoic sediments rest directly upon the older Precambrian gneisses, with the Potsdam missing. Map No. I has been prepared, by joining adjacent portions of maps 703A and 704A of the Geological Survey of Canada, to show the areal extent of the Potsdam sandstone in Quebec. A narrow band of Potsdam is also shown in the lower left corner of Map No. II (Laval map sheet in pocket, Clark, 1952).

Commencing from the east the Potsdam sandstone first occurs in Quebec approximately 12 miles north of Three Rivers. To the east of this point the Precambrian gneisses are in contact with younger Paleozoic sediments. To the southwest the Potsdam sandstone occurs as a narrow, irregular band as far as Papineau, just south of St. Jerome. This band is generally not more than a mile or so in width. West of Papineau, along the Ottawa river, the Potsdam sandstone occurs as a few isolated outcrops as far as Des Chats Lake, approximately 35 miles west of Ottawa. At Papineau, the band of Potsdam sandstone swings southward and broadens into an anticlinal fold, the axis of which known as the Oka anticlinal axis (Clark, 1944b, p. 254), trends a little east of south. At St. Benoit, where the band again comes in contact with the Precambrian basement, it is over 12 miles wide. From this point to the southwest tip of the island of Montreal the structure is more complicated. A band of sandstone extends westward from Ile Perrot to the provincial boundary where it extends into Ontario. From Ile Perrot southward the Potsdam sandstone again occurs in a broad anticlinal fold the axis of which, called the Beauharnois axis, extends north-south and is the extension of the Oka axis to the north. Logan first mentioned the Beauharnois anticline i n 1851. "The anticlinal axis can be identified by a change in dip about two miles west of the Beauharnois canal power house." (Clark, 1952, p. 22). At Beauharnois the Potsdam band is approximately 7 miles across. To the south it first narrows and then broadens rapidly until it is over 25 miles in width at the point where it crosses the international boundary. Near Montreal the Northern limit of the area containing exposures of the Potsdam sandstone is the Sainte-Anne-de-Bellevue fault along which the north side has moved down relatively to the south side, thus dropping Beekmantown dolomite down to the same level as the Potsdam (Clark, 1952, p. 21).

Wherever the contact between the Potsdam sandstone and the underlying Precambrian gneisses has been observed, the Potsdam fills irregularities in the surfaces of the gneisses. In these localities, wherever the bedding deviates from the horizontal, the dip is practically always away from the gneisses

(Clark, 1944b, p. 254). In most of its exposures the Potsdam sandstone is approximately horizontal. Dips are rarely greater than 5° (Ells, 1895; Clark, 1952, p. 21).

"Wherever the Potsdam sandstone is succeeded by younger strata, these are always the dolomites of the Beekmantown group" (Clark,1944b, p. 255). It would appear that in some localities the two formations grade into one another, whereas in others they are disconformable. Among those who considered the Potsdam sandstone and Beekmantown dolomite to be conformable are Logan (1852, 1863), Ells (1895, 1896a), Ells and Barlow(1895, and Cummings (1915). They considered the Theresa formation to be the "passage beds", or the gradation of the Potsdam sandstone into the Beekmantown dolomite. Wilson (1946) considers the Nepean sandstone and Beekmantown dolomite to be conformable. Most of the recent workers in Quebec consider a disconformity to exist between the Potsdam formation and the Beekmantown group (Parks, 1931, p. 15; McGerrigle, 1938, p. 43; Clark, 1944b, p. 282; 1952, p. 125). As the present work involves only the top 504 feet of Potsdam sandstone core from one drill hole the writer is in no position to express an opinion on the subject. However, one of the reasons given for the existence of such a disconformity by some of its proponents, is the presence of many wind-blown, rounded, frosted and occasionally pitted sand grains in the Theresa formation, whereas the Potsdam formation is made up mainly of angular, bright, waterborne grains. In the examination of several thin sections from the top 504 feet of Potsdam sandstone from the Mallet well drill core, the writer found good evidence (Plate XII, fig's 1,2) that most of the sand grains that are now angular owe this angularity to authigenic (secondary) growth subsequent to deposition, and that most of the grains were originally rounded to well rounded. In such cases the individual grains have generally been cemented firmly together by silica. When such a rock is broken, the break tends to extend right across the grains so that they would appear bright and angular. Another suggestion is that a very thin coating of secondary silica would probably reduce the roundness of the grains somewhat and cover up the dull, frosted surface so that the grains would appear bright and shiny. At the same time, as only a relatively small amount of silica had been added, the rock would not necessarily be well cemented. Because of its dolomitic cement the sand grains in the Theresa formation would have little chance to become enlarged by authigenic crystallization of silica. The writer does not mean to suggest that a disconformity does not occur between the Potsdam formation and the Beekmantown group; but that the relative rounding and frosting of the grains as they are now observed may not be of much use as an indication that one does exist.

Description:

Good descriptions of the Potsdam sandstone have been given by various writers, among which are Logan (1852a, 1863), Parks (1912, 1914), Clark (1944, 1952), and Wilson (1946b).

The information given below applies principally to the Potsdam sandstone in Quebec, and has been taken mainly from the reports mentioned above.

The Potsdam sandstone is predominantly a white sandstone containing over 99 percent of quartz grains. According to the definition given by Krumbein and Sloss (1951, p.130) the Potsdam may be called a pure quartz sandstone. It is rarely, grey, blue-grey, buff, yellow, brown, pink, reddish or greenish. The grain size ranges from a conglomerate with pebbles up to 6 inches in diameter (up to 2 feet in diameter in eastern Ontario - Ells, 1904), to a fine siliceous shale, although most of it is a hard, even, fine-to coarse-grained, pure quartz sandstone.

The rock is commonly bedded with the thickness of the beds ranging in size from paper-thin laminae to beds 4 feet thick, although few are greater than a foot thick. The bedding is shown by changes in colour and grain size. Beds of conglomerate commonly occur at the base of the formation and contain pebbles and boulders of the underlying Predambrian gneisses. Cross-bedding is nearly always present, although in places the bedding is remarkably uniform. Ripple marks are common and mud cracks are present occasionally. Fossils are rare, although locally Scolithus, presumably a worm burrow, are common. The quartz grains are commonly rounded and frosted; but the greater number of them are angular, bright, water-borne grains.

For the most part the Potsdam is cemented by silica and is a good orthoquartzite; but in places, particularly near the top, calcite and dolomite act as cementing agents, while in a few places iron oxide or a white argillaceous material cements the grains together. In places the grains are so poorly cemented that the rock crumbles easily in the fingers.

In addition to quartz, a few feldspar grains are occasionally present, though rarely in sufficient amounts to make the rock a feldspathic sandstone (Picher, 1917). Thin beds of siliceous shale are present, but rare, although minute black laminae are common. Some layers contain microscopic grains of heavy residue minerals such as garnet and magnetite. Pyrite, biotite, kaolin, limonite, and flakes of shale are common locally.

Thickness:

According to present knowledge the Potsdam sandstone in Quebec ranges from 0 to 1,696 or more feet in thickness, the latter figure being the thickness of Potsdam drilled through in the Mallet well at Sainte-Thérèse without reaching the base of the formation. Although outcrops are scarce it has been established that "within several scores of miles of Montreal, the sandstone is rarely more than 200 feet thick, and nowhere more than 600" (Clark, 1952, p. 22). Throughout most of the area in Quebec underlain by it, the thickness of the formation probably ranges from zero to only a few hundred feet, the greatest measured thickness being at Covey Hill (formerly Hemmingford Mt.), along the international boundary 33 miles south-southwest of Montreal, where it is said to be 540 feet thick (Logan, 1863, p. 88).

Clark (1952, p.22) concluded that the 1,696 feet of Potsdam sandstone logged in the Mallet well was a local development "over a restricted and specialized topography". In explaining the occurrence of this thickness of sandstone Clark (1952, fig. 2 and p. 24) says that it "can best be explained as the result of the filling of a channel or gorge which had been dug in the old "peneplain", or of a structural depression antedating the deposition of the Potsdam sandstone. Clark (1952, p. 24) also concluded that there was a relief of at least 3,000 feet on the old surface, so that at least locally the old surface possessed a relief comparable to that of the present Laurentians. The writer is unable to suggest a better explanation of the abnormal thickness of Potsdam sandstone encountered in the Mallet well.

<u>Fossils and Age of Potsdam:</u>

For the most part, the Potsdam sandstone is devoid of fossils. The few fossils that have been found in the Potsdam have been described by Logan (1852, 1863), Owen (1851, 1852), Billings (1856), and Clark and Usher (1948). The worm burrow <u>Scolithus</u> is common in some of the beds, and the giant trails Climactichnites and Protichnites have been observed in a few localities. A poorly preserved fragment of a trilobite was found in the core from the Mallet well (Clark, 1952). Lingulella acuminata is also known to occur, and, on th the basis of the presence of this fossil and on the existence of a disconformity between the Potsdam formation and the Beekmantown group, the Potsdam is generally considered to be Upper Cambrian, although it may in part be Lower Ordovician.

The age of the Nepean sandstone, which is probably of the same age as the Potsdam, has been discussed by Wilson (1946b, pp 16 - 17), who believes that the Nepean sandstone was probably deposited in earliest Ordovician times. One reason given for this conclusion is the absence of any apparent break or disconformity between the Nepean formation and the Beekmantown group. Also, the evidence from fossils is considered to be too indefinite for exact correlation.

Uses:

The Potsdam sandstone has been used for building stone, and the Nepean sandstone, which has better prerequisites, is still used for building. Formerly, the Potsdam sandstone was used for road material; but it was found generally to be unsatisfactory.

At the present time the St. Lawrence Alloys Company at Melocheville uses Potsdam sandstone in the production of ferro-silicon (Clark, 1952, p. 25). Certain beds of the Potsdam are pure enough for use as glass sand.

The Mallet Well

General:

The following discussion is based mainly on a megascopic examination of the top 504 feet of Potsdam drill core from the Mallet well. In some instances, however, information obtained from microscopic studies has been used wherever it helps to round out the picture.

Rock Type. As it is observed in the top 504 feet of Potsdam sandstone core from the Mallet well, the Potsdam is predominantly a white, cross-bedded sandstone, with quartz grains making up approximately 98 percent of the rock (obtained from Graph No. 1, p. 37). According to the definition given by Krumbein and Sloss (1951, p. 130)the Potsdam may be called a pure quartz sandstone. Rarely, fine-grained conglomerate bands occur, never more than 5 inches thick. Shale bands are equally rare, and have a maximum thickness of 1 foot 8 inches, but are usually less than one inch thick. Shaly partings and smears, or wisps, are uncommon.

Colour. The rock is predominantly white, but in places it is light-grey or rust-coloured. More rarely it is buff, yellowish, reddish, pale-green to green, greenish-grey or grey.

The rust colour is often distributed in bands or spots and is probably formed by the weathering of authigenic crystals of pyrite or of a ferruginous carbonate. The various shades of green are observed mainly in the shaly bands; but are sometimes observed in the matrix of the quartz sandstone where the green colour is due mainly to the presence of chlorite and clay minerals. In one or two cases the green colour may be caused by a stain. The greatest variations in colour occur toward the base of the 504 foot core section. A detailed log of this section is given in the appendix (pp. i - xxxix).

Grain Size. The grains range in size from granules up to 4 mm. in diameter, with rarely a few small pebbles up to 12 mm ($\frac{1}{2}$ in.) in diameter down to particles of clay size (0.0017 mm.). Most of the grains, however, are of fine to medium sand grain size. (Table VII).

Rounding and Frosting. Rounded and frosted (presumably wind-blown) grains occur practically throughout the core (Appendix, pp. xxxviii - xxxix), and make up the bulk of the rock in 217.5 feet of the core, whereas 250.5 feet of the core contains mainly subrounded to angular vitreous grains. Much of the angularity and brightness shown by grains in the latter group appear to be due to authigenic crystallization of silica, so that probably much more of the rock than now appear was originally composed of rounded frosted grains. In addition to being frosted many of the grains are pitted.

<u>Bedding and Inclusions.</u> Bedding is practically always apparent and shows up because of changes in colour and grain size, the individual beds ranging in thickness from paper-thin laminae to massive beds approximately 3 feet thick. Most of the beds are composed predominantly of fine-to medium-sized sand grains, these two grain sizes being commonly interbedded. Cross-bedding is nearly always present, although a few massive beds are present and some of the beds of shale possess uniform bedding. Assuming the drill hole to be vertical, dips range from horizontal to a few degrees in regular bedding and up to 35 degrees in cross-bedded parts, although the dip in the latter is generally considerably less.

Thin beds of shale occur throughout, but are particularly abundant in the basal part of the core and range in thickness from minute laminae to a bed 1 ft. 8 in. thick at an elevation of 1243.5 feet above the bottom of the drill hole. Usually the beds are less than 1 inch thick. The shale is commonly thinly laminated and frequently containes small inclusions of white quartz sandstone. Grains of quartz ranging from fine grained to granular are also common in the shale. Many tiny sericite flakes and pyrite crystals are frequently observed on the face of shale partings much of the shale being somewhat calcareous.. What appears to be a lamina of calcite occurs at an elevation of 1452.5 feet above the bottom of the drill hole. In another place the outline of a minute black lamina resembles a stylolitic structure which may have been caused by differential settling of the sand grains prior to cementation, by pressure solution along the boundaries of the grains (Pettijohn, 1949, p. 481), or it may be the result of the solution of a lamina of limestone. At 1244 feet, what may be a band of chert 1 inch thick occurs approximately 2 feet below lamprophyre intrusions of alnoite (principally biotite, olivine, pyroxene and/or hornblende, melilite; feldspar free) and vibetoide (principally hornblende, titanaugite, titaniferous magnetite, apatite; lacking in olivine, biotite, melilite). More probably it is very fine-grained quartz sandstone that was recrystallized by the instrusions.

Flakes and nodules of shale up to a maximum of 1 inch across, in some cases calcareous, occur at various horizons. A large number of these inclusions appear to have been rolled and possess wispy terminations. It is possible that a thin bed of shaly material was laid down on the sand and then slightly indurated. Later due to changed conditions, this shaly band was broken up and largely destroyed, except for a few particles which were rolled or transported, a short distance at the most, before coming to rest in a little hollow, or some place where they were protected from erosion. These particles were then covered up by sand grains and hence were preserved. Several inclusions of sandstone occur in these shale flakes and nodules. These may have been picked up by the rolling shale particles and rolled up into them, although they may have been present in the shaly band before it was broken up.

As mentioned on p. 42, the shale laminae and beds frequently contain small inclusions of white quartz sandstone. The writer believes that these inclusions may have been broken from a main body of sand grains, which were at least poorly cemented together, and then deposited in the shale during times when wave action was more intense, as for instance during a storm. These sandstone inclusions are generally fine-grained which may indicate that they were broken from a bed of sandstone occurring adjacent to the area where the shale was being deposited. Probably the shale beds containing the sandstone inclusions are only local lenses which were deposited in depressions in the sand.

Sorting. Mineralogically, individual layers of Potsdam sandstone are almost invariably well sorted, the beds containing little else but quartz grains. The beds of shale are composed mainly of quartz grains and clay mineral grains and crystals. In many cases quartz comprises much of the shale beds (Table IX, H.M. Sep'n Nos. A, B, 47).

The Potsdam sandstone is also generally well sorted as to grain size, especially in the finer grades.

In the coarser-grained beds, however, two grade sizes or modes are frequently present, each grade size generally well sorted in itself. Thus coarse grains occur in a fine-grained matrix, with only a few medium-sized grains present.

Pettijohn (1949, pp. 39 - 45) discussed this phenomenon of polymodal distribution together with the various explanations given for it. One explanation is that the finer grains correspond to the suspension load and the coarser grains to the traction load. Other explanations are that it may be due to incomplete mixing by natural agencies; that it may be produced by entrapment of the fines in the interstices of the coarser grains; or, that there may be a dearth of material in the intermediate grade size.

At various horizons throughout the drill core fine-and coarse-grained bands alternate with very little gradation. Considering the general evenness of grain sizes, during the deposition of the coarse-grained bands, the coarse grains were probably deposited from the traction load, while the finer grains in the suspension load were carried on and deposited elsewhere. After a coarse-grained bed had been built up, a reduction in current velocity occurred; hence fine grains were then deposited and carried in the traction load. Because they were carried in the traction load, fine grains continued to be supplied to the Mallet well site of deposition. Immediately preceding the reduction in velocity, medium-grained material was being carried in suspension with finer grains. When the reduction in velocity occurred the medium-and fine-grained material, in suspension above the site of deposition, was deposited. This accounts for the medium-grained material in the gradational areas between the coarse-and fine-grained bands. The reduction in velocity must have occurred fairly suddenly in order to prevent much medium-grained material from being supplied to the Mallet well site of deposition. Before the reduction in current velocity occurred the medium-sized grains were carried past the Mallet well site of deposition and deposited elsewhere, and after the reduction in current velocity the medium-sized grains were deposited before they reached the Mallet well site of deposition. Thus at any one time fine grains were being deposited at one locality, medium-sized grains at another and coarse grains at still another locality.

A second possibility is that because of the grain sizes of the source rocks, and for other reasons, very little medium-grained material was being supplied to the area at the time of deposition of the alternating fine-and coarse-grained beds. This may also explain the very small number of beds in the core section that are composed of grains larger than the coarse-grained size.

Cementation. Most of the core is cemented by silica which occurs in the interstices and as authigenic growths on the quartz grains. At many horizons the grains are so well cemented that the core breaks across the grains.

Carbonate, mainly dolomite, is also a cement in many beds. The vertical extent of the beds so cemented is generally small, except at the top of the section just below the Beekmantown group where the main cement is dolomite. Dolomite is the principal carbonate cement, although calcite and siderite also occur. In some thin sections calcite can be plainly seen to have crystallized in the interstices. At several horizons silica and carbonate are both present as cementing agents, whereas in others, beds cemented with silica alternate with beds cemented by carbonate. Insufficient evidence was obtained to determine whether all these cements are primary or whether one replaces another. In the cases where carbonate-cemented beds alternate with silica-cemented beds, and where silica and carbonate cements occur together, it would seem that, if one replaces the other, the silica probably replaces the carbonate. This is indefinite however.

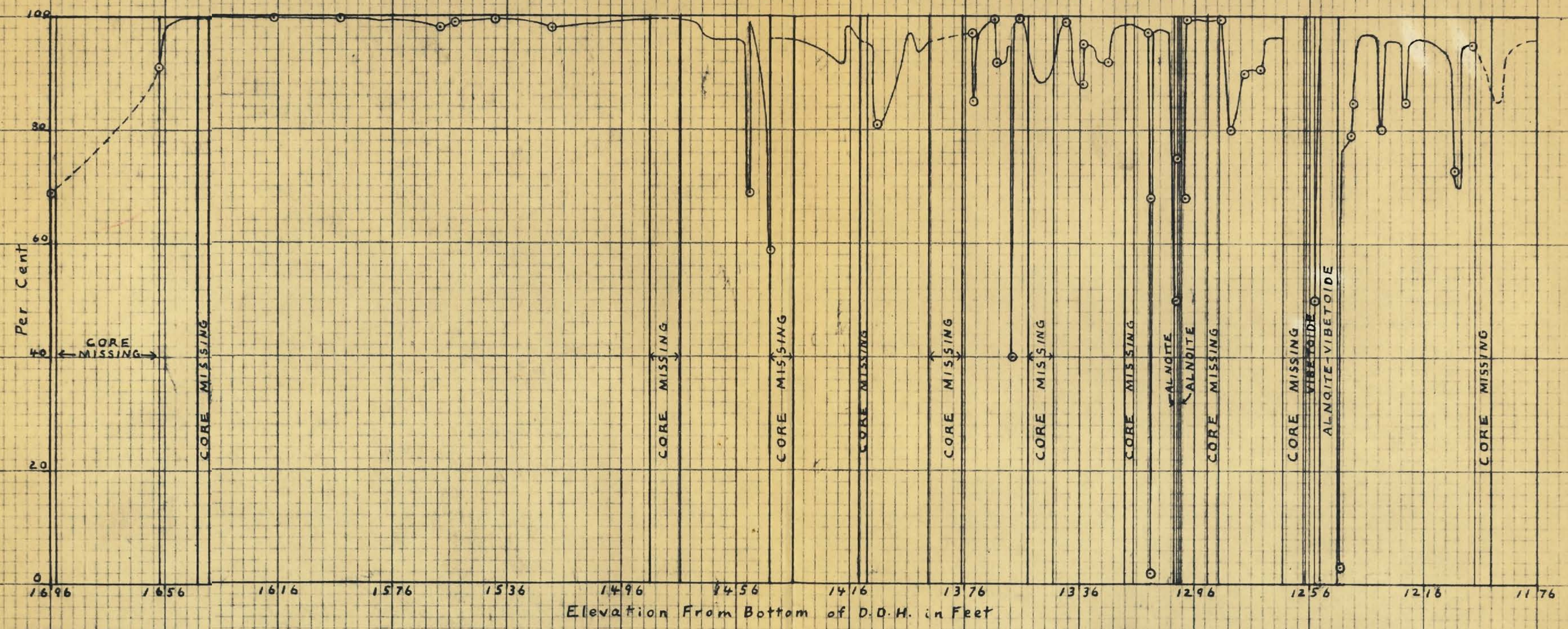
Occasionally white to light-green argillaceous material, possibly one or more minerals of the Kaolin group, is the cementing agent. Rarely pyrite and iron oxide appear to be the principal cementing agents.

The core is generally well cemented, although in a few places core is missing probably because it crumbled during the drilling operation, and in fact in several places the core can be easily crumbled by hand. The sandstone often has a sugary texture where it is poorly cemented. Generally the well cemented sections correspond to the horizons in which silica is the cementing agent, whereas the most poorly cemented sections appear to be those cemented mainly by argillaceous material. Carbonate and pyrite-iron oxide cements act as moderately good cementing agents, although in a few places the carbonate has been largely weathered out so that the core is easily crumbled.

Porosity. Except for a few horizons in which the grains are very well cemented by silica, and where all the pore spaces are filled up by the cementing material, the sandstone core examined appeared to be fairly pourous. It was noticed while wetting the core in order to observe the bedding better, that in most parts of the core the water readily sank into the interstices. As the Potsdam sandstone is considered to be highly porous (Clark, 1952, p. 140), it should be a good reservoir for artesian water and natural gas and oil for it rests on and is capped by relatively impervious rock formations. This observation is not new. Adams and Le Roy (1904, p. 71) recognized the possibility that the Potsdam sandstone might possibly contain artesian water, although itdid not seem to be indicated by the borings for wells. Parks (1931, p. 15) stated that the Potsdam could be an effective reservoir for natural gas but that it lay below any oil forming strata.

Minerals. The Potsdam sandstone drill core that

GRAPH I - MINERAL FREQUENCY GRAPH FOR QUARTZ



Note: ⊙ - Thin Section and Light Residue Analyses.

was examined is composed mainly of quartz grains which make up approximately 98 percent of the core. This figure was obtained from Graph I which was drawn up in the following way. The percentage figures determined for quartz (including secondary silica) in the thin section analyses (Table VII) and in the light residue analyses (Table IX) were plotted as ordinates and the elevations of the thin section and light residue (heavy mineral) samples above the bottom of the drill hole were plotted as abscissae. The resulting points were connected by a curve which was constructed as follows: A comparative examination was made of the percentages of quartz in the thin section and light residue (heavy mineral) samples, and the core at the horizons from which the thin section and light residue samples were selected. The entire core section was then re-examined and the percentages of quartz grains, occurring in the core between the points at which the above samples were taken, was estimated. Finally a curve was drawn on the graph connecting the points mentioned above. Chemical analyses have been made on samples from other districts (e.g. Clark, 1952, p. 151) which show that the Potsdam contains 99 percent or more silica. Considering all the possible errors involved in making Graph I, the figure of 98 percent that was obtained agrees surprisingly closely with the chemical analyses mentioned above. Some of the quartz grains appear to be aggregates of smaller grains cemented together.

In addition to quartz, flakes of clay minerals are often observed in interstices, nodules, and in beds of shale. Carbonates, mainly dolomite, but also calcite and siderite, are seen occasionally crystallized in the interstices. Calcite occurs rarely in tiny veinlets (Plate III, Fig. 2), and as nodules to ½ inch across. Sometimes carbonates are present in sufficient quantities to warrant the term calcareous quartz sandstone (Pettijohn, 1949, p. 237, after Grout), the adjective indicating the cement. Euhedral crystals and irregular masses of fresh to occasionally weathered pyrite are usually observed. A few feldspar grains are generally present and have weathered to a soft white mineral (kaolinite ?) on the surface. In one or two instances feldspar grains are present in sufficient numbers for the rock to be called a feldspathic sandstone (Pettijohn, 1949, p. 227). Rounded pink garnet grains are but rarely present. Rounded, black, opaque grains are sometimes present. Most of these believed to be tourmaline, although some are probably magnetite, ilmenite, or rutile. In one or two places iron oxide, mainly limonite, is present in sufficient amounts to warrant the name quartz-iron oxide sandstone (Krumbein and Sloss, 1951, p. 130). Other minerals still more rarely observed are serpentine or chlorite, biotite, and possibly talc. Sericite flakes are common on the faces of shale partings. A few crystals of gypsum were observed at one locality in a shale lamina.

A list of minerals, including those mentioned above and those observed in thin section and light and heavy residue analyses, is given in Table V. Whether each mineral occurs as detrital grains, authigenic growths and crystals, or in both forms, is also noted. The minerals examined microscopically will be discussed in subsequent sections.

Table V - List of Minerals, With The Occurence, of Each, in the Top 504 ft. of Potsdam Sandstone, Mallet Well, Ste. Thérèse, Que.

Mineral	Occurrence	Mineral	Occurrence
Actinolite	D	Hornblende	D
Aegirine	D	Hypersthene	D
Albite	D	Ilmenite	D
Anatase	D	Iron Oxide (Undiff.)	D & A
Andesine	D	Kaolinite	A & D?
Anhydrite	A	Kyanite	D
Anorthoclase	D	Lawsonite	D?
Antigorite	D & A	Labradorite	D
Apatite	D & A	Leucoxene	D & A?
Augite	D	Limonite	A
Biotite	D	Magnetite	D
Brookite	D	Mica (Undiff.)	D
Calcite	A & D?	Microcline	D & A?
Carbonate (Undiff.)	A & D?	Monazite	D
Cassiterite	D	Muscovite	D
Chalcopyrite	A	Oligoclase	D
Chert	D & A	Orthoclase	D & A
Chlorite (Undiff.)	D & A?	Pigeonite	D
Clay Minerals (Undiff.)	A & D?	Plagioclase (Undiff.)	D & A
Diopside	D	Pyrite	A & D?
Dolomite	A & D?	Pyroxene (Alt'd)	D
Enstatite	D	Quartz	D & A
Epidote	D & A?	Rutile	D
Feldspar (Undiff.)	D & A	Sanidine	D
Fluorite	D	Sericite	A
Garnet (Undiff.)	D	Siderite	A
Gypsum	A	Sphalerite	A?
Hematite	A	Sphene	D
		Tourmaline	D
		Zircon	D & A

Note:
D - detrital; A - authigenic;
D & A - detrital and authigenic with first mentioned predominating.
? - doubtful.
Undiff. - undifferentiated.
Alt'd - altered.

In Table VI the minerals given in Table V are listed in the order of their relative frequency of occurrence. The most abundant mineral, quartz, occurs at the top of the left hand column and the least abundant at the bottom of the right hand column. The order of these minerals was determined by comparing the relative percentages obtained for them in the thin section and light and heavy residue analyses. Some of the minerals, such as plagioclase feldspars, and also the carbonate minerals, have been grouped together. By averaging the percentage figures for quartz in the thin section and light residue analyses an average figure of 80 percent is obtained for the quartz grains. However, if the analyses on shale samples are disregarded an average figure of 88 percent is obtained. This figure is undoubtedly low as nearly all the samples were taken from horizons which appeared to contain the greatest amount of heavy minerals and accordingly the least amount of quartz. The figure of 98 percent obtained from Graph I is probably close to the correct value. Clay minerals, carbonates, and feldspar make up over 1 percent of the core, so that all other minerals combined make up less than 1 percent. This third group is composed almost totally of heavy minerals, exclusive of carbonates. Zircon, tourmaline, leucoxene and biotite are the most abundant detrital heavy minerals, zircon being nearly 2½ times as abundant as tourmaline, and tourmaline twice as abundant as leucoxene. Zircon and tourmaline comprise over half of the detrital heavy minerals by volume. Carbonates and pyrite, in that order are the most abundant anthigenic minerals. Chlorite and clay minerals are probably in part detrital and in part secondary.

Table VI - Minerals Listed in Order of Relative Frequency of Occurrence

Quartz	Antigorite	
	Hornblende	
Clay Minerals	Epidote	
	Alt'n Products	
Carbonate	Cassiterite	
	Aegirine	
Microcline	Sphalerite	
Plagioclase	Pigeonite	
Orthoclase	Pyroxene Alt'd	
Zircon	Chalcopyrite	
Pyrite	Augite	
	Actinolite	
Tourmaline	Diopside	
Leucoxene	Iron Oxide	
Biotite	Hematite	
Chlorite	Anatase	
Limonite	Enstatite)	
Chert	Fluorite)	
Apatite	Sanidine)	Equal
Sericite	Sphene)	
Hypersthene		
Ilmenite	Anhydrite)	
Rutile	Brookite)	
Anorthoclase	Gypsum)	
Magnetite	Kyanite)	Equal
Garnet	Lawsonite)	
Muscovite	Monazite)	

Fluroescence. The core from 1279 - 1338 feet (59 ft.) from the bottom of the drill hole was examined by exposing it to ultra-violet rays. Fluorescent and occasionally phosphorescent areas were observed to occur, apparently as rare isolated grains. No attempt was made to determine the mineral, or minerals, possessing the properties of fluorescence and phosphorescence. It was noted that no new or distinct mineral was found in the thin sections, or light and heavy residues in the vicinity of the above areas.

Intrusives. Five small igneous dykes or sills intrude the Potsdam sandstone at elevations of 1300.5 - 1303.5 feet and 1246 - 1257 feet, the largest one being 3 feet 9 inches thick. As observed in the drill core these intrusives appear to occur parallel to the bedding of the sandstone and if such is actually the case, these intrusive bodies are sills. It would not seem likely that the contacts of 5 dykes would all appear to be conformable locally in the same vertical line, although this might be the case.

Near the intrusive contacts the Potsdam sandstone is glassy and recrystallized. Shaly beds are indurated, possess a slightly baked appearance, and have a larger number of sericite flakes developed along the parting planes than is usual. The metamorphic effects extend from 4 - 5 feet into the Potsdam sandstone from the contact.

Two types of intrusions are present which probably originated from the same magmatic source. In three of the sills, the rock type is alnoite which ranges from light-grey to dark greenish-grey, and from fine-to course-grained. Phenocrysts of calcite and biotite up to 6 millimeters across are often present.

Two thin sections were examined and in addition to calcite and biotite, phenocrysts of olivine, augite and hornblende also occur. Calcite phenocrysts occur as individual crystals and as crystal aggregates. The rock was observed to be holocrystalline, melanocratic, allotriomorphic, and to possess a porphyritic texture. The range in grain size is from 1:500 to 1:1700. Biotite makes up to 45 percent of the rock and occurs as colourless to brown, pleochroic, anhedral to subhedral, shredded, tabular crystals which have an optic angle of almost 0 degrees. Olivine is a prominent constituent and occurs as anhedral colourless crystals which are generally much altered to chlorite (mainly antigorite), and magnetite along the edges and fractures. The optic angle is large, nearly 90 degrees,and the sign is positive in some crystals and negative in others. Therefore, the olivine is mainly the subspecies chrysolite. Ilmenite, partly altered to white to yellowish leucoxene, occurs as irregular opaque masses. Anhydrite is believed to occur in one of the thin sections (No.19) examined, either as an original mineral or as an alteration product. It occurs as colourless, anhedral crystals associated with calcite which generally surrounds the crystals. The crystals are biaxial positive, have a moderate optic angle, and show high birefringence. They also have cleavage in three directions at right angles, the cleavage being perfect in two directions and good in the third. Extinction positions are parallel to the cleavage traces. Part of the thin section sample was crushed and the indices were determined, by using index oils, to be: Nx - 1.570, Ny - 1.577, Nz - 1.613. Analcite crystals are present as colourless, isotropic sheaves. Magnetite, as distinct crystals and anhedral masses, comprises up to 20% of the rock, and melilite and nepheline are present in quantities up to 10%. Anhedral crystals of yellowish-brown melanite were present in one of the thin sections. Other minerals present are: apatite, mainly as inclusions in biotite, cancrinite, mesolite, perovskite, pyrite, and rutile.

The second type of intrusive, of which one thin section was examined, was found to be vibetoide (Eckermann, 1948). It is a dark greenish-grey, fine-to coarse-grained rock with a poor porphyritic texture. In thin section (Plate II) it was found to be holocrystalline and melanocratic with and allotriomorphic groundmass containing phenocrysts of pyroxene, mainly augite, biotite, and olivine. The range in grain size was estimated to be 1:1050. Approximately 30 percent of the rock is composed of euhedral crystals of a pale-brown augite which may be ferroaugite. These crystals often show excellent zoning (Plate II).

Plate II

Vibetoide: T.S. No.22,x16, crossed nicols. au - augite, hb - hornblende, ol - olivine, pl - plagioclase. Tiny black crystals in groundmass are magnetite. Also in groundmass are: melilite, nepheline, plagioclase, wollastonite, zeolites (e.g. analcite, natrolite).

Some of the crystals have optic angles as low as 20°; these may approach the composition of pigeonite. Pale-blue anomolous interference colours are frequently observed around the periphery of the zoned crystals. Hornblende also makes up to 30 percent of the rock and is present as rather small, euhedral crystals which are pleochroic from pale yellowish brown to brown. Some of the crystals have almost parallel extinction and are believed to be basaltic hornblende. Zeolites, such as analcite and natrolite, occur in the groundmass as radiating and bladed crystals, and crystal agreegates. They comprise 25 per cent of the thin section examined. Magnetite, possibly in part ilmenite, comprises 10 per cent of the rock. Other minerals occurring in the groundmass are: apatite, calcite, chlorite, enstatite, melilite, nepheline, olivine, pyrite and wollastonite. A few long slender crystals, almost needles, of twinned albite also occur.

It is obvious from the petrography of these two similar rock types that they originated either from similar bodies of magma, or from the same magmatic body. The latter is probably correct. These so-called sills are probably of about the same geological age, although no proof was found of this. They are correlated with the Monteregian intrusives.

Thin Section Analyses:

The method used in examining thin sections has already been described (pp.10-17). Twenty-one thin sections were prepared from specimens of different facies of the Potsdam in the top 504 feet of sandstone core from the Mallet well. The results of the microscopic analyses of these sections are tabulated in detail in Tables VII and VIII. Those features which were observed only in thin sections will now be discussed.

TABLE VII - THIN SECTION ANALYSES

MALLET WELL, STE. THERESE, QUE.

(FIGURES ARE PER CENT BY VOLUME)

MINERALS

ELEVATION FROM BOTTOM OF D.D.H. IN FEET.	1696.	1658.	1617.5	1593.5	1559.5	1554.	1540.	1520.	1451.5	1444.	1406.5	1373.5	1364.5	1335.5	1311.5	1302.5	1302.	1301.	1299.5	1256.5	1254.	1247.5	1241.5	1204.5
THIN SECTION NO.	1	2	3	4	6	7	8	9	11	12	13	42	14	15	16	17	18	19	20	22	23	24	25	26
ANORTHOCLASE												T	T			T	√		√		√			
APATITE		T	T	T			T							T	T	T	1		T		T		T	T
BIOTITE	T	T	T												T	T								
CALCITE	√	√							30	39							T				T		T	
CARBONATE	29	8						T																
CHERT		1	T	T	T	T	T	T		T	T	T	T	2					T		T		1	T
CHLORITE	T	T	T?			T?		T?			T													
CLAY MINERAL	T	T	T	T	T	T		T			T		T	1	14	40	12		25		40		17	20
DOLOMITE	√	√											T											
FELDSPAR																	7		2		2		2	
GARNET	T	T																						
HEMATITE	T	T										T								E				
HORNBLENDE	T?																	E		D		E		
ILMENITE										T					T			T	T	I		T		
IRON OXIDE		T				T												I		O		I		
LEUCOXENE	T	T		T		T				T		T	T	2	T	2	3	O	1	T	1	O	T	2
LIMONITE										T	15	T		T	T			N		E		N		
MAGNETITE	T	T																L		B		L		
MICROCLINE	T			T						T	2	T	5	6	8	5	√	A	√	I	√	A	√	3
MONAZITE		T?																		V				
MUSCOVITE	T	T																						
ORTHOCLASE													1	1	T?	T	√		√		√		√	T
PLAGIOCLASE	T									T	1	T			T?				√					T
PYRITE	T	T	T	T	1+	T	T	T	T	T	T	T	T	1	7	2	1		3		6		1	T
QUARTZ	69	90	99+	99+	98	99	99+	98	69	59	81	97	92	86	68	50	75		68		50		78	73
RUTILE	T	T							T	T	T			T	T	T	T		T		T		T	T
SANIDINE													T								√			
SERECITE															2		T		T				T	
SIDERITE	T											2												
TOURMALINE	T	T	T	T	T	T		T	T	T	T	T	T	T		T	T		T		T		T	T
UNKNOWNS	1	T																						
ZIRCON	T	T	T	T	T	T	T	T	T	T	T	T	T	T		T	T		T		T		T	T
GRAIN SIZE	a	c	b	c	b	a	c	b	b	b	c	a	b	b	e	e	d		c		e		e	d
ROUNDNESS	I	II	II	II	I	I	I	II	I	I	III	I	II	IV	IV	III	III		II		IV		V	III
SPHERICITY	X	Y	Z	Y	Y	Y	Y	Y	X	Y	Y	X	X	Y	Z	Y	Y		Y		Z		Z	Y

LEGEND

D.D.H.- Diamond Drill Hole.

T - Trace.

√ - % Undetermined.

? Slight Uncertainty in Identification.

GRAIN SIZE

a - Coarse-Grained.

b - Medium-Grained.

c - Fine-Grained.

d - Very Fine-Grained.

e - Silt Size.

ROUNDNESS

I - Well Rounded.

II - Rounded.

III - Subrounded.

IV - Subangular.

V - Angular.

SPHERICITY

X - High Sphericity.

Y - Moderate Sphericity.

Z - Low Sphericity.

Note: (i) ROUNDNESS AND SPHERICITY VALUES REFER MAINLY TO THE QUARTZ GRAINS.

(ii) ROUNDNESS AND SPHERICITY VALUES ARE PRIOR TO AUTHIGENIC GROWTH.

Plate III

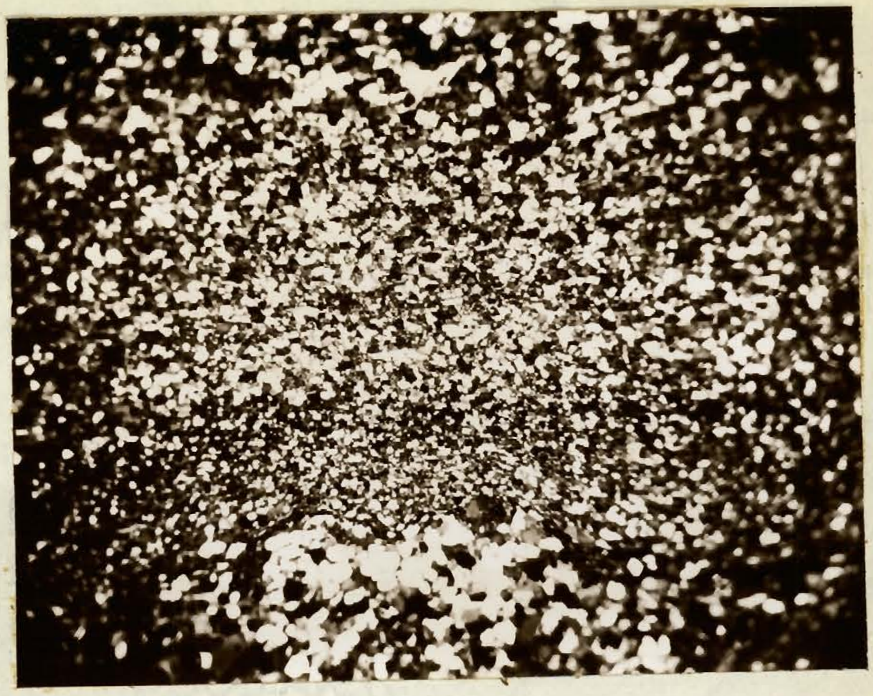


Fig. 1 - Sandstone: T.S. No.18, x 16, crossed nicols showing fine bedding. Clay mineral in interstices.

Fig. 2 - Shale, Shaly Sandstone: T.S.No.23, x 16, crossed nicols. Small movement along joint on right side with a calcite veinlet formed along the jointing plane. Shale band has been partially eroded, top centre and left. Visible grains mainly quartz.
I - Area of lighter colour with pyrite around periphery.

<u>Bedding and Small Structures</u>. Bedding was observed in practically all of the thin sections and was shown by differences in grain and colour (Plate 111). The beds generally have low dips, are even-grained, and tend to die out within a short distance horizontally. Several beds of various grain sizes were observed in some thin sections, although the corresponding hand specimens appeared to be of uniform grain size. In thin section 18 (Plate 111, Fig 1) nine tiny beds, with grains ranging from silt size to fine-grained, occur within a thickness of 13.2 mm. Laminae of shale 0.03 mm. thick were observed in another thin section.

Several beds have a conglomeratic texture (Plate 1V, Fig 1) with some larger grains, up to 3.8 mm. in diameter in one case, occurring in a very fine-to coarse-grained matrix. The grains in the matrix are more poorly rounded than the larger grains. Generally the beds are even-grained, and have little or no matrix. In some cases however, the matrix forms the bulk of the rock.

In many cases the matrix also acts as the cement; but in most instances the cement, which is generally quite minor, was introduced after the deposition of the detrital grains. The cements observed in thin section are; silica (mostly quartz, rarely minor chert), dolomite, calcite, siderite, pyrite, iron oxides, and clay minerals. Where the cementing material is not silica, authigenic growths are invariably lacking, and the quartz grains remain predominantly rounded to well rounded.

Plate lV

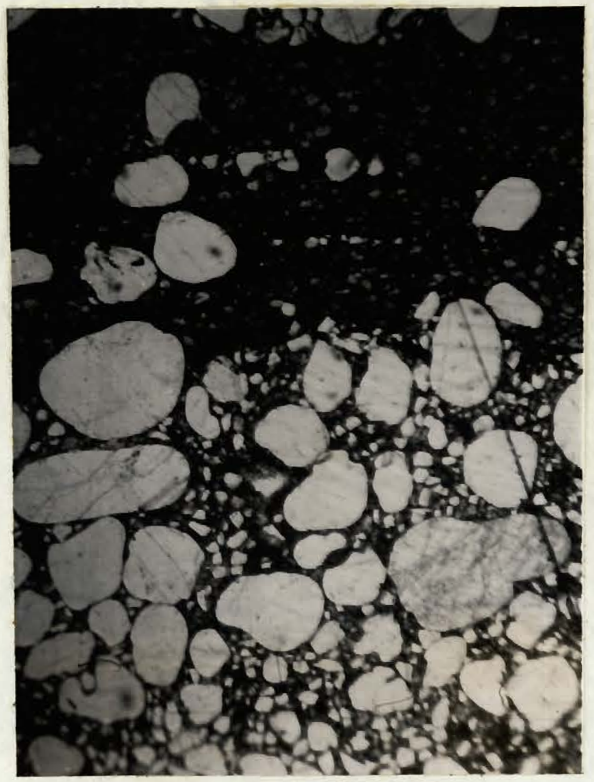


Fig 1 - T.S. 1, x18.5, plane polarized light. Contact with Beekmantown group. Rounded quartz grains, some of which are "floating" in a dolomitic cement. Some larger grains are cloudy and show rows of inclusions.

Fig 2 - T.S. 12, x16, plane polarized light. Rounded quartz grains "floating" in calcite cement. Some of quartz grains show rows of bubble inclusions; others are cloudy.

In a few sections, quartz grains appear to be "floating" in dolomite (Plate lV, Fig. 1), and in calcite (Plate lV, Fig. 2). Anderson's explanation as given by Pettijohn (1949, p. 483) is regarded by the writer as the most plausible explanation of this phenomenon. He suggests that, in such cases, the rock was originally a mixture of clastic quartz and clastic carbonate. The clastic carbonate was probably deposited as shells and other calcareous material which was readily dissolved and reprecipitated, thereby losing all traces of its clastic origin.

Three other explanations are offered by Pettijohn (1949, pp. 483 - 484). The first is, that the quartz grains only "appear" to be isolated. This is true in some cases. The second, after Waldschmidt, is that the quartz grains have been pushed apart by the force of the interstitial cement on the growing crystals. The third explanation is that the separation of the quartz grains, in some cases, appears to be due to corrosion, the smaller grains and borders of the larger grains being replaced by calcareous cement. In some of the thin sections examined by the writer (Plate lV, Fig. 2) quartz grains appear to have been slightly corroded; but not enough to effect a separation of quartz grains. In thin section 1 (Plate lV, Fig. 1), the linear alignment of the isolated quartz grains indicates that these grains may have been deposited in chemically precipitated carbonate during fluctuations in the carrying power of the currents. In thin sections 1 and 12 (Plate lV) the carbonate appears to have been slightly broken up, and the particles subsequently recemented together. This, however, fails to indicate whether the carbonate was first deposited chemically, or as clastic carbonate.

Lenses and nodules of sandstone, ranging from a fraction of an inch to several inches in diameter, and containing a calcareous cement, occur throughout the length of core. The lenses grade into areas containing a siliceous cement. It is not known whether the carbonate cement is authigenic or allogenic in these lenses and nodules; but the writer thinks that these areas, especially the nodules, may indicate the presence of former shells, and other calcareous material which was deposited with the sand grains and subsequently recrystallized.

Some thin sections (Plate lll, Fig l) reveal small channels which have been eroded in shale laminae, with subsequent deposition of coarser material in the channels. This indicates that deposition was discontinuous, and that there were periods of non-deposition and erosion. The writer believes that these periods were relatively short compared with the period required for deposition of the Potsdam sandstone as a whole.

Within the shale laminae, many small oblong patches occur

occur which are lighter in colour than the main band of shale (Plate lll, Fig. 2). These areas are usually less than 1 mm. long, and contain one or more, tiny crystals of pyrite which occur either near the centre, or around the edges, mainly at the ends, of the patches. The lighter colour is due to migration of ions of iron or iron sulphide toward a centre of crystallization where pyrite was formed.

Relationship of Grain Size to Roundness and Sphericity.

The values for these three properties were determined for the grains in each thin section and are tabulated in Table Vll. In most cases quartz grains compose the bulk of the rock, therefore the values obtained refer mainly to quartz grains. Because secondary crystallization has, in most cases reduced the roundness and sphericity of the quartz grains, the values of these properties were determined for the grains prior to authigenic crystallization.

The relationship existing between these three properties is illustrated in Table Vlll, which is a rearrangement of the values given previously in Table Vll. It is observed that both the roundness and sphericity decrease directly as the grain size decreases, and that the more rounded grains are also the more spherical ones. These observations are in accordance with the conclusions reached by other writers (Pettijohn, 1949, pp. 53 -54; Krumbein and Sloss, 1951, pp. 81, 84) who have studied mature sands.

Table V111 - Relationship of Grain Size to Roundness, Sphericity.

Grain Size	No. of Sections	Roundness					Sphericity		
		1	11	111	1V	V	X	Y	Z
a	3	3	0	0	0	0	2	1	0
b	7	3	3	0	1	0	2	4	1
c	5	1	3	1	0	0	0	5	0
d	2	0	0	1	1	0	0	2	0
e	4	0	0	1	2	1	0	1	3

Orientation of Grains. Observations of the orientation of grains were confined mainly to quartz grains. A few observations were also made of shale minerals, and of a few heavy minerals. In general elongated grains tend to occur with the longer of the two observed dimensions parallel or nearly parallel to the bedding plane. Optical orientation of grains was observed only rarely in shale laminae and in quartz veins.

Quartz grains and most of the other minerals are generally elongated in one direction, and in many of the quartz grains there is a tendency for this direction to be parallel to the crystallographic axis. This is in accordance with the observations made by some writers (Pettijohn, 1949, p. 91). Although the writer does not know the reason for the above tendency, he thinks that it may be a primary characteristic. The elongation of the quartz grains in most of the thin sections has been accentuated by authigenic growths, mainly on the ends of the grains and parallel to the bedding. This is in accordance with Riecke's principle, and indicates that the greatest forces in operation at the time of deposition of the secondary silica were vertical forces.

Crystals of shale minerals were found to be generally elongated parallel to the bedding. In a few thin sections the crystals also possess a preferred optic orientation, the crystals showing an extinction parallel to the elongation and to the bedding plane, which in these cases coincided. In two of the thin sections groups of crystals of shale minerals were found to possess the same optic orientation. The elongation and optic orientation of the above crystals of shale minerals (Plate III, Fig. 2) is believed to have been formed during the period of lithification of the Potsdam sandstone.

In a few cases a group of carbonate crystals was observed to possess the same optic orientation. There appeared to be no definite relationship between this optic orientation and the bedding.

Light Residue Analyses:

Microscopic analyses were made of 17 of the light residues obtained from the heavy mineral separations. In addition, microscopic analyses were made of two samples taken from shale laminae (Table IX, Separation No.A,B). The main purpose of these analyses was to obtain an idea of the relative amounts of quartz grains present in the light residues and to determine whether or

Table 1X

LIGHT RESIDUE ANALYSES

Mallet Well, Ste. Thérèse, Que.
(Figures are per cent by volume of light residue)

Elevation From Bottom of D.D.H. In Feet	-1373	-1359.5	-1365.5	-1357.5	-1341.5	-1335.5	-1326	-1312.5	-1311	-1299	-1286.5	-1283.5	-1279	-1273	-1245	-1241	-1231	-1222.5	-1199
H.M. Separation No.	A^x	B^x	33	34	35	36	37	38	39	40	41	42	43	44	47	48	49	50	52
Albite		^																	
Carbonate	^		^	^	^	^	^		^	^				^		10	19		
Clay Mineral	^	40			T	T			90	T	T	2?	^	^	85	1	^	^	^
Feldspar	^	^						^			T	^			^				
Heavy Minerals	^	^		^	^	^	^	^	^	^	^	^	^	^	^	^	^	^	^
Microcline		T				T					T		^	^				^	^
Oligoclase					T	4					T?	^?							
Orthoclase		T										2	^		^?			^	^
Plagioclase		^			T	T		^				15?	^	^		^	T	^	^
Pyrite	10	10			T	^	^	^	^	T	T	T	^		^	^			^
Quartz	85	40	99	99+	99+	95	92	97	^	99+	99+	80	90	90	^	85	80	85	95

Note: x - Determinations for shale laminae, no sep'n performed.
^ - Per cent undetermined.
T - Trace.
? - Slight uncertainly in identification.
H.M. - Heavy mineral.

not good separations of the heavy minerals from the light were being obtained. As the heavy residues formed one per cent or less of the original sample, the figures obtained for quartz in the light residue analyses were taken as the amount present in the original sample (Graph 1). The results of these analyses are tabulated in Table lX. In many light residues several grains of heavy residue minerals were observed (higher specific gravity than bromoform). This contamination could be reduced greatly by performing an additional separation on the light residue. Some of the impurities occurred as a result of the attachment of a grain of high specific gravity to a grain of low specific gravity, the resultant specific gravity of the particle being less than the specific gravity of the bromoform.

Heavy Residue Analyses:

Most of the laboratory work for this thesis consisted of examining the heavy residues microscopically, and determining the minerals present, their frequencies, and their physical and optical properties. At first, due to a lack of previous experience in examining detrital grains through a microscope, considerable difficulty was encountered in determining the minerals. With practice, however, this difficulty was overcome. The results of the heavy residue analyses are given in Tables X, Xl and Xll. Only those topics related solely to the analyses of heavy residues will be discussed in this section.

Abundance of Heavy Residues. The method of determining the abundance of the heavy residue obtained from each sample has been discussed previously. These rough estimates were made in an attempt to ascertain whether any relationship exists between the grain size of the original sample and the amount of heavy residue contained in the sample. In Table X the grain size of the different samples is compared with the abundance of the heavy residues obtained from these samples.

Table X - Relationship of the Abundance of Heavy Residues to Grain Size:

Grain Size of Sample	Sample Number	Total Samples	Abundance A	B	C	D
Very Coarse-Grained	29,33	2		1		1
Coarse-Grained	10,11,19,25,26, 28,32,34,36,37, 42,44,49	13	5	2	5	1
Medium-Grained	6-8,12,14,15,18, 20-23,35,48,52	14	8	3	2	1
Fine-Grained	1-5,9,13,16,17, 24,27,30,31,39-41, 43,45,46,50,51	21	5	10	4	2
Very Fine-Grained	38	1			1	
Silt	47	1				1
Total		52	18	16	12	6

From an examination of Table X it is observed that the greatest abundance of heavy residues was obtained from the medium-grained samples. It is observed also that there is a more or less gradual decrease in the amount of heavy residue obtained as the grains range from the medium both to the coarser and to the finer-grained sizes. There are several possible explanations of this. The first is that it was merely by chance that some of the samples selected (medium-grained) contained a larger amount of heavy residue minerals than the others. A few more analyses would be required before this possibility could be discarded or retained. However, the writer thinks that additional analyses would emphasize further the observation made above. The second explanation is that a larger amount of heavy residue minerals was being supplied by the source rocks to the site of deposition when the medium-grained beds were being deposited. This does not appear to be a logical explanation as it necessitates a very fine adjustment between the size of the grains deposited and the erosion of the source rocks. The third explanation is that, in general, the grain sizes of the different heavy minerals, together with the various hydraulic conditions in the area of deposition, were such that a larger amount of heavy mineral grains were "hydraulic equivalents" to the medium-grained light minerals than to the other grain sizes (Rittenhouse, 1943b; Pettijohn, 1949, pp. 426-428). This would seem to be the best explanation to the writer. A fourth explanation, however, must also be considered for the samples below the medium-grained size range. It is that a proportionately larger amount of the heavy residue mineral grains passed through the 150-mesh screen as the grain size of the sample decreased. This explanation is substantiated by the fact that the lower limits of the fine-and very fine-grained sizes are 0.125 and 0.0625 mm. respectively, whereas the diameter of the openings in the 150-mesh screen is 0.104 mm. Furthermore, it was observed that the heavy residue mineral grains are almost invariably of smaller grain size than the associated light minerals. To what extent this explanation bears on the results given in Table X is not known; but for very fine-grained samples below the fine-grained size range it is undoubtedly considerable. It is believed by the writer that the results for the fine-grained samples were not greatly affected, so that it is probably true that the medium-grained beds contain the greatest abundance of heavy residues. A fifth explanation may have considerable bearing in accounting for the smaller amount of heavy residues in the coarser-grained samples. It is that certain minerals such as apatite and zircon are of much smaller grain size than are the others in the parent rock from which they come. (Pettijohn, 1949, p. 428.)

Mineral Frequencies. The frequencies of the different minerals in each heavy residue were determined microscopically

TABLE XI - HEAVY MINERAL SEPARATIONS

MALLET WELL, STE. THERESE, QUE.

(FIGURES ARE PER CENT BY VOLUME OF HEAVY MINERAL CONCENTRATE)

ELEVATION FROM BOTTOM OF D.D.H. IN FEET.	1695.5	1657.5	1642.	1629.5	1626.5	1617.	1606.5	1602	1596.5	1585.5	1575.	1562.5	1556.5	1549.	1542.5	1530.	1522.5	1516.5	1506.	1502.	1492.5	1468.5	1465.	1456.	1446.5	1433.5
H.M. SEPARATION NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
ACTINOLITE					1		2								T											
AEGIRINE										10																
ALT'N PRODUCTS								2				7	T	T				T							8	
ANATASE																			T							
ANHYDRITE																							T			
ANTIGORITE							T	T?			1?1	7			T					?4			T?			
APATITE										T									3				T	2	1	T
AUGITE							4							T												T
BIOTITE	14	9	25	18	13	12	3	T	3	2	13	11	1	2	3			25	20	15	1		T	T	T	T
BROOKITE																									T?	
CALCITE	T	T	T														√									√
CARBONATE						T			1	2	6						18	3		T						89
CASSITERITE													1	3	2	2	2		T							
CHALCOPYRITE	5	?					T?																			
CHLORITE	T	T	15	18	15	17	10	1	25	T	14	10	T	T		T			T	T			T	T	T	
CLAY		7		1		T	1	T			9		1	T	1	T	T		T	T		1		31	T	
DIOPSIDE						T?		T						T									T	T		
DOLOMITE																	√									√
ENSTATITE																									T	
EPIDOTE					10	7	T?	T											1					T		
FLUORITE							T																	T		
GARNET	2				5	7	10	T			2?	4					T		T	2		T	T		T	T
HEMATITE					T				T																	
HORNBLENDE						20		2								T					1			T		
HYPERSTHENE	2	T	1	T	10	15	33	1		T	13								T	1		T				
ILMENITE		T			23	2	1	10		T	5	6	1	4	3	T	3		T							T
IRON OXIDE		T			T			2					T				T		T							
KYANITE																									T	
LAWSONITE																										
LEUCOXENE	2		T	1	6	1	1	5		T	4	4				1	T		T	T	1	14	4	8	3	T
LIMONITE																										
MAGNETITE	2	5	7	17	2	3	1	1	5	T	4		T	1	T	T	T	T	2	T		T		T		T
MONAZITE																										
MUSCOVITE	3					10	2	T	4	3		4														
PIGEONITE							9																			
PYRITE	65	65	35	18	3	4	15	T	3	5	7	7	73	10	T	2	2	6	1	15	5	56	59	5	24	3
PYROXENE ALT'D						T	5	T											T?							
RUTILE						T		2		1			2	1	T	T			T		1	1	T	1	2	T
SIDERITE		T	T																							√
SPHALERITE												11														
SPHENE							T?			T?																
TOURMALINE	2	12	16	18	12		T		4	2			2	4	10	9	9	25	10	2	33	13	8	24	14	T
UNKNOWNS						1	T	T		T			T				T									
ZIRCON	2	1	T	8			1	71	55	74	11	29	18	74	80	85	65	40	60	60	57	14	28	28	47	7
ABUNDANCE	A	C	A	A	A	A	B	D	D	A	A	A	A	A	A	B	B	A	A	A	A	B	B	B	B	C

ELEVATION FROM BOTTOM OF D.D.H. IN FEET.	1424.5	1408.	1404.	1395.	1374.5	1373.5	1365.5	1357.5	1341.5	1335.5	1326.	1312.5	1311.	1299.	1286.5	1283.5	1279.	1273.	1268.5	1252.	1245.	1241.	1231.	1222.5	1211.	1199.
H.M. SEPARATION NO.	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
ACTINOLITE																										
AEGIRINE																										
ALT'N PRODUCTS																				T						
ANATASE											T?		T										T?			
ANHYDRITE																										
ANTIGORITE			T							T?	T	T						T	T?							
APATITE	T	1	1	T	T	1	T	1	11	14	2	T	16	1	2	5	T	2	5	2		10	5	T	2	T
AUGITE																					T					
BIOTITE			T		T	2		T	T	1		1			T	1	T	T			2		2		T	T
BROOKITE																										
CALCITE																	13	16			T	11	29			
CARBONATE																										
CASSITERITE																										
CHALCOPYRITE																										
CHLORITE		T		T	T			T	1	T	T	T	T	T	10	2	T	T			4	2	2	2	2	T
CLAY		1							1	T		8	32	37	17	5	2	T	T	3	59	2	3	1	2	T
DIOPSIDE	T		2			T	T																T			
DOLOMITE	4	23	68	63		4	22	19	1	T	2				40	3			30	69				1	2	2
ENSTATITE			T																							
EPIDOTE													T													
FLUORITE																										
GARNET			T		T?		T	T	T	1			T			T		1		3		5	T		T	T
HEMATITE									√	T		T	T	T												
HORNBLENDE		T	T												T		T									
HYPERSTHENE			3	2		T		T		T									T	T		T				
ILMENITE				T	T	1	T	1	T		1	1	T	T	T	T	9	4	1	T			T	T		
IRON OXIDE																										
KYANITE																										
LAWSONITE		T																								
LEUCOXENE	5	2		2	T	3	3	3	10	17	7	4	21	1	2	15	20	8	13	8		21	T	2	41	3
LIMONITE					96				6	12		25	T	T	T	3			T	4				T	T	
MAGNETITE						T					T	T	T			T	T	1	T							
MONAZITE									T																	
MUSCOVITE				T									T													
PIGEONITE																										
PYRITE	29	36	14	1	2	23	9	10	17	30	37	51	9	53	19	37	20	38	6	2	34	19	42	67	14	90
PYROXENE ALT'D																										
RUTILE	T	3	1	1		1	T	4	2	4	3		3	T	T	4	2	3	5	2		2	T	1	3	T
SIDERITE	T	4	4	2		34	51	19	1	T	2	9		T	T											
SPHALERITE																										
SPHENE																										T
TOURMALINE	36	6	3	14	1	6	4	20	30	11	10	T	15	2	7	16	29	11	11	2	T	15	9	5	15	2
UNKNOWNS																										
ZIRCON	25	23	3	14	T	24	10	22	19	9	35		3	5	2	8	4	15	28	4		12	7	20	18	2
ABUNDANCE	B	C	D	B	D	D	B	B	C	C	C	C	C	C	C	C	B	A	B	B	D	A	A	B	B	C

MINERALS

LEGEND

D.D.H.- Diamond Drill Hole.

H.M.- Heavy Mineral.

T.- Trace.

√ - % Undetermined.

?- Slight Uncertainty in Identification.

ABUNDANCE

A - RARE

B - OCCASIONAL

C - COMMON

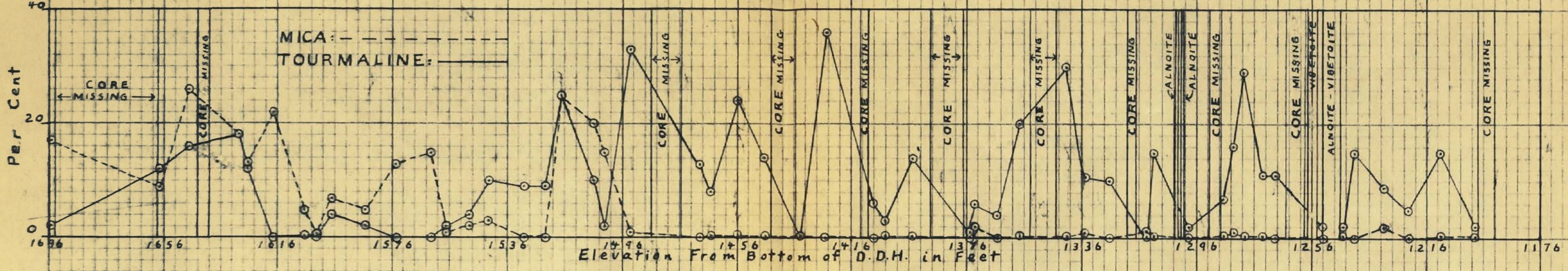
D - ABUNDANT

as percentages by volume of each heavy residue, the results being given in Table XI. The table also gives the abundance of each heavy residue. Using these results, mineral frequency graphs (II-V) were drawn up for leucoxene, magnetite-ilmenite, mica, tourmaline, rutile, and zircon, among the detrital minerals, and carbonate, and pyrite among the authigenic minerals.

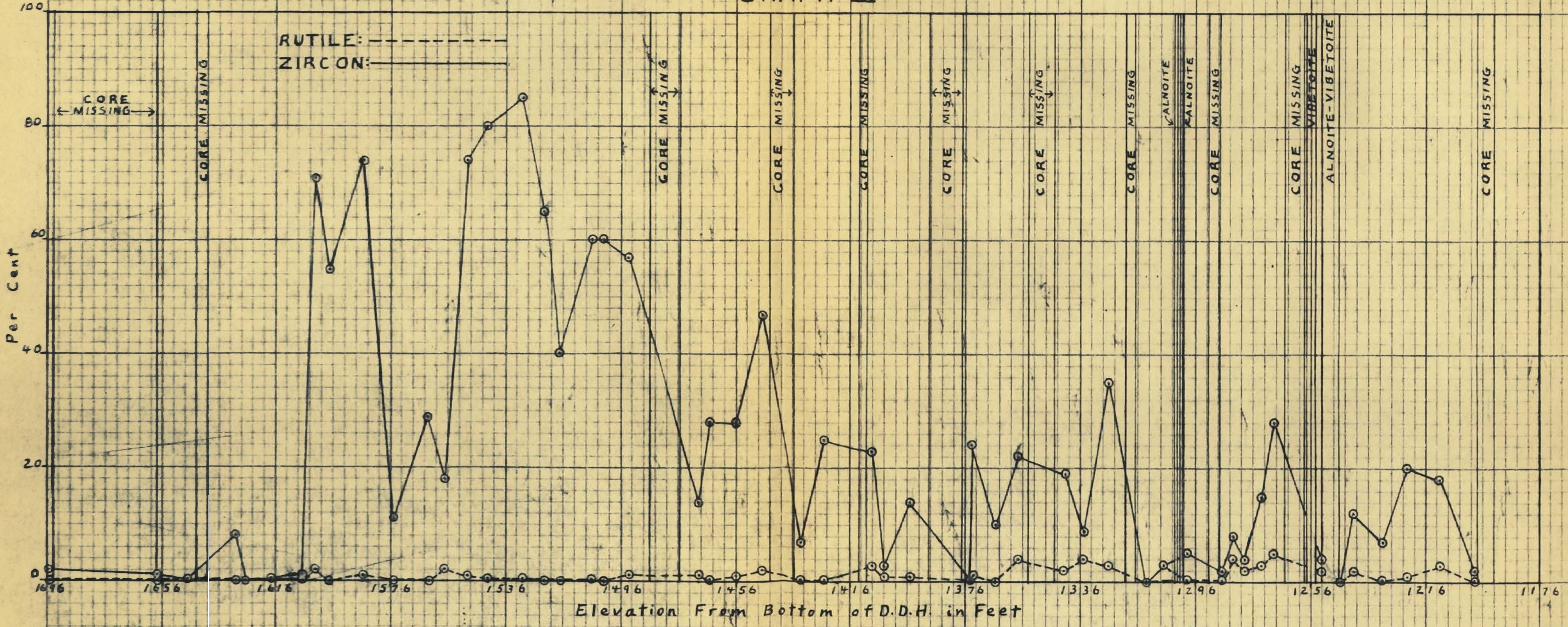
Upon examining Table XI in conjunction with Graphs II-V it is evident that, relative to one another, some of the detrital minerals, such as tourmaline and rutile, show almost no change in frequency from the top to the bottom of the core length. Other detrital minerals, such as biotite and zircon, show a general increase in frequency toward the top of the core section (increase in mineral frequency with decreasing age). Still others, such as apatite and leucoxene, show a general increase in frequency toward the bottom of the core section. Table XII lists the more important detrital heavy minerals in the three divisions outlined above. The numbers refer to the relative order of the mineral frequencies as determined for heavy minerals. The minerals in each column are listed in order of their persistence. Their order was determined by taking into account the abundance of each mineral and the number of heavy residues in which each mineral occurred. In general the most abundant minerals also appear to be the most persistent, or stable. The order given here corresponds fairly well with those given by other writers (Pettijohn, 1949,

MINERAL FREQUENCY GRAPHS FOR DETRITAL MINERALS

GRAPH II



GRAPH III



pp. 86-90, 415, 485-496).

Table XII - Persistence Table of the Principal Detrital Heavy Minerals

Relatively Constant Frequency	Increasing Frequency With Decreasing Age	Decreasing Frequency With Decreasing Age
2-Tourmaline	1-Zircon	3-Leucoxene ?
11-Rutile	5-Biotite	4-Clay Minerals ?
13-Garnet	7-Chlorite ?	6-Limonite ?
15-Antigorite ?	9-Hypersthene	8-Apatite ?
17-Diopside	10-Ilmenite	
	12-Magnetite	
	14-Muscovite	
	16-Hornblende	

Note: ? - Probably Secondary (at least in part)
1 - Order of Abundance
(Relative Order of Abundance)

A relatively constant mineral frequency for a mineral indicates that a fairly uniform amount of that mineral is being supplied to the sight of deposition from the source rocks. This is probably the case with tourmaline, rutile and garnet. Antigorite, however, is largely secondary and is present mainly as traces. Diopside is also present mainly as traces and in at least one instance was present as an inclusion in a quartz grain. Bramlette (1941, pp. 32-36) and Boswell (1941, pp. lvi-lxxv) concluded that stable minerals are stable because of their greater resistance to decomposition rather than to abrasion.

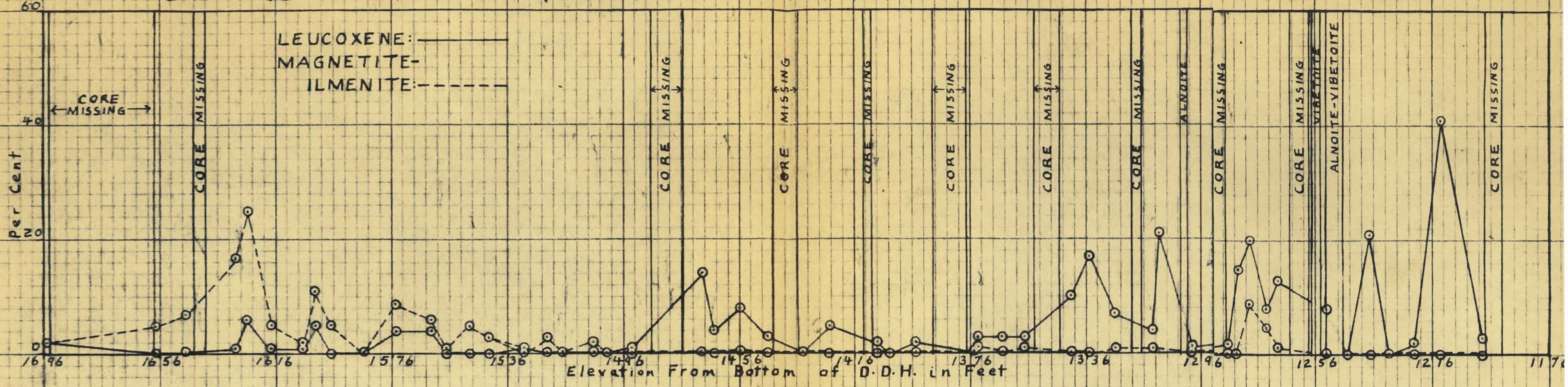
If a mineral has an increasing frequency of occurrence with decreasing age of the sediment involved, it may indicate that an increasingly relative amount of that mineral is being brought to the site of deposition from the source rocks. Krynine (Pettijohn, 1949, pp. 491-492) considers this to be so in most cases.

Another possibility, which most writers seem to favour, is that the mineral was originally deposited, but was subsequently removed from the rock, in part or totally, by intrastratal solutions. Thus younger sediments appear to be more complex than older sediments, although this may not have been the case originally. Bramlette (1941, pp. 32-36) and Boswell (1941, pp. lvi-lxxv), among others, are proponents of this viewpoint. Pettijohn (1949, p. 492) concludes that the truth probably lies somewhere in between these two points of view, and this is also the point of view of the writer. A good example in support of this viewpoint is provided by biotite which becomes increasingly leached toward the bottom of the core section where it is generally grey to colourless. Coincidentally, the grains become well rounded and an increasing proportion of them reveal alterations around the periphery to concentrically arranged laths of antigorite. A further indication that intrastratal solutions play a large part lies in the fact that most of the minerals of this group have irregular or ragged edges. Zircon, however, occurs nearly always as well rounded grains.

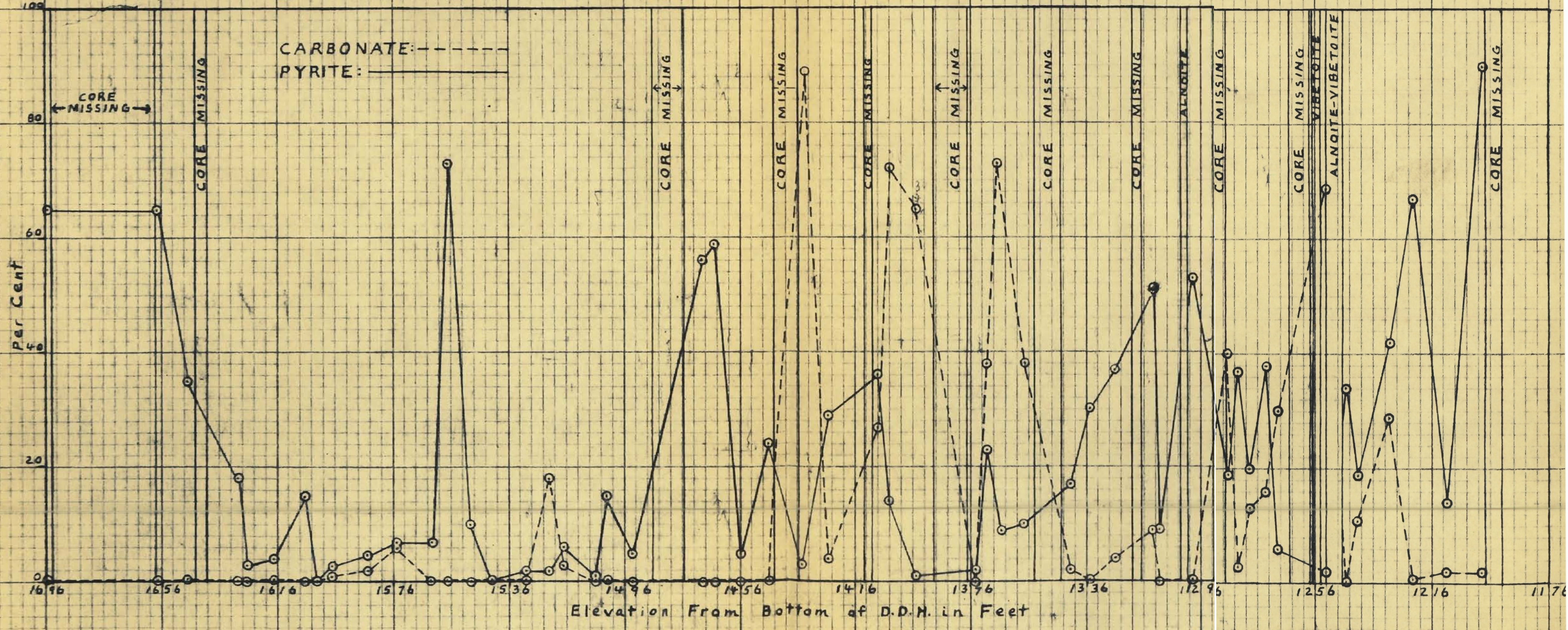
Zircon, like biolite, has an increasing relative frequency toward the top of the core; but because zircon is one of the most stable minerals present it is probable that little zircon has been removed by intrastratal solutions. The writer suggests that the material now found at the top of the core section underwent more weathering prior to deposition than did the material at the bottom. Because the less stable minerals were removed more readily than the more stable, the relative amount of the latter, such as zircon, in the consolidated rock increases toward the top of the core section.

In the third group of minerals, which have a decreasing frequency with decreasing age, it is observed that three of the four minerals listed are, at least in part, secondary. This indicates that alteration probably began soon after the sediments were laid down; therefore the greatest amount of alteration and alteration minerals occur in the older beds. Occasionally grains of ilmenite and more rarely rutile are observed to be only partly altered to leucoxene. Other well rounded grains are composed entirely of leucoxene. The ragged nature of the clay mineral grains and the presence of grains which are only partly altered to clay minerals indicate that these clay minerals are probably secondary. Similarly

GRAPH IV - MINERAL FREQUENCIES OF DETRITAL MINERALS



GRAPH V - MINERAL FREQUENCIES OF AUTHIGENIC MINERALS



the limonite grains are believe to be a secondary alteration of ferruginous carbonate and pyrite. The decreasing frequency of apatite with decreasing age is believed to correspond with the conclusions that were made for zircon. Apatite, being less resistant than zircon, was probably eroded from the younger beds by a reworking of the sediments prior to their final deposition.

As shown in Table XII, the mineral frequencies for rutile are fairly constant, whereas those for ilmenite show an increase toward the top of the section, and those for leucoxene show a decrease toward the top of the section. In the microscopic examinations of the heavy residues it was observed that, particularly toward the base of the core section, many ilmenite grains show a partial alteration to leucoxene. It is concluded, therefore, that the leucoxene grains have been derived mainly from ilmenite grains. It is thought that probably the increased proportion of leucoxene in the lower part of the core section, together with the small amount of ilmenite, indicates that here the ilmenite has been largely altered to leucoxene, whereas less and less alteration has taken place toward the top of the core (Graph IV). It is not certain whether this alteration occurred before or after deposition. However, taking into account the fact that the shape of the ilmenite and leucoxene grains are very similar (Table XIII), it would appear that the alteration occurred after the deposition of the sediments. A few grains of rutile were observed to be partly altered to leucoxene, which is considered by some writers to be an aggregate of rutile or, rarely, anatase (Winchell, 1951, p. 64).

The results of the heavy residue analyses of the principal authigenic minerals, pyrite and the carbonates, are given in Graph V. It is observed that the curve for pyrite has a series of peaks approximately 50 and 100 feet apart. This cyclic variation represents a corresponding variation in the composition of the Potsdam sandstone, the peaks indicating the horizons at which the largest amount of pyrite forming material was deposited. There does not appear to be any relationship between the formation of the pyrite and the intrusion of the alnoite-vibetoide sills or dykes. It is believed that most of the pyrite in the core section was not deposited as such; but that the pyrite was formed after the deposition of the Potsdam sandstone and is therefore authigenic. Evidence that at least some of the pyrite was formed after the deposition of the Potsdam sandstone was observed in some of the thin sections (Plate III, Fig. 2). In some of the shale laminae small oblong areas occur within which there has been a migration of material toward a centre of crystallization to form pyrite. The pyrite occurs mainly as irregular crystal masses and commonly as well formed cubes, pyritohedrons and octahedrons. Many striations were observed. In some heavy residues the pyrite was observed to occur largely as tiny spherulites with a rough surface and greenish-yellow colour. It appeared, in some cases, that the spherulites were composed of minute crystals. There spherulites may have been deposited with the sediments, and therefore may be primary. Rarely, an inclusion of pyrite was observed in a detrital quartz grain, hence in these cases the pyrite was detrital.

The largest development of carbonate, mainly dolomite and siderite with minor calcite, was observed to occur approximately in the centre part of the core section and appears to have no connection with the formation of pyrite or the intrusion of the alnoite-vibetoide sills or dykes. There is a slight indication that the greatest amount of carbonate occurs at horizons which were found to contain the least amount of pyrite and vice versa. Though the writer is not certain whether the carbonate was brought in after the deposition of the Potsdam sandstone, whether it was chemically precipitated and later recrystallized, or whether it was clastic carbonate which was later recrystallized, he leans toward the last view point. Often the carbonate crystals are zoned with a small darker-coloured rhomb in the centre of a larger, lighter-coloured, crystal.

The chlorite and clay minerals are probably, in large part, authigenic. In several heavy residues pyroxene and

TABLE XIII - ROUNDNESS DETERMINATIONS ON HEAVY MINERALS

MALLET WELL, STE. THERESE, QUE.

VALUES FOR MINERAL GRAINS OCCASIONALLY – ALWAYS DETRITAL

ELEVATION FROM BOTTOM OF D.D.H. IN FEET	1695.5	1657.5	1642.	1629.5	1626.5	1617.	1606.5	1602.	1596.5	1585.5	1575.	1562.5	1556.5	1549.	1542.5	1530.	1522.5	1516.5	1506.	1502.	1492.5	1468.5	1465.	1456.	1446.5	1433.5	1424.5	1408.	1404.	1395.	1374.5	1373.5	1365.5	1357.5	1341.5	1335.5	1326.	1312.5	1311.	1299.	1286.5	1283.5	1279.	1273.	1268.5	1252.	1245.	1241.	1231.	1222.5	1211.	1199.
H.M. SEPARATION NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
ACTINOLITE					IV		V								✓																																					
ALT'N PRODUCTS								V				V	✓	V				✓							✓																					✓						
ANATASE																			✓																		I		II										V			
ANTIGORITE							V	✓			✓	✓			✓					✓			✓						✓							✓	✓	✓						V	V							
APATITE										I									I				I	I	I	I	III	II	I	V	I	I	I	I	I	I	I	I	I	I	I	I	III	I	✓	I		I	II	I	I	II
AUGITE							IV							V												V																					V					
BIOTITE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	V	✓	✓	✓	✓			V	II	✓	III		III	✓	III	V			III		II	V		II	II	I		IV			II	II	II	V			✓		II		II	V
BROOKITE																									IV																											
CASSITERITE													✓	I	I	✓	✓		✓																																	
CHLORITE	✓	✓	✓	✓	✓	✓	V	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓			V	✓	✓			✓		✓	V			V	V	✓	V	V	II	V	V	V	V	✓			V	V	V	V	V	III
CLAY MINERAL		✓		✓		✓	✓	✓			V		✓	✓	✓	✓	✓		✓	✓		✓		✓	✓			✓							V	IV		V	IV	V	V	II	V	V	V	V	V	V	V	✓	IV	✓
DIOPSIDE						✓		IV						✓									✓	IV			V		V			V	V																V			
EPIDOTE					✓	✓	✓	✓											✓					V															III													
FLUORITE							II																	✓																												
GARNET	✓				V	V	V	✓			✓	II					✓		✓	III		✓	III		IV	IV			IV		V		V	III	III	V			II			II		V		V		V	V		✓	V
HEMATITE					✓				✓																										II	✓		✓	✓	✓												
HORNBLENDE						V		✓								✓					✓			V				III	✓												V		V									
HYPERSTHENE	V	✓	V	V	✓	IV	V	✓		V	V								V	IV		V							V	V		✓		✓		✓									V	✓		V				
ILMENITE		✓			III	✓	✓	V		✓	✓	✓	III	✓	✓	II	II		III							V				I	IV	I	III	✓	III		III	III	II	I	II	I	V	V	IV	✓			IV	✓		
IRON OXIDE		II			✓			V					✓				✓		✓																																	
KYANITE																									I																											
LAWSONITE																												V																								
LEUCOXENE	I		✓	✓	II	✓	✓	I		✓	✓	✓				II	✓		IV	✓	II	IV	I	IV	II	✓	II	III		I	II	I	III	II	III	III	III	IV	II	IV	IV	III	✓	V	V	V		III	V	IV	III	III
LIMONITE																															IV				II	IV		V	IV	V	V	V			V	V				V	V	
MAGNETITE	✓	I	✓	V	✓	✓	✓	✓	✓	✓	✓		IV	✓	✓	✓	✓	✓	IV	✓		✓		III		V						V					✓	V	V			✓	V	V	V							
MONAZITE																																			I																	
MUSCOVITE	✓					✓	✓	V	✓	II		✓																		III									I													
PIGEONITE							V																																													
PYROXENE ALT'D						✓	III	✓											V																																	
RUTILE						✓		I		I			I	✓	✓	✓			✓		✓	✓	I	III	II	IV	V	I	I	I		I	IV	I	II	IV	I		III	I	I	II	II	II	I	I		I	II	I	II	III
SPHENE							✓			I																																										II
TOURMALINE	I	✓	✓	✓	I		✓		✓	I			I	I	✓	I	I	I	I	I	II	I	I	II	I	I	I	I	I	I	II	I	I	I	I	I	I	IV	I	I	II	II	II	II	II	III	I	I	I	I	I	II
ZIRCON	I	II	✓	✓			I	I		I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	II	II	I	I	I	I	I	I		I	II	II	II	II	II	I	I		I	II	I	II	I

MINERALS

LEGEND

✓ - Mineral Preser Roundness Un- determined.

D.D.H. - Diamond Drill Hole.

H.M. - Heavy Mineral

ROUNDNESS

I - WELL ROUNDED

II - ROUNDED.

III - SUBROUNDED.

IV - SUBANGULAR.

V - ANGULAR.

amphibole grains were observed to be partly altered to chlorite. Also, in several light and heavy residues feldspar grains were observed to be partly altered to clay minerals, mainly kaolinite. Whether these alterations occurred before or after the deposition of the grains is not known, although the generally irregular to ragged nature of the grains seems to indicate either authigenisis, or the presence of intrastratal solutions, or both.

Roundness of Heavy Mineral Grains. Roundness determinations were made of most of the minerals observed in the heavy residues. The results are given in Table XIII. The determinations were made of minerals which were occasionally to always detrital, hence pyrite and the carbonates, which are believed to occur practically always as authigenic minerals, are omitted. Minerals, such as enstatite, which were found in only a few heavy residues have also been omitted. Roundness values given for such minerals as antigorite, chlorite, and clay minerals may have little value as these minerals are probably in part detrital and in part secondary. The persistently well rounded nature of zircon, tourmaline, apatite, and to a lesser extent rutile, is worthy of note. On the other hand, it is observed that minerals having good cleavages such as the micas, pyroxenes and amphiboles are generally quite angular, the angularity undoubtedly being due to the ease with which these minerals break along the cleavage planes. In fact, in a good number of the heavy residues these minerals appear to have been broken during crushing; however, in determining the roundness an attempt was made to select edges that appeared to have been formed by sedimentary processes. Where this was not possible, the roundness was not determined. Occasionally grains of apatite, ilmenite, magnetite, rutile, tourmaline, or zircon were observed to occur as poorly to well formed crystals. Most of these grains were probably inclusions in quartz grains which were freed by crushing, although some of them appear to be authigenic crystals. More than one or two such grains were rarely present, therefore the roundness values were not noticeably affected in most cases.

Possible Errors in Mineral Identifications. Whenever there was a slight uncertainty in the identification of a mineral in a heavy residue a question mark was placed by the frequency value in Table XII. Some of these identifications are more uncertain than others. Among these are the identification of anatase and brookite.

There was some uncertainty in differentiating cassiterite from rutile, and it is possible that the presence of cassiterite was overlooked in some of the heavy residues. On the other hand, it may be that rutile was mistaken for cassiterite in some of the heavy residues. The identification of cassiterite was based largely on the rolled appearance of the grains and lower birefringence than rutile.

It was found to be quite difficult to differentiate chalcopyrite from pyrite. A microchemical test was made for copper in heavy residue 1, and a positive result was obtained. Chalcopyrite is believed to have been present in heavy residues 2 and 7 and may have been present in other heavy residues.

The presence of fluorite in heavy residues 7 and 24, and especially of sphalerite in heavy residue 12 is thought to have been due to contamination from an outside source. Fluorite could be detrital, but the writer does not think that sphalerite could be a detrital mineral in the Potsdam sandstone. If it were an authigenic mineral it would seem probable that sphalerite would have been observed in other heavy residues. If contamination occurred, it probably did so during the crushing and screening of the heavy residue samples. There was little difficulty in identifying the minerals.

Description of Minerals:

ACTINOLITE

General. A few detrital grains of actinolite were observed in heavy residues 5 and 7. The grains are pale-green in colour and are generally faintly pleochroic, the pleochroism ranging from pale-yellowish-green to pale-green. They occur as angular, prismatic, elongated, and irregularly shaped cleavage grains with an extinction angle of 16 to 17 degrees measured in longitudinal sections.

Special Features. Tiny inclusions were observed in a few of the grains, and one of the grains contained minute hexagonal inclusions.

AEGIRINE

General. Detrital grains of aegirine, associated with titaniferous magnetite were observed in heavy residue 10. The grains are light greenish-brown, prismatic, and have an extinction angle of 7 to 11 degrees in longitudinal sections. The refractive indices were determined to be: Nx - 1.77, Ny - 1.81, and Nz - 1.82.

ALBITE

General. It is believed that albite was present in several of the thin sections and light residues, although in most cases it was not differentiated from the other plagioclase feldspars. It occurs as angular, unaltered to slightly altered, colourless, detrital grains possessing albite twinning. The refractive indices were invariably less than 1.54 and one grain, properly orientated for the use of the Michel-Lévy method, had an extinction angle of 19^o.

ALTERATION PRODUCTS

This heading is used as a wastepaper basket term under which are placed those grains which have been altered to such an extent that it is difficult to determine their properties, and therefore to determine the mineral itself. Some of the minerals which are believed to occur as altered minerals or/and alteration products are: chlorite, clay minerals, epidote, feldspars, iron oxides, micas, and pyroxenes.

ANATASE

General. A grain of anatase was observed in each of 4 heavy residues. In three of these the grains are detrital, rounded to well rounded, and faint-yellow. In the fourth an angular, fractured, translucent, indigo-blue grain was observed. In all cases the grains possess very high dispersion and birefringence.

ANDESINE

General. Detrital andesine grains are believed to have been present in some of the thin sections and light residues; but in most cases they were not differentiated from the other plagioclase feldspars. It is less abundant than albite. The grains are mainly angular, colourless, show some alteration, and are generally optically negative with an extinction angle of 14 degrees using Michel-Lévy's method.

ANHYDRITE

General. A few tabular cleavage fragments of anhydrite were observed in heavy residue 23. They show no signs of weathering; therefore, they are probably authigenic. The grains possess very high birefringence, cleavage in three perpendicular directions and are mainly colourless. A few fragments are very slightly pleochroic from faint-yellow to bluish-white.

ANORTHOCLASE

General. Angular to rounded detrital grains of anorthoclase were observed in several thin sections. The grains, like most detrital feldspar grains, are smaller than the quartz grains in the same thin sections. They are also colourless, or light-brown due to alteration (probably to kaolinite). The optic angle ranges between 45 and 50 degrees and the extinction angle between the optic plane and (001), measured in the plane perpendicular to one of the optic axis, is approximately 5 degrees. Fine lamellar twinning is often observed.

Special Features. Some grains possess a perthitic structure, with thin laminae of anorthoclase alternating with thin laminae of what is probably a plagioclase feldspar. This latter feldspar has a higher refractive index than anorthoclase and is usually partly altered to what is believed to be kaolinite.

ANTIGORITE

General. Antigorite grains were observed in several heavy residues, thin sections and light residues. In the latter two, antigorite was not differentiated from the other chlorites. The grains are colourless, greyish to faint-yellowish, and pale-green. They occur as anhedral crystal aggregates, generally of a fibro-lamellar nature, elongated grains, and irregular fractured grains, all of which possess perfect basal cleavage. The optic angle ranges from moderately low to almost 90 degrees. The fibro-lamellar aggregates are probably authigenic. Some of the other grains are probably detrital. In one heavy residue antigorite apparently occurred as an alteration product of diopside and hypersthene.

Special Features. Some of the grains contain a few minute inclusions, and one larger grain appeared to contain needle-shaped inclusions, also of antigorite.

APATITE

(Plate V)

General. Apatite grains were observed in over half of the thin sections and heavy residues that were examined and in several of the light residues. The frequency of occurrence increases toward the base of the core section. The grains are detrital except for a few authigenic growths around detrital muclei of the same mineral. Apatite occurs mainly as well rounded, spherical to egg-shaped grains, although tabular or poorly rounded grains are sometimes observed. The weathered surface is generally minutely pitted (Plate V, Fig. 1). This is believed to be due to solution which may have played a large part in rounding the grains, either before or after their deposition. The presence of authigenic growths indicates that rounding by solution may have taken place after the deposition of the grains. The grains are practically always colourless, although a few grains have a faint-blue tinge, and a light-brown grain is rarely observed. One pale-pink grain was observed. A few grains were observed to possess a poor basal cleavage or/and a poor cleavage parallel to the length. In general the indices range between the limits 1.63 and 1.64, the birefringence being weak. Evidence of alteration was observed in one or two grains only.

Special Features. Authigenic growths were observed in a few heavy residues. The growths invariably possess a hexagonal outline, have formed around well rounded grains of apatite, and in optical continuity with these nuclei.

A few of the grains, in each heavy residue in which apatite was found, were observed to contain one or more of the following types of inclusions.

(1) Tiny needle-shaped inclusions, colourless to dark coloured, with high birefringence, and generally orientated parallel to the length of the apatite grains - possibly rutile.

(2) Minute bubble-like inclusions (gaseous or liquid?), many of which are arranged in rows.

(3) Minute dust-like inclusions which are white, brown, or dark to opaque, and many of which are arranged in rows or parallel rows. Some of the opaque inclusions are white in reflected light and may be leucoxene.

(4) One inclusion of leucoxene was observed.

PLATE V

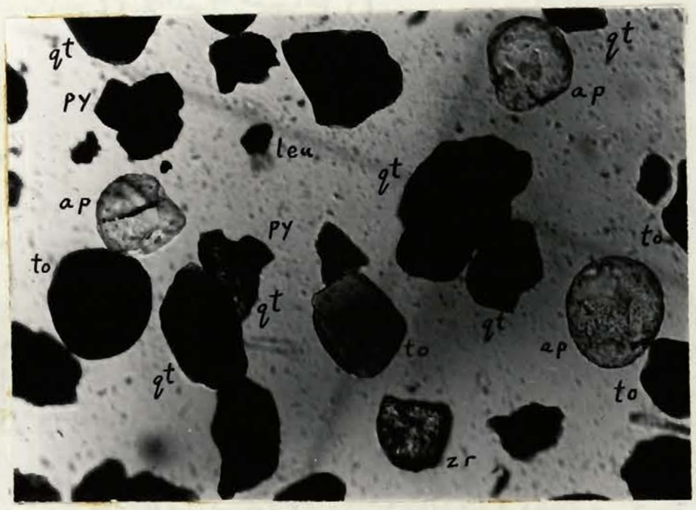


Fig. 1 - H.M. No. 24, X135, plane polarized light. ap - apatite, leu - leucoxene, py - pyrite, qt - quartz, to - tourmaline, zr - zircon.

Fig. 2 - H.M. No. 36, X60, plane polarized light. ap - apatite, leu - leucoxene, py - pyrite, to - tourmaline, zr - zircon.

AUGITE

(Plate VIII)

General. Augite was observed in only four of the heavy residues. It occurs as broad, irregular shaped cleavage fragments of detrital origin which are generally somewhat altered. The grains are light-green, pale-yellowish to brownish-green, or green, and are occasionally faintly pleochroic. The characteristic pyroxene cleavage almost at right angles is observed in most grains and the extinction angle is about 45 degrees. The optic angle is approximately 60 degrees.

Special Features. The following inclusions were observed in different grains.

(1) Magnetite - ilmenite inclusions.

(2) Tiny tabular inclusions, pleochroic from green to brownish-green, probably a pyroxene.

BIOTITE

General. Detrital grains of biotite were observed in most of the heavy residues, and in some of the thin sections and light residues. Biotite occurs as angular to rounded platy cleavage flakes, many of which have one or more broken or jagged edges. Occasionally a grain is elongated. A few flakes are euhedral, and possess a hexagonal outline. These flakes may have been inclusions which were freed by crushing. In colour the grains are yellowish-light-green, olive-green, yellowish-green, greenish-brown, reddish-brown, light-brown, or brown. Colourless, leached grains become more prominent toward the base of the core section. The following pleochroic formulae were observed; pale yellowish-green to reddish-brown or dark-brown, almost colourless to olive-green, light-green to dark-blue-green, and light-brown to dark-brown (almost black). Practically every grain was observed to possess perfect cleavage in one direction. The extinction direction is generally parallel, or almost parallel, to the cleavage traces. A few grains show wavy extinction. The optic angle ranges from 0 to approximately 30 degrees. Generally, the leached grains have a higher optic angle than the unaltered grains. The birefringence is strong.

Special Features. The following inclusions were observed in several of the grains.

(1) Leucoxene and ilmenite

(2) Magnetite

(3) Brown coloured inclusions

(4) Acicular, dark-coloured inclusions - probably rutile.

Around the edges of the colourless leached grains, and arranged concentrically, are generally found small, thin, tabular crystals of chlorite, probably antigorite. These are obviously alteration products of biotite.

BROOKITE

<u>General</u>. One subangular detrital grain of what is believed to be brookite was observed in heavy residue 25. The grain was light-brown, and had extremely high refringence and birefringence. Also, the grain was striated, the extinction being parallel to these striae and poor.

CALCITE

<u>General</u>. Calcite was observed in some of the light and heavy residues and thin sections. It occurs mainly as anhedral crystals or as euhedral cleavage rhombs. A few of the crystals are euhedral. Most of the calcite is undoubtedly authigenic, either being recrystallized from the original carbonate that was deposited, or introduced later (Plate III, Fig. 2). However, some of it may be primary, an example being the band of calcite that occurs in the drill core at an elevation of 1452.5 feet. The crystals are generally colourless to cloudy; but a few are altered and are yellowish, brown, or greyish-green. Some crystals are altered to limonite. The cloudiness is probably due in part to alteration. Perfect rhombohedral cleavage is generally observed and twinning is fairly common. In general N_o ranges between 1.66 and 1.67.

<u>Special Features</u>. A few crystals contain inclusions of

pyrite. Some of the cloudy crystals appear to have inclusions; but more likely this appearance is caused by alteration.

CARBONATE

(Graph V)

General. In several cases, due to alteration or to too few grains in the residue it was difficult to determine the type, or types, of carbonate present. In these cases the general term carbonate is used. In most of these cases the carbonate is believed to be a ferro-dolomite and to range in composition from dolomite to siderite. The crystals generally have a poor crystal shape and the cleavage is often obscured. The crystals are generally yellow, brown or grey, the colour of many being spotty due to alteration. Some of the crystals are slightly pleochroic. The indices vary considerably.

CASSITERITE

General. A few detrital grains of what are believed to be cassiterite were observed in heavy residues 13 - 17 and 19. The grains are usually elongated, rounded to well rounded and have a rolled appearance. In colour the grains are brownish-grey, light to dark-brown, or almost black. In many grains the colour is blotchy. Very slight pleochroism was observed in one grain. The extinction angle is parallel to the length of the grains. The indices are very high, being approximately the same as those for zircon. The birefringence is extreme; but is lower than the birefringence of rutile. Interference colour rings are often observed around the edges of the grains and are sometimes a bright shade of red, blue or green. The grains are uniaxial positive. A few grains possess striations nearly at right angles to one another due to twinning.

Special Features. A few inclusions were observed in some of the grains. These are:

(1) Dark-coloured needle-shaped inclusions - possibly rutile.

(2) Dark-reddish-brown inclusions, occasionally minute.

CHALCOPYRITE

General. Chalcopyrite was observed to be present in heavy residues 1, 2 and 7, and was probably present in several more. It occurs as irregular shaped authigenic crystals which are brass-yellow to dark-brass-yellow with a greenish tinge. The presence of chalcopyrite in heavy residue 1 was strongly suggested by a positive reaction obtained in a microchemical test for copper.

CHERT

General. Chart is present in most of the thin sections that were examined. It occurs mainly as authigenic chert filling the interstices in some of the drill core. In these cases the chert occurs as fibro-lamellar aggregates of tiny fibres having low birefringence and parallel extinction. The crystals generally have slightly lower indices than quartz. Occasionally an angular to rounded grain of chert is present in a thin section. These grains are believed to be detrital. Occasionally a grain of chert is observed to be partly altered to quartz, the contact being gradational between the two types of silica.

CHLORITE

General. Chlorite grains or crystals were observed in most of the heavy residues and in some of the light residues and thin sections. They occur generally as angular cleavage fragments and irregular aggregates of tiny tabular crystals. Most of the chlorite grains are probably authigenic, however, a few rounded, massive grains are occasionally observed which may be detrital. Most of the grains are some shade of green, varying from colourless to pale-green, dark-green, pistachio-green, blue-green, or almost black. Brown grains are rarely observed. The grains vary from nonpleochroic to slightly pleochroic, the colour varying from one shade of green to another. One grain was observed to vary from light-green to pale-buff. Good to perfect basal cleavage is generally observed in the grains. The extinction angle, measured against the cleavage is generally parallel or almost so, but in a few grains it is as much as 13 degrees. Wavy extinction is often observed. The indices, for the most part, range between 1.57 and 1.66 and the birefringence is weak to moderate. Anomalous red and blue interference colours are rarely observed. The grains are biaxial negative and positive, hence different types of chlorite are present. In heavy residue 25 the variety thuringite may be present. Epidote was found to be associated with chlorite in heavy residue 5.

Special Features. A few inclusions were observed in some of the grains. Pyrite crystals were observed in some chlorite grains which indicates that the chlorite, in this case, is probably authigenic. The inclusions that were observed are:

(1) Ilmenite and/or leucoxene.

(2) Magnetite and/or ilmenite.

(3) Pyrite.

(4) Dark-coloured inclusions.

CLAY MINERALS

General. Crystals and grains of clay minerals were observed in most of the light and heavy residues and thin sections. No attempt was made to differentiate the various clay minerals; but from the properties that were observed kaolinite is believed to be the most abundant. Montmorillonite is also believed to be present in a few cases. The clay minerals occur mainly as tabular crystals and irregular aggregates of tiny crystals. A few large crystals with pseudo-hexagonal outlines are observed. In some cases rounded grains of clay minerals are present and these may be detrital. Practically all of the grains, however, are authigenic. The clay minerals range in colour from colourless, cloudy or greyish, faint-yellow, light-to dark-brown and occasionally green. In some grains the colour is spotted, probably due to alteration. No pleochroism was observed. Some grains have a well developed basal cleavage while others appear to have no cleavage at all. The extinction angle measured with the cleavage ranges from 0 to 20 degrees, but is generally low. Some grains appear almost isotropic while others have no good extinction. The range in the refractive indices is considerable. The following determinations were made in various heavy residues:

Nx	Nz
1.547	1.565
1.543 - 1.558	1.555 - 1.565

In addition N = 1.57 (approximately), and N = 1.61 - 1.62. In general the indices are slightly less than 1.57. The optic angle, where observed, is low, ranging from 0 to 25 degrees.

The birefringence is weak to very weak. Most of the clay minerals are believed to have been formed from feldspar, as all gradations from unaltered feldspar to clay minerals (mainly kaolinite?) are frequently observed.

Special Features. The following inclusions were observed:

(1) Black-coloured inclusions, some of which are opaque.

(2) Minute inclusions and tiny bubble inclusions?

(3) Leucoxene.

(4) Pyrite.

Inclusions of pyrite crystals are fairly common, and as with chlorite, indicate that the pyrite and clay minerals in these cases are authigenic.

DIOPSIDE

(Plate VI)

General. Detrital grains of diopside were observed in some of the heavy residues and occur as angular, short prismatic, and irregular shaped grains. Smaller, rounded grains are sometimes observed. Euhedral crystals with pyramidal terminations are rarely observed, and are probably inclusions released by crushing. One euhedral inclusion of diopside was observed in a quartz grain. The grains are colourless, pale-green, blue-green, and green, and are usually faintly pleochroic. Some of the grains are slightly altered to chlorite along cleavage planes and fractures. Good cleavage in two directions at 87 degrees is generally present, but in some grains the cleavage is poorly developed and irregular fractures appear to be more prominent. In other grains a third cleavage is present. Broad, rather indistinct twinning is also present in a few grains. In general the extinction angle $Z \wedge c$ ranges from 37 to 42 degrees. The indices of refraction were determined in heavy residue 29 as Nx - 1.650, Ny - 1.672, and Nz - 1.700. The birefringence is moderately strong and the optic angle is approximately 60 degrees.

<u>Special Features.</u> The following inclusions were observed in various grains.

(1) Ilmenite and leucoxene inclusions.

(2) Tiny opaque inclusions, dark in reflected light.

(3) Tiny, elongated, parallel inclusions.

PLATE VI

Fig. 1, H.M. No.29, x74, plane polarized light.
di - diopside, do - dolomite, hy - hypersthene,
py - pyrite, qt - quartz, si - siderite,
to - tourmaline, zr - zircon.

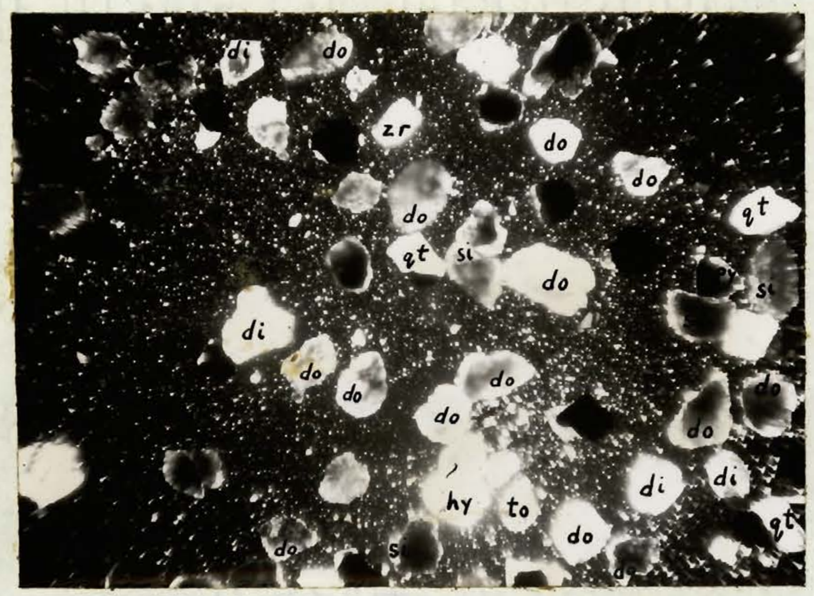


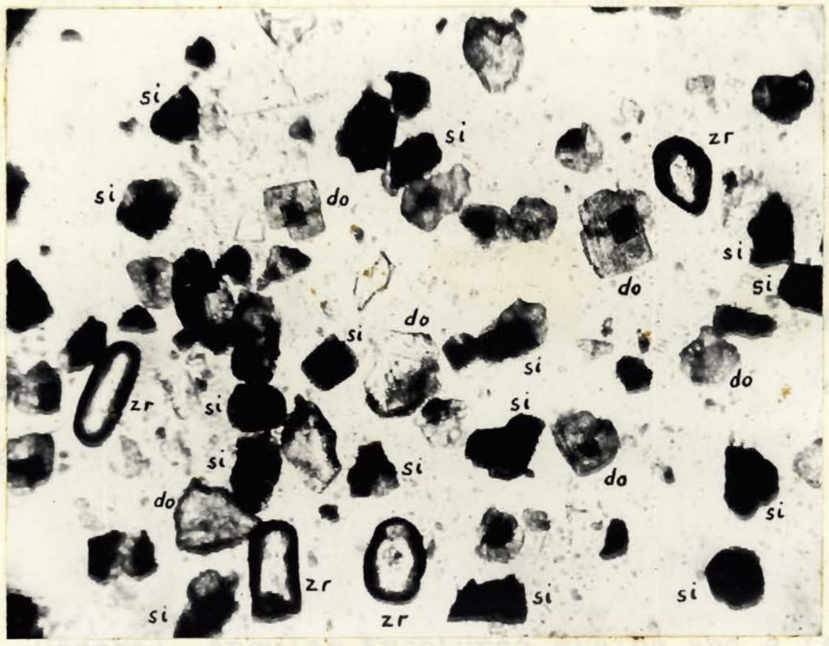
Fig. 2, H.M. No.29 x74, crossed nicols.
di - diopside, do - dolomite, hy - hypersthene,
py - pyrite, qt - quartz, si - siderite.
to - tourmaline, zr - zircon.

DOLOMITE

(Plates VI, VII)

General. Authigenic crystals of dolomite were observed in several heavy residues and in some of the light residues and thin sections. Dolomite occurs as euhedral to subhedral crystals and cleavage rhombs. A few of the crystals have a hexagonal outline. Also, some of them appear to be rounded and may possibly be detrital, although this is doubted. In some thin sections the carbonate appears to have been slightly broken up after deposition and then recemented. The crystals may be colourless, white to light-grey, and yellowish to brown. A few grains were observed to be slightly pleochroic from light-brown to brown. The colour of the crystals is due to the weathering of iron contained in the dolomite. The crystals have perfect rhombohedral cleavage. The index of refraction Ne was observed to range from 1.50 to 1.547, the higher values corresponding to a ferruginous dolomite. The indices for the dolomite at the contact of the Potsdam sandstone with the Beekmantown group were determined to be N_o - 1.517 and N_e - 1.68. A twinkling effect is often observed due to the extreme birefringence.

PLATE VII



H.M. No. 26, x80, plane polarized light.
do - dolomite, si - siderite, zr - zircon.

Special Features. Some crystals show a subsequent growth around an earlier authigenic core, both growths being rhombohedral (Plate VII). The core is invariably darker in colour than the second growths which are in optical continuity with the cores.

The following inclusions were observed in some of the grains.

(1) Pyrite crystals, often several tiny ones disseminated in a dolomite crystal.

(2) Rounded, brown inclusions.

(3) Opaque inclusions of iron oxide (brown to black in reflected light.

optic axis figure. One grain has a pitted appearance.

Special Features. The following inclusions were observed in a few of the grains:

(1) Chlorite inclusions.

(2) Tiny inclusions with $n < 1.72$.

(3) Tiny black inclusions.

(4) Magnetite inclusions.

FELDSPAR

In some cases it was difficult and tedious to determine with any degree of accuracy the mineral frequency of each type of feldspar present in light residues and thin sections. This was due to alteration and to the necessity of determining the properties of practically each grain before the type of feldspar could be determined. In these cases the different types of feldspar occurring were noted; but only the mineral frequency of all the feldspars grouped together was determined.

FLUORITE

General. One detrital grain of what is believed to be fluorite was observed in each of heavy residues 7 and 24. The grain that was observed in heavy residue 7 is elongated and rounded at one end, light-brown and isotropic. The grain that was observed in heavy residue 24 is a fractured, mauve-coloured, isotropic grain with dark-coloured spots. Possibly, these grains were introduced into the samples during the crushing and grinding (see pp. 63-64).

Special Features. Three minute, angular, white, anisotropic inclusions were observed in the grain found in heavy residue 24.

GARNET

(Plate VIII)

General. Garnet grains were observed in approximately half of the heavy residues and in two of the thin sections. Little attempt was made to determine the different types of garnet; but from the various properties it would appear that almandite, grossularite and spessartite are the most common. The grains are rounded to angular, some having a rough pitted surface while others are smooth. In some grains the crystal shape can still be seen, the edges being only slightly rounded in a few cases. Many dodecahedral and trapezohedral forms are observed. So far as could be determined the grains are all detrital, although a few are so little worn that they might be authigenic. These slightly worn grains may also indicate very little erosion before deposition or possibly they were inclusions that were freed by crushing. The grains are usually colourless, white, pale-pink, or pale-brown, and rarely green, pale-purple, deep-red, or faint-blue. Most of the grains are unaltered; but a few are slightly altered, mainly to chlorite. A poor cleavage or parting in two directions not quite at right angles is sometimes observed. A poor conchoidal fracture is observed in a few grains. A few of the grains are also slightly anisotropic.

Special Features. The following inclusions were observed in different grains.

(1) Tiny, acicular, slightly bent inclusions - rutile ?

(2) Tiny, tabular, light-coloured inclusions.

(3) A few white inclusions, N $<$ garnet.

(4) A few brown inclusions.

GYPSUM

General. A few crystals of gypsum were observed in a shale lamina at an elevation of approximately 1355 feet in the drill core. The crystals are tabular with arrowhead terminations and occur in a poor sheaf-like aggregate. They are definitely authigenic. A small amount of anhydrite may also be present.

HEMATITE

General. Hematite grains were observed in a few heavy residues and thin sections. They occur as irregular, angular to occasionally rounded, opaque grains which are red in reflected light. The grains are authigenic except for one grain which occurs as an inclusion in quartz and which could be authigenic or detrital. In most cases the hematite grains occur with limonite grains as an alteration product of carbonate, mainly siderite. In a few cases they also appear to have been formed by the weathering of pyrite. Quartz - hematite grains are sometimes observed.

HORNBLENDE

General. Detrital hornblende was observed in several heavy residues. It occurs mainly as elongated, or bladed, cleavage grains and angular fractured grains. The grains range in colour from almost colourless to various shades of green and black. They were observed to be pleochroic as follows: colourless to pale-green, yellowish-green to pale-green or dark greenish-blue, pale-green to dark-green, and light olive-green to black. A few grains are altered to chlorite but one was observed to be partly altered to biotite. Excellent cleavage is usually present in two directions at 56 degrees to one another. The extinction angle, measured in longitudinal sections, ranges from 12 to 31 degrees. The birefringence ranges from rather weak to fairly strong and the optic angle from 55 to 80 degrees. The grains are optically negative. One grain was observed to be positive with an optic angle of approximately 60 degrees and an extinction angle of 28 degrees. It may be pargasite, a variety of hornblende.

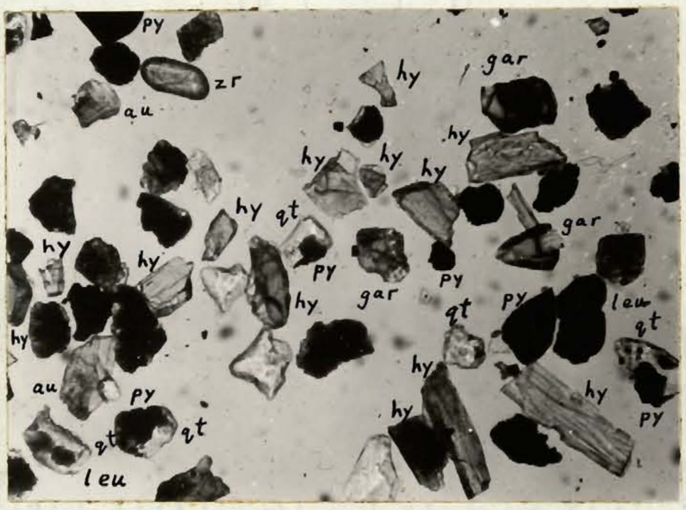
Special Features. Inclusions of ilmenite were observed in a few grains.

HYPERSTHENE

(Plate VIII)

General. Detrital grains of hypersthene were found in nearly half of the heavy residues, and are slightly more prominent toward the top of the core section. Hypersthene occurs mainly as elongated, lath-like cleavage prisms, although some grains are broad and irregular in shape. The grains are generally some shade of green and, occasionally, are colourless, pale-yellow, pale-brown, pinkish, or reddish. Pleochroism is generally present as follows: colourless to pale-yellowish, reddish, or pale-green; pale-green to green, pale-green or bluish-green to pale-pink, and pale-green to reddish. A few grains are altered to chlorite, probably antigorite, and one grain is partly altered to a reddish-brown material. Cleavage in two directions, nearly at right angles, is generally observed; although in a few grains the cleavage appears to be little better than a parting. The extinction is parallel to the cleavage in prismatic sections. The birefringence is rather weak and the optic angle ranges from 65 to 90 degrees. Twinning on (101) was observed in one grain.

PLATE VIII



H.M. No.7, x55, plane polarized light.
au - augite, gar - garnet, hy - hypersthene,
leu - leucoxene, py - pyrite, qt - quartz.

<u>Special Features.</u> A few grains have a schiller structure developed, with the inclusions occurring along the cleavage planes.

The following inclusions were observed in different grains:

(1) Ilmenite - leucoxene inclusions.

(2) Magnetite inclusions.

(3) Colourless, needle-shaped inclusions, arranged parallel to the lenth of the grains.

(4) Quartz inclusions.

(5) Pyrite inclusions.

(6) Tabular inclusions, one with a square outline

ILMENITE

(Graph IV)

General. Detrital grains of ilmenite were observed in approximately two thirds of the heavy residues and in some of the thin sections. The grains are generally subrounded, but range from angular to well rounded, and are somewhat elongated. Some are irregularly shaped and a few have minutely pitted surfaces, probably due to solution. A few euhedral, rhombohedral crystals occur as inclusions in quartz grains. The grains are believed to be practically all detrital; but a very few grains containing rutile, ilmenite and leucoxene indicate that the rutile has been altered to ilmenite and leucoxene. This alteration may or may not have occurred prior to the deposition of the grains. The grains are opaque in transmitted light, and greyish-black, purplish-black, and black in reflected light. Many ilmenite grains show some alteration to leucoxene, and some have a salt and papper appearance with tiny grains of ilmenite and leucoxene interdisseminated. In other grains, ilmenite and leucoxene are interbanded. A small amount of pyrite is sometimes present with leucoxene and ilmenite. No cleavage was observed. The grains range from nonmagnetic to slightly magnetic and in one or two instances, they were observed to range from nonmagnetic to highly magnetic (magnetite).

Special Features. Inclusions of leucoxene and/or pyrite occur in some of the ilmenite grains and are alteration products.

IRON OXIDE

<u>General</u>. In a few of the heavy residues and thin sections, angular to rounded grains were observed which are believed to be some form of iron oxide. The grains are opaque to slightly anisotropic. The grains appear to have been formed mainly from carbonate and pyrite and in these cases are authigenic. Some grains occur with rounded quartz grains and are probably detrital. In reflected light the grains are black to reddish-brown, or brown. The grains are generally altered, and in some cases a grain has several different shades of colour. In these cases it was not possible to determine the type of iron oxide.

KAOLINITE

<u>General</u>. Although the clay minerals were not differentiated, most of the grains are believed to be authigenic grains of kaolinite which have been formed by the alteration of feldspar grains. Most of the grains are irregular or shredded; although a few are well rounded, indicating the alteration of detrital grains, probably after deposition. A few are elongated, bent, and exhibit accordion-like shapes. A few others have pseudohexagonal outlines. The crystals and grains range in colour from colourless, pale-brown, to brown. Cleavage is perfect in one direction and the extinction is

parallel to almost parallel to the cleavage. The indices of refraction range between the limited 1.55 and 1.57, and the birefringence is weak. The optic angle ranges from low to high.

Special Features. Pyrite and/or leucoxene inclusions are found in a few of the grains.

KYANITE

General. A few detrital grains believed to be kyanite were observed in heavy residue 25. They are colourless, well rounded, elongated and tabular. They possess a good cleavage parallel to, and in some cases a poor cleavage, or parting, perpendicular to the elongation. The extinction angle is approximately 25 degrees measured from the direction of elongation. The birefringence is fairly low.

LAWSONITE

General. A few grains, probably of lawsonite, were observed in heavy residue 28. The grains are mainly angular, rhombic sections, and are thought to be detrital; although they may be authigenic. They are also colourless, and many have a faint bluish tinge. Good cleavage is generally present in two directions at right angles, and the extinction is parallel to the cleavages. The mineral is biaxial positive and has an optic angle of 80 degrees or more.

LABRADORITE

General. A few detrital grains of labradorite were observed in thin section 42. The grains are solourless and the extinction angle,(Michel-Lévy's method) was determined to be 30 degrees. The indices are slightly greater than those for quartz. The extinction angle of 30 degrees indicates a composition of Ab 46 An 54.

LEUCOXENE

(Plate IX, Graph IV)

General. Leucoxene grains were observed in most of the heavy residues and thin sections, and in a few of the light residues. Leucoxene becomes increasingly abundant toward the bottom of the core section. The grains range in shape from rounded to subangular, and from spherical to irregularly shaped. The grains are believed to be mainly detrital; but some may be authigenic. A few grains have ilmenite and leucoxene interbanded, some have a salt and pepper appearance with ilmenite and leucoxene interdisseminated, a few have ilmenite cores, and occasionally, one is seen with a band of rutile remaining in the centre. These occurrences indicate that the leucoxene has formed from ilmenite and to a lesser extent rutile; but it is not known how much of this alteration, if any, occurred after the grains were deposited. Many of the grains are aggregates of tiny, elongated crystals. The grains are opaque in transmitted light, and generally milky-white to grey, or occasionally light-green or brown, in reflected light. One pale-pink grain was observed in reflected light. Nearly all of the grains possess a dull, earthy lustre, although a few are subvitreous. The grains are sometimes associated with chlorite, or clay minerals, and rarely with altered pyroxene.

Special Features. Inclusions of ilmenite, rutile, and rarely pyrite have been observed. The ilmenite and rutile probably occur as unaltered areas and the pyrite as a secondary mineral. A few tiny specks of a light-orange coloured mineral occur in some of the grains.

Plate IX

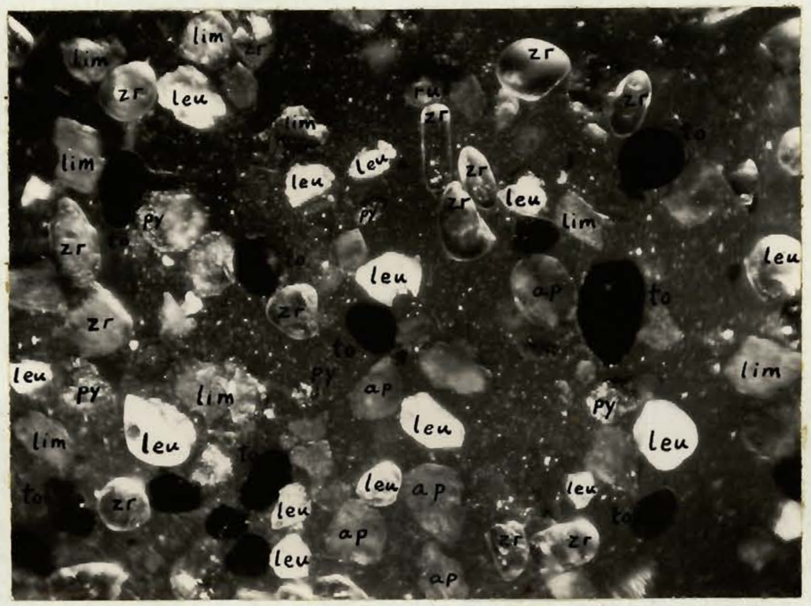


Fig. 1 - H.M. No. 35, x66, reflected light
ap - apatite, leu - leucoxene, lim - limonite,
py - pyrite, ru - rutile, to-tourmaline,
zr - zircon.

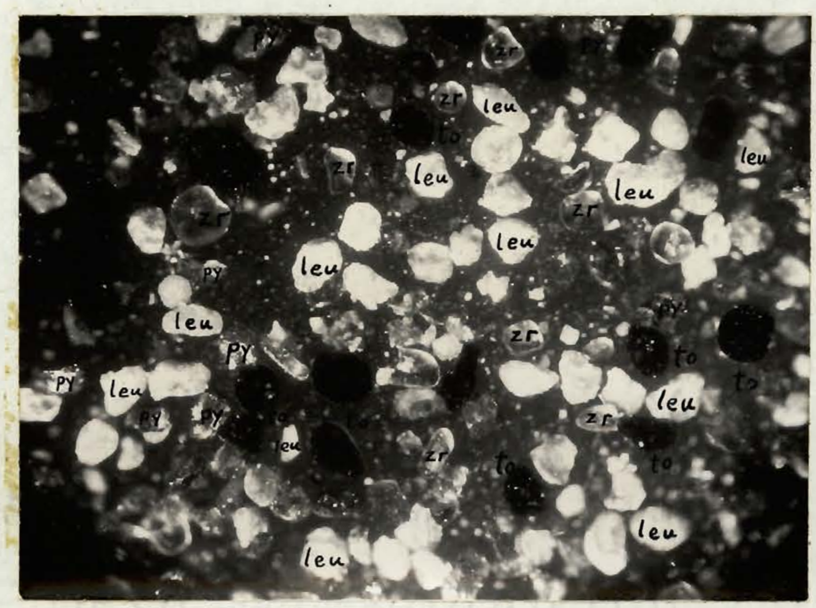


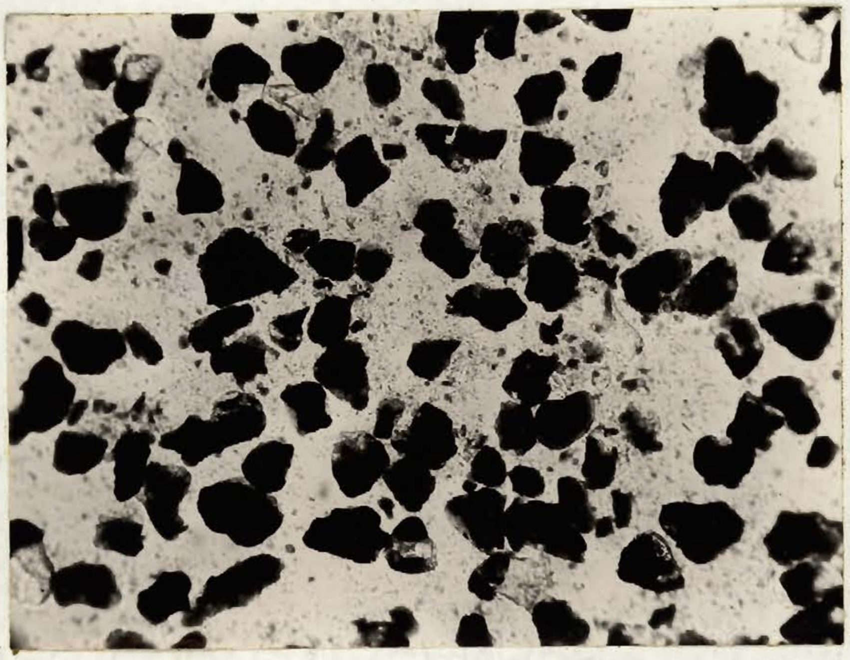
Fig. 2 - H.M. No.51, x51, reflected light.
leu - leucoxene, py - pyrite, to - tourmaline,
zr - zircon.

LIMONITE

(Plate X)

General. Authigenic limonite grains were observed in some of the heavy residues, light residues, and thin sections. The grains are more abundant toward the bottom of the core section. They are rounded to angular, and generally have an irregular shape. A few cubic grains, formerly pyrite but now altered to limonite, are occasionally observed. Limonite occurs mainly, however, as an alteration product of carbonates, (chiefly dolomite and siderite) and pyrite. All gradations from the unaltered carbonates and pyrite to limonite were observed. Rounded quartz - limonite grains were observed in some cases, and the limonite in these grains could be detrital. It could, however, be authigenic, and is probably altered iron oxide or pyrite. Limonite is sometimes associated with hematite grains which were probably formed from limonite. In thin sections,limonite was found to occur mainly in shale laminae. The limonite grains are translucent to opaque and range in colour from yellow to brown, brownish-black and reddish when viewed with reflected light, and from yellow to brown, and brownish-black when viewed with transmitted light.

Plate X



H.M. No. 31, x65, plane polarized light.
quartz - limonite grains.

MAGNETITE

(Graph IV)

General. Detrital grains of magnetite were observed in over half of the heavy residues, and in thin sections 1 and 2. Much of the magnetite occurs as inclusions in quartz grains. Inclusions of magnetite in chlorite, epidote, muscovite, tourmaline, and zircon have also been observed. As inclusions, magnetite occurs mainly as octahedra and poorly developed crystals. Some cubes and dodecahedrons were observed. As separate grains, magnetite occurs as well rounded to angular grains which have the crystal edges only slightly rounded. The grains are opaque in transmitted light, and steel-blue-black with a metallic lustre in reflected light. They are also highly magnetic. In heavy residue 10 nonmagnetic to highly magnetic grains were observed. Many of the grains possessing least magnetism show alteration to leucoxene, hence these grains probably range in composition from ilmenite to titaniferous magnetite and magnetite.

MICA

(Graph II)

General. Except for one flake of muscovite the micas were not differentiated in the light residue of heavy min. sep'n 35. Mica is included in heavy minerals in Table IX. Also, in Graph II the micas were grouped together.

MICROCLINE

General. Microcline was observed in over half of the thin sections and in several of the light residues. The grains are angular to rounded, are generally smaller than the associated quartz grains, and are mainly detrital. Several grains have authigenic growths around detrital nuclei. The growths appear to be mainly orthoclase; but in one case the twinning was observed to continue on into the secondary growth. The secondary growths are colourless, as are several of the detrital grains. Most of the detrital grains show some alteration and are a cloudy grey, or more rarely, a light-brown. Much of the alteration is to a clay mineral, probably kaolinite. Good cleavage in at least one direction is generally present. The extinction angle on 010 is 5 degrees with the cleavage. The optic angle was not observed owing to the fine twinning which prevented the formation of interference figures. The birefringence is weak. Polysynthetic twinning and the resultant cross-hatched appearance is usually present, and the lamellae are usually spindle-shaped.

One grain was studied using a universal stage. It was observed to be negative, the optic angle being slightly greater than 81 degrees. The extinction angle in the 001 plane is about 15 degrees from the 010 cleavage, the angle being measured from X to 010. The grain was twinned on 010.

Special Features. Several grains have authigenic growths, mainly orthoclase, around a detrital nucleus. In some cases the extinctions in both parts of the grains coincide, hence in these grains the authigenic growths are in optical continuity with the nucleus, both parts being microcline. Twinning was observed in only one of these growths. The authigenic growths tend to form crystal outlines, some having most of their faces complete. These secondary growths appear to have formed earlier than se condary growths on quartz grains, because where the growths on feldspar occur adjacent to quartz grains,these growths have grown partly around the quartz grains, which in these cases, do not possess secondary growths. The authigenic growths on feldspar are believed to be of sedimentary origin. The occurrence of authigenic feldspars has been discussed by several writers (Berg, 1952, pp.221-223; Gouldich, 1934, pp.89-95; Pettijohn, 1949, pp.500-502; Tester, and Atwater, 1934, pp.23-31).

MONAZITE

General. A few detrital grains which are believed to be monazite were observed in thin section 2 and in heavy residue 35. The grains are well rounded and slightly elongated. One angular fractured grain was observed. The grains range in colour from light-yellow to colourless. Cleavage parallel to the length was observed in one grain. The extinction is almost parallel to the length of the grains. The grains are biaxial positive and have a small optic angle.

MUSCOVITE

General. Detrital grains of muscovite were observed in some of the heavy residues, and in two of the light residues and thin sections. It is less common than biotite; but like biotite, it is more prominent in the upper part of the core section. The grains occur mainly as well rounded to angular platy grains. Some of the grains are irregularly shaped and others are thin tabular cleavage grains which are sometimes bent. The grains are green, olive-green, brown and colourless. Some of the grains are pleochroic from green to olive-green, and from brown to reddish-brown. Some grains are slightly altered to a brown mineral along the edge. The grains possess perfect basal cleavage and the extinction angle with the cleavage ranges from 0 to 2 degrees. Some grains have undulose extinction. The birefringence is strong and the optic angle ranges from 30 to 45 degrees.

Special Features. Inclusions of magnetite, ilmenite, limonite, and of dark-brown needles occur separately in some grains.

Rounded, colourless grains of mica become relatively more prominent toward the bottom of the core section. The optic angles in these grains range from 10 to 30 degrees. These grains are probably leached biotite.

OLIGOCLASE

General. Detrital grains of oligoclase were observed in some of the light residues, and possibly in thin section 35. The grains are mainly rounded to subangular, and colourless to light-grey, or light-brown, due to alteration. The grains are generally somewhat altered to a clay mineral, probably kaolinite, or more rarely to sericite. The extinction angle, using Michel-

Lévy's method ranges from 0 to 10 degrees. Generally Ny is slightly less than 1.54. Polysynthetic twinning is always present.

Special Features. It was observed that a few grains contain inclusions of leucoxene.

ORTHOCLASE

General. Detrital grains and authigenic crystals of orthoclase were observed in almost half of the thin sections and in some of the light residues. The detrital grains are angular to well rounded, and grey to light-brown due to alteration. They are rarely colourless. Some alteration to a clay mineral, probably kaolinite, is usually present. The authigenic crystals tend to be euhedral, are not twinned, and are generally clear and colourless. The detrital grains are also generally untwinned, probably because most of the detrital grains are only part of a twin lamella. The extinction in 001 is parallel. The birefringence is weak, and the optic angle is generally about 70 degrees. A poor perthite structure was observed in a few grains, which were generally altered.

Special Features. Authigenic orthoclase occurs as individual crystals which formed without the aid of a nucleus, and as secondary growths around nuclei of detrital microcline. The latter are more common. As stated when discussing microcline, these authigenic growths appear to have occurred prior to those on quartz grains. Reference has been made, in the discussion on microcline, to several writers who have discussed authigenic feldspars.

PIGEONITE

<u>General</u>. A few detrital grains of pigeonite were observed in heavy residue 7. The grains are angular cleavage fragments. They are pale-green, or rarely pale-yellow and are not pleochroic. Cleavage almost at right angles and typical of pyroxenes was generally observed. The extinction angle is 30 degrees with the cleavage. The birefringence is fairly low and the optic angle is small, less than 40 degrees.

<u>Special Features.</u> An inclusion of leucoxene was observed in one grain.

PLAGIOCLASE

<u>General.</u> In Table VII which gives the results for thin section analyses, the Plagioclase feldspars have been grouped together. The same has been done for some of the plagioclase feldspars observed in light residue analyses, the results of which are tabulated in Table IX. This was considered to be advisable for in several cases it was difficult to ascertain the type of plagioclase feldspar, and in a few cases it was merely determined that the feldspar was a plagioclase. The difficulty was due to the

alteration of many of the grains, and the presence of only a very few grains in some cases. Furthermore it was generally necessary to determine the properties of each grain before the type of plagioclase was known. For these reasons only the mineral frequencies of the plagioclase feldspars as a group were determined.

Special Features. Several detrital plagioclase grains had secondary growths, probably mostly of orthoclase, but some may be plagioclase. Alteration of plagioclase grains is generally to a clay mineral, probably kaolinite.

PYRITE

(Plate XI, Graph V)

General. Pyrite is the second most abundant heavy mineral found in the core. It was observed in every heavy residue and thin section, and was present as an impurity in most of the light residues. In the heavy residues the mineral frequencies range from a trace to 90 per cent. Pyrite occurs chiefly as authigenic crystals; but some of the pyrite inclusions in quartz grains may be detrital. Pyrite occurs as cubes, octahedrons, pyritohedrons and irregular masses of tiny crystals commonly associated with quartz. Many complex combinations are seen, as are also spherical aggregates of tiny crystals, or spherulites which may be primary (Pettijohn, 1949, pp. 345-347).

In some thin sections pyrite occurs mainly in veinlets, and in most of the thin sections disseminated pyrite crystals occur mainly in shale laminae. The grains are opaque in transmitted light and pale-brassy-yellow in reflected light. Some of the crystals are almost white (marcasite?); others, especially the spherulites, are greenish-yellow. Some crystals have a greenish tinge and others have a good yellow colour, both of which may be due to alteration. However, a positive reaction was obtained for a micro-chemical test for copper made on heavy residue 1, hence chalcopyrite is probably present in heavy residue 1 and also in other heavy residues and thin sections. In some cases pyrite shows some alteration to limonitic material.

PYROXENE ALT'D

(Plate VIII)

General. In a few of the heavy residues altered pyroxene grains were observed which could not be further differentiated. The grains are irregular in shape and sometimes have a poor crystal outline, one grain possessing an almost square cross-section. The grains themselves are detrital; but the alteration probably occurred, at least in part, after the deposition of the grains. In colour the grains range from grey, yellow, light-to dark-green, or dark-brown, to almost black. Some grains are faintly pleochroic. The alteration is mainly to chlorite. Epidote was observed in a few grains. Cleavage tends to be obscured by the alteration; but the typical pyroxene cleavage can sometimes be observed.

Special Features. Inclusions of ilmenite and/or leucoxene were observed in a few grains. Magnetite was also observed to occur as inclusions.

QUARTZ

(Plates III, IV, XII; Graph I)

General. Quartz grains make up approximately 98 per cent of the core. The grains are larger than the associated mineral grains, are generally well rounded to subrounded and usually have moderate sphericity. They have a tendency to be elongated parallel to the c axis and tend to lie with the elongation parallel to the bedding. The grains are detrital; but they generally have authigenic growths developed around them. The largest growths occur generally in the direction of original elongation. One or two rounded grains of chert and quartz were observed in which the chert appeared to be altering to quartz. If this is so, then this quartz also would be authigenic. The quartz grains are colourless to occasionally cloudy, due to slight alteration to, or replacement by, sericite. Recrystallization usually occurs at the contact of two adjacent quartz grains. A few grains reveal the effects of solution by the presence of sawtooth edges. One grain was observed to possess poor cleavages in two directions at approximately 81 degrees with each other. Often the grains are biaxial, have a small optic angle, and have undulose extinction due to strain. A few rounded quartz grains possess interlocking sections of different optic orientation. Most of these grains are probably gneissic quartz and possibly vein quartz; but some of them may be grains from a previous quartzite. Several of the quartz sections are ringed by what is probably iron oxide, and more rarely, tiny pyrite crystals.

Special Features. Authigenic growths of quartz on quartz are quite common. They invariably occur in optical continuity with the detrital core. The joining surface in most cases is marked by a thin film of what is probably iron oxide. Also tiny pyrite crystals and a clay mineral, in some cases, indicate the outline of the detrital quartz grains prior to the formation of the secondary growths.

Many different types of inclusions were observed in the quartz grains and are listed below. Needle-shaped inclusions appear to be more common than other types.

(1) Rows of tiny bubble inclusions, often in parallel rows and in streamers.

(2) Needle-shaped to occasionally hair-like inclusions. Most of the needle-shaped and hair-like inclusions are probably rutile and are brown to reddish-brown. Some needle-shaped inclusions of brown tourmaline occur, and white to light-coloured needle-shaped inclusions have been observed.

These needle-shaped inclusions occur in different arrangements: (a) random orientation, (b) parallel to the long direction of the quartz grains, (c) three sets with the crystals in the second set making an angle of 59 degrees with the first and the third set making an angle of 56 degrees with the second set, the angles being measured in a clockwise direction, (d) three sets as above; but the angles being 90 and 31 degrees respectively, (e) three sets as above; but the angles being 67 and 53 degrees respectively, (f) three sets as above; but the angles being 70 and 50 degrees respectively, (g) two sets at 48 degrees to each other, (h) two sets at 35 degrees to each other.

The writer is unable to explain the relationships described above. The arrangements could be the result of metamorphism before the grains were eroded from the source rocks, or they might have resulted from differential forces acting on the Potsdam sandstone. A third possibility is that the inclusions were formed at the same time as the original quartz crystals were, and that the arrangements of the inclusions is controlled by the crystal structure of quartz. Finally, the different angular relationships may be only apparent because, in many cases, the plane containing the needle-shaped inclusions was probably not parallel to the microscope stage so that the true angular relationships were not observed. It is also possible that the different sets of inclusions do not all lie in exactly the same plane. It is clear however that in (b)-(h) above there is an orderly arrangement of needle-shaped inclusions.

(3) Cubic inclusions or outlines of inclusions which may have been occupied by halite but are now filled with Canada balsam.

(4) Tabular tourmaline crystals.

(5) Inclusions of apatite crystals.

(6) Inclusions of zircon.

(7) Inclusions of biotite.

(8) Inclusions of pale green chlorite, probably secondary.

(9)Minute, irregular, opaque inclusions.

(10) Inclusions of magnetite.

(11) Inclusions of ilmenite - leucoxene.

(12) Inclusions of what are possibly garnet crystals.

(13) Inclusions of pyrite.

(14) Inclusions of what is possibly a pyroxene.

The crystals are colourless to white, bladed, N > quartz, and have an extinction angle that ranges from 15 to 41 degrees from the centres towards the edges of the crystals.

Plate XII

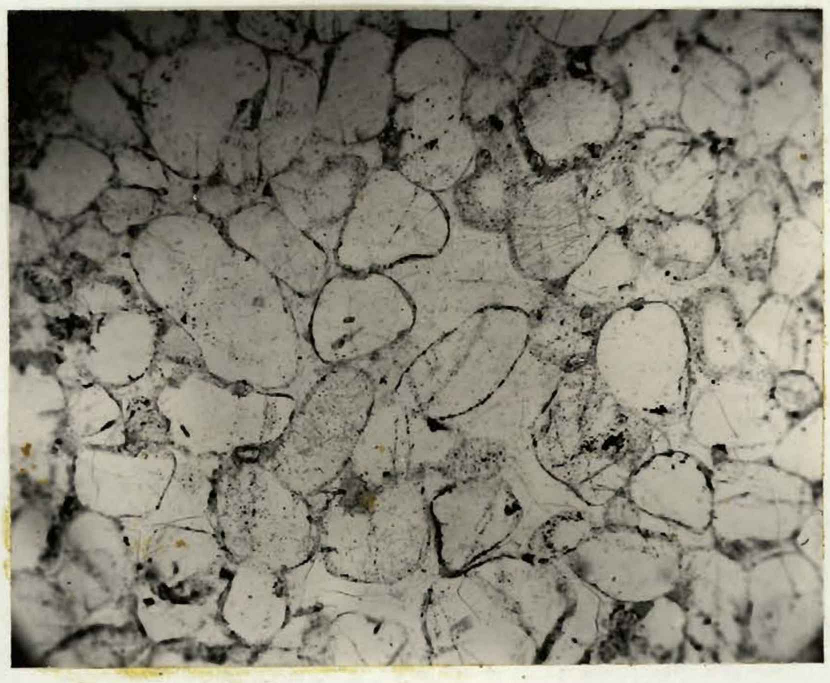


Fig. 1, T.S. No.6, x60, plane polarized light. Rounded to well rounded quartz grains cemented by silica. Opaque stain around detrital edges. Note needle, tabular and irregular opaque inclusions.

Fig. 2, T.S. No. 6, x60, as above, crossed nicols. Note angularity of grains due to secondary growths in optical continuity with detrital core.

RUTILE

(Plate XIII, Graph III)

General. A small number of rutile grains were observed in most of the heavy residues, in over half of the thin sections, and as impurities in some of the light residues. Rutile grains become relatively slightly more abundant toward the bottom of the core section (Graph III). The grains are generally elongated and rounded to well rounded. Some angular fractured grains are present, and some prismatic grains, with or without bipyramidal terminations, are observed with the crystal edges only slightly rounded. A few of the prismatic grains are striated parallel to the elongation. Needle-shaped grains are rare and some of these may be inclusions released by crushing. Knee-shaped twins were observed in some of the heavy residues, especially those from the top part of the core section. A few of these grains have angles of 50 degrees between the limbs whereas others have limbs approximately at right angles. A few broad tabular grains are present. The grains are detrital with one or two exceptions in which authigenic rutile growths occur around detrital cores, which are also of rutile. The grains are generally brown, reddish-brown or black and occasionally yellow or yellowish-brown in transmitted and reflected light. A few grains are somewhat irregular in colour such as black with brown spots. Some of the grains are slightly pleochroic with $E > O$. The rutile grains are translucent to opaque in transmitted light and have a metallic to adamantine lustre. Alteration to leucoxene has occurred in some of the grains, and a few of the grains appear to have been partly altered to ilmenite. Some of the altered grains have a band of rutile in the centre with leucoxene on either side, whereas others have rutile on one side and leucoxene on the other. Poor to good prismatic cleavage was observed in a very few grains. The grains have very high relief and extreme birefringence. Occasionally a grain is observed which has a concentric colour zoning which is parallel to the crystal faces. In some cases this zoning may be due to twinning. Sixling twinning was observed in one or two grains.

Special Features. One or two grains were observed with authigenic growths of rutile around detrital cores, which are also of rutile. In one case the nucleus was euhedral and a lighter colour than the growth.

The following inclusions were observed in two grains:

(1) A tiny black inclusion.

(2) An opaque, steel blue-black inclusion, possibly ilmenite or magnetite.

(3) A minute translucent inclusion (brown?), possibly rutile.

PLATE XIII

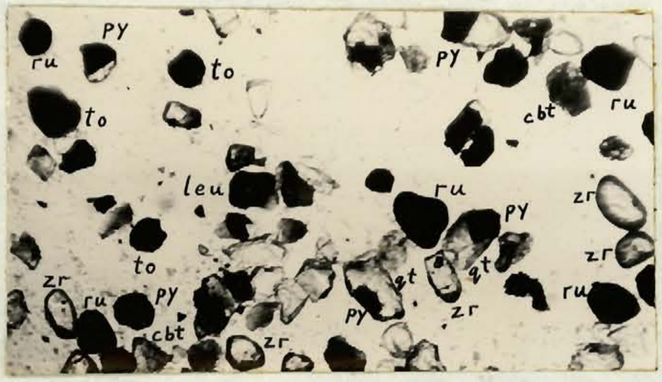


Fig. 1 - H.M. No.28, x47, plane polarized light.
cbt-carbonate, leu-leucoxene, py-pyrite,
qt-quartz, ru-rutile, to-tourmaline, zi-zircon.

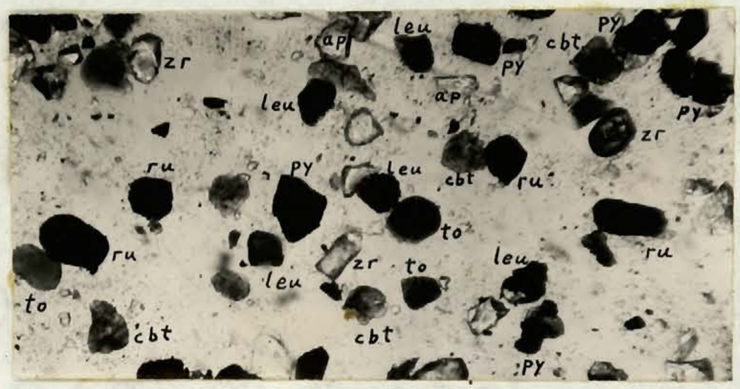


Fig. 2 - H.M. No.34, x48, plane polarized light.
ap-apatite, cbt-carbonate, leu-leucoxene,
py-pyrite, ru-rutile, to-tourmaline,zr-zircon.

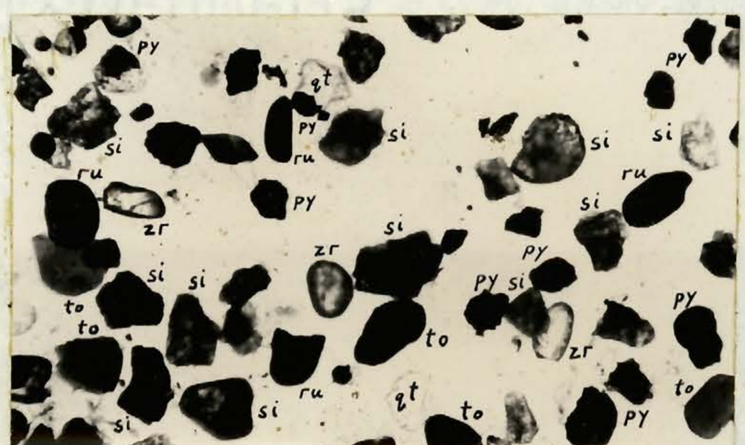


Fig. 3 - H.M. No.31, x63,plane polarized light.
py-pyrite, qt-quartz, ru-rutile,
si-siderite, to-tourmaline, zr-zircon.

SANIDINE

General. A few detrital grains of sanidine were observed in two thin sections, and as impurities in two heavy residues. The grains are angular to rounded, and tend to be somewhat elongated and platy, probably due to cleavage. They are colourless, and occasionally cloudy or light-grey due to alteration. One grain showed alteration to a thin needle-shaped mineral which may be antigorite or kaolinite. Another grain appears to be practically pure $K AlSi_3O_8$. The extinction angle with the cleavage ranges from 0 to 5 degrees. The grains have low relief and weak birefringence. Some grains appear to be uniaxial negative, whereas others are biaxial negative and have a very small axial angle. A very few grains showed carlsbad twinning.

SERICITE

General. A few authigenic sericite crystals were observed in four thin sections. The crystals are platy to thin and tabular. Many occur as thin plates interwoven among other grains and having a somewhat wavy extinction. Sericite occurs mainly with clay minerals. The extinction angle with the cleavage is 0 to 1 degrees.

SIDERITE

(Plate XIV Graph V)

General. Authigenic siderite crystals were observed in several heavy residues, in two thin sections and as impurities in two light residues. The relative amounts of carbonates in the heavy residues, in general, increases toward the bottom of the core section examined (Graph V), siderite having its main occurrence in that part of the section between the elevations 1286.5 and 1433.5 feet above the bottom of the drillhole (Table XI). In the thin sections siderite occurs as secondary angular aggregates of crystals in interstices. In the heavy residues it occurs mainly as angular cleavage fragments, many of which have a rhombohedral outline. A few crystals have a hexagonal to almost spherical outline (Plate XIV, Fig. 2). In a few heavy residues some of these latter crystals have a radiating structure dividing them into six equal segments, although in a few cases a core, or nucleus is also present. Some crystals possess zoning with a rhombohedron in the centre having a darker colour than the rest of the crystal. The crystals are generally yellow to brown, reddish-brown or dark-brown, and are rarely colourless to grey. Slight absorption is often visible. Siderite, in several cases shows varying degrees of alteration to liminote, and to a lesser extent, hematite. The typical carbonate cleavage is generally very well developed. In heavy residue 32, N_e for siderite, was determined to be greater than 1.61 and less than 1.62. The birefringence is extreme.

PLATE XIV

Fig. 1 - HM No.26, X68, plane polarized light.
do-dolomite, si-siderite.

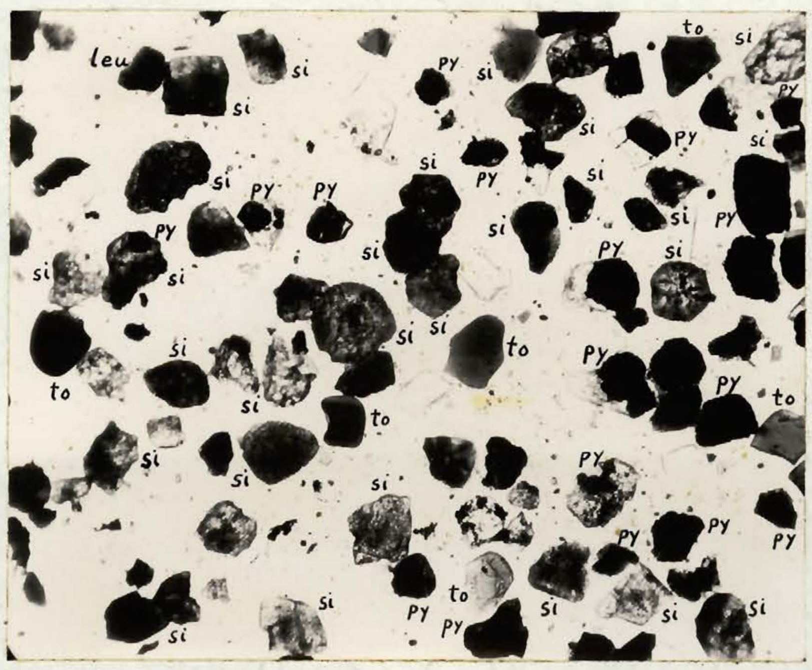


Fig. 2 - HM No.32, X69, plane polarized light.
leu-leucoxene, py-pyrite, si-Siderite,
to-tourmaline.

SPHALERITE

General. A few grains of sphalerite were observed in heavy residue 12. Their presence is thought to be due to contamination which probably occurred during the drushing and screening of the sample, although this may not be so. The grains occur as cleavage fragments exhibiting perfect dodecahedral cleavage. They are yellow, possess an adamantine to resinous lustre, are isotropic, and possess an extremely high index of refraction. The grains broke into bits when slight pressure was applied to the cover glass.

SPHENE

General. A few detrital grains of sphene were observed in three heavy residues. The grains are rather irregular in shape, tending to be rounded and well rounded. They are yellow and dark reddish-brown in colour, and have a vitreous lustre. The extinction is poor. The indices of refraction are very high (>1.82), and the birefringence is extreme. Some grains appear to be uniaxial, whereas others (e.g. HM No. 52) are biaxial positive, having an axial angle of approximately 20 degrees. The interference figures observed in the latter grains were typical for sphene (Milner, 1952, p. 345).

TOURMALINE

(Plate XV, Graph II)

General. Tourmaline grains were observed in all but four of the heavy residues, in all but two of the thin sections, and in several of the light residues. Next to zircon it is the most abundant detrital heavy mineral. The grains are detrital, and nearly all of them are rounded to well rounded. They are elongated parallel to the crystallographic axis. Many ellipsoidal or egg-shaped grains are seen, and some almost spherical grains are observed. A few grains possess striations parallel to the c axis. Euhedral crystals are observed in a few heavy residues, and may be inclusions that have been released from quartz grains by crushing. They could also be authigenic crystals; but none was observed in the thin sections. The grains are usually some shade of brown; although some grains are black, a few are yellowish, and some are green or blue. Grains showing colour zoning were observed in a very few heavy residues. The grains are pleochroic, the following pleochroisms being observed: colourless to pale yellowish-green, pale brownish-green and olive green; colourless to yellowish-brown, orange-brown and reddish-brown; faint-yellow to greenish-brown; light-brown to olive-green, brown, dark-brown and almost black; dark-brown to black; yellowish-green to green; pale-green to dark olive-green; pale-pink to to faint-green, very dark-green and blue; light-grey to blue-grey; faint-red to blue; faint-blue to slaty-blue; blue to black, and pale-mauve to dark-blue. Only a very few slightly altered grains were observed, the rest being unaltered. In some cases they show a parting parallel to the c axis, and in other cases a poor basal parting.

Special Features. The following inclusions were observed in different grains.

(1) Spherical, colourless inclusions which are generally tiny, and, in some cases at least, are probably bubbles.

(2) Dark coloured needle inclusions, some of which are probably rutile.

(3) Needle wisps to thin-bladed inclusions, either colourless (transparent) or the same colour as the enclosing tourmaline grain.

(4) Euhedral and anhedral inclusions of magnetite.

(5) Leucoxene inclusions.

(6) Inclusions of pyrite.

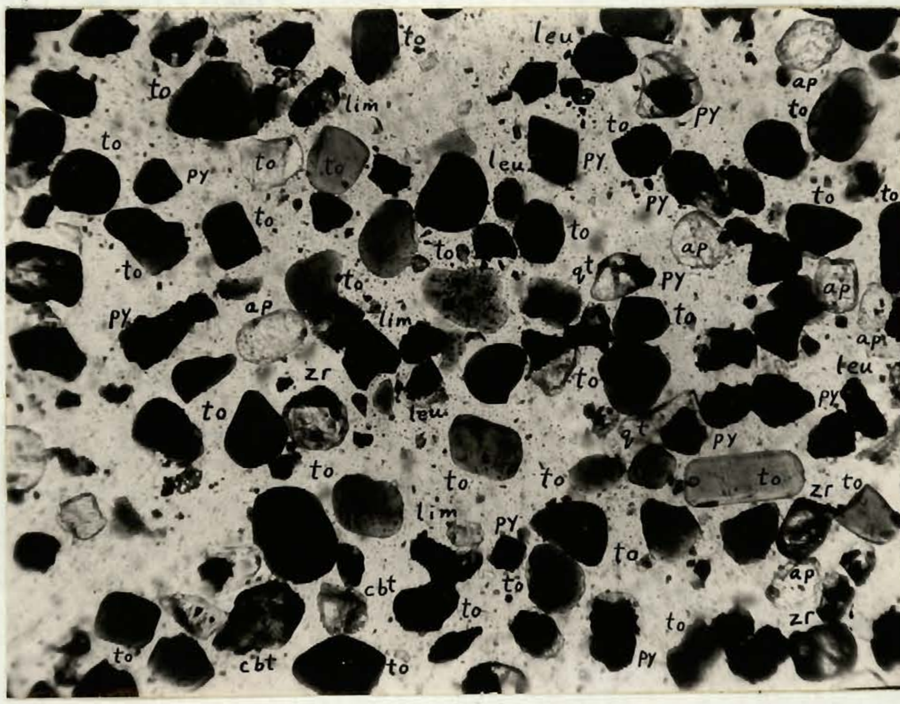
(7) Inclusions of tourmaline in tourmaline.

(8) Minute, subhedral, green and red inclusions.

(9) An inclusion of zircon, also containing an inclusion.

(10) A few euhedral to anhedral, colourless or white to dark-coloured crystals; some of which are needle-shaped or tabular. Some of these have lower indices of refraction than tourmaline whereas others have higher indices.

PLATE XV



H.M. No. 35, X74, plane polarized light.
ap-apatite, cbt-carbonate, leu-leucoxene,
lim-limonite, py-pyrite, qt-quartz,
to-tourmaline, zr-zircon.

UNKNOWNS

The author was unable to determine one or two minerals in a few of the heavy residues and thin sections. There was not more than a trace of any one of these minerals present, and in most cases alteration had made the determination of optical properties difficult or impossible. In a few cases only one or two grains were present, and the indices of the unknown could not be determined.

ZIRCON

(Plate XVI, Graph III)

General. Zircon is the most abundant heavy mineral. Grains were observed in all but four heavy residues, in all but one thin section, and as impurities in two of the light residues. Practically all the grains are rounded to well rounded, and are generally elongated, the elongation often being parallel to the c crystallographic axis. A few of the grains are long and thin and many are slightly curved, others are ellipsoidal and a few are spherical. Some have a knobby surface and a few geniculated twins and were probably inclusions in quartz grains that have been released by crushing. A few of the larger grains also have undergone very little, if any, weathering. The surface on most of the grains is minutely pitted and frosted. In some of these grains the pitting has resulted from the weathering out of inclusions, but in most of them it has probably resulted from solution. The grains are generally smaller than most of the other detrital mineral grains. Practically all of them are detrital, although in a few heavy residues, euhedral to subhedral grains or crystals are observed and may be authigenic. Nearly all of the zircon grains are colourless; but some are white, pale-yellow, pink, mauve, yellowish-brown and light dusky-brown. They are all non-pleochroic. A very few of the grains, especially zoned ones, appear to be slightly altered; although the cloudiness may be due to a large number of inclusions, perhaps of dust. A few small alteration spots were observed which probably represent the alteration of inclusions. No cleavage was observed; but one grain has radial fractures. The grains possess a dark ring around their margins, which is due to their high indices of refraction.

Special Features. In some heavy residues, a few euhedral to subhedral grains or crystals are observed and may be authigenic. These generally have a dusky appearance and possess zoning in the outside part about a nucleus. Both parts are in optical continuity. The nuclei are also of zircon, and range in shape from rounded to euhedral. The rounding is thought to be due to erosion, although it is possible that the more rounded nuclei are anhedral inclusions. One or two grains possess no nuclei, and the zoning extends right through the grain. One grain possesses zoning in one end only, there being an irregular but definite separation line between the two ends. The zoning in the grains is made up of straight bands which are alternately white or colourless, and light-brown or brown. The surfaces of the grains often possess euhedral forms whose crystal faces appear to have undergone little to no weathering. These grains, because of the above facts, are believed to be authigenic growths. The number of these grains is less than one percent of all the zircon grains observed. These authigenic growths could have been formed during a previous cycle of deposition after which they were surrounded by a protective coating of secondary silica. The coating would have protected the zircon grains from erosion during most or all of the last erosion cycle. This would account for the small amount of weathering undergone by some of these grains. The unweathered grains may have been released from their protective silica shells by crushing in the laboratory. Another possibility is that the authigenic growths were developed at the present site of deposition. Grains and crystals representing both types seem to be present.

The following inclusions were observed in different grains.

(1) Brown and dark-coloured needles of rutile, a few of which may possibly be cassiterite.

(2) A few white needle-shaped inclusions, possibly rutile.

(3) Unidentified needle-shaped inclusions, mainly parallel to the c axis of the zircon grains. Some also perpendicular to the c axis and others at various angles to the c axis.

(4) Tiny, white, brown and opaque inclusions of various shapes.

(5) Colourless, white, grey, and opaque, ellipsoidal, and spherical inclusions, some of which are bubble inclusions.

(6) A few inclusions of zircon which are usually euhedral.

(7) A few inclusions of tourmaline.

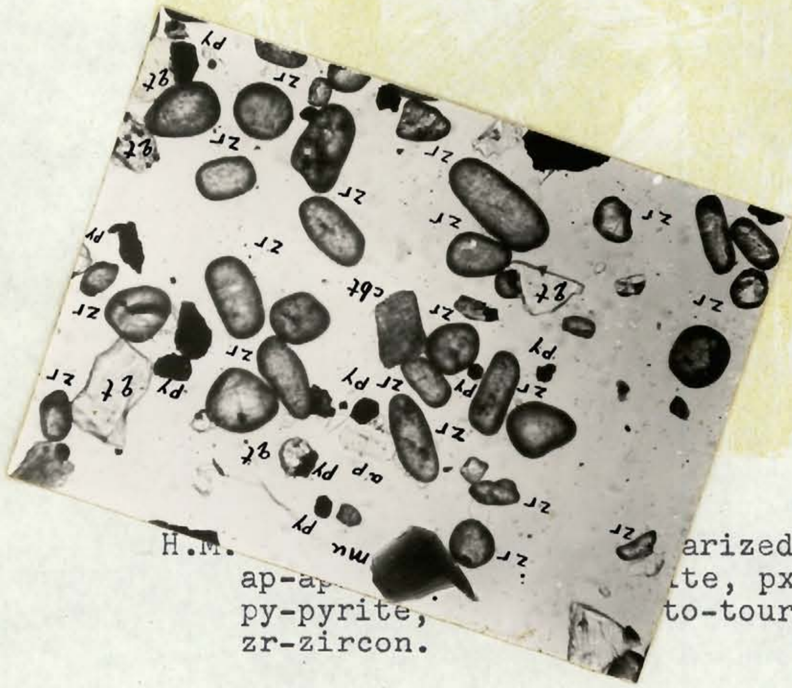
(8) A few inclusions of leucoxene.

(9) A hexagonal inclusion of apatite.

(10) An inclusion of magnetite.

(11) An opaque acicular inclusion of ilmenite showing some alteration to leucoxene.

PLATE XVI



H.M. ... arized light.
ap-ap... ...ite, px-pyroxene,
py-pyrite, ... to-tourmaline
zr-zircon.

Weathering, Transportation, Site of Deposition:

Preceding the deposition of the Potsdam sandstone the Precambrian rocks of the Canadian Shield had undergone a long period of subaerial weathering, which is indicated by the sporadic and rare occurrence of the less resistant minerals in the crill core. It is also indicated by the persistently high degree of rounding and sphericity possessed by most of the grains composing the Potsdam sandstone. Quartz grains, which make up 98 percent of the rock examined, are mainly rounded to well rounded, have a moderate to high sphericity, and are generally frosted. Tourmaline and zircon grains which comprise over half of the heavy residues examined, are almost always rounded to well rounded. Apatite and rutile grains are generally rounded to well rounded, and many ilmenite and leucoxene grains are rounded to the same degree. Although several other detrital minerals have been identified, most of them are present only in small amounts and in only a few of the heavy residues. This predominance of only a few of the most stable minerals is also an indication of a long period of weathering, a long period of transportation, or both, before the grains were finally deposited. That a long period of weathering preceded the deposition of the Potsdam sandstone, receives further corroboration in the predominance of quartzites at the base of the Cambrian sections throughout most of North America.

Care must be taken in interpreting the roundness and sphericity of the mineral grains present in a sediment as well as the absence of certain minerals. Several factors should always be kept in mind. These will not be discussed in detail, but will only be mentioned.

It should be recognized that the various mineral grains do not start out with the same shapes, and that the initial shapes depend on cleavage, parting, fracture, tenacity, and indirectly the Mohs hardness (Alling, 1950). Although abrasion and solution modify the shapes of the grains, the final shape appears to be determined largely by the initial shape (Pettijohn, 1949, p. 54; Alling, 1950).

Another factor that must be considered is solution. Many or probably most of the quartz, zircon, tourmaline, apatite, and other rounded mineral grains are minutely pitted on the weathered surface. This may be due to solution rather than wind action. According to various authors solution plays a larger part in rounding and in destroying mineral grains than is generally realized (Galloway, 1919; Russell, 1937; Boswell, 1941). Krynine (1942), however, considers sediments which are poor in unstable minerals to be reworked sediments, and that intrastratal solutions exist only on a limited, local, and erratic scale. The latter conclusion would seem to be an extreme view to the writer. If the amount of geologic time is considered, it is realized that solution can be very important indeed, and Russell (1937) suggests that the persistent detrital minerals appear to be those that are more resistant to chemical processes, resistance to mechanical processes being of minor importance. He also reached the conclusion, from his investigation of the sediments along the Mississippi River, that the importance of abrasion in eliminating mineral species during transport is probably overestimated. Because of solution, it is concluded by some (Galloway, 1919) that rounded or well rounded grains are not in themselves safe criteria of abrasion or of a long period of transportation. It is also pointed out that, generally, mineral grains increase relatively rapidly in roundness and sphericity when abrasion and solution first act on them; but that as the processes continue, less and less change is discernible, until finally, additional abrasion and solution do not produce any observable increase in the roundness and sphericity. Pettijohn (1949, p. 418) has pointed out that grains once rounded by solution become highly irregular in outline as a result of chemical corrosion. It would appear that this would depend on the properties of the mineral involved (e.g. cleavage, internal structure).

Before conclusions can be drawn, a careful examination must be made of the possible reasons why almost the entire detrital assemblage in the drill core examined, and indeed throughout the Potsdam sandstone, is composed of a very few principal minerals. One possibility is that there was only a limited number of minerals in the parent rocks. This, however, is contrary to observations made on the Grenville and other Precambrian types that were probably the source rocks (Harding, 1931; Quebec Dept. of Mines, 1944, pp. 52-226).

The second possibility is that the minerals were present in the parent rocks, but were disintegrated and as far as possible decomposed during weathering and transportation before they were deposited. This would increase the relative amounts of the more resistant detrital minerals in the sediments, such as quartz, zircon, and tourmaline. Most of the amphibole, chlorite, clay, and pyroxene mineral grains are quite irregular in shape and many appear to be corroded. This condition, however, could equally well be the result of solution after deposition. The predominance of quartz grains throughout the Potsdam sandstone, the exceptionally large proportion of zircon and tourmaline in the detrital heavy minerals of the drill core examined, and the predominance of quartzites at the base of Cambrian sections in North America, indicate that there is little doubt that Potsdam sandstone is the result of a long period of weathering and erosion. This produced a vast mantle or regolith of weathered material which spread over much of the southeastern part of the Canadian Shield (Clark, 1952, p. 21).

A possibility which must not be overlooked, however, is that a greater variety of minerals and a larger amount of perhaps most of the minerals now present may have been supplied to the site of deposition. Some of these minerals may have been subsequently removed, either partially or totally, by solution and possibly by reworking of the sediments. There is ample evidence in the presence of authigenic carbonates and pyrite and authigenic growths on quartz, feldspar, apatite, and zircon grains that chemical reactions took place after the deposition of the Potsdam sandstone. In addition, several of the feldspar grains are so altered that it appears unlikely that they were transported in that state. As mentioned before, many of the amphibole, chlorite, clay, and pyroxene mineral grains are corroded. In some thin sections the edges of quartz grains are slightly corroded. In places some of the carbonate is altered to liminite, and occasionally hematite. Pyrite crystals are also partly altered to limonite in places. Other indications of solution, and alteration after the deposition of the Potsdam sandstone, are the increase in the relative amount of leucoxene accompanied by a corresponding decrease in ilmenite with depth in the section examined, a decrease in the amount of mica present with depth accompanied by an increase in alteration, a decrease in amphiboles, pyroxenes, and chlorite with depth, and an increase in clay minerals and limonite (alteration products?) with depth. Thus, although it is undoubtedly true that a long period of erosion preceded the deposition of the Potsdam sandstone, it is also true that solution and alteration after deposition have also played a prominent part and made it appear as though the amount of erosion was greater than is probably the case.

Cross-bedding occurs throughout the core section that was examined, and also throughout the Potsdam sandstone, and varies continually in direction. Thin shale laminae, wisps and nodules of shaly material, and a few fossils such as Climactichnites, Protichnites, and Scolithus also occur in the Potsdam. These occurrences and the clean appearance of the rock itself all indicate deposition in a standing body of shallow water with oscillating currents. Clark (1952, pp. 124 - 125) suggests that in the Upper Cambrian the area was invaded by the waters of the expanding Appalachian geosyncline. The waters oscillated back and forth as the level of the waters gradually rose, and the sands may have been rolled around on a wide off-shore platform by the changing tides. The winds are believed to have provided much of the material for the waves to work on, and the predominance of rounded to well rounded, generally frosted, quartz and zircon grains indicates that probably most of the weathering was subaerial and occurred under desert conditions.

At the close of the Cambrian period it is postulated by Clark (1952, p. 125) and most other writers on the Potsdam sandstone, that the sea was drained off, resulting in a local unconformity at the top of the Potsdam sandstone. This theory is based on the supposed predominance of angular, bright, water-borne grains in the Potsdam as compared with the rounded, frosted grains in the Theresa. The writer has shown that most of the quartz grains in the Potsdam were originally rounded to well rounded, and generally frosted, and that they owe their present angularity to secondary growths. The writer, therefore, suggests that the sea did not drain off at the close of Cambrian time. Instead, the so-called "passage-beds", known as the Theresa formation, represent either a fairly constant depth of water or a slight increase in the waters' depth. The Theresa formation, therefore, represents a transition zone from the Potsdam sandstone deposits to the Beauharnois formation, which was probably deposited in quieter and slightly deeper waters than was the Potsdam, which was deposited on the old Precambrian land surface.

Source of Sediments:

It is quite obvious that the Precambrian rocks in the area, including those now overlain by the Paleozoic formations, were the source rocks for the Potsdam sandstone. The rock types which provided the material and the direction from which the material was brought will now be discussed. The answer to the first problem will obviously aid considerably in answering the second question.

Pettijohn (1949, Table 26, p. 98) has drawn up a table giving detrital mineral suites which are characteristic of source-rock types. In this table the more common minerals in each suite are differentiated from the less common. Krumbein and Sloss (1951, Table 4-11, p. 108) have somewhat modified Pettijohn's table. The minerals identified in the present investigation, together with their properties, have been compared with these tables, and the characteristic minerals have been listed under the corresponding source-rock type heading in Table XIV. The source-rock types are listed in their order of importance, which was determined by taking into account relative mineral frequencies, including the presence or absence of a mineral, abrasion, and the inherent physical and optical properties of the mineral grains.

Table XIV - Detrital Mineral Suites Characteristic of Source Rock Types.

(1) Acid Igneous Rocks

Apatite
Biotite
Hornblende
Magnetite
Microcline
Monazite- Trace in 1 heavy residue
Muscovite
Quartz- Igneous variety
Sphene- Traces in 3 heavy residues
Tourmaline- Few small pink grains, 1-2 euhedra
Zircon- Odd euhedra

(2a) Reworked Sediments

Chert- Traces- 2% in 16 thin sections
Leucoxene- Possibly largely secondary
Quartz- Possibly few worn overgrowths none identified positively.
Quartzite fragments- Few fragments observed. May be mostly high-rank metamorphic
Rutile - Rounded
Tourmaline - Rounded
Zircon - Rounded

(2b) Basic Igneous Rocks

Anatase- Traces in 4 heavy residues
Augite
Brookite- Trace in 1 heavy residue
Hypersthene
Ilmenite
Leucoxene- Possibly largely secondary
Magnetite
Plagioclase- Intermediate
Rutile
Serpentine (Antigorite)

(3a) High Rank Metamorphic Rocks

Biotite
Epidote- Small amount
Feldspar- Only small amount of acid plagioclase
Garnet
Hornblende- (Green,only 1-2 blue green grains)
Kyanite- Trace in 1 heavy residue
Magnetite
Muscovite
Quartz- Only a few metamorphic grains

(3b) Low Rank Metamorphic Rocks

Biotite
Chlorite- Possibly clastic in part
Feldspar- Present, should be generally absent
Leucoxene- Possibly largely secondary
Quartz and Quartzite- Only a few metamorphic quartz grains and quartzite grains
Tourmaline- Few pale brown euhedra

(3c) Pegmatites

Albite- A few grains
Fluorite- Traces in 2 heavy residues
Garnet
Microcline
Monazite- Trace in 1 heavy residue
Muscovite
Tourmaline- Few blue grains (indicolite)

Mackie (1899) classified the inclusions found in quartz grains into four main groups.

R - Regular inclusions of quartz, magnetite, rutile, apatite, zircon, etc.

A - Acicular inclusions mainly of rutile and sillimanite.

I - Irregular inclusions of fluid lacunae sometimes accompanied by gas bubbles; many arranged in streams or parallel rows.

N - Inclusions absent or so small as to escape notice.

If two or more groups were present Mackie gave the acicular types precedence over all the others, and regular-shaped inclusions precedence over the irregular group. He concluded that "R" and "N" inclusions are characteristic of gneisses and younger schistose rocks, and that "A" and "I" types are characteristic of quartz from granite, quartz diorite, related rocks and quartz veins.

Gilligan (1919) agreed with the conclusions reached by Mackie, as did Tyler (1936) generally; but Tyler concluded that the gneisses should be classes with granites rather than with the metamorphic rocks. He also suggested that the same minerals now present as inclusions in sedimentary quartz grains indicate what other minerals were supplied to the sediment by the igneous source rocks, absent now because they have been destroyed. Keller and Littlefield (1950) agree in general with Mackie; but they concluded that regular inclusions are characteristic of schists, but not of gneisses; that acicular and irregular inclusions are characteristic of igneous rocks, and that globular inclusions, which Mackie classed with irregular inclusions, are characteristic of igneous rocks and gneisses. Krynine (Bokman, 1952, after Krynine, 1940), however, concluded that the inclusions in metamorphic quartz are usually much more acicular than those in igneous quartz.

In the core section examined by the writer, needle or acicular inclusions appear to be more common than other types. Bubble inclusions are also quite abundant and many are arranged in rows. Regular inclusions are common, and a large number of quartz grains appear to have no inclusions at all. By comparing these results with those obtained by the workers mentioned above, the writer concludes that most of the quartz was derived originally from igneous rocks, mainly acidic igneous rocks, and that a considerable amount was also derived from schists and gneisses.

Krynine (1946) used tourmaline grains to determine the source of the sediments, and classified tourmaline grains into five main groups.

(1) Granitic tourmaline.

(2) Pegmatitic tourmaline.

(3) Tourmaline from pegmatized injected metamorphic terranes.

(4) Sedimentary authigenic tourmaline.

(5) Reworked tourmaline from older sediments.

Each group, according to Krynine, has distinctive optical and physical properties which are indicative of the source rock from which the tourmaline grains were derived.

In comparing the results of the present investigation with Krynine's classification, most of the tourmaline grains probably belong to groups (1) and (5). From the general shapes of the grains, group (5) would appear to predominate over group (1); but this is not necessarily so. A few blue tourmaline grains indicate the presence of pegmatitic tourmaline. No authigenic growths were observed. A few tiny euhedral crystals were observed and possibly belong in group (3).

Harding (1931) investigated the relations of the Grenville sediments and the Potsdam (Nepean?) sandstone in eastern Ontario, and concluded that the latter was derived from the former. He noted the increased rounding and the smaller number of mineral species in the latter and that the mineral species common to both rocks are the more stable ones, such as zircon and tourmaline, which accordingly have a greater relative mineral frequency in the Potsdam sandstone. Similarly, the predominance of rounded to well rounded grains of zircon and tourmaline in the heavy residues from the drill core examined may be explained as being supplied largely by the eroded Grenville sedimentary gneisses and schists, therefore those grains have generally undergone two cycles of erosion. Possibly the less stable minerals were derived largely from acidic igneous rocks and hence have generally undergone only one cycle of erosion. It is noted that the less stable mineral grains are generally less well rounded than the more stable. This may in part be due to the properties of these minerals; but it may also mean that the more unstable grains are totally eroded before they can become well rounded, and that they have undergone only one cycle of erosion. Several writers (Krynine, 1942; Pettijohn, 1949, pp. 96 - 97; Krumbein and Sloss, 1951, pp. 107) consider the absence of less stable species and a relatively large abundance of the more stable heavy minerals to indicate a derivation from earlier sediments.

It is finally concluded that the largest single source for the sedimentary material in the drill core examined was acid igneous rocks. The second largest source was reworked sediments, followed closely by basic igneous rocks. High rank metamorphic rocks were the fourth largest source, and were followed closely by low rank metamorphic rocks, which in turn were followed by pegmatites. The following percentages indicate the proportions involved and are not meant to be quantitative.

40% - Acid igneous rocks

40% - Reworked sediments
Basic igneous rocks

20% - High rank metamorphic rocks
Low rank metamorphic rocks
Pegmatites

Considerably more field work would be required in order to determine the direction from which the sediments were brought to form the Potsdam. It is observed in reviewing the geological map of Canada (Geol. Surv. Can., Map 820A, 1945) that the Precambrian rocks north and west of Montreal and Ste. Therèse are composed mainly of acid igneous rocks with patches of sedimentary and derived metamorphic rocks (Grenville) and basic and ultra basic igneous rocks. This corresponds with the conclusions made regarding the source rocks. With the exception of the Adirondacks, which are composed largely of acidic igneous rocks with minor Grenville-type rocks, nothing is known of the Precambrian rocks south of Montreal, as they are overlain by younger rock types. Assuming that the Potsdam sandstone was laid down by waters overlapping from the west side of the Appalachian geosyncline, it would seem that the sediments were brought principally from the north and west.

SUMMARY AND CONCLUSIONS

Analyses of Samples

The laboratory work was done in the following steps:

(1) The drill core was logged.

(2) The thin section specimens were selected.

(3) The heavy mineral samples were selected.

(4) The heavy mineral samples were crushed by hand using a steel mortar and pestle.

(5) Screening was done by hand, and the 100-150 mesh grade size was selected for microscopic work.

(6) Heavy mineral separations were carried out using a single separatory funnel, bromoform as the heavy liquid, and benzene as the washing liquid.

(7) The relative percentage by volume of the minerals present in the thin sections, light residues and heavy residues were determined using the areal method. The results are given in Tables V11, 1X, X1. Graphs 1 - V, showing relative mineral frequencies of some of the minerals, were also drawn up. The properties of the minerals were also determined.

(8) The arithmetical average diameters of the grains in the thin sections were determined with a calibrated micrometer eyepiece, the results being given in Table V11.

(9) A rough estimate of the abundance of each heavy residue

was made and the results recorded in Table Xl.

(10) The roundness of the mineral grains in the thin sections and heavy residues was determined by comparing the grains with a chart prepared by Pettijohn (1949), and the results recorded in Tables Vll and Xlll.

(11) The two dimensional sphericity of the grains occurring in the thin sections was determined by comparing the grains with a chart prepared by Rittenhouse (1943a). The results are given in Table Vll.

(12) Sources of error in the selection of samples, crushing, heavy mineral separations, and in the determination of grain counts, grain size, roundness, sphericity and mineral frequencies are discussed.

General Description of the Potsdam

The earliest work was done on the Potsdam sandstone in Canada by Sir William Logan (1849-1863). Except for the work done by Ells (1895-1904), nothing of real importance was added to Logan's work until the present time when Clark (1939a -1952), began a systematic survey of the area.

The greatest areal developments of the Potsdam in Quebec occur northwest and southwest of Montreal. Quartz grains generally make up over 99 per cent of the rock and range in type from rounded and frosted (presumably wind-blown), to angular, bright, water-borne grains. In places the contact with the overlying Beekmantown formation appears to be conformable, and in others it appears to be disconformable. The Potsdam sandstone ranges from 0 to 1696 feet, or more, in thickness; but it is rarely more than a few hundred feet thick. Fossils are rare and consist mainly of the trails Climactichnites, Protichnites and Scolithus. The Potsdam has generally been considered to be Upper Cambrian, though Wilson (1946b) and Clark (1952) incline to a Lower Ordovician age. Its principal use at present in Quebec is in making ferro-silicon.

The Mallet Well

As it is observed in the top 504 feet of Potsdam sandstone core of the Mallet well, the Potsdam is the same as it is throughout its extent in Quebec province. It is predominantly a hard, white, fine-to medium-grained, cross-bedded, pure quartz sandstone. Rounded, frosted grains occur practically throughout the core and make up most of the rock. Laminae, beds, and inclusions of shale are commonly present. The rock is generally well sorted, and is cemented by silica. Other materials occurring as cements are: argillaceous material, carbonates (calcite, dolomite, siderite), pyrite and iron oxide. The core throughout most of its length is fairly porous. It is composed of approximately 98 per cent quartz grains, over 1 per cent carbonate, clay and feldspar minerals, and less than 1 per cent heavy minerals including pyrite, but not carbonates. Zircon, tourmaline, leucoxene and biotite are the most abundant detrital heavy minerals, zircon being nearly 2½ times as abundant as tourmaline, and tourmaline twice as abundant as leucoxene. Zircon and tourmaline make up over half of the detrital heavy minerals by volume. Carbonates and pyrite, in that order, are the most abundant authigenic minerals. Chlorite and clay minerals are probably in part secondary.

Five small igneous dykes, or possibly sills, 3 of alnoite and 2 of vibetoide, intrude the Potsdam sandstone at elevations from 1300.5 to 1303.5 feet and from 1246 to 1257 feet. The metamorphic effects extend 4 to 5 feet into the Potsdam sandstone from the contacts.

The following observations were made from the microscopic examination of 21 thin sections.

(1) Bedding was observed in practically all of the thin sections. The thinnest observed bed was a shale lamina 0.03 mm thick.

(2) The beds vary from even-grained to occasionally conglomeratic.

(3) Quartz grains were observed "floating" in calcite and dolomite, one explanation being that the quartz grains were deposited with clastic carbonate which was later recrystallized.

(4) As shown in Table V111, the roundness and sphericity of the grains decreases directly as the grain size, and the more rounded grains are also the more spherical ones.

(5) Secondary crystallization has, in general, reduced the roundness and sphericity of the quartz grains.

(6) Elongated grains tend to occur with the elongation approximately parallel to the bedding plane.

(7) In quartz grains this direction often shows a tendency to be parallel to the c crystallographic axis.

(8) The elongation of quartz grains in most thin sections has been accentuated by authigenic growths in accordance with Riecke's principle, which indicates that vertical forces predominated at the time of deposition of the secondary silica.

(9) Crystals of shale minerals are generally elongated parallel to the bedding.

(10) Optic orientation of grains occurs only rarely in quartz grains and in shale laminae, and in the shale laminae is believed to have been formed during the period of lithification of the Potsdam sandstone.

(11) Secondary growths on feldspar grains formed earlier than the secondary growths on quartz grains.

(12) The secondary growths on feldspar are mainly of orthoclase, about a nucleus of microcline and occasionally plagioclase. Microcline and plagioclase also occur as overgrowths in one

or two cases. A few authigenic orthoclase crystals were observed which had formed without the aid of a nucleus. The authigenic feldspar appears to have been formed by sedimentary processes.

Microscopic analyses were made of 17 light residues and the following observations were made:

(1) There was considerable contamination by heavy mineral grains.

(2) The feldspar grains showed various degrees of alteration to kaolinite.

(3) The carbonate was often partly altered to limonite and occasionally to hematite.

Microscopic examinations were made of 52 heavy residues from which the following observations and conclusions were made.

(1) The greatest abundances of heavy residues were obtained from the medium-grained samples (Table X), with continually lesser amounts from the coarser-and finer-grained sizes.

(a) One explanation is that the grain sizes of the different heavy minerals, together with the various hydraulic conditions in the area of deposition, were such that a larger amount of heavy mineral grains were "hydraulic equivalents" to the medium-grained light minerals than to the other grain sizes.

(b) In the finer-grained sizes, however, a larger proportion of the heavy mineral grains undoubtedly passed through the 150 mesh screen. Although this probably did not greatly affect the fine-grained samples, the results from the very fine-and finer-grained samples were probably considerably affected.

(2) There appears to be a slight increase in the number of heavy minerals present toward the top of the core section.

(3) Several heavy minerals, such as zircon, biotite, and hypersthene (Table X11), have an increasing relative frequency toward the top of the core section which may indicate that,

(a) an increasing relative amount of these minerals were being supplied to the site of deposition,

(b) intrastratal solutions have partially or totally removed the minerals, particularly from the lower part of the section.

(4) A second group of heavy minerals such as tourmaline, rutile and garnet maintains a relatively constant frequency, which indicates that a fairly uniform amount of those minerals were being supplied to the site of deposition.

(5) A third group of minerals shows a decreasing relative frequency toward the top of the core section. Most of the minerals in this group, such as leucoxene, clay minerals and limonite are at least in part secondary, and the decreasing relative frequency may indicate that,

(a) alteration began soon after the sediments were laid down, hence the largest amount of alteration, and therefore the largest relative amount of these minerals, occurs in the older beds.

(b) A second explanation is needed for minerals such as apatite. The decreasing frequency here may be explained by a constant reworking of the sediments with a greater destruction of the less stable minerals. This may also apply to the other minerals in this group.

(c) A third explanation is that relatively less of these minerals was being supplied to the younger beds.

(6) The relationships of leucoxene and ilmenite show that the former was derived largely from the latter.

(7) The two main authigenic minerals are carbonates and pyrite. A small amount of pyrite occurs as spherulites and may possibly have been formed when the sediments were deposited. Most of the carbonate is authigenic; but whether it was originally deposited as clastic carbonate or as chemically precipitated carbonate is not certain. Only a few tiny calcite veinlets have been introduced at a later stage.

(8) Chlorite and clay minerals are probably, in large part, authigenic.

(9) Roundness determinations were made for most of the heavy minerals and are given in Table XLII. It is noted that the greatest degree of rounding is obtained by the most stable minerals such as zircon and tourmaline.

Excluding undifferentiated feldspars, carbonates and micas, 54 mineral species (Table V) were determined along with many of their distinctive properties. 41 of these were observed in the heavy residues. These minerals have been described under the headings of general and special features. Inclusions, authigenic crystals and growths, perthitic structures, etc., are described under the latter heading.

Care must be taken in interpreting the roundness and sphericity of mineral grains for the following reasons:

(1) Because of the different properties of individual minerals they do not begin with the same shapes.

(2) The part played by solution in the rounding of grains before deposition is not certain; but may be considerably greater than is generally realized.

(3) The relationship of roundness and sphericity to abrasion and solution is not a straight line relationship; but the roundness and sphericity increase relatively rapidly at first and then increase quite slowly until a point is reached where they appear to remain practically constant.

The examination of mineral suites in sedimentary rocks must be made with care because of the following reasons:

(1) The limited number of minerals in a suite may be explained by:

(a) a correspondingly limited number of minerals in the source rocks,

(b) elimination of mineral species during weathering and transportation of the sedimentary material by differential erosion,

(c) reduction in the relative frequencies of some minerals, or even elimination of mineral species by intrastratal solutions.

(2) Care must be taken not to confuse detrital and authigenic minerals, and also authigenic crystals and inclusions released from detrital grains by crushing.

It is concluded that, preceding the deposition of the Potsdam sandstone, the Precambrian rocks of the Canadian Shield underwent a long period of weathering and subaerial erosion, probably under desert conditions. This prolonged condition is probably the main cause for the predominance of a relatively few mineral species in the Potsdam sandstone; but the evidence leaves little doubt that intrastratal solutions subsequently played a large part.

The Potsdam sandstone is considered to have been deposited in the shallow oscillating waters of the expanding Appalachian geosyncline. It is suggested by the writer that the sea did not drain off at the close of Cambrian times; but that the Theresa formation represents a change from shallow oscillating waters to slightly deeper, quieter waters.

The material composing the Potsdam sandstone in the core section examined was derived from Precambrian rocks, possibly those lying to the north are west. The largest single source was acid igneous rocks, which supplied approximately 40% of the sedimentary material. Second, were reworked sediments, followed closely by a third source which was basic igneous rocks. These last two sources combined and also believed to have supplied approximately 40% of the sedimentary material in the Potsdam. Fourth on the list are high rank metamorphic rocks followed closely by low rank metamorphic rocks in fifth place and pegmatites in sixth place. These last three sources combined are believed to have supplied about half as much material as acid igneous rocks, or about 20% of the material. The percentages given above indicate the proportions involved and are not meant to be quantitative.

BIBLIOGRAPHY

Part 1 - General

Alling, H.L., (1950): Initial Shape and Roundness of Sedimentary Rock Mineral Particles of Sand Size; Jour. of Sedimentary Petrology, Vol. 20, No.3, pp. 133 - 147., Sept.1950.

Berg, R.R., (1952): Feldspathized Sandstone; Jour. of Sedimentary Petrology, Vol. 22, No.4 pp. 221-223, Dec.1952.

Bokman, J., (1952): Clastic Quartz Particles as Indices of Provenance; Jour. of Sedimentary Petrology, Vol. 22, No.1 pp.17 - 24, Mar. 1952.

Boswell, P.G.H., (1933): On the Mineralogy of Sedimentary Rocks; Thomas Murby and Co., London, 1933.

(1941): The Stability of Minerals in Sedimentary Rocks; Jour. Geol., Vol. 97, Pt. 2 of Anniversary Address, pp.lvi - lxxv, 1941.

Bramlette, M.N., (1941): The Stability of Minerals in Sandstone; Jour. of Sedimentary Petrology, Vol. 11, No.1, pp.32 - 36 Apr.1941.

Carroll, D.C., (1941): Grain Counts with the Petrographic Microscope; Jour. of Sedimentary Petrology, Vol.11, No.1, pp.44 - 45, Apr. 1941.

Clarke, F.W., (1924): The Data on Geochemistry; U.S.G.S. Bull 770, 840 pp., 1924.

Cogen, W.M., (1935): Some Suggestions for Heavy Mineral Investigation of Sediments; Jour. of Sedimentary Petrology, Vol. 5, No.1, pp.3-8, Aug. 1935.

Cohee, G.V., (1937): Inexpensive Equipment for Reclaiming Heavy Liquids; Jour. of Sedimentary Petrology, Vol. 7, No.1, pp 34 - 35, Apr. 1937.

Cordell, D., (1949): A Key to the Common Rock-Forming Minerals in Thin Sections; W.H. Freeman and Co., San Francisco, California, 1949.

Eckermann, H.V., (1948): The Alkaline District of Alno Island; Stockholm, Fig. 2, p.15, 1948.

Galloway, J.J., (1919); The Rounding of Sand Grains by Solution; Am. Jour. Sci., Vol. 197, pp. 270 - 280.

Geol.Surv.Can., (1945): Geological Map of the Dominion of Canada, Map 820A, Scale: 1 in. to 60 mi.

Gilligan, A., (1919): The Petrology of the Millstone Grit of Yorkshire: Geol. Soc. London Quart. Jour. Vol. 75, pp. 260 - 262, 1919.

Gouldick, S.S., (1934): Anthigenic Feldspar in Sandstones of Southeastern Minnesota; Jour. of Sedimentary Petrology, Vol. 4, No.2, pp. 89-95, Aug. 1934.

Howard, A.D., (1932): A Simple Device for the Manipulation of Individual Detrital Grains of Minute Size; Jour. of Sedimentary Petrology, Vol. 2, No. 3, pp. 160 - 161, Dec. 1932.

Johannsen,A., (1922): Essentials for the Microscopic Determination of Rock-Forming Minerals and Rocks; The University of Chicago Press, Chicago, Illinois, 1922.

Keller, W.D., and Littlefield, R.F., (1950): Inclusions in the Quartz of Igneous and Metamorphic Rocks; Jour. of Sedimentary Petrology, Vol. 20, No. 2., pp. 74 - 84, June 1950.

Krumbein, W.C., (1932): A History of the Principles and Methods of Mechanical Analysis; Jour. of Sedimentary Petrology, Vol. 2, No. 2, pp. 89 - 124, Aug. 1932.

(1941): Measurement and Geological Significance of Shape and Roundness of Sedimentary Particles; Jour. of Sedimentary Petrology, Vol. 11, No.2, pp. 64 - 72, Aug. 1941.

Krumbein, W.C., and Pettijohn, F.J., (1938): Manual of Sedimentary Petrography; D. Appleton Century Co. Inc., New York, 548 pp, 1938.

Krumbein, W.C., and Sloss, L.L., (1951): Stratigraphy and Sedimentation; W.H. Freeman and Co., San Francisco, 497 pp., 1953.

Krynine, P.D., (1940): Petrology and Genesis of the Third Bradford Sand; Pennsylvania State Coll. Bull. 29, 1940.

(1942): Provenance Versus Mineral Stability as a Controlling Factor in the Composition of Sediments; Bull. Geol. Soc. Am., Abstract, Vol. 53. pp. 1850 - 1851, 1942.

(1946): The Tourmaline Group in Sediments; Jour. Geol., Vol. 54, No.2, pp. 65 - 87, Mar. 1946.

Larsen, E.S., and Berman, H., (1934): The Microscopic Determination of the Nonopague Minerals; U.S.G.S. Bull. 848., U.S.G.S., Washington, D.C., 1934.

Milner, H.B., (1952): Sedimentary Petrography; Thomas Murby and Co., London, 666pp., 1952.

Otto, G.H., (1933): Comparative Tests of Several Methods of Sampling Heavy Mineral Concentrates; Jour. of Sedimentary Petrology, Vol. 3, No.1, pp. 30 - 39, Apr. 1933.

Pettijohn, F.J.,(1931): Petrography of the Beach Sands of Southern Lake Michigan; Jour. Geol., Vol. 39, No. 5, pp. 432 - 455, 1931.

(1949): Sedimentary Rocks, Harper and Bros., New York, U.S.A., 525 pp., 1949.

Raeburn, C., and Milner, H.B., (1927): Alluvial Prospecting; Thomas Murby and Co., London Eng., 478 pp., 1927.

Rittenhouse,G., (1943a): A Visual Method of Estimating Two-Dimensional Sphericity; Jour. of Sedimentary Petrology, Vol. 13, No.2, pp. 79 - 81, Aug. 1943.

(1943b): Transportation and Deposition of Heavy Minerals; Bull. Geol. Soc. Am., Vol. 54, pp. 1725 - 1780, Dec. 1943.

Rittenhouse, G., and Bertholf, W.E., Jr., (1942): Gravity Versus Centrifuge Separation of Heavy Minerals from Sand; Jour. of Sedimentary Petrology, Vol. 12, No.2, pp. 85 - 89, Aug. 1942.

Rogers, A.F., and Kerr, P.F., (1942): Optical Mineralogy; McGraw-Hill Book Co., Inc., New York., U.S.A., 390 pp., 1942.

Rubey, W.W., (1933): The Size-Distribution of Heavy Minerals Within a Water-Laid Sandstone; Jour. of Sedimentary Petrology, Vol. 3, No. 1, pp. 3 - 29, Apr. 1933.

Russell, R.D., (1935): Frequency Percentage Determination of Detrital Quartz and Feldspar; Jour. of Sedimentary Petrology, Vol. 5, No.3, pp. 109 - 114, Dec. 1935.

(1936): The Size-Distribution of Minerals in Mississippi River Sands; Jour. of Sedimentary Petrology, Vol. 6, No.3, pp.125 - 142, Dec. 1936.

(1937): Mineral Composition of Mississippi River Sands; Bull, Geol. Soc. Am., Vol. 48, pp. 1307 - 1348, 1937.

Short, M.N. (1940): Microscopic Determination of the Ore Minerals; U.S.G.S. Bull. 940, U.S.G.S., Washington D.C. 1940.

Taggart, A.F., (1951): Elements of Ore Dressing; John Wiley and Sons, New York, pp. 388 - 389, 1951.

Tester, A.C. and Atwater, G.I., (1934): The Occurrence of Authigenic Feldspars in Sediments; Jour. of Sedimentary Petrology, Vol. 4, No.1, pp. 23 - 31, Apr. 1934.

Thomson, E., (1930): Quantitative Microscopic Analysis; Jour. Geo., Vol. 38, No.3, pp. 193 - 222, 1930.

Twenhofel, W.H., and Tyler, S.A., (1941): Methods of Study of Sediments; McGraw-Hill Book Co. Inc., New York, 183 pp., 1941.

Tyler, S.A., (1936): Heavy Minerals of the St. Peter Sandstone in Wisconsin; Jour. of Sedimentary Petrology, Vol. 6, No.2, pp. 55 - 84, Aug. 1936.

United States, Agriculture, Dept. of (1950): Annotated Bibliography on Sedimentation; Sedimentation Bull. No.2, U.S. Govt. Printing Office, Washington 25, D.C., Feb. 1950.

Waddell, H., (1932): Volume, Shape and Roundness of Rock Particles; Jour. Geol., Vol. 40, pp. 433 - 451, 1932.

Wahlstrom, E.E., (1951): Optical Crystallography; John Wiley and Sons Inc., New York, 247 pp., 1951.

Wentworth, C.K., Wilgus, W.L., and Koch, H.L., (1934): A Rotary Type of Sample Splitter; Jour. of Sedimentary Petrology, Vol. 4, No.3, pp. 127 - 138, Dec. 1934.

Winchell, A.N. and Winchell, H., (1951): Elements of Optical Mineralogy; Part II - Description of Minerals, John Wiley and Sons Inc., New York, 551 pp., 1951.

Part II - Potsdam Sandstone

Adams, F.D. and LeRoy, O.E., (1904): The Artesian and Other Deep Wells on the Island of Montreal; Geol. Surv. Can., Ann. Rept., Vol. 14, Pt. O, pp. 1 - 74, 1904.

Ami, H.M., (1896a): Preliminary Lists of the Organic Remains Occurring in the Various Geological Formations Comprised in the South-West Quarter-Sheet Map of the Eastern Townships of the Province of Quebec, (Appendix to rept. by Ells, R.W., 1896a); Geol. Surv. Can., Ann. Rept., Vol. 7, Pt. J, pp. 113 - 157, 1896.

(1896b): Notes on Some of the Fossil Organic Remains Comprised in the Geological Formations and Outliers of the Ottawa Paleozoic Basin, (Communicated by Ells, R.W.,); Roy. Soc. Can., Proc. and Trans., Ser. 2, Vol. 2, Sec. 4, pp. 151 - 158, 1896.

(1900a): On the Geology of the Principal Cities in Eastern Canada; Roy. Soc. Can., Trans., Ser. 2, Vol. 6, Sec.4, pp. 125 - 174, 1900.

(1900b): Synopsis of the Geology of Canada (being a summary of the principal terms employed in Canadian geological nomenclature); Roy. Soc. Can., Trans., Ser. 2, Vol. 6, pp. 187 - 225, 1900. Note p. 201.

Billings, E., (1856): Fossils of the Potsdam Sandstone; Sea Weeds, Shells, and Foot Prints on the Rock at Beauharnois; Can. Nat., Vol. I, pp. 32 - 39, 1856.

Clark, T.H., (1939a): The St. Lawrence Lowlands of Quebec, Geologie der Erde: Geology of North America, Vol. 1, pp. 579 - 588, Berlin (1939).

(1939b): Description of Log of a Deep Well near Montreal (abstract); Roy. Soc. Can., Proc., Vol. 33, p. 198 (1939).

(1940): Montreal Area (advance report); Que. Bur. Mines, P.R. No. 147, 1940.

(1941): Preliminary Report on Montreal Area; Que. Bur. Mines, P.R. No. 158, 1941.

(1944a): Structure and Stratigraphy in the Vicinity of Montreal; Roy. Soc. Can., Trans., Ser. 3, Vol. 38, Sec. 4, pp. 23 - 33, 1944.

(1944b): The Unfolded Palaeozoic Rocks of the Saint-Lawrence Lowlands; Contribution to the book by Dresser, J.A., and Denis, T.C., The Geology of Quebec Gol. 2, Descriptive Geology, Que. Dept. Mines, Geol. Rept. 20, pp. 250 - 291, 1944.

(1952): Montreal Area, Laval and Lachine Map-Areas; Que. Dept. Mines, Geol. Rept. 46, 1952.

Clark, T.H., and Usher, J.L., (1948): The Sense of Climactichnites., Amer. Jour. Sci., Vol. 246, pp. 251 - 253, 1948.

Cumming C.L., (1915): The Artesian Wells of Montreal; Geol. Surv. Can., Mem. 72, 1915.

Dresser, J.A., (1897): Geological report and map of the district about Montreal; Can. Rec. Sci., Vol. 7, pp. 247 - 255, 1897.

Ells, R.W., (1895): The Potsdam and Calciferous Formations of Quebec and Eastern Ontario; Roy. Soc. Can., Trans., Ser. 1, Vol. 12 Sec. 4, pp. 21 - 30, 1895.

(1896a): Report on a portion of the Province of Quebec Comprised in the Southwest Sheet of the "Eastern Townships" Map (Montreal sheet); Geol. Surv. Can., Ann. Rept., Vol. 7, Pt. J, pp. 1 - 92, 1896.

(1896b): Palaeozoic Outliers in the Ottawa River Basin; Roy. Soc. Can., Proc. and Trans., Ser. 2, Vol. 2, Sec. 4, pp. 137 - 149, 1896.

(1900): The Physical Features and Geology of the Polaeozoic Basin Between the Lower Ottawa and St. Lawrence Rivers; Roy. Soc. Can., Trans., Sec. 2, Vol. 6, pp. 99 - 120, 1900.

(1901): Report on theGeology of Argenteuil, Ottawa, and part of the Pontiac counties, Province of Quebec, and Portions of Carleton, Russell and Prescott Counties, Province of Ont., Geol. Surv. Can., Ann. Rept., Vol. 12, Pt. J, pp. 1 - 143, 1901.

(1904): Report on the Geology of a Portion of Eastern Ont., Geol. Surv. Can., Ann. Rept., New Series, Vol. 14, Pt. J, 1904.

Ells, R.W., and Barlow, A.E., (1895): The Physical Features and Geology of the Route of the Proposed Ottawa Canal between the St. Lawrence River and Lake Huron; Roy. Soc. Can. Proc. and Trans; Ser. 2, Vol 1, Sec. 4, pp. 163 - 190, 1895.

Emmons, E., (1842): Geology of New York, Part II; Albany, N.Y., 1842.

Gauthier, H., (1917): Road materials in Two Mountains and the Southern Portion of Argenteuil Counties, Quebec; Geol. Surv. Can., Sum. Rept., 1916, pp. 198 - 201, 1917.

(1919): Road Material Surveys in the City and District of Montreal, Quebec; Geol. Surv. Can., Mem. 114, 1919.

Harding, W.D., (1931): The Relations of the Grenville Sediments and the Potsdam Sandstone in Eastern Ontario; American Mineralogist, Vol. 16, pp. 430 - 436, 1931.

Kindle, E.M., and Burling, L.D., (1915): Structural Relations of the Pre-Cambrian and Palaeozoic Rocks North of the Ottawa and St. Lawrence Valleys; Geol. Surv. Can., Mus. Bull., No. 18, 1915.

Logan, W.E., (1847): On the Geology of the Ottawa River Region; Geol. Surv. Can., Rept. Prog. to 1845 - 6, pp. 5 - 98 and 119 - 122, 1847.

(1849): On the Geology of the Country on the South Side of the St. Lawrence from Montreal and Lake Champlain to the Chaudiere River; Quebec; Geol. Surv. Can., Rept. Prog. 1847 - 48, pp. 5 - 92, 1849.

(1851): On the Occurrence of a Track and Foot Print of an Animal in the Potsdam Sandstone of Lower Canada; Geol. Soc. London, Quart. Jour., Vol. 7, pp. 247 - 250, 1851.

(1852a): On the Foot-Prints Occurring in the Potsdam Sandstone of Canada; Geol. Soc. London, Quart. Jour., Vol. 8, pp. 199 - 213, 1852.

(1852b): Geology South of Saint Lawrence River; Geol. Surv. Can., Rept. Prog. 1851 - 52, pp. 5 - 56, 1852.

(1854): Geology North of Saint Lawrence River; Geol. Surv. Can., Rept. Prog. 1852 - 53, pp. 5 - 74, 1854.

(1860): On the Track of an Animal Lately Found in the Potsdam Formation; Can. Nat. & Geol., Vol. 5, pp. 279 - 285, 1860.

(1863): Report on the Geology of Canada; Geol. Surv. Can. Rept. Prog. from its Commencement to 1863, 1863.

McGerrigle, H.W., (1938): Lachute Map-Area: Part II - the Lowland Area; Que. Bur. Mines, Ann. Rept. 1936, Pt. C, pp. 41 - 62, 1938.

Osborne, F.F. (1938): Lachute Map-Area: Part I, General and Economic Geology; Que. Bur. Mines, Ann. Rept. 1936, Pt. C, pp. 3 - 40, 1938.

Owen, R., (1851): Description of the Impressions on the Potsdam Sandstone, Discovered by Mr. Logan in Lower Canada; Geol. Soc. London, Quart. Jour., Vol. 7, pp. 250 - 252, 1851.

(1852): Description of the Impressions and Footprints of the Protichnites from the Potsdam Sandstone of Canada; Geol. Soc. London, Quart. Jour. Vol. 8, pp. 214 - 225, 1852.

Parks, W.A., (1912): Report on the Building and Ornamental Stones of Canada; Mines Branch, Dept. Mines, Ottawa, Vol. I, - Ontario South of Ottawa and French Rivers, Pub. No. 100, pp. 121 - 139, 1912.

(1914): Report on the Building and Ornamental Stones of Canada; Mines Branch, Dept. Mines, Ottawa, Vol. 3 - Province of Quebec, Pub. No. 279, 1914.

(1931): Natural Gas in the St. Lawrence Valley, Quebec; Que. Bur. Mines, Ann. Rept. 1930, Pt. D, pp. 1 - 98, 1931.

Picher, R.H., (1917): Road Materials in Soulanges and Vaudreuil Counties, Quebec; Geol. Surv. Can. Sum. Rept. 1916, pp. 201 - 206, 1917.

Quebec Dept. Mines, (1944): Geology of Quebec, Vol. 2, Descriptive Geology (Compiled by J.A. Dresser and T.C. Denis); Que. Dept. Mines, Geol. Rept. 20, pp. 52 - 226, 1944.

Raymond, P.E., (1913): Ordovician of Montreal and Ottawa; Geol. Surv. Can., Guide Book No. 3, p. 139, 1913.

Resser, C.E., (1938): The Cambrian Rocks of New York, Vermont, and Quebec; Smith. Inst. - Explorations and Field-Work of, in 1937, Pub. No. 3480, pp. 5 - 8, 1938.

Valiquette, J.H., (1912): Report on the Montreal Quarries; Mines Branch, Dept. Colon., Mines and Fisheries, Quebec, 1911, pp. 52 - 70, 1912.

Wilmarth, M.G., (1938): Lexicon of Geologic Names of the United States; U.S. Geol. Sur., Bull. 896, Pt. I & II, 1938.

Wilson, A.E., (1937): Erosional Intervals Indicated by Contacts in the Vicinity of Ottawa, Ontario; Roy. Soc. Can., Trans., Ser. 3, Vol. 31, Sec. 4, pp. 45 - 60, 1937.

(1941a): Valleyfield Map; Geol. Sur. Can., Map 660A, 1941.

(1941b): L'Orignal Map; Geol. Sur. Can., Map 662A, 1941.

(1946a): Ottawa - Cornwall Map; Geol. Sur. Can., Map 852A, 1946.

(1946b): Geology of the Ottawa - St. Lawrence Lowland, Ontario and Quebec; Geol. Sur. Can. Mem. 241, 1946.

APPENDIX

DETAILED GEOLOGICAL LOG

Of The Top 504 Feet of Potsdam Sandstone

Mallet Well, Sainte-Thérèse, Quebec

Notes: (1) All lengths and distances given in the descriptions are measured from the top of the individual core section being described.

(2) T.S. #2, 0-1 in. - Sample for #2 thin section taken at 0-1 in. of 6 in. section of core (see column titled "Thickness".)

(3) H.M. #2, 3-4 in. - Sample for #2 heavy mineral separation taken at 3-4 in. of 6 in. section of core (see column titled "Thickness".)

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
1696	0		Contact with the Beekmantown formation. Immediately above the Potsdam formation are 9 inches of dark-grey shale with small lenses of a very fine-grained, light-grey calcareous quartz sandstone. At the contact the Beekmantown is mainly dolomite with a lesser amount of calcite.
	0	1	Coarse-grained calcareous quartz sandstone, well rounded, frosted grains, light-grey. T.S. #1, 0 - 1 in.
	0	2	Medium-grained calcareous quartz sandstone; rounded, frosted grains, white, few minute grey shale laminae.
	0	6	Fine-grained calcareous quartz sandstone, few coarse-grained frosted grains, white, few rusted spots - pyrite? H.M. #1, 2-3 in.
	1	3	Medium-grained calcareous quartz sandstone, angular to well rounded frosted, white, cross-bedded at 8 inches, pink garnet grain, few rusted pyrite crystals, few minute shale laminae.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
1694			
	36	0	Missing, from a log of the core by the G.S.C., (Wickenden R.T.D., Wilson A.E., 1937) it is white sandstone.
1658			
	0	6	Fine-grained calcareous quartz sandstone, sub-rounded, inequigranular, white, cross-bedded, minute shale laminae, few disseminated rusted grains. T.S. #2, 0-1 in. H.M. #2, 3 - 4 in.
	0	1	Fine-grained quartz sandstone, white, as above; but not calcareous.
	0	5	As above; but slightly calcareous in places, white to light-grey.
	0	3	As above; but not calcareous.
	0	7	Coarse-grained quartz sandstone, well rounded and sorted, frosted, white to light-grey cross-bedded.
	0	1	Fine-grained quartz sandstone, rest as above, grades into medium-grained below.
	0	3	Medium-grained quartz sandstone, white, rest as above.
	1	8	Fine-grained quartz sandstone, white, odd pink garnet grain, rest as above.
	0	8	Medium-grained quartz sandstone, white, rest as above.
	0	2	Missing.
	0	4	Fine-grained quartz sandstone, white to light-grey, rest as above.
1652			
	0	3	Coarse-grained quartz sandstone, white to light-grey, rest as above.
	0	3	Fine-grained quartz sandstone, white to light-grey, rest as above.
	1	0	Coarse-grained quartz sandstone, subangular fairly well sorted, frosted, white, cross-bedded.

Distance from bottom of hole Feet	Thickness Feet	Inches	
	1	10	Medium-grained quartz sandstone, subangular well rounded, some frosted grains, white to light grey, cross-bedded.
	2	8	Fine-grained quartz sandstone, subangular, occasional grain of dark mineral, rest as above. H.M. #3; 1 ft. 7 - 8 in.
	0	7	Medium-grained quartz sandstone, rounded, frosted, fairly well sorted, white cross-bedded.
	0	5	Fine-grained quartz sandstone, rest as above.
1645			
	0	11	Coarse-grained quartz sandstone. Several rusted grains from 1 - 2 inches, light-grey, subangular rest as above.
	4	0	Missing.
	1	5	Medium-grained quartz sandstone, rounded, white to light-gray, rest as above.
	3	11	Fine-grained quartz sandstone, subangular to well rounded, white to light-grey, rest as above.
	0	7	Missing.
	0	7	Medium-grained quartz sandstone, rounded, white to light-grey, rest as above.
	0	10	Fine-grained quartz sandstone, rounded, white to light-grey. H.M. #4, 8-9 in.
	2	2	Medium-grained quartz sandstone, rounded, frosted, well sorted, white to light-grey, cross-bedded.
	1	1	Fine-grained quartz sandstone, well rounded, several rusted grains from 10 - 12 in., white, rest as above.
	1	6	Missing
1628			
	0	6	Medium-grained quartz sandstone, well rounded and sorted, frosted white, few minute dark-grey shale laminae, cross-bedded.
	2	8	Fine-grained quartz sandstone, as above. H.M. #5, 1 ft. 1 - 2 in.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	5	Missing.
	0	7	Medium-grained quartz sandstone, rounded, well sorted, white to light-grey, cross-bedded, few grains of black mineral, few minute shale laminae.
	0	2	Fine-grained quartz sandstone, no shale laminae, rest as above.
	1	5	Medium-grained quartz sandstone, white, no shale laminae, rest as above.
	0	7	Fine-grained quartz sandstone, white, few minute shale laminae, rest as above.
	3	7	Medium-grained quartz sandstone, white, few minute shale laminae, several from 9 - 13 in., rest as above.
	0	1	Missing.
1618			
	0	1	Fine-grained quartz sandstone, white, no shale laminae, rest as above.
	0	2	Medium-grained quartz sandstone, white, no shale laminae, rest as above.
	0	2	Fine-grained quartz sandstone, white, a thin lamina of black mineral at 0 in., rest as above.
	0	10	Medium-grained quartz sandstone, white, occasional thin lamina of black mineral, rest as above. T.S. #3, 1-2 in. H.M. #6, 8-9 in.
	3	3	Fine-grained quartz sandstone, white to light-grey, cross-bedded, several thin black shale laminae.
	0	9	Missing.
	0	2	Medium-grained quartz sandstone, white to light-grey, as above.
	0	8	Fine-grained quartz sandstone, white to light-grey, cross-bedded, a few thin black shale laminae.
	0	5	Medium-grained quartz sandstone, light-grey, rest as above.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	3	2	Fine-grained quartz sandstone, white to light-grey, a few thin black shale laminae and inclusions, tendency to break across grain and frosted surfaces less prominent.
	0	4	Missing.
	0	5	Medium-grained quartz sandstone, white, cross-bedded.
	0	6	Fine-grained quartz sandstone, white to light-grey, cross-bedded from 4 - 6 in., odd inclusion of light-coloured clay or shale.
	3	1	Medium-grained quartz sandstone, white to light-grey, cross-bedded, several minute black shale laminae, slightly calcareous at 2 ft. 3 in. H.M.#7, 5-6 in.
	1	0	Fine-grained quartz sandstone, white, cross-bedded, several minute black shale laminae.
1603			
	1	5	Medium-grained quartz sandstone, well rounded grains, frosted, white, cross-bedded at 9 in., several minute black laminae, slightly calcareous at 4 in. H.M. #8, 1 ft. 0 - 1 in.
	0	6	Fine-grained quartz sandstone, rounded grains, frosted, white, cross-bedded.
	0	11	Medium-grained quartz sandstone, well rounded grains, white, cross-bedded, a few minute black laminae.
	0	3	Fine-grained quartz sandstone, as above.
	1	0	Medium-grained quartz sandstone, as above, a few minute black laminae (mineral grains?), 0 - 7 in.
	0	7	Missing.
	0	11	Fine-grained quartz sandstone, as above.
	0	6	Medium-grained quartz sandstone, as above.
	0	9	Fine-grained quartz sandstone as above, a white feldspar grain and a dark grain at 4 in. H.M.#9, 4 - 5 in.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	6	Medium-grained quartz sandstone as above, no black laminae.
	0	7	Fine-grained quartz sandstone, no black laminae, some dark mineral grains at 7 in., rest as above.
	0	10	Medium-grained quartz sandstone, as above, some minute black laminae at 9 in.
	1	2	Fine-grained quartz sandstone, as above, few minute black laminae. T.S. #4, 9 - 10 in.
	0	3	Missing.
	1	0	Medium-grained quartz sandstone, well-rounded grains, frosted, white.
	1	7	Fine-grained quartz sandstone, as above, occasional grain of dark mineral.
	0	10	Medium-grained quartz sandstone, rounded grains, frosted, white.
	0	4	Fine-grained quartz sandstone, as above.
	0	5	Medium-grained quartz sandstone, as above.
	0	2	Fine-grained quartz sandstone, as above.
	0	2	Medium-grained quartz sandstone, rounded grains, frosted white, cross-bedded, minute black laminae.
	0	2	Coarse-grained quartz sandstone, rounded grains, many break across grain, siliceous cement?, vitreous lustre, white.
	1	0	Medium-grained quartz sandstone, cross-bedded at 1 in., calcareous at 2 in., several thin black laminae, rest as above.
	0	11	Fine-grained quartz sandstone, rounded grains, vitreous lustre, white, cross-bedded.
	0	1	Medium-grained quartz sandstone, rounded, vitreous lustre, white.
	0	2	Fine-grained quartz sandstone, as above.
1586			
	0	2	Medium-grained quartz sandstone, as above.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	3	Coarse-grained quartz sandstone, rounded grains, vitreous lustre, white, cross-bedded, thin black laminae, H.M. No. 10, 2-3 in.
	0	3	Fine-grained quartz sandstone, as above
	1	5	Medium-grained quartz sandstone, as above, also some black mineral grains and calcareous material at 11 in.

Note: p. via continues on from p. vi and p. vii continues on from p. via.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	6	Missing.
	0	9	Fine-grained quartz sandstone, as above.
	0	5	Medium-grained quartz sandstone, as above.
	0	4	Fine-grained quartz sandstone, as above, not cross-bedded.
	0	1	Medium-grained quartz sandstone, rounded grains, vitreous lustre, white.
	0	5	Fine-grained quartz sandstone, as above, cross-bedded.
	0	9	Medium-grained quartz sandstone, rounded grains, vitreous lustre, white, cross-bedded, a few minute black laminae, pink garnet grain at 0 in., few black mineral grains.
	0	1	Fine-grained quartz sandstone, rounded grains, vitreous lustre, white.
	0	1	Medium-grained quartz sandstone, as above, cross-bedded.
	0	2	Fine-grained quartz sandstone, rounded grains, vitreous lustre, white, some dark shale at 0 in.
	0	7	Medium-grained quartz sandstone, as above, cross-bedded, some black mineral at 7 in.
	0	10	Fine-grained quartz sandstone, as above, cross-bedded, some black mineral at 1 in., thin laminae of black shale.
	0	3	Medium-grained quartz sandstone, rounded grains, vitreous lustre, white.
	0	3	Fine-grained quartz sandstone, as above.
	0	5	Missing.
1578			
	0	7	Fine-grained quartz sandstone, well rounded grains, frosted, white.
	0	1	Very fine-grained quartz sandstone, white, few black mineral grains.

Note: p. viia continues from p. vii.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	3	Medium-grained quartz sandstone, well rounded grains, frosted, white, cross-bedded, some thin black laminae.
	0	2	Fine-grained quartz sandstone, well rounded and sorted grains.
	0	3	Medium-grained quartz sandstone, as above.
	0	1	Coarse-grained quartz sandstone, as above.
	0	5	Medium-grained quartz sandstone, as above.
	0	3	Fine-grained quartz sandstone, rounded grains, fairly well sorted, white, cross-bedded, few thin black mineral grains, few thin black laminae (some pyrite?).
	0	3	Very fine-grained quartz sandstone, subrounded grains, fairly well sorted, white, cross-bedded.
	0	4	Fine-grained quartz sandstone, subrounded grains, fairly well sorted, white, cross-bedded, odd black mineral grain.
	0	2	Medium-grained quartz sandstone, well rounded grains, fairly well sorted, white.
	0	2	Fine-grained quartz sandstone, rounded grains, fairly well sorted, white, cross-bedded.
1575			
	0	1	Coarse-grained quartz sandstone, well rounded and sorted grains, white. H.M. #11, 0 - 1 in.
	0	6	Medium-grained quartz sandstone, as above.
	0	1	Missing.
	3	0	Fine-grained quartz sandstone, rounded grains, well to rather poorly sorted, white, cross-bedded, some very thin black laminae.
	0	11	Medium-grained quartz sandstone, as above, no black laminae.
	1	5	Fine-grained quartz sandstone, rather poorly sorted, white, cross-bedded, minute black laminae.

Note: p. viii continues from p. viia.

Distance from bottom of hole Feet	Thickness Feet	Inches	
	0	11	Medium-grained quartz sandstone, vitreous lustre, fairly well sorted, white, cross-bedded some minute black laminae from 3 - 4 in.
	0	1	Missing.
	1	0	Fine-grained quartz sandstone, rather poorly sorted, vitreous and frosted grains, white, cross-bedded, few minute black laminae, black mineral grains at 5 in.
1567			
	0	9	Medium-grained quartz sandstone, white, cross-bedded, few minute black laminae.
	0	7	Fine-grained quartz sandstone, rather poorly sorted, white, cross-bedded.
	0	7	Medium-grained quartz sandstone, white, cross-bedded, few minute black laminae.
	0	5	Fine-grained quartz sandstone, fairly well sorted, white, cross-bedded.
	1	9	Medium-grained quartz sandstone, as above.
	0	3	Fine-grained quartz sandstone, white, cross-bedded.
	0	4	Medium-grained quartz sandstone, as above, some dark mineral grains at 4 in. H.M. #12, 0 - 1 in.
	0	4	Fine-grained quartz sandstone, white.
1562			
	3	11	Medium-grained quartz sandstone, well rounded and sorted, white to light-grey, cross-bedded, odd pink garnet grain and few lenses of black mineral grains. T.S. #6, 3 ft. 6 - 7 in.
	0	1	Missing.
	0	2	Fine-grained quartz sandstone, well rounded and sorted, white, cross-bedded.
	0	5	Medium-grained quartz sandstone, as above, white to light-grey, some minute black laminae.
	2	4	Fine-grained quartz sandstone, well rounded and sorted, white, cross-bedded, minute black laminae. H.M. # 13, 9 - 10 in.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	2	Coarse-grained quartz sandstone, well rounded and sorted, white.
	0	7	Fine-grained quartz sandstone, as above, several minute black laminae from 4 - 6 in.
	0	2	Medium-grained quartz sandstone, well rounded and sorted, white.
	0	1	Fine-grained quartz sandstone, as above, minute black laminae.
	0	3	Coarse-grained quartz sandstone, well rounded and sorted, white, cross-bedded, T.S. #7, 1 - 2 in.
	0	3	Fine-grained quartz sandstone, well rounded and sorted, white.
	0	7	Missing.
1553			
	0	5	Fine-grained quartz sandstone, subangular grains, frosted, well sorted, white, cross-bedded, few minute black laminae.
	0	10	Medium-grained quartz sandstone, well rounded and sorted grains, white, cross-bedded, some pyrite at 10 in.
	0	1	Very fine-grained quartz sandstone, white, subangular grains, well sorted.
	1	0	Fine-grained quartz sandstone, subrounded grains, fairly well sorted, white, cross-bedded.
	1	11	Medium-grained quartz sandsone, well rounded and sorted grains, white, occasionally cross-bedded, black mineral at 0,5, and 7 in., pink garnet grain at 4 in. and 21 in. H.M. #14, 1 ft. 6 - 7 in.
	0	3	Fine-grained quartz sandstone, rather poorly sorted, white.
	0	7	Medium-grained quartz sandstone, well rounded and sorted grains, white, cross-bedded from 6 - 7 in.
	0	5	Fine-grained quartz sandstone, subangular grains, white, cross-bedded.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	4	Medium-grained quartz sandstone, rounded grains, white, cross-bedded.
	0	6	Fine-grained quartz sandstone, subangular grains, white, cross-bedded, some minute black laminae.
	2	8	Medium-grained quartz sandstone, well rounded and sorted grains, vitreous, white to light-grey, cross-bedded, few minute black laminae, odd pink garnet grain, pyrite crystal from 4-6 in.
	0	10	Fine-grained quartz sandstone, white, cross-bedded, minute black laminae.
	0	2	Missing.
1543			
	0	4	Fine-grained quartz sandstone, subangular grains, white, cross-bedded, few minute black laminae.
	0	3	Medium-grained quartz sandstone, well rounded and sorted grains, white, pink garnet grain at 1 in. H.M. #15, 0 - 1 in.
	2	7	Fine-grained quartz sandstone, subangular grains, well sorted, white, cross-bedded, some black mineral grains at 4 in., some pyrite at 2 ft. 5 in., T.S. #8 at 2 ft. 5 - 6 in.
	0	1	Missing.
	3	10	Medium-grained quartz sandstone, well rounded and sorted grains, frosted, white, cross-bedded, few minute black laminae.
	0	2	Coarse-grained quartz sandstone, well rounded and sorted grains, frosted, white.
	0	1	Missing.
	0	9	Fine-grained quartz sandstone, rounded and well sorted grains, white, pink garnet grain at 0 in.
	0	5	Medium-grained quartz sandstone, well sorted, white, cross-bedded, odd minute black laminae, pink garnet grain at 2 in.

Distance from bottom of hole Feet	Thickness Feet	Inches	
	0	4	Fine-grained quartz sandstone, white, cross-bedded, odd minute black laminae.
	0	2	Medium-grained quartz sandstone, vitreous lustre, white.
1534			
	0	3	Fine-grained quartz sandstone, white, cross-bedded, odd thin black lamina.
	0	7	Medium-grained quartz sandstone, vitreous, lustre, siliceous cement? white.
	3	6	Fine-grained quartz sandstone, well rounded grains, well to poorly sorted, frosted to vitreous lustre, siliceous cement?, white, cross-bedded, minute black laminae, pink garnet grain at 1 ft. 8 in. H.M. #16, 1 ft. 8 - 9 in.
	0	2	Medium-grained quartz sandstone, white.
	0	7	Fine-grained quartz sandstone, white, cross-bedded, minute black laminae, pink garnet grain at 5 in.
	0	6	Medium-grained quartz sandstone, white, cross bedded, irregular minute black laminae, resemble stylolitic structure, pink garnet grain at 5 in.
	0	5	Missing.
1528			
	0	8	Medium-grained quartz sandstone, well rounded and sorted grains, subvitreous frosted, white, cross-bedded, black mineral grain at 4 in., minute black laminae.
	0	5	Coarse-grained quartz sandstone, well rounded grains, white, cross-bedded, minute black laminae.
	2	2	Medium-grained quartz sandstone, well rounded grains, white, cross-bedded.
	1	3	Fine-grained quartz sandstone, well rounded grains, white, cross-bedded, inclusion of grey shale at $\frac{1}{2}$ in., few minute black laminae.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	5	Medium-grained quartz sandstone, well rounded grains, grey.
	0	1	Missing.
1523			
	0	3	Fine-grained quartz sandstone, well rounded grains, light-grey, mottled appearance, cross-bedded.
	0	5	Medium-grained quartz sandstone, well rounded grains, grey, cross-bedded, nodules and lenses to 1 in. long of dark-coloured mineral.
	0	3	Fine-grained quartz sandstone, well rounded grains, light grey, cross-bedded, small amount of dark material. H.M. #17, 0 - 1 in.
	2	2	Medium-grained quartz sandstone, well rounded grains, white to grey, cross-bedded, few nodules to 1 cm or more across of dark-grey and black material, calcareous cement crystallized in interstices from 1 ft. 6 in. - 2 ft. 2 in., dark material above is possibly calcareous. T.S. #9, 1 ft. 11 in. - 2 ft.
	1	3	Coarse-grained quartz sandstone, well rounded grains, grey, cross-bedded, calcareous cement crystallized in interstices, some black mineral grains.
	0	5	Missing.
	0	10	Medium-grained quartz sandstone, well rounded and frosted grains, light-grey, cross-bedded, practically vertical tiny calcite veinlet from 3 - 10 in., calcareous cement crystallized in interstices from 0 - 3 in., some dark mineral grains in tiny lenses and nodules.
	0	2	Coarse-grained quartz sandstone, grey, as above, end of calcite veinlet.
	1	0	Medium-grained quartz sandstone, light-grey to grey, as above. H.M. # 18, 11 - 12 in.
	0	4	Fine-grained quartz sandstone, rounded and frosted grains, light-grey, cross-bedded.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	1	9	Medium-grained quartz sandstone, white to light-grey, as above.
	0	5	Fine-grained quartz sandstone, white, as above.
	0	9	Medium-grained quartz sandstone, white, as above, some black mineral grains at 9 in.
1513			
	0	6	Fine-grained quartz sandstone, white, cross-bedded, few minute black laminae.
	0	5	Medium-grained quartz sandstone, as above.
	2	1	Fine-grained quartz sandstone, as above, a pink garnet grain at 1 in.
	0	1	Medium-grained quartz sandstone, as above, slightly calcareous.
	0	3	Fine-grained quartz sandstone, subvitreous, lustre, white, cross-bedded, occasionally breaks across grain (siliceous cement?).
	0	11	Medium-grained quartz sandstone, as above.
	0	4	Coarse-grained quartz sandstone, as above.
	0	5	Missing.
1508			
	0	4	Coarse-grained quartz sandstone, white, cross-bedded, pink garnet grain at 0 in., calcareous at 1 in., pyrite at 2 in.
	1	7	Medium-grained quartz sandstone, white, occasionally cross-bedded.
	0	2	Coarse-grained quartz sandstone, as above, H.M. #19, 0 - 1 in.
	1	0	Medium-grained quartz sandstone, as above, calcareous from 0 - 1 in.
	1	3	Fine-grained quartz sandstone, as above, not calcareous.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	5	Medium-grained quartz sandstone, as above.
	0	3	Fine-grained quartz sandstone, as above.
1503			
	0	7	Medium-grained quartz sandstone, well rounded and sorted grains, subvitreous lustre, white.
	0	7	Fine-grained quartz sandstone, as above, cross-bedded, occasional black mineral grain, pink garnet grain at 5 in., few minute black laminae.
	0	3	Medium-grained quartz sandstone, well rounded and sorted grains, subvitreous lustre, grey, pink garnet grain at 1 in., few black mineral grains. H.M. # 20, 0 - 1 in.
	0	7	Fine-grained quartz sandstone, well rounded and sorted grains, subvitreous lustre, white, cross-bedded, few black mineral grains.
	0	4	Medium-grained quartz sandstone, as above.
	0	7	Fine-grained quartz sandstone, as above, sub-angular grains.
	0	1	Medium-grained quartz sandstone, as above, well rounded and sorted grains.
1500			
	0	1	Coarse-grained quartz sandstone, as above.
	1	2	Fine-grained quartz sandstone, as above.
	0	3	Medium-grained quartz sandstone, as above, pink garnet grain at 1 in.
	2	8	Fine-grained quartz sandstone, as above, pink garnet grain at 1 ft. 2 in. and at 2 ft.
	0	1	Coarse-grained quartz sandstone, well rounded and sorted grains, subvitreous lustre, white.
	0	2	Medium-grained quartz sandstone, as above, cross-bedded.
	1	7	Fine-grained quartz sandstone, as above, cross-bedded, occasionally calcareous (calcite?), pink garnet grain at 1 ft. and at 1 ft. 7 in., few black mineral grains.

Distance from bottom of hole Feet	Thickness Feet	Inches	
	0	1	Coarse-grained quartz sandstone, well rounded and sorted grains, subvitreous lustre, white, cross-bedded, calcareous (calcite?).
	0	7	Fine-grained quartz sandstone, as above, calcareous from 0 - 2 in. (Calcite?).
	0	1	Missing.
	0	9	Medium-grained quartz sandstone, as above, calcareous from 4 - 6 in. H.M. # 21, 6 - 7 in.
	0	10	Fine-grained quartz sandstone, as above, not calcareous.
	0	8	Medium-grained quartz sandstone, as above, not calcareous, some angular grains.
1491			
	1	6	Fine-grained quartz sandstone, subvitreous lustre, white, cross-bedded, occasional pink garnet grain, siliceous cement.
	0	2	Medium-grained quartz sandstone, subvitreous lustre, white, cross-bedded.
	0	6	Fine-grained quartz sandstone, as above, siliceous cement.
	0	1	Medium-grained quartz sandstone, as above.
	0	6	Missing.
	0	1	Coarse-grained quartz sandstone, rounded grains, subvitreous lustre, white, cross-bedded.
	1	0	Medium-grained quartz sandstone, as above, pink garnet grain at 5 in.
	0	11	Fine-grained quartz sandstone, as above.
	10	8	Missing.
	2	3	Fine-grained quartz sandstone, as above, occasional pink garnet grain, chalcopyrite at 10 in. (soft, brassy yellow).

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	7	Medium-grained quartz sandstone, well rounded grains, subvitreous lustre, white, cross-bedded, pink garnet grain at 3 in.
	1	5	Fine-grained quartz sandstone, rounded grains, subvitreous lustre, white, cross-bedded from 11 in. - 1 ft 5 in.
	2	5	Medium-grained quartz sandstone, rounded to well rounded grains, well to rather poorly sorted, white, cross-bedded, pink garnet grain at 10 in., thin black lamina at 2 ft. 4 in.
	0	2	Poor conglomerate, grey, cross-bedded, frosted grains, fine-grained matrix containing grains ranging from medium-grained to granular in size, a few grains appear to be aggregates of tiny grains (may be due to weathering along fractures?), some feldspar grains, black mineral grains, pyrite.
	0	5	Poor conglomerate as above, white to light grey, medium-grained matrix which is main part of rock. H.M. #22, 1 - 2 in.
	0	4	Coarse-grained quartz sandstone, well rounded and frosted grains, white, cross-bedded, poorly cemented.
1468			
	0	5	Coarse-grained quartz sandstone, well rounded and sorted grains, frosted, white, cross-bedded, very poorly cemented.
	0	6	Medium-grained quartz sandstone, as above, few pink garnet grains.
	0	1	Fine-grained quartz sandstone, as above, no pink garnet grains.
	0	9	Coarse-grained quartz sandstone, as above, light grey, occasional rusted grain, poorly cemented.
	2	2	Medium-grained quartz sandstone, well rounded grains, frosted, white to light-grey, cross-bedded, poorly to occasionally well cemented, occasional pink garnet grain, several minute black shale laminae to 1/16 in. thick. H.M. # 23, 1 ft. 3 - 4 in.

Distance from bottom of hole Feet	Thickness Feet	Inches	
	0	7	Fine-grained quartz sandstone, frosted grains, white, cross-bedded, few black shale laminae to 1/8 in. across, several small lenses contain a small amount of a pale-green cement (probably argillaceous).
	0	4	Coarse-grained quartz sandstone, light-grey, cross-bedded, poorly to well cemented.
	0	2	Fine-grained quartz sandstone, as above.
1463			
	1	8	Coarse-grained quartz sandstone, well rounded and sorted grains, frosted, white, cross-bedded, well cemented, occasionally pale-green cement as above, occasional minute black laminae, pink garnet grain at 8 in.
	2	8	Medium-grained quartz sandstone, well rounded and sorted grains, frosted, light grey, cross-bedded, pink garnet grain at 2 in., few thin laminae of black to grey or pale-green shale to $\frac{1}{4}$ in. across.
	0	2	Coarse-grained quartz sandstone, light-grey, cross-bedded, very poorly cemented.
	0	1	Very coarse-grained quartz sandstone, as above, pink garnet grain at 1 in.
	0	5	Fine-grained quartz sandstone, as above.
1458			
	0	7	Coarse-grained quartz sandstone, well rounded and sorted grains, frosted, light-grey, cross-bedded, few minute black laminae, slightly calcareous at 3 in, poorly cemented.
	0	11	Medium-grained quartz sandstone, as above, white well cemented, calcareous and siliceous cements, occasional pink garnet grain.
	0	3	Coarse-grained quartz sandstone, as above, slightly calcareous.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	10	Fine-grained quartz sandstone, as above, white to light-grey, slightly calcareous from 0 - 2 in. and at 7 in., some sericite at 7 in. H.M. #24, 5 - 6 in.
	1	4	Medium-grained quartz sandstone, as above, white, slightly calcareous from 1 ft. 1 - 4 in.
	0	10	Coarse-grained quartz sandstone, as above, white, slightly calcareous at 3 in.
	0	1	Missing.
	1	7	Medium-grained quartz sandstone, as above, white to light-grey occasionally calcareous, small calcite vein? (lamina?) from 1 ft. 6 - 7 in., is dark-grey on the fresh surface and grey-green on the weathered, T.S. #11, 1 ft. 6 - 7 in.
	0	2	Very fine-grained quartz sandstone, white, cross-bedded, minute black laminae, slightly calcareous.
	0	4	Coarse-grained quartz sandstone, as above.
	0	2	Fine-grained quartz sandstone, as above.
1449	1	11	Medium-grained quartz sandstone, well rounded grains, frosted, white to light-grey, cross-bedded, few minute black laminae with few small mica (sericite?) flakes, matrix occasionally has slightly calcareous greenish spots, occasional calcite nodule to $\frac{1}{2}$ in. across.
	0	2	Coarse-grained quartz sandstone, white, cross-bedded, few thin black laminae, calcareous, calcite nodules to $\frac{1}{2}$ in. across, matrix rusted.
	0	4	Missing.
	1	0	Medium-grained quartz sandstone, white, cross-bedded, well cemented, few minute black laminae, occasionally slightly calcareous.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	1	3	Coarse-grained quartz sandstone, as above, well rounded and sorted grains, frosted, calcite vein from 2 - 4 in. pyrite at 9 in. H.M. # 25 9 - 10 in.
	1	0	Medium-grained quartz sandstone, as above, laminae contain flakes of white mica (sericite), few pale-green calcite nodules to $\frac{1}{4}$ in. across.
	0	7	Coarse-grained quartz sandstone, as above, light-grey, calcareous from 0 - 4 in., calcite nodules to 3/8 in. across.
	0	8	Medium-grained quartz sandstone, as above, rather poorly sorted, dark-grey crystalline calcite cement from 2-8 in. T.S. # 12, 7-8"
1444			
	8	4	Missing.
	0	4	Medium-grained quartz sandstone, well rounded grains, frosted, white, cross-bedded.
	0	4	Coarse-grained quartz sandstone, as above, calcareous at 1 in. and rusty weathering.
1435			
	0	6	Medium-grained quartz sandstone, white, cross-bedded, slightly calcareous, occasionally rusted.
	1	4	Coarse-grained quartz sandstone, well rounded grains, frosted, white, cross-bedded, occasionally calcareous and rusted matrix, rather poorly cemented. H.M. # 26, 1 ft. 2 - 3 in.
	2	0	Medium-grained quartz sandstone, white, cross-bedded, well cemented, matrix, occasionally rusted.
	0	7	Coarse-grained quartz sandstone, as above.
	0	3	Missing.
	1	8	Fine-grained quartz sandstone, as above.
	0	9	Coarse-grained quartz sandstone, as above from 4 - 6 in. have a conglomerate texture with very coarse grains to 1 or 2 pebbles in a medium-grained matrix, small amount of pyrite, calcareous at 8 in.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	2	2	Fine-grained quartz sandstone, white, cross-bedded, rusted in spots, silica cement crystallized in interstices, calcareous from 1 ft. 11 in. - 2 ft. 2 in., occasional pyrite crystal.
	0	4	Coarse-grained quartz sandstone as above.
	0	5	Missing.
1425			
	1	7	Fine-grained quartz sandstone, rounded grains, frosted, rather poorly sorted, white, cross-bedded, a few coarse grains appear to be aggregates of fine grains and therefore to have been derived from a previous sandstone?, weathered along fractures?, formed while material still loose?, few rusted spots, slightly calcareous at 11 in. pyrite at 1 ft., 6 in. H.M. # 27, 7 - 8 in.
	0	3	Coarse-grained quartz sandstone, well rounded grains, frosted, white.
	0	3	Fine-grained quartz sandstone as above.
	0	11	Coarse-grained quartz sandstone as above, rusted in spots, slightly calcareous at 7 in.
1422			
	0	2	Very-coarse-grained quartz sandstone, as above some of grains appear to be aggregates of fine grains as above, calcareous at 2 in.
	0	10	Coarse-grained quartz sandstone, well rounded grains, frosted, white.
	0	5	Fine-grained quartz sandstone, white, cross-bedded.
	0	3	Coarse-grained quartz sandstone, as above.
	0	4	Medium-grained quartz sandstone, as above.
1420			
	0	2	Fine-grained quartz sandstone, vitreous, white, well cemented by silica, breaks across the grains,
	0	3	Coarse-grained quartz sandstone, as above, well rounded grains, some frosted, cross-bedded.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	8	Fine-grained quartz sandstone, as above.
	0	7	Coarse-grained quartz sandstone, as above, rusted in spots, few coarse grains of a black mineral from 5 - 6 in. rather poorly cemented at 5 in., slightly calcareous from 5 - 7 in. several rusted spots, pyrite at 6 in.
	0	1	Fine-grained quartz sandstone, as above.
	0	1	Very coarse-grained quartz sandstone, rounded grains, frosted, white, rusted.
	0	1	Conglomerate, mainly quartz grains the size of granules, white, pyrite, slightly calcareous.
1416	2	1	Medium-grained quartz sandstone, rounded grains, white to light-grey, rusted in spots and veinlets, cross-bedded, well cemented, siliceous and minor calcareous cements, pyrite at 1 ft. 2 in.
	0	4	Missing.
	1	0	Coarse-grained quartz sandstone, white, cross bedded, some of grains appear to be aggregates of fine grains as above, slightly calcareous from 1 - 2 in, few pyrite crystals.
	0	2	Fine-grained quartz sandstone, white, cross-bedded, vitreous and occasionally breaks across the grain.
	0	3	Coarse-grained quartz sandstone, as above.
	0	6	Medium-grained quartz sandstone, as above, light-grey, pyrite at 4 in.
	0	7	Coarse-grained quartz sandstone, light-grey cross-bedded, occasionally rusted in spots.
	0	10	Medium-grained quartz sandstone, as above, white, few grains of a black mineral and one of pink garnet at 9 in.
	2	6	Missing.

Distance from bottom of hole Feet	Thickness Feet	Inches	
	0	7	Fine-grained quartz sandstone, white, cross-bedded, rusted in spots.
	2	3	Coarse-grained quartz sandstone, as above, poorly cemented in places. H.M. # 28, 1 ft. 0 - 1 in., rusted spots probably dolomite or pyrite.
1407			
	0	8	Fine-grained quartz - iron oxide sandstone, white to light-grey, cross-bedded, few minute black shale laminae with sericite flakes, a green mineral grain at 3 in., pyrite at 8 in., rusted in spots. T.S. # 13, 5 - 6 in.
	0	5	Coarse-grained quartz sandstone, white, cross-bedded, rusted in spots, poorly cemented.
	0	8	Fine-grained quartz sandstone, white, cross-bedded, few minute black laminae, rusted spots probably a carbonate or pyrite.
	0	10	Coarse-grained quartz sandstone, white, cross-bedded, poorly cemented.
	0	2	Fine-grained quartz sandstone, white, cross-bedded.
	0	2	Very coarse-grained quartz sandstone, as above, poorly cemented H.M. # 29, 1-2 in.
	0	4	Fine-grained quartz sandstone, white to light-grey, cross-bedded, rusted in spots.
	0	1	Missing.
	1	3	Coarse-grained quartz sandstone, as above, poorly cemented, in places has a fine-grained matrix, some of coarse grains appear to be aggregates of fine grains.
	1	1	Fine-grained quartz sandstone, white, cross-bedded, rusted in spots, few minute black laminae.
	0	11	Medium-grained quartz sandstone, as above, poorly cemented from - 0 - 5 in., few small nodules of pyrite.

Distance from bottom of hole Feet	Thickness Feet	 Inches	
	0	1	Very coarse-grained quartz sandstone, white, poorly cemented.
	0	6	Fine-grained quartz sandstone, light-grey cross-bedded, some minute black laminae, occasionally slightly calcareous, rusted in spots.
	1	1	Coarse-grained quartz sandstone, white to light-grey, cross-bedded, rusted in spots, occasionally poorly cemented, few granules and conglomeratic texture.
	1	2	Medium-grained quartz sandstone, white to light-grey, cross-bedded, some pyrite, few minute black laminae, occasionally poorly cemented.
	0	11	Coarse-grained quartz sandstone, white, cross-bedded, few black mineral grains.
	2	1	Fine-grained quartz sandstone, well sorted, white, cross-bedded, few black mineral grains, slightly calcareous at 1 ft. 10 in. H.M. # 30, at 1 ft. 8 - 9 in. is medium grained.
	1	0	Medium-grained quartz sandstone, white, cross-bedded, some pyrite.
	0	5	Missing.
	2	3	Coarse-grained quartz sandstone, as above, few greenish shale nodules to $\frac{1}{4}$ in. across, crystallized calcite cement from 1 ft. 9 - 11 in.
	0	7	Medium-grained quartz sandstone, white, cross-bedded, some pyrite.
	0	3	Coarse-grained quartz sandstone, as above.
	0	8	Fine-grained quartz sandstone, as above, few minute black laminae.
1388.5	0	11	Coarse-grained quartz sandstone, white, cross-bedded, rusted in spots, greenish tinge from 9 - 11 in.
	11	7	Missing.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	9	Coarse-grained quartz sandstone, white, cross-bedded, rusted and poorly cemented from 7 - 9 in.
	1	2	Fine-grained quartz sandstone, white to rusted, cross-bedded, poorly sorted.
	0	3	Medium-grained quartz sandstone, white, cross-bedded, few thin black laminae, some pyrite.
	0	2	Coarse-grained quartz sandstone, white, cross-bedded, poorly cemented.
	0	10	Fine-grained quartz sandstone, white, cross-bedded, rusted in bands and spots, some pyrite, few thin black laminae. H.M. # 31, 0 - 1 in.
	2	1	Coarse-grained quartz sandstone, white to light-grey, cross-bedded, rusted in spots, some pyrite, few minute black laminae, H.M. # 32, 1 - 2 in. T.S.# 42,0 - 1 in.
	0	2	Missing.
1371.5			
	0	2	Medium grained quartz sandstone, white, cross-bedded.
	1	0	Coarse-grained quartz sandstone, white, cross-bedded, some pyrite, tiny calcite veinlet at 5 in. poorly cemented from 7 in.- 1 ft.
	1	8	Medium-grained quartz sandstone, white, cross-bedded, rusted in spots, calcareous at 5 in., poorly cemented, few minute black laminae, few nodules to ¼ in. of pale green shale.
	2	1	Coarse-grained quartz sandstone, white, cross-bedded, rusted in spots, poorly cemented, pyrite from 1 ft. 10 - 11 in.
	0	4	Missing.
	2	2	Medium-grained quartz sandstone, some areas very coarse-grained as at 8 in., white to light-grey, cross-bedded, rusted in spots, calcareous at 1 in., pyrite laminae from 1 ft. 6 - 8 in. H.M. # 33, 8 - 9 in., T.S. # 14, 1 ft. 7-8 in.

Distance from bottom of hole Feet	Thickness Feet	Inches	
	0	5	Very coarse-grained quartz sandstone, as above, pyrite.
	0	7	Coarse-grained quartz sandstone, as above, minute black laminae, no pyrite.
	0	8	Fine-grained quartz sandstone, white, cross-bedded, rusted in spots.
	0	7	Medium-grained quartz sandstone, white.
	0	1	Missing.
	1	4	Coarse-grained quartz sandstone, as above, rusted in spots, poorly cemented, few small pebbles.
	0	2	Conglomerate, quartz grains as large as granules in a fine-grained matrix, white, pyrite at 1 in.
	0	8	Medium-grained quartz sandstone, light-grey cross-bedded, poorly cemented, rusted in spots, pyrite.
	0	4	Very coarse-grained quartz sandstone, as above, not rusted.
	0	3	Fine-grained quartz sandstone, white, pyrite.
1359	0	6	Missing.
	3	2	Coarse-grained quartz sandstone, white to light-grey, cross-bedded, poorly to well cemented, occasionally breaks across grains, rusted in spots, pyrite, some gypsum or talc and calcite veinlet ¼ in. wide from 2 ft. 4 - 6 in. H.M. # 34 1 ft. 3-4 in.
	0	11	Medium-grained quartz sandstone, white to brown, cross-bedded, rusted in spots.
	0	2	Very coarse-grained quartz sandstone, white.
	0	1	Fine-grained quartz sandstone, white.
	0	1	Coarse-grained quartz sandstone.
	9	2	Missing.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	9	Coarse-grained quartz sandstone, white, cross-bedded, poorly cemented.
	0	8	Medium-grained quartz sandstone, white, to buff, rusted, cross-bedded, few minute black laminae.
	0	3	Very coarse-grained quartz sandstone, white to light-grey, many granules, poorly cemented.
	0	5	Fine-grained quartz sandstone, white to light-grey, cross-bedded.
	0	2	Very coarse-grained quartz sandstone, white to light-grey, cross-bedded, poorly cemented.
1341	1	8	Medium-grained quartz sandstone, as above, rusted in spots, slightly calcareous from 8 - 10 in., few minute black laminae from 10 in. - 1 ft. 8 in. H.M. # 35, 11 - 12 in.
	1	1	Coarse-grained quartz sandstone, white to light-grey, cross-bedded, poorly to well cemented, rusted in spots.
	0	11	Fine-grained quartz sandstone white to light-grey, cross-bedded.
	0	4	Very coarse-grained quartz sandstone, white to light-grey, cross-bedded, few minute black laminae, some pyrite, few granules and pebbles.
	0	2	Coarse-grained quartz sandstone, as above, no pyrite, poorly cemented.
	0	10	Fine-grained quartz sandstone, as above, rusted in spots, light-grey bands to 1/4 in. thick.
	0	2	Missing.
1337.5			
	0	5	Coarse-grained quartz sandstone, white to light-grey, cross-bedded.
	0	10	Medium-grained quartz sandstone, as above, well cemented, siliceous cement.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	1	Very coarse-grained quartz sandstone, white, cross-bedded.
	0	2	Fine-grained quartz sandstone, as above.
	1	5	Coarse-grained quartz sandstone, white, to light-grey, rusted in spots, cross-bedded, granules from 4 - 10 in., occasionally well cemented. T.S. # 15, 5-6 in., H.M. #36, 8-9 in.
	0	7	Fine-grained quartz sandstone, white, cross-bedded.
1334			
	0	2	Missing.
	3	2	Coarse-grained quartz sandstone, white, rusted in spots, cross-bedded, few granules, poorly cemented.
	2	9	Fine-grained quartz sandstone, white to light-grey, pyrite.
	0	6	Coarse-grained quartz sandstone, white, cross-bedded.
	0	1	Missing.
	0	7	Fine-grained quartz sandstone, white, cross-bedded, slightly rusted from 0 - 2 in., slightly calcareous from 5 - 6 in.
	0	7	Medium-grained quartz sandstone, as above, slightly calcareous from 6 - 7 in.
	0	3	Coarse-grained quartz sandstone, light-grey, occasionally rusted, cross-bedded, H.M. # 37, 1 - 2 in.
	3	0	Fine-grained quartz sandstone, vitreous lustre from 2-3 ft., white, cross-bedded, few minute black shale laminae with sericite flakes.
	0	1	Coarse-grained quartz sandstone, vitreous lustre, white, cross-bedded, well cemented, siliceous cement.

Distance from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	1	Fine-grained quartz sandstone, as above.
	0	5	Missing.
	1	2	Medium-grained quartz sandstone, as above, rusted to red (hematite?) colour in places, few minute black shale laminae with sericite flakes.
1320	1	2	Fine-grained quartz sandstone, white to grey, cross-bedded, rusted in few places, slightly calcareous from 5 - 7 in.
	3	0	Missing.
	0	5	Fine-grained quartz sandstone, white, cross-bedded, band of dark-grey shale $\frac{1}{4}$ in. across at 3 in.
	0	2	Shale, dark-grey, cross-bedded, pyrite.
	0	5	Missing.
	1	8	Fine-grained quartz sandstone, rounded grains, white, cross-bedded, well cemented by silica, breaks across grains, few minute black laminae.
	0	1	Missing.
	0	10	Medium-grained quartz sandstone, subrounded grains, white, cross-bedded, well cemented by silica, breaks across grain, 2 thin shale laminae.
	2	1	Very fine-grained quartz sandstone, light-grey, inter-laminated with dark greyish-green shale, sulphide (pyrite?), rarely calcareous, some sericite, H.M. # 38, 8-9 in., T.S. # 16 (shale), 1 ft. 9 - 10 in.
	0	2	Shale, dark grey, cross-bedded and thinly laminated.
	0	7	Fine-grained quartz sandstone, light-grey, cross-bedded, well cemented by silica, breaks across grain, some dark-grey shale laminae, sulphide. H.M. # 39, 0 - 1 in.

Elevation from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	2	Shale, grey, interlaminated with very fine-grained cross-bedded quartz sandstone.
	1	0	Fine-grained quartz sandstone, white, cross-bedded, pyrite, calcareous from 10 - 12 in.
	1	5	Missing.
1308			
	4	7	Fine-grained quartz sandstone, subrounded grains, white to grey, well cemented by silica, breaks across grain, few thin dark-grey to black laminae, pyrite, tiny calcite veinlet from 7 in. - 2 ft., calcareous from 4 ft. 1 - 2 in., greatest induration at contact at 4 ft. 8 in.
	0	1	Missing.
	1	1	Alnoite, sill?, contact in the core is parallel to the bedding, fine to coarse-grained, dark-green to greenish-grey, calcareous.
	0	8	Very fine-grained sandstone and shale, reddish to grey, cross-bedded, laminated, in places appear cherty, and breaks across grain, pyrite. In places has fine grains in a shaly to very fine-grained matrix, T.S. # 17,0-1 in., T.S. #18,5-6 in.
	0	2	Medium-grained quartz sandstone, well cemented by silica, breaks across grain, pyrite.
	0	9	Alnoite, as above, fine-grained, calcite phenocrysts. T.S. # 19; 3 - 4 in.
	1	11	Fine-grained sandstone to quartz sandstone, white to light-grey and greyish-green, cross-bedded, few calcareous grey shale laminae from 0 - 15 in., few calcareous green shale nodules to ½ in. across from 1 ft. 5 - 11 in. T.S. # 20, 1 ft. 4 - 5 in., H.M. # 40, 1 ft. 5 - 6 in.
	0	9	Missing.
1298			
	0	4	Fine-grained quartz sandstone, white, cross-bedded, well cemented, pyrite, calcite crystallized in interstices.
	0	2	Very coarse-grained quartz sandstone, as above, well rounded and frosted grains.

Elevation from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	4	Fine-grained quartz sandstone, as above.
	0	6	Medium-grained quartz sandstone, as above.
	0	3	Very coarse-grained quartz sandstone, white, cross-bedded, poorly cemented, pyrite, calcareous at 1 in.
	0	5	Fine-grained quartz sandstone, as above, calcite crystallized in interstices.
	1	10	Medium-grained quartz sandstone, white, cross-bedded, calcareous.
	0	7	Fine-grained quartz sandstone, as above, rusted in spots, pyrite.
	0	5	Coarse-grained quartz sandstone, as above, not rusted.
	0	2	Missing.
1293			
	0	2	Very coarse-grained quartz sandstone, as above.
	1	5	Fine-grained quartz sandstone, as above.
	4	1	Missing.
	1	10	Fine-grained quartz sandstone, white to light-grey, cross-bedded, well cemented by silica, breaks across grain, pyrite, calcareous in places, few minute black laminae, H.M. # 41, 11 - 12 in.
	0	2	Coarse-grained quartz sandstone, light-grey, cross-bedded, slightly calcareous.
	1	3	Fine-grained quartz sandstone, white, cross-bedded, some minute black laminae, well cemented by silica, breaks across grain, calcareous in places, slightly rusted in places.
	0	1	Missing.
1284			
	0	2	Very coarse-grained quartz sandstone, light-grey, cross bedded.
	0	3	Medium-grained quartz sandstone, as above.

Elevation from bottom of hole	Thickness		
Feet	Feet -	Inches	
	0	4	Coarse-grained feldspathic sandstone, as above, well rounded grains, frosted, poorly cemented, calcareous, dark-grey shale lamina, ¼ in. thick at 4 in. H.M. # 42.
	1	7	Medium-grained quartz sandstone, white to light-grey, cross-bedded, calcareous, tiny calcite veinlet from 5 - 10 in.
	0	2	Coarse-grained quartz sandstone, white, cross-bedded, slightly calcareous.
	2	0	Fine-grained quartz sandstone, white, cross-bedded, rusted in spots, well cemented by silica, breaks across grain, tiny calcite veinlet from 4 - 9 in.
	0	6	Missing.
1279			
	4	10	Fine-grained quartz sandstone, white, cross-bedded, well cemented by silica, breaks across grain, calcareous from 1 ft. - 1 ft. 4 in., 3 ft. 0 - 3 in. and 3 ft. 7 in. -4ft. 2 in., few minute black laminae to 3 ft., grey shale laminae from 3 ft. 0 - 3 in., some gypsum and pyrite from 3 ft. 0 - 3 in. H.M. # 43, 2 - 3 in.
	0	2	Missing.
	0	8	Medium-grained quartz sandstone, white to grey, calcareous from 1 - 4 in., well cemented by silica, breaks across grain.
	0	5	Coarse-grained quartz sandstone, white, cross-bedded, well cemented by silica, breaks across grain, calcareous from 1 - 2 in., H.M. # 44, 1 - 2 in.
	1	1	Fine-grained quartz sandstone, as above, calcareous from 10 - 12 in.
	0	10	Medium-grained quartz sandstone, as above, not calcareous, minute black laminae and rusted from 0 - 6 in.
1271			
	0	7	Missing.

Elevation from bottom of hole	Thickness		
Feet	Feet	Inches	
	2	7	Fine-grained quartz sandstone, as above, calcareous from 2 - 5 in., some minute black shale laminae, pyrite in places. H.M. # 45, 1 ft. 9 - 10 in.
	1	6	Medium-grained quartz sandstone, white cross-bedded, well cemented by silica, breaks across grain, calcareous from 1 ft. 2 - 6 in. pyrite at 1 ft. 6 in.
	1	6	Fine-grained quartz sandstone, as above, slightly calcareous in places, tiny calcite veinlet from 9 - 10 in., pyrite from 0 - 4 in.
	6	10	Missing.
1258			
	0	6	Fine-grained quartz sandstone, white to yellow and reddish cross-bedded, well cemented by silica from 3 - 6 in., pyrite, some minute white clay laminae, calcareous in places.
	0	1	Missing.
	3	1	Vibetoide, sill?, dark greenish-grey, medium-grained, calcareous in places, T.S. # 22, 10 - 11 in.
	0	7	Very fine-grained sandstone, light-grey to yellowish and reddish, rock fairly soft and all mixed up, cross-bedded?, few small shale inclusions, few tiny quartz - calcite veinlets, some serpentine or chlorite developed, pyrite. T.S. # 23, 2 - 3 in.
	0	1	Medium-grained quartz sandstone, sandy colour, well cemented by silica.
	0	4	Missing.
1252	1	4	Fine-grained quartz sandstone, white, well cemented by silica, breaks across grain, calcareous in places, few tiny calcite veinlets, tiny white to grey soft rounded inclusions of clay mineral (kaolin?) to 1/5 in. across from 10 - 11 in. H.M. # 46, 1 ft. 3 - 4 in.
	2	1	Vibetoide, sill?, dark greyish - green, fine-grained, calcareous in places.
	3	9	Alnoite, sill?, grey, fine-grained, phenocrysts of calcite and biotite to 6 m.m. diameter. T.S. # 24, 2 ft. 2-3 in.

Elevation from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	9	Fine-grained sandstone, light-greenish, calcareous from 0 - 1 in., pale-buff laminae of shale, pyrite disseminated and in tiny veinlets.
	1	3	Shale, grey, small inclusions of white quartz sandstone, much clay mineral, H.M. # 47, 7 - 8 in.
	0	1	Very fine-grained quartz sandstone, grey, appears aphanitic - chert?.
	0	7	Missing.
	1	8	Shale, grey to greenish, cross-bedded in places, inclusions of very fine-grained white quartz sandstone, pyrite, biotite flakes, calcareous in places.
	0	3	Medium-grained sandstone, greenish-grey, very well cemented by silica, breaks across grain, pyrite.
	0	2	Shale, green, sandstone inclusions, slightly calcareous, siliceous, silt size. T.S. # 25, 1 - 2 in.
	0	7	Medium-grained quartz sandstone, white, laminae of green shale, poorly cemented, calcareous from 3 - 7 in. H.M. # 48, 6 - 7 in.
	2	6	Fine-grained quartz sandstone, pale green, cross-bedded, poorly cemented, white calcite crystallized in interstices at several places, pyrite.
	0	4	Missing
1238			
	1	6	Very fine-grained quartz sandstone, white to pale-green, cross-bedded with minute black laminae, rusted and calcareous in places, pyrite.
	0	3	Missing.
	5	0	Fine-grained quartz sandstone, white to pale-green or rusted, cross-bedded, few thin black shale laminae, pink garnet grains at 7 in., few grains of black mineral, poorly cemented, calcareous in places, calcite crystallized in interstices at 4 ft. 8 in.

Elevation from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	2	Coarse-grained calcareous quartz sandstone, fine-grained matrix, white cross-bedded, poorly cemented, rusted in places, pyrite. H.M. # 49, 1-2 in.
	0	1	Missing.
1231			
	6	5	Fine-grained quartz sandstone, white to rusted and occasionally pale-green, cross-bedded, some minute black laminae and areas of pale-green clay mineral, poorly cemented, calcareous in places, pyrite, some sulphide is a deeper yellow-chalcopyrite?.
	0	1	Coarse-grained quartz sandstone, fine-grained matrix, pale green, cross-bedded.
	0	3	Very fine-grained quartz sandstone, white, cross-bedded, calcareous, pyrite.
	0	1	Shale, grey, finely cross-bedded.
	0	5	Fine-grained quartz sandstone, white, cross-bedded, well cemented by silica, breaks across grain, pyrite.
	0	9	Medium-grained quartz sandstone, white, cross-bedded, pyrite.
1223			
	3	5	Fine-grained quartz sandstone, white to occasionally light-grey, cross-bedded, pyrite, sugary texture in places. H.M. # 50, 6 - 7 in.
	0	2	Shale, grey, cross-bedded.
	0	1	Missing.
	3	1	Fine-grained quartz sandstone, white to rusted, cross-bedded, rather poorly cemented and sorted in places, pyrite, slightly calcareous at 2 ft.
	1	0	Very fine-grained quartz sandstone, white, occasionally cross-bedded.
	0	8	Fine-grained quartz sandstone, as above, pyrite.
	0	2	Shale, grey.

Elevation from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	4	Very fine-grained quartz sandstone, as above.
1205	9	1	Fine-grained quartz sandstone, white, pale-green from 2 ft. 0 - 3 in., cross-bedded, locally medium-coarse-grained, sugary texture, rather poorly cemented in several places, pyrite, few feldspar grains weathered white. H.M. # 51, 2 ft. 2 - 3 in.
	0	3	Medium-grained quartz sandstone, white to rusted, few rounded grains of a black mineral.
	0	1	Very fine-grained quartz sandstone, light-grey, cross-bedded, few white feldspar grains. T.S. # 26, 0 - 1 in.
	0	8	Fine-grained quartz sandstone, as above.
	0	4	Coarse-grained quartz sandstone, grey, as above.
	0	7	Fine-grained quartz sandstone, light-grey, as above.
	0	1	Missing.
1203	3	1	Fine-grained quartz sandstone, white, cross-bedded, pyrite, few small nodules of clay (kaolinite?) mineral from 2 ft. 0 - 2 in.

Elevation from bottom of hole	Thickness		
Feet	Feet	Inches	
	0	3	Coarse-grained quartz sandstone, white, cross-bedded, pyrite.
	0	2	Very coarse-grained quartz sandstone, white to rusted, pyrite.
	0	8	Medium-grained quartz sandstone, white, cross-bedded, poorly cemented from 0 - 2 in. H.M. # 52, 7 - 8 in.
	0	5	Fine-grained quartz sandstone, white to light-grey, cross-bedded.
	0	3	Very fine-grained quartz sandstone, grey, cross-bedded, some coarse grains.
	6	2	Missing.
1192			

Total - 504 ft.

Notes:

(1) The minute black laminae are mainly black shale. A few of them appear to be composed of heavy minerals, others of weathered pyrite and some may contain hydrocarbons.

(2) The black mineral grains are probably mainly tourmaline grains with a few magnetite, ilmenite and rutile grains.

RESUME OF FROSTING OF QUARTZ GRAINS, etc.

Distance from bottom of hole Feet	Thickness FEET	
1696 - 1694	2	Grains mainly frosted, generally poor sorting.
1694 - 1658	36	Missing.
1658 - 1603	55	Grains mainly vitreous due to authigenic crystallization, generally well sorted.
1603 - 1578	25	As above, considerable number of frosted grains. The vitreous grains are so mainly by authigenic crystallization; but some have a vitreous to subvitreous lustre which is believed to be original.
1578 - 1503	75	Grains mainly vitreous due to authigenic crystallization, generally well sorted.
1503 - 1468	35	Grains practically all vitreous due to authigenic crystallization, odd grain still shows frosting, well sorted.
1468 - 1435	33	Grains mainly frosted, generally well sorted, some grains vitreous to subvitreous due to authigenic crystallization.
1435 - 1408	27	Grains mainly frosted, considerable vitreous, rather poorly sorted and cemented.
1408 - 1337.5	70.5	As above, only a few areas containing vitreous grains.
1337.5-1308	29.5	Grains mainly vitreous, due to authigenic crystallization, considerable number of frosted grains, rather poorly sorted, poorly cemented in a few places.
1308 - 1279	29	Mainly frosted grains in vicinity of alnoite sill?, the sandstone is vitreous due to authigenic crystallization.
1279 - 1248	31	Grains mainly vitreous due to authigenic crystallization, alnoite and vibetoide sills?. present.

Distance from bottom of hole	Thickness	
Feet	FEET	
1248 - 1192	56	Grains mainly frosted, considerable number of vitreous to subvitreous grains due to authigenic crystallization.
Total	504 ft.	

	Mainly Frosted	Mainly Vitreous (1)	Missing	Total
Feet	217.5	250.5	36	504

(1) Due principally to authigenic crystallization.

Map No. 2.

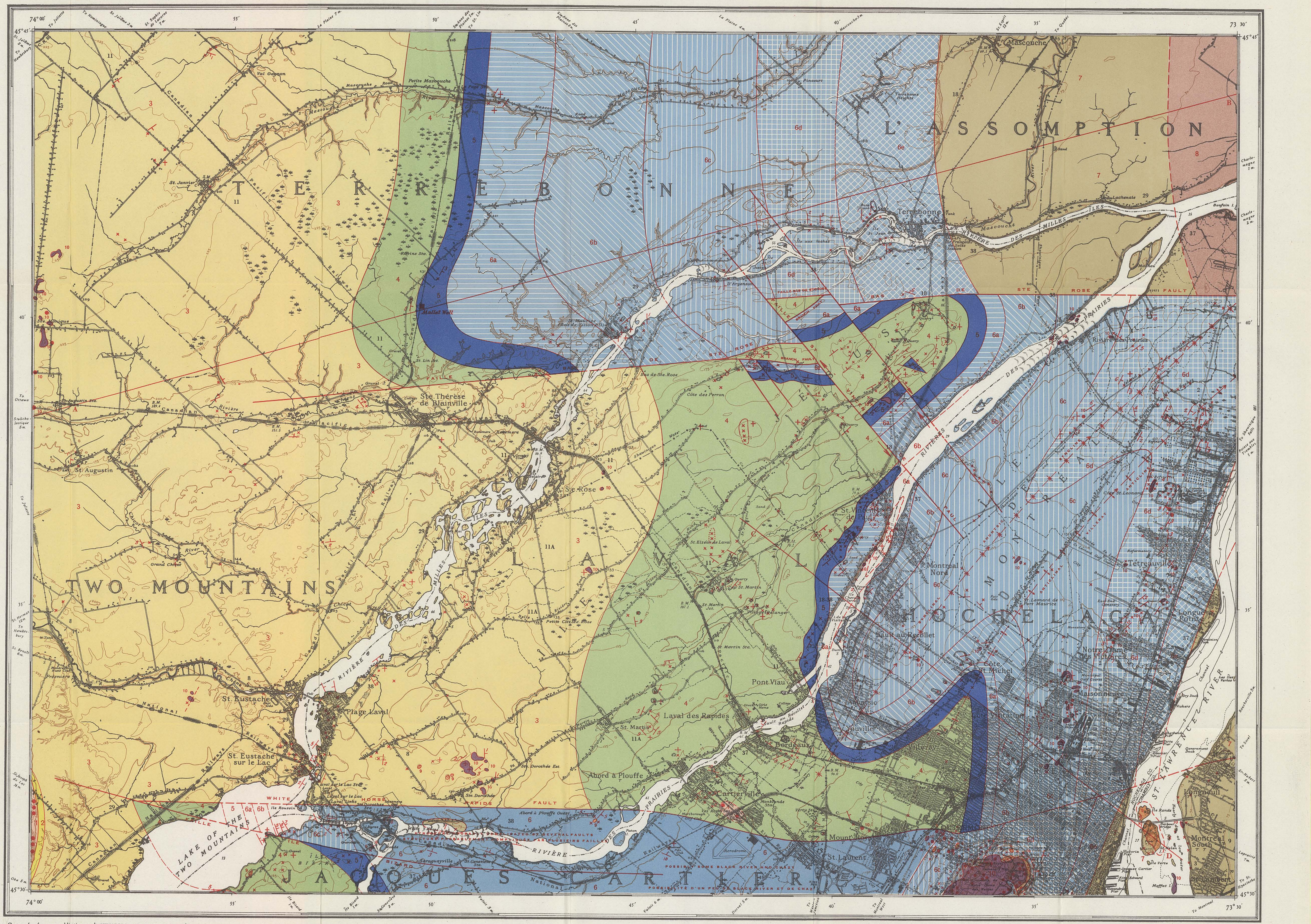
Laval Map Sheet, Que.

(Que. Dept. Mines Map No. 800)

PROVINCE DE QUÉBEC, CANADA
MINISTÈRE DES MINES
L'honorable C. D. FRENCH, ministre — A. O. DUFRESNE, sous-ministre

1950

PROVINCE OF QUEBEC, CANADA
DEPARTMENT OF MINES
Honourable C. D. FRENCH, Minister — A. O. DUFRESNE, Deputy Minister



LÉGENDE — LEGEND

10	Monteregian intrusives / *Roches intrusives Montérégiennes*
9	Breccia / *Brèches*
8	Lorraine / *Lorraine*
7	Utica shale / *Argile schisteuse d'Utica*
6e	Terrebonne / *Terrebonne*
6d	Tétreauville / *Tétreauville*
6c	Rosemount / *Rosemount*
6b	St-Michel / *St-Michel*
6a	Mile End / *Mile End*
6	Undifferentiated / *Non-différencié*
5	Black River Group / *Groupe Black River*
4	Chazy limestone / *Calcaire de Chazy*
3	Beekmantown dolomite / *Dolomie du Beekmantown*
2	Potsdam sandstone / *Grès de Potsdam*
1	Precambrian / *Précambrien*

CALCAIRE DE TRENTON — TRENTON LIMESTONE (6–6e)

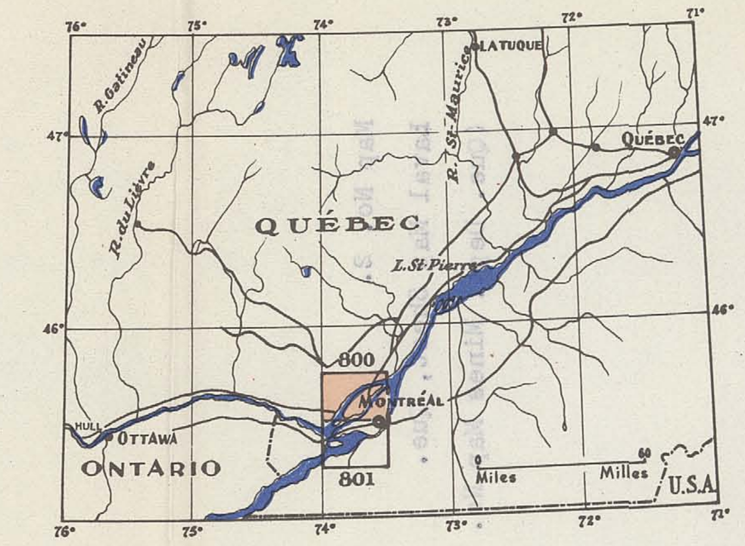
(a) (b) Strike and dip of bedding: (a) inclined, (b) horizontal
Direction et pendage des couches: (a) incliné, (b) horizontal

(a) (b) Outcrops or groups of outcrops of formations: (a) 2 to 8, (b) 1, 9, 10
Affleurements ou groupes d'affleurements des formations: (a) 2 à 8, (b) 1, 9, 10

Fault
Faille

Geological boundary
Contact Géologique

(a) (b) Axis and plunge: (a) of anticline, (b) of syncline
Axe et plongée: (a) d'anticlinal, (b) de synclinal



Carte préparée pour publication par le SERVICE DE LA CARTOGRAPHIE DU MINISTÈRE DES MINES pour accompagner le Rapport Géologique No. 46, Région de Montréal.

GÉOLOGIE:—
T. H. CLARK, 1938 - 39 - 40 - 41
Avec quelques modifications jusqu'à 1949.

TOPOGRAPHIE:—
Plans topographiques fournis par le Ministère de la Défense Nationale, Ottawa.

REFERENCE

Main Highway (wide) — Route principale (large) — 38
Other roads — Autres chemins — Wagon / de voiture
Path — Sentier
Railways: double track / single track / along road — Chemin de fer: voie double / voie unique / sur le chemin — Principal station / Gare; Tunnel; Station; Culvert / Ponceau; Embankment / Remblai; Cutting / Deblai
Electric power line — Ligne d'énergie électrique
Post office — Bureau de poste — P
Telephone trunk route — Ligne principale, téléphonique
Telegraph office — Bureau de télégraphe — T
Telephone exchange — Bureau de téléphone — T
Boundary: provincial — Limite de province
,, county — ,, comté

LAVAL
QUEBEC

Scale 1 mile to 1 inch or 1: 63,360 — Échelle 1 mille au pouce 1: 63,360

Miles / Milles; Yards / Verges — 1,000 0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 8,000 9,000

Contour interval 25 Feet
All Elevations in Feet above Mean Sea Level

Équidistance des courbes de niveau 25 pieds
Les hauteurs sont données en pieds au-dessus du niveau moyen de la mer

No. 800

REFERENCE

Church with spire — Église, avec clocher (centre of circle is centre of spire) (le centre du cercle est le centre du clocher)
,, ,, tower — ,, ,, tour
,, without either — ,, sans clocher ou tour
School — École — S
House — Maison
Barn — Grange
Saw mill — Scierie — S.M.
Grist mill — Minotière — G.M.
Cheese factory — Fromagerie — C.F.
Other mill or factory — Autre moulin ou usine
Cemetery — Cimetière — C
Quarry — Carrière
Sand or gravel pit — Sablière ou Gravière
Altitudes (in feet) — Altitudes (en pieds) — 179
Bench marks — Repère d'altitude — B.M. 875
Triangulation station — Repère de triangulation
Survey monument — Borne — 924
Contours: elevation / depression — Courbes de niveau: d'élévation / de dépression — 125, 100, 125
Rapids / Rapides; Bridge / Pont; Swing bridge / Pont tournant; Dam / Barrage; Ford / Gué — (C) cement (S) stone (I or W) iron or wood — (I ou W) en fer ou en bois (C) en béton (S) en pierre
Ferry / Traverse; Canal; Locks / Écluses; Marsh / Marais; Cliff / Falaise; Lighthouse / Phare; Submarine contours (in fathoms) / Courbes bathymétriques (en brasses); W.L. 50

Map prepared for publication by the MAPS AND DRAFTING BRANCH OF DEPARTMENT OF MINES to accompany Geological Report No. 46, Montreal Area.

GEOLOGY:—
T. H. CLARK, 1938 - 39 - 40 - 41
with some modifications to 1949.

TOPOGRAPHY:—
Topographic plans supplied by the Department of National Defence, Ottawa.