A PETROGRAPHIC STUDY OF VARIOUS SAND HORIZONS OF MANITOBA AND EASTERN SASKATCHEWAN.

BY

GARNET C. McCARTNEY B.A., B.Sc.

#################

Presented in partial fulfillment of the requirements for the Master of Science degree in the University of Manitoba.

April 1928.

ACKNOWLEDGMENT

The writer is indebted to the National Research Council of Canada for financial assistance in carrying on this research.

Contents.

I. Introduction

The science of petrography has been and continues to be concerned mainly with the study of thin rock sections. Although first applied to sedimentary rocks the science soon became more important in igneous and metamorphic rock geology. In recent years however, the realization that important results can also be obtained from a microscopic analysis of sediments has turned the attention of many petrologists to this branch of the science. Since the petrographic study of sediments, particularly sands is concerned mainly with the heavy minerals occurring in the sand, it is necessary, first, to concentrate and to separate this part of the sand from the lighter part; the study may be carried on with sections of the heavy minerals but usually the grains are examined in their natural condition. The object of the study is the identification and the examination of the properties and interrelations of the minerals.

The rejuvenation of this science is due mainly to British workers Ref. (2) (17)*but it is also being carried on by a few American petrologists. The interest in the petrography of sediments is increased as a result of its application to oil field development. In many oil fields the scarcity of fossils in the strata makes it very difficult to correlate one formation with another; this is especially the case with subterranean strata; in many cases of this kind correlation can only be made from the evidence afforded by samples from wells. A thorough examination of the heavy minerals has shown that it is possible to correlate the formations encountered in one drill hole with those in another, provided correlations are attempted only in limited areas.(1). Further interest is found in the petrography of sediments since it furnishes very valuable data in regard to the interpretation of their origin and geological history.

*Numbers in brackets refer to the bibliography given at end of thesis.

11. Nature of Research and the Horizons Studied.

The work consists of a study of the physical characters of sands from different stratigraphical horizons of the Middle West; the study may be divided conveniently into two main parts.

A. The Petrographic Analysis of the Sands

(1) Heavy Mineral Content

(2) Shape and Surface Features of the Sand Grains

B. The determination of a rapid method for quantitatively measuring the roundness of sand grains.

The sand horizons studied are listed below in their stratigraphical position in the geological column.

Grand Beach Sand	- - - - - - - -	Pleistocene
Smith Siding	- - - - - - - - - -	"
Beausejour	- - - - - - - - - - -	"
Melbourne	- - - - - - - - - - - -	"
Estevan Sandstone	- - - - - - -	Eocene - Base of Tertiary
Boissevain "	- - - - - - -	Fox Hill - Upper Cretaceous
Dakota "	- - - - - - -	Lowest part of " " of Manitoba
Silurian "	- - - - - - -	Base of Silurian of Manitoba
Winnipeg "	- - - - - - -	Lower Ordovician of Manitoba

111. Methods Employed and Treatment of Material.

The sand horizons considered in this investigation are nearly all sufficiently unconsolidated, that it is possible to screen the material into the various grade sizes without preliminary treatment. The Tyler standard screens are used for grading the material; the grading being accomplished by placing the screens in a mechanical shaker operated for a period of fifteen minutes. The heavy mineral separation is made from the sand after the material is screened; the sand being thoroughly washed in water or dilute acid to remove any cementing materials which may interfere with the separation. A weighed portion of the sand, about five grams is found to be sufficient for making a separation; as a rule only the 150 and 200 grade sizes are found to be satisfactory for separating. The heavy minerals are separated from the light by means of the heavy solution, bromoform; it has a specific gravity of about 2.9 and will thus separate minerals with a specific gravity greater than that from those specific gravity is less; in this way the heavy minerals are separated from the quartz and feldspar of the light crop.

The separation is made in a wide funnel with a large stem, attached to which is a piece of rubber tubing with a pinch-cock grip. The bromoform is poured into the funnel and then the sand is added to it; after an interval of about half an hour, with frequent stirring during that time, the heavy minerals with part of the bromoform solution are drawn off by opening the pinch-cock. The bromoform is recovered from the heavy and the light residues by placing each in separate filters; the bromoform which remains in the capillary spaces between the grains is recovered by a final washing with alcohol; it then is removed from the alcohol by washing the solution with water. The heavy mineral crop is dried and weighed and the percentage of heavy mineral in the sand is calculated. A portion of each residue is mounted on a slide with Canada Balsam for microscopic examination and another portion of each is preserved for microscopic examination without being mounted.

The mounted portion of the heavy mineral residue is examined with the object of first, the identification of the minerals, second, the recording of any particular characteristic features of the minerals, third, the estimation of the relative abundance of any of the minerals.

The mounted portion of the light residue is examined mainly to determine the amount of feldspar in the sand and its degree of alteration.

The unmounted heavy mineral portion is used for Refractive Index tests and for determining the magnetic properties of certain minerals.

The unmounted light portion is examined to determine the shape and surface features of the grains.

In the identification of the minerals only simple petrographic methods are employed, e.g. the determination of color, shape, fracture, parting, cleavage, abrasion, relative refractive index, lustre, pleochroism, isotropism or anisotropism, birefringence, extinction, interference figure, and sign. The relative abundance or scarcity of each species of heavy mineral present in a sand is recorded on a percentage basis and this is obtained by counting the number of grains in a certain number of fields of the microscope and from this calculating the average; in this way it is possible to refer the mineral to one of the following groups:

Dominant - - - - - - - - over 50%

Abundant - - - - - - - - 25 - 50%

Common - - - - - - - - - - 10 - 25%

Present - - - - - - - - 5 - 10%

Rare - - - - - - - - - - - 1 - 5%

Trace - - - - - - - - - - less than 1%

IV. Petrographic Examination of the Sands in General.

(1) Detailed Description of the Heavy Minerals Identified.

Anatase - occurs as small tabular or square shaped grains always showing a considerable degree of rounding. Cleavage is sometimes evident in two directions. Color is either clear yellow or brownish yellow. The mineral is not common.

Apatite - prismatic, clear, colorless grains and somewhat rounded gray pitted grains occur. Well defined pyramidal endings usually cap the prismatic grains and the prism edges can sometimes be seen. A few pleochroic grains from yellow to colorless have been noted; inclusions arranged parallel to the principal axis are common; sometimes these inclusions when minute give the centre of the grain a very dark appearance. Basal six sided isotropic sections are sometimes seen. The mineral is very similar to zircon but differs from that mineral in having lower R.I. and lower polarization colors.

Biotite - grains are irregular, tabular or six sided in shape. The color is dark from dark green to brown or brownish black. Pleochroism is very seldom evident. The mineral occurs more frequently in the coarse grade sizes.

Epidote - grains are always irregular in shape. The color is very characteristic being a deep yellowish green; the distinct pleochroism from yellowish green to green is the best guide in identifying the mineral.

Garnet - irregular shape, often appears freshly broken giving a conchoidal fracture. Grains are usually colorless but pink colored grains are found in some sands. The surface of the grains is either smooth or very rough giving a pebbly appearance. It is always isotropic. Though seldom abundant the mineral is present in every horizon.

Glauconite - is not a common mineral except in certain parts of the Dakota sandstone; grains are all quite rounded and vary in color from shades of green, olive to brownish yellow; they are usually crowded with small dark inclusions, probably iron. The mineral is opaque.

Glaucophane - grains are very irregular in shape and in some, distinct cleavage is evident in one direction; the ends of the grains are commonly very uneven, consisting of a series of fine projections. The pleochroism is the outstanding feature of the grains, it ranges from a rose color in the horizontal position to blue in the vertical. The extinction angle is about five degrees.

Hematite - irregular shape, opaque and gives a reddish brown color in reflected light.

Hornblende - generally occurs in prismatic grains with irregular broken ends. Cleavage is usually evident especially in cross - sections, where the two cleavages intersect at 124 degrees. Color varies from dark green to brownish green; some grains are very nearly colorless, giving a bleached appearance to the mineral. Pleochroism is usually evident in the dark colored varieties.

Ilmenite - is very like magnetite in general appearance but it is differentiated from that mineral by (a) its characteristic development of good crystal faces, the grains being either three or six sided (b) it is not attracted by the magnetized needle (c) a crimson color is sometimes noticed on the very thin edges of the grains.

Kyanite - elongated prismatic grains with irregular terminations are common. Well defined cleavage in two directions is typical. Grains are colorless, or grayish blue with pearly lustre. Pleochroism is absent.

Limonite - occurs in irregular, amorphous aggregates. Dull brown color in reflected light.

Magnetite - the most consistent occurring mineral, is found in well rounded and in irregular shaped grains; occasionally well crystallized octahedron shaped grains are found. A bluish metallic lustre is very characteristic.

Monazite - this mineral always appears well rounded and always shows a very high refractive index. The citron yellow color of the grains is distinctive; most of the grains are pleochroic from citron yellow to a greenish yellow.

Muscovite - occurs as cleavage flakes irregular in outline. Colorless grains with low polarization colors are usual. Inclusions are common in some grains; the grains being sometimes nearly filled with fine radiating needle-like inclusions, probably rutile.

Pyrites - occurs in well developed crystals and in clusters of small crystals. The mineral is brass yellow in color and is very common in some horizons, being especially abundant in samples taken from bore-holes. It sometimes occurs surrounded by a cluster of quartz or muscovite grains, thus causing these minerals to be carried down into the heavy residue.

Rutile - is dark foxy-red and yellow in color; the grains are usually dull, rounded or irregular but occasionally bright clear prismatic grains with distinct cleavage are seen. The mineral is present in practically every separation but it is never abundant.

Staurolite - occurs in irregular shapes with very sharp reentrant angles and shown a characteristic hackly fracture. The color ranges from nearly colorless, yellow to a light brown. Inclusions are common. Pleochroism is often quite pronounced from brown to yellow. Polarization colors are always high, reds and blues.

Titanite - (Sphene) grains are prismatic and irregular in shape; an occasional diamond shaped grain with good cleavage and very high polarization colors is seen. Both clear yellow and dark brown grains are present, the yellow grains yield good biaxial figures with colored isogyres very prominent, the dark brown grains do not give good figures but do show well defined cleavage at right angles, they also show distinct pleochroism.

Topaz - Irregular and prismatic grains occur. Good cleavage is sometimes seen in two directions. A few grains are vertically striated. Inclusions are quite common in some grains and in part at least appear to be fluid. The mineral is generally colorless but sometimes a faint pleochroism is evident.

Tourmaline - the common shapes are prismatic, grains with striations parallel with the length, well rounded grains and irregular angular grains occur. Inclusions are common. The color range is considerable, purple, mauve, very light brown, brown, brownish black, light and dark blue, bluish gray, green, rose, and olive colored grains have been observed. Pleochroism is very marked in some of the brown and mauve varieties but is noticeably absent in the dark blue variety.

Zircon - occurs as round grains and as prismatic grains with the pyramidal ends generally quite rounded. Clear colorless grains are not nearly as common as the dusky yellow to brown colored ones. Inclusions are common and quite often are arranged in a zonal fashion. A very few slightly pleochroic yellow grains have been noted. Rose to purple colored grains occur in certain horizons.

The following minerals are found in the light residue.

Feldspar -

Orthoclase - is common in some sands. Clear prismatic grains showing Carlsbad twinning are usual.

Plagioclase - occurs along with the orthoclase and is characterized by irregular outline, presence of twin lamellae, and by superficial decomposition. Nearly all the feldspar grains are clouded with alteration products.

Calcite - occurs partly as cleavage rhombs and partly irregular in shape. Pale shades of yellow, colorless and brown grains occur, the brown color evidently being due to impurity. This mineral is common in some sands and if the sample is not treated with acid part of it comes down into the heavy residue.

Quartz - is the predominating mineral, making up practically all of the light residue. Grains are nearly all clear and colorless, and many of them contain inclusions either fluid, bubble or needle-like, the last type probably being rutile needles.

(2) Detailed Description of the Shape and Surface Features of Sand Grains.

The general shape of the sand grains is determined by microscopic examination; by this means the grains can only be designated as "well-rounded", "rounded", "subangular", or "angular". However, the method is of considerable value in giving a relative idea of the extent of rounding or of angularity of the grains.

An examination of the surface features of the grains shows whether they appear clear and fresh or dull and coated with cementing materials. In addition to these surface features of grains there is another greatly more important; the feature referred to is the frosted and pitted appearance of many sands; this feature can be seen under the low power of an ordinary microscope. The surface of the grains show an evenly distributed series of very fine little holes or pits and it is this series of closely set pits that gives the frosted or the ground glass appearance to the grains. In addition to the frosting there is often seen comparatively large indentations of irregular shape; these larger pits when present partly obscure the finer ones. Where the pitting is very minute the high power objective of the microscope is used and with either the low or the high power the frosting and pitting is observed with all reflected light and part of the transmitted light cut off.

The frosted and pitted character of sand grains is dealt with here rather fully because this feature is considered to be direct evidence that sometime during the history of the sand it has been subjected to long continued wind action. The result of the aeolian activity is this frosting and pitting which is produced by actual abrasion; the pits on the grains being the result of the grains striking any hard rock objects in the path of the sand and the result of striking one another. With long continued sifting to and fro of the sand, the striking of the grains one against the other is considered to be the main factor in producing the phenomenon described. Ref. (7)

V. The Petrographic Analyses of the Heavy Mineral Content and the Shape and Surface Features of the Sands Considered in this Investigation.

1. The Winnipeg Sandstone

The Winnipeg sandstone is the basal section of the Ordovician of Manitoba; it is a partially consolidated sand resting directly on the PreCambrian surface. Ref. (29)

The heavy mineral separation of this sand reveals only a very small crop; varying from a trace to .11%. The number of different minerals is very limited, only the following being noted.

Dominant - Zircon
Common - Tourmaline, Magnetite
Present - Staurolite
Rare - Rutile
Trace - Garnet, Hornblende

The minerals are exceedingly well rounded, the tourmaline and magnetite particalarly.. The zircon grains are prismatic with well rounded ends and are nearly all a dusky yellow or brown color. The tourmaline varies in color from brown to olive, blue or violet and inclusions are not common. The other minerals mentioned above are very insignificant. In two oil well samples of the Winnipeg sandstone the heavy mineral residue in each case is flooded with pyrite. The general rounding of the heavy minerals of this sand is readily seen in Plate 1.

The shape of the Winnipeg sandstone grains may be classed as "well-rounded"; in the coarse grade sizes i.e. from 20 to 48 mesh many of the grains are very nearly perfect spheres, in the fine grade sizes from 65 to 200 mesh the grains are "subangular" to "angular". The "well-rounded" grains occur in every grade size but the percentage of "angular" grains in relation to the round ones gradually increases as the finest grade is approached.

The surface features of this sand shows the development of frosting and pitting to a high degree. The large grains show very clearly the frosting and pitting but the small grains only show the frosting. Many of the pits on the large grains are quite deep into the grain and are triangular or roughly horse-shoe shaped. Plate 11. shows the pitted character of a typical Winnipeg sand grain.

2. The Silurian Sandstone

This formation occurs at Stonewall, Man., and is considered to be the transition series from the Ordovician to the Silurian systems. Ref.(29) The rock is over 75% limestone and the remainder is sand, distributed through the limestone.

The heavy mineral content and the shape and surface features of this sand is very similar to the Winnipeg sandstone. The same minerals are found although only as a trace and the degree of rounding, frosting and pitting parallels the Ordovician sandstone in every way. The only difference between this sand and the last described is the high calcium carbonate content.

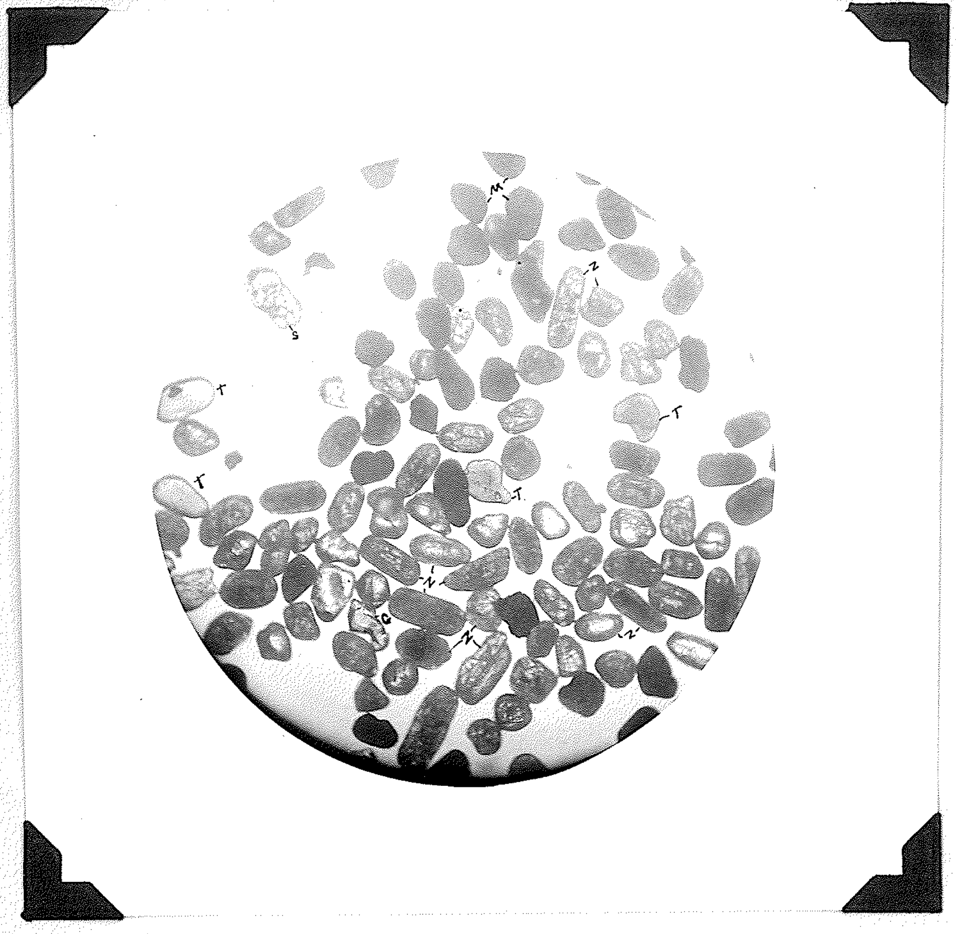


PLATE I

Dominant - Zircon
Common - Tourmaline, Magnetite
Present - Staurolite
Rare - Rutile
Trace - Garnet, Hornblende

PLATE II

Frosting and Pitting of a Winnipeg Sandstone Grain.

3. The Dakota Sandstone

The Dakota sandstone is the oldest formation of the upper Cretaceous of Manitoba; it is a marine deposit resting directly on the eroded surface of the Devonian rocks. Ref. (29).

The percentage of heavy minerals in this sand is fairly high, varying from .51 - .97%. There is present a much greater variety of minerals than in the Winnipeg sandstone.

Abundant - Magnetite, Glauconite
Common - Staurolite, Apatite, Tourmaline, Pyrite, Muscovite
Present - Kyanite, Ilmenite, Limonite, Biotite, Zircon
Rare - Hornblende, Anatase, Garnet
Trace - Titanite, Rutile

The general description of the minerals given previously applies to those above. Plates 111, 1V and V are all taken from Dakota samples and they show in a graphic manner the variations occurring in the heavy minerals taken from different geographical and stratigraphical positions in the same horizon; these three samples are from different grade sizes and this is an additional factor that helps to explain the difference in mineral assemblage. The sum total of the minerals in different separations varies little except in the case of the flood of a certain mineral, e.g. glauconite in the one separation. It is noticed in Plate 111 the relative abundance of apatite; the flood of this mineral occurs in a very fine grade size, being finer than 200 mesh. Plate 1V shows clearly typical grains of kyanite, the cleavage so pronounced in the picture is very helpful in identifying the mineral. The heavy minerals are all quite angular and many of them appear to be freshly broken, e.g. the large garnet grain in Plate 1V which shows clearly the conchoidal fracture lines typical of freshly broken surfaces of that mineral.

The Dakota sandstone is very angular, many of the quartz grains show very sharp corners and edges. The surfaces of most of the grains appear very clear as though the grains had been freshly broken. In addition there are present many grains which are well rounded. These

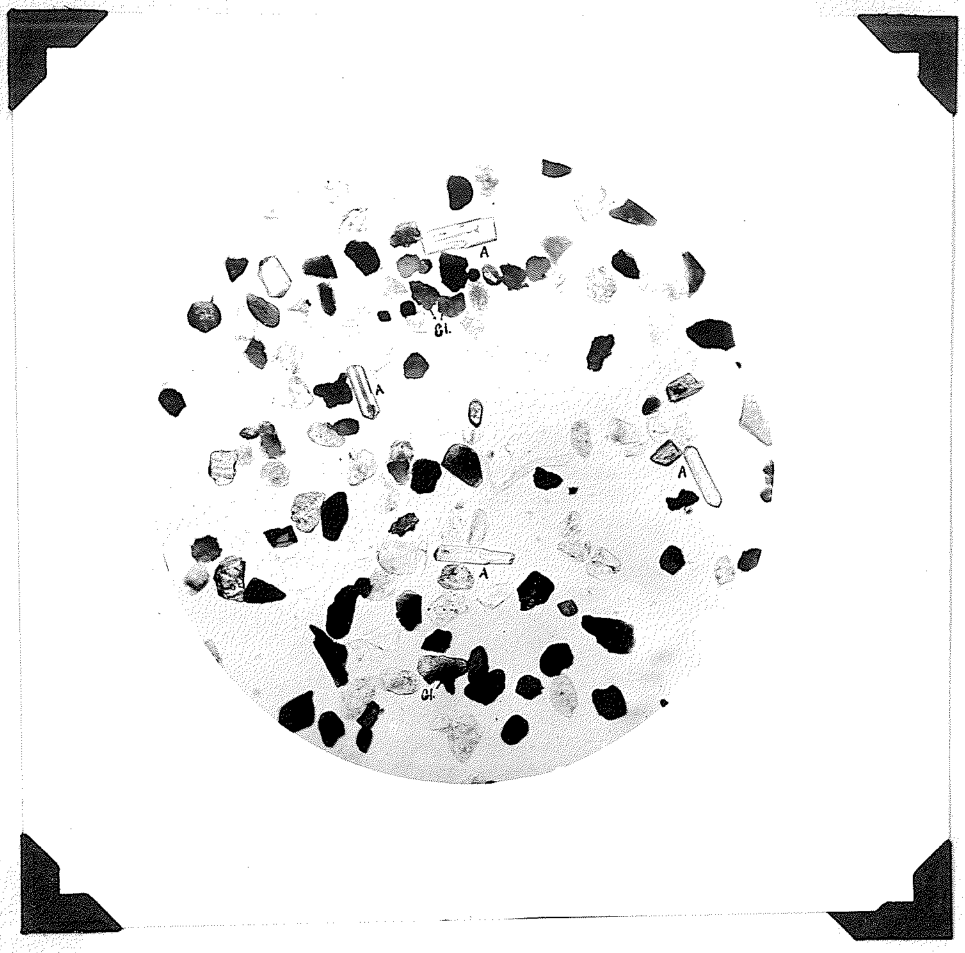


PLATE III

Dominant	-
Abundant	- Glauconite
Common	- Apatite, Magnetite, Biotite, Muscovite, Pyrite
Present	- Tourmaline
Rare	- Staurolite, Rutile, Zircon, Hornblende
Trace	- Kyanite, Garnet

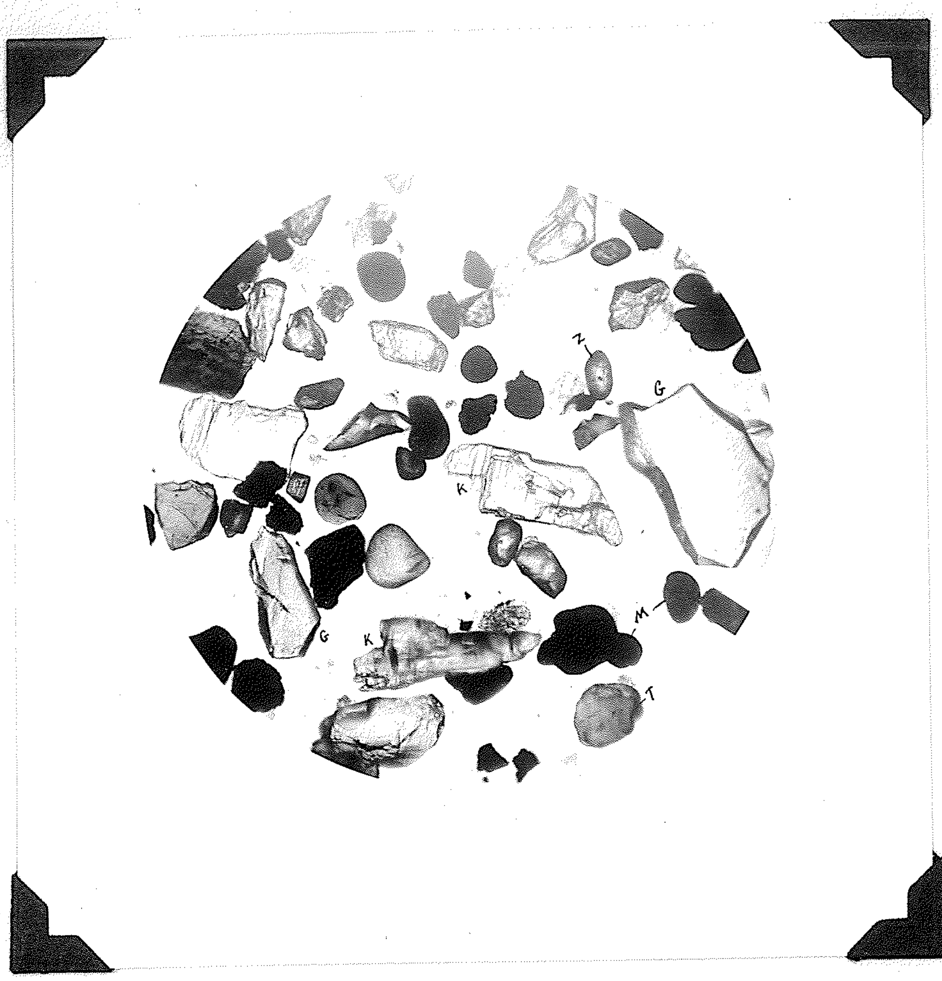


PLATE IV

Dominant -
Abundant - Kyanite, Garnet
Common - Staurolite, Magnetite, Muscovite
Present - Rutile
Rare - Tourmaline, Zircon
Trace -

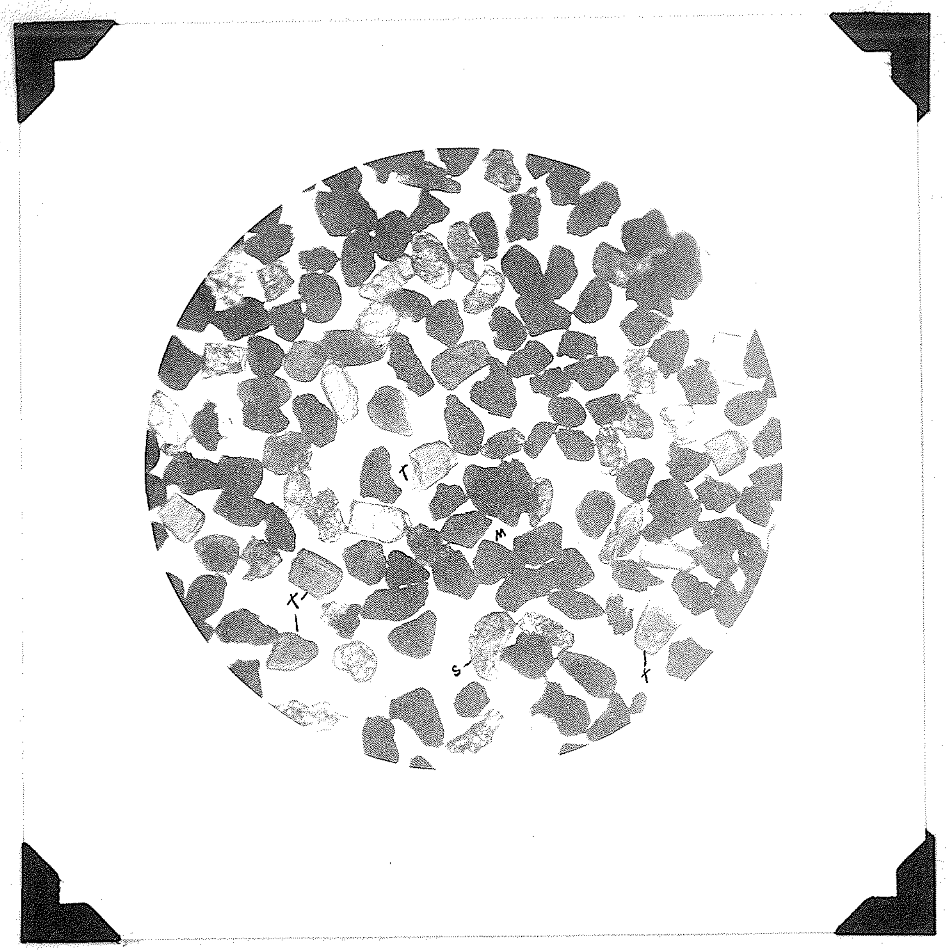


PLATE V

Dominant -
Abundant - Tourmaline, Magnetite
Common - Staurolite, Muscovite
Present - Kyanite, Ilmenite, Glauconite
Rare - Apatite, Hornblende, Zircon, Rutile
Trace - Garnet, Titanite

rounded grains show frosted and pitted surfaces similar to the Winnipeg sand.

4. The Boissevain Sandstone

This sandstone outcrops south of Boissevain, Man.; it is considered to be Fox Hill which is the top of the upper Cretaceous. Ref.(29).

It is very different in heavy mineral content from either the Winnipeg or the Dakota; the heavy mineral content is exceedingly high, about 3.05%; the outstanding feature of the heavy minerals is the dominance of prismatic shaped, dark green hornblende; this mineral shows very little evidence of alteration and is never in the slightest degree rounded, in fact, the ends of the prismatic grains are usually a series of fine projections. The hornblende occurs in relatively so great a percentage that at first it seems to be the only mineral present, however the following additional minerals have been noted.

Common - Biotite, Magnetite
Present - Garnet, Zircon, Epidote, Ilmenite
Rare - Anatase, Apatite, Tourmaline
Trace - Kyanite, Titanite, Rutile, Calcite

Plate VI shows the flood of well shaped hornblende grains occurring in this sand. The cleavage traces parallel with the length of the grains can readily be seen. The general description of the minerals given previously applies to those present in this sand but it is interesting to note in the case of the zircons, that a few of them are a distinct rose color and a few others are purple.

The light residue is also quite different from the other sands studied. There is a relatively high percentage of feldspar, both plagioclase and orthoclase in addition to the quartz; some of the feldspar grains are clear and colorless but most of them are greatly altered. Calcite is more abundant than feldspar and occurs as a coating on the other grains and as a cement. Treatment of the sample with acid accounts for the scarcity of this mineral in the separation.

The Boissevain sand grains in the natural condition are very irregular in shape but after treatment with acid which removes the thick

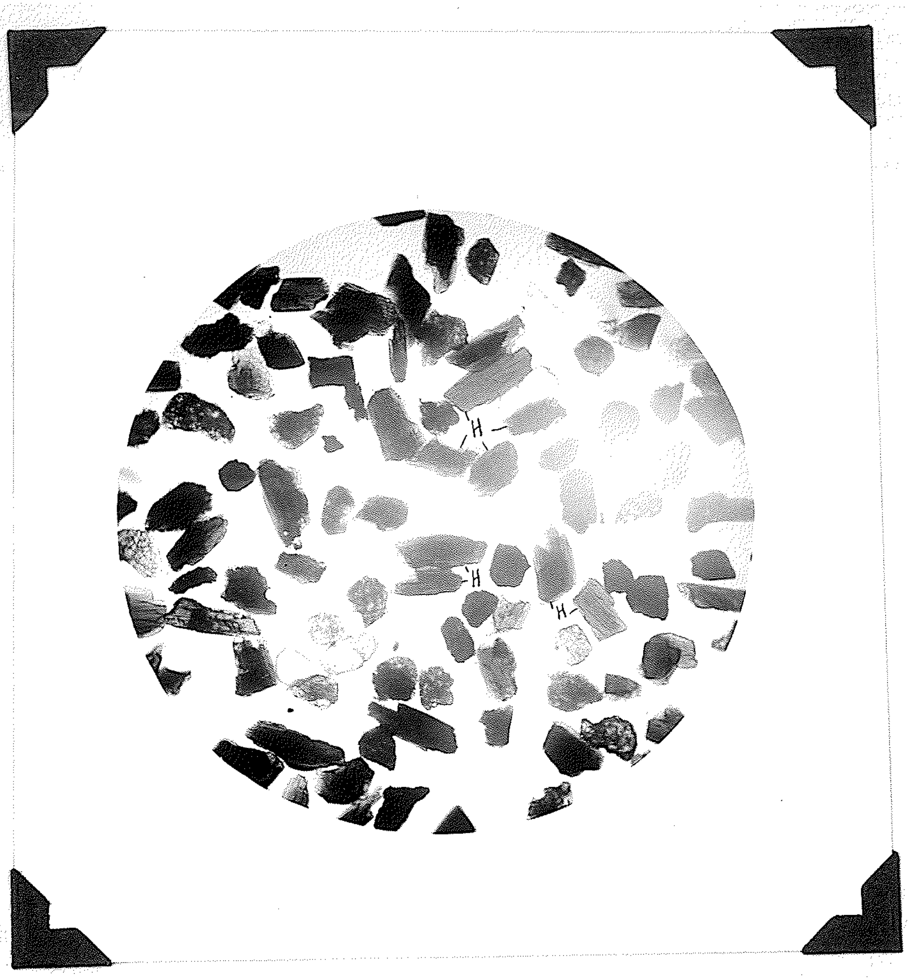


PLATE VI

Dominant - Hornblende
Abundant -
Common - Biotite, Magnetite
Present - Garnet, Zircon, Epidote, Ilmenite
Rare - Tourmaline, Anatase, Apatite
Trace - Rutile, Kyanite, Titanite, Calcite

calcareous coating they are found to be quite angular and fresh. The peculiar shape of the grains is due to the irregular fashion in which the calcite crystals have developed and to the uneven coating of iron oxide. No frosting or pitting is evident in this sand.

5. The Estevan Sandstone

The Estevan is a continental deposit occupying a position at the base of the Tertiary; it is considered to be Eocene. Ref. (8).

The heavy mineral content of this sand is similar in amount and in variety to the Boissevain. The similarity is evident in the accompanying block diagram representation of the relative amounts of the various minerals present in each sand.

The outstanding feature of the heavy minerals of this sand is the great variation in the hornblende grains. This mineral varies in color from dark green to colorless; the colorless grains appear to be bleached amphiboles of some kind and since in some grains a gradation in color from brownish green in the centre to colorless on the borders occurs, the colorless grains probably represent hornblende grains that have completely changed over from the dark to the light color, and further the different shades of color seen in other grains of this mineral probably represent various stages of the process of bleaching. Many of the bleached grains are crowded with inclusions, probably decomposition products. In all the color varieties of the mineral the characteristic prismatic shape of hornblende grains is retained. The bleached and altered character of the grains is shown in Plate Vll, the indefinite borders of the grains is a result of their altered condition.

Again in this sand as in the Boissevain occur rose and purple zircon grains. Pleochroism is evident in some of these deep colored varieties; the colored grains are rounded and quite small. A very few yellow zircons also occur; these grains are pleochroic from yellow to colorless.

The sand grains are very angular and fresh, and no frosting or

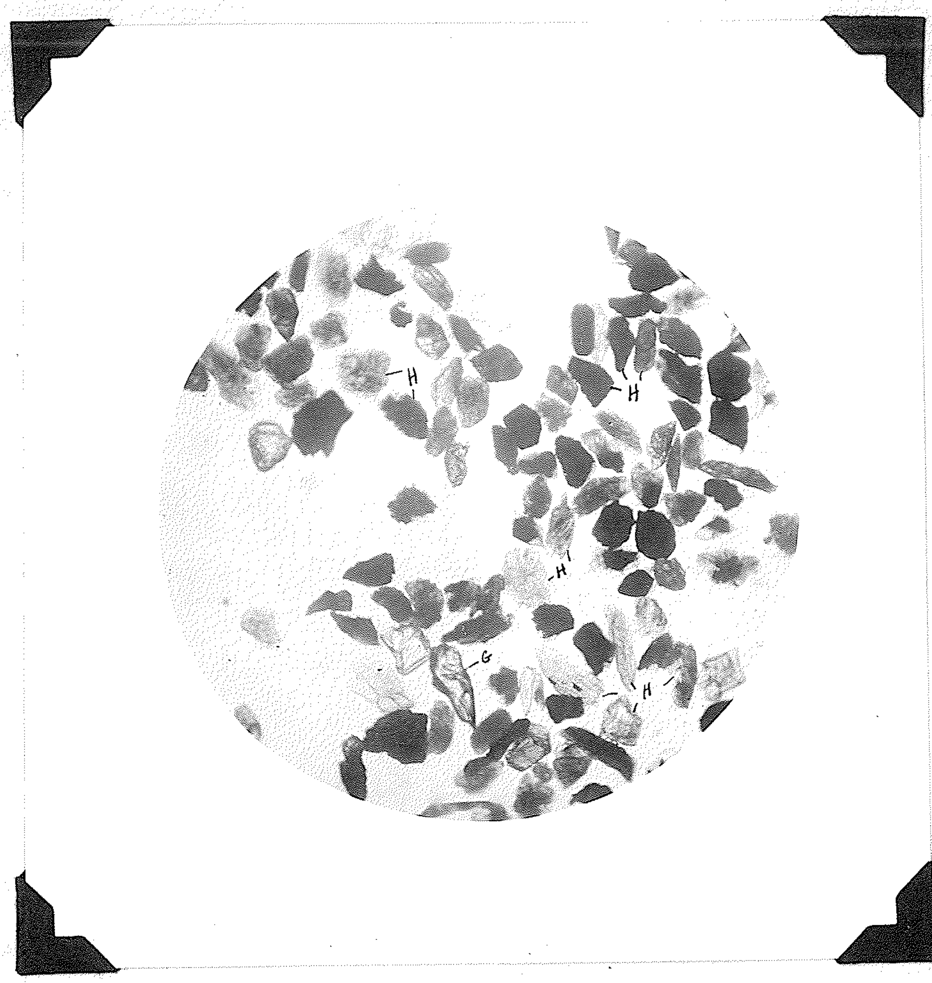


PLATE VII

Dominant - Hornblende
Abundant - Magnetite
Common - Garnet
Present - Epidote, Zircon, Ilmenite
Rare - Tourmaline, Rutile, Kyanite, Titanite
Trace - Biotite

pitting of the grains is evident.

The Pleistocene Sands

The icesheets which movedsouthwards over the province left deposits in the form of sheets of till, moraine ridges and drumlins, eskers and outwash gravel fans and erratics, while the lakes which were impounded in front of the ice formed beaches and delta deposits.Ref.(29) The results of examinations of four of these typical Pleistocene deposits are recorded below.

6. The Melbourne Sand

The sand is a very fine grained wind blown deposit.

Hornblende is the abundant mineral of the heavy residue, a few of the grains are bleached or very nearly colorless. The outstanding feature is however, the occurrence of apatite; the grains are well rounded, white or gray in color and generally have a rough pitted surface; a few of the grains possess higher polarization colors than is common for this mineral.

The light residue shows the quartz grains are partly coated with iron oxide and some feldspar grains are present. In general the sand may be said to be angular but a few, especially the larger grains are rounded. A very fine frosting is seen on the grains, this feature is not nearly as well developed as on the Palaeozoic sands and real pitting is practically absent.

7. The Beausejour Sand

This is considered to be an esker sand. Ref.(28)

The heavy mineral percentage is high, about 2.2%. The heavy minerals of this sand, which is typical of the Pleistocene, are very interesting since in addition to the usual minerals found in other sands, too more have been identified; the minerals referred to are monazite and glaucophane. Hornblende is again the dominant mineral, the grains are prismatic in shape, green and blue in color. One hornblende grain exhibits distinct twinning; the dark grains are pleochroic from green to bluish green. Plate Vlll is a picture of the heavy minerals of this sand; it shows the dominance of hornblende and the presence of a few other minerals such as magnetite and garnet.

The light residue shows the presence of feldspar with fine twin lamellae. Quartz grains dominate the light residue and a few of these show inclusions of rutile needles. The sand is angular but it also contains rounded grains which are finely frosted and triangular shaped pits are evident on some of the grains.

8. The Smith Siding Sand

An outwash sand found geographically close to Lake Winnipeg and the Winnipeg sandstone.

The heavy residue is again dominated by hornblende. Glaucophane and Monazite are both present and a third mineral topaz is noted for the first time.

This sand closely approaches the Winnipeg sandstone in degree of rounding, frosting and pitting; the grains of the two sands are so much alike that differentiation between the two is difficult. Porosity tests-last section of work-indicate the close similarity in rounding of this sand and the Winnipeg sand.

9. Grand Beach

A beach sand deposit located on the south east shore of Lake Winnipeg.

The heavy minerals, hornblende, magnetite, epidote, rutile, monaz ite, garnet, zircon, tourmaline, topaz, glaucophane, muscovite, staurolite, typical of Pleistocene sands are found. Plate lX is a picture of the heavy minerals of this sand.

The shape of the quartz grains may be classed as "subangular" to "rounded"; the larger grains being well rounded. Frosting and pitting is very well developed; the larger nearly spherical grains show a development of frosting and pitting that equals the Winnipeg sandstone, which outcrops farther north in the same lake. The small "subangular" to "angular" grains are quite fresh in appearance.

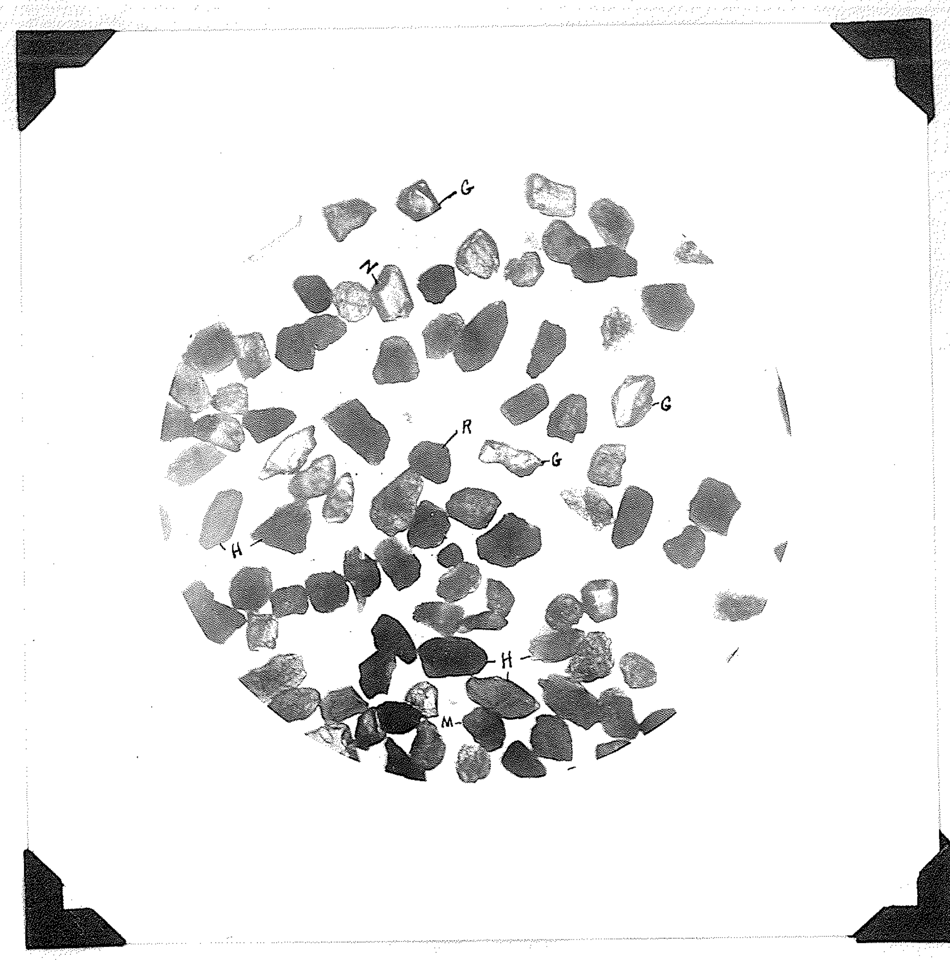


PLATE VIII

Dominant	- Hornblende
Abundant	-
Common	- Epidote, Garnet, Magnetite
Present	- Zircon, Rutile
Rare	- Monazite, Glaucophane, Staurolite Tourmaline, Hematite
Trace	-

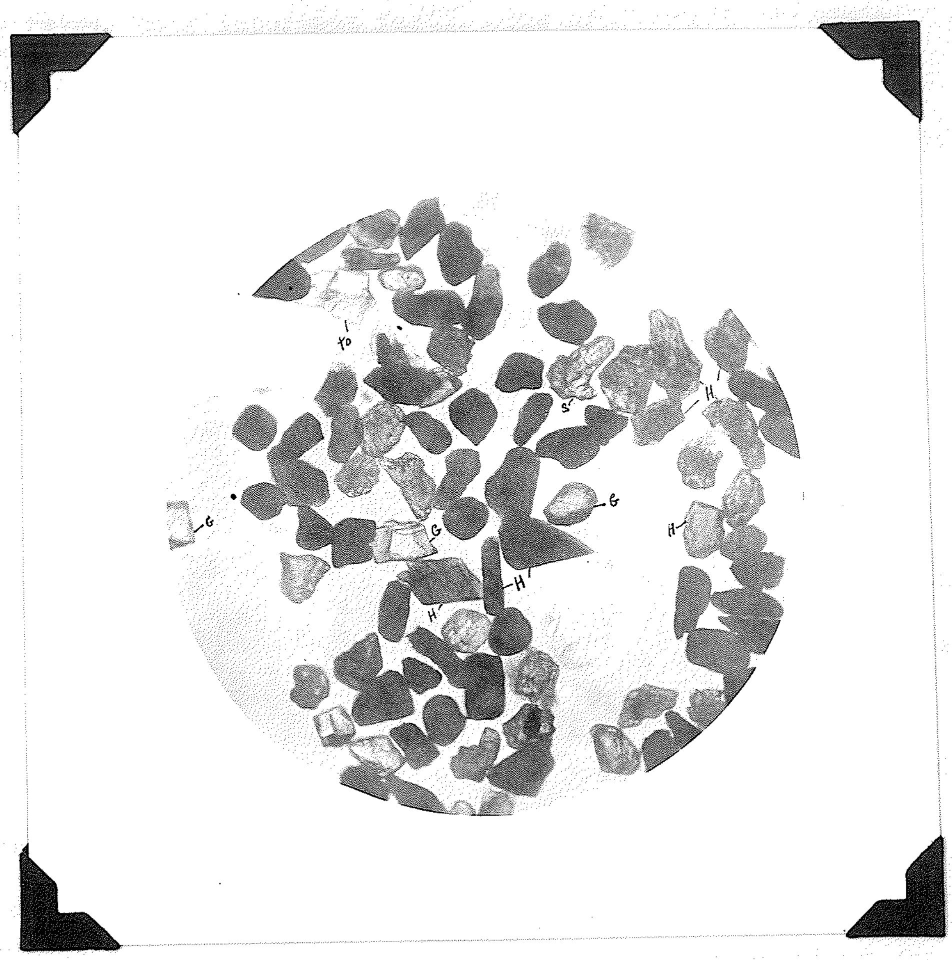


PLATE IX

Dominant - Hornblende
Abundant -
Common - Magnetite
Present - Epidote, Monazite, Rutile,
Garnet, Zircon
Rare - Staurolite, Tourmaline, Glaucophane
Trace - Topaz, Muscovite

VI. Results and Conclusions of the Petrographic Analyses of the Various Horizons.

The petrographic analyses of the horizons studied in this investigation reveal many important facts. The application of these facts is concerned in helping to interpret the geological history of the horizons and to establishing means of correlating the various horizons. Many of the heavy mineral suites and surface features of the grains are characteristic of certain definite horizons, and in this way, they can be used in correlative work. An example of the application of these features to the correlation of horizons may be given; a core from an oil well drilled in the Palaeozoic formations of Manitoba yielded a section, which in part was difficult to identify in the hand specimen. A petrographic examination of this part showed it to be identical in both heavy mineral content and in degree of rounding, frosting and pitting to the Winnipeg sandstone, which outcrops east of this well. In this way petrographic analysis may profitably be used to correlate formations and to verify macroscopic identifications.

The Winnipeg Sandstone

It is evident from the results of the petrographic analysis of the Winnipeg sandstone, that conditions must have been very different in early Ordovician times, to the conditions during the history of any sand of later time.

The small heavy mineral content, the high degree of rounding of both the heavy minerals and the quartz grains, and the development of well frosted and pitted grains are all important indications that the sand passed through an enormously long period of being shifted around by the wind before it was finally deposited.

The only heavy minerals found commonly in the sand are zircon, tourmaline and magnetite; normally these minerals, especially zircon constitute only a small percentage of the total of the heavy minerals present in any sand younger than Palaeozoic. The reason for the concentration of these, the most stable of all heavy minerals is that all the other common heavy minerals, which are less stable, such as, hornblende, kyanite, garnet and epidote have been worn away. These minerals were very likely common at one time, but through continued abrasion they have since been caused to disappear.

"A predominance of the more stable minerals, such as, zircon, tourmaline, rutile and iron ores, probably to the total extinction of other species, implies a derivation from pre-existing sediments."Ref.(17).

This is the situation in regard to the Winnipeg sandstone although a little staurolite and garnet occurs as well. Whether or not, this sand is derived from a pre-existing sediment is difficult to say for certain, but in view of its position directly overlying the PreCambrian rock, it is more likely that the sand was derived from this basal rock; the sand being moved by the wind over this surface until the agents of erosion were able to wear away all unstable minerals, to round off all remaining minerals and finally to give the frosted and pitted character to the sand grains.

In order for the quartz grains to become so well rounded, frosted and pitted the time interval must have been very long and not only that, but there must have been great freedom of movement of the grains, i.e. there could have been no obstruction, such as, a vegetable cover to prevent the wind moving the sand around. An environment of this kind probably was to be found over the PreCambrian surface. An idea of the conditions necessary to produce such prominent frosting and pitting like occurs on the Winnipeg sand grains is given when it is compared with the Melbourne sand. This is also a wind blown sand but there is only a development of a very fine frosting and no sign whatever of real pitting; the heavy minerals of the Melbourne sand give no indication of rounding and many fairly unstable minerals are found. It is evident this sand has not as yet suffered erosional effects as great as those of Winnipeg sandstone time. The two sands cannot be compared too closely however, because the Melbourne is a finer grained sand than the Winnipeg and this factor also tends to prevent extensive development of frosting and pitting.

It is thought the deposits of this sandstone were of much greater extent originally than they are today. This seems quite likely since there is evidence of many of the deposits of later time containing in them either Winnipeg sandstone grains or grains very similar to them.

The Winnipeg sandstone and the Potsdam sandstone(which is of Upper Cambrian time)must have had a very similar history. An analysis of a specimen of Potsdam sandstone, from near Ottawa shows the presence of the same suite of minerals as that found in the Winnipeg sandstone. The rounding, frosting and pitting of the two sands is also very similar.

The pyrite so abundantly encountered in drill hole samples of the Winnipeg sandstone is evidently secondary, it very often shows well developed crystal shapes and is never rounded. This mineral is evidently not stable when exposed to the atmosphere as it is rarely found in surface samples.

The Silurian Sandstone

The great similarity in the heavy mineral content, the shape, the frosting and pitting of this sand to the Winnipeg sandstone is very evident. The similarity is so great that the quartz grains are either actual Winnipeg sandstone grains or they are grains that passed through the same geological history previous to their present deposition. In either case the sand was deposited by wind or by water with subsequent infiltration of the lime or else during the time of lime deposition in the sea, there was sand being drifted over the land surface and some of it became incorporated in the lime deposit.

The Dakota Sandstone

The heavy mineral content of this sand includes a large number of different species. It is quite probable the PreCambrian rock supplied at least part of this sand. The association of some of the minerals found in this sand indicates a metamorphic rock type as the source of at least part of the sand, e.g. the staurolite - kyanite - garnet suite. Ref. (17). Again the association of apatite and zircon, which also occurs in the Dakota, is indicative of acid or intermediate rock-types as possible sources of supply. Ref. (29). Both metamorphic and acid or intermediate rock types occur in the PreCambrian and this may be the source of supply for these minerals.

The glauconite found so abundantly in certain zones serves as a good horizon marker for the formation but it does not help in determining a source for the sand.

The presence of minerals with good cleavage, such as, kyanite, together with the marked angularity of the sand indicates that the sand was not subjected to very severe erosional agencies, such as wind, or the minerals with good cleavage would be destroyed, the light minerals, such as, muscovite and biotite would be blown away and the quartz would show some rounding. In fact, the great angularity, the sharp edges and corners and the fresh looking fractures of the quartz grains along with the broken nature of some of the heavy minerals are all factors difficult to explain unless some crushing agency, such as, glacier ice played a part in the history of the sand.

In this angular sand there are a few very well rounded quartz grains; these grains are frosted and pitted similar to the Winnipeg sandstone grains. It is quite possible that the frosted and pitted grains came from the Winnipeg sandstone or a similar formation and were carried by rivers or by wind and deposited in the Dakota sea.

The Boissevain Sandstone

This sand contains the greatest heavy mineral content of any examined; this is due to the abundance of hornblende. The high percentage of heavy mineral indicates that the sand has had very little travel, even a moderate amount of travel would destroy some of the minerals found. Another factor suggesting little or no travel of the sand is the character of the hornblende grains themselves, frequently these prismatic shaped grains are terminated at both ends, by a series of little fine projections, even the slightest movement of the sand prior to deposition would be expected to break or wear off these tiny projections. Further evidence showing that the sand has never been subjected to erosional effects is the high content of feldspar, both plagioclase and orthoclase normmally are not very stable and their presence in this sand is explained by considering them to have been derived from the parent rock quite close to the present site of deposition.

The marked angularity of grain, the presence of much biotite and the absence of frosting and pitting are all points indicating the sand was never subjected to erosional activities of the wind.

The calcite present is likely secondary; it serves as a cementing medium and probably entered the sand after it was deposited.

A source for a sandstone of this nature is an amphibole rock and from the nature of the minerals, the sandstone resulting today is either the result of disintegration of the parent rock in place or is the result of deposition soon after disintegration. Milner Ref. (17), mentions the characteristic association of ilmenite, anatase, rutile and brookite which points to a derivation from basic or ultrabasic rock-types. The first three minerals of this association are found in this sandstone.

The Estevan Sandstone

This sand closely parallels the Boissevain both in heavy mineral content and in variety of minerals with the one great difference that the hornblende grains in this sand are greatly altered and bleached.

"Common hornblende and basaltic hornblende in some instances alter by the loss of color and subsequent passage into pale or colorless amphibole." Ref. (13).

Definite gradations from the deep green hornblende of the Boissevain to the colorless amphibole of the Estevan seem to occur, since in many grains in the Boissevain a partial alteration is seen where the grains are green or brown in the centre and pass gradually to pale green or colorless at the edges.

Reasoning along these lines it may be that the Estevan sand first passed through a history similar to the Boissevain and then was subjected to conditions that caused the alteration of the amphibole. The similarity in the suite of heavy minerals found in the two sands and in the character of the grains both support an origin of this kind. The interesting association of small rounded rose and purple zircons in both the Boissevain and Estevan sand further indicate a similar origin for the two sands.

"The purple or rose-colored variety of zircon is especially characteristic of those British sediments in which minerals derived from regionally-metamorphosed rocks are abundant, and of fresh appearance." Ref. (5).

Whether or not the metamorphosed rocks which are common in the PreCambrian contain colored zircons is yet to be determined.

The garnet-staurolite-kyanite and the ilmenite-anatase-rutile suites of minerals mentioned by Milner are present in the Estevan as well as the Boissevain. An ultimate origin for these minerals from the PreCambrian rock seems likely since many of these minerals are known to occur in certain areas of the PreCambrian today.

The Pleistocene Sands

There is great similarity in the heavy mineral content of all the Pleistocene sands examined. Hornblende is the dominant mineral in every separation; the grains for the most part being dark green and fresh looking.

A very characteristic feature of the Pleistocene sands and one that serves to differentiate them from all other sands studied is the presence of monazite and glaucophane. These minerals are diagnostic characters of the ice-deposited sands investigated and they appear to be valuable indicators for surface correlations of this type of sand.

The Melbourne Sand

The wind blown nature of this sand is shown by the fineness of the sand, by the abundance of iron oxide coating the grains and by the fine frosting on the larger rounded grains; the frosting having been developed since the sand was dumped by the ice. The unusual type of apatite grains occurring in this sand makes it a useful species for a horizon marker.

The Beausejour Sand

The prismatic, clear, pleochroic, red grains of rutile showing cleavage indicate that little reworking of the sand has occurred since it was released by the parent rock. In most of the occurrences of rutile in the older sands, the grains are rounded and somewhat clouded or dull in appearance. That little reworking of the sand has occurred is further supported by the angular nature of the heavy minerals and the quartz grains. Frosting is evident on many grains and a few grains suggestive of Winnipeg sandstone show development of deep triangular shaped pits.

Smith Siding Sand

The typical heavy mineral suite of Pleistocene sands is again found with the addition of topaz. This mineral is very rare and may have been overlooked in some of the other sands. The extensive development of rounding, frosting and pitting is very suggestive of a Winnipeg sandstone origin for a great part of this sand.

Grand Beach Sand

This sand is very similar in every way to the Smith Siding except there are probably more angular grains in this sand.

In the last three deposits discussed there seems to have been two different sources for the sand in each case. The angular quartz grains and the great variety of heavy minerals indicate a source with very little subsequent reworking. The minerals present are found in igneous and metamorphic rocks and both of these types of rock are common in the

PreCambrian; a source for this part of the sand from the PreCambrian is no doubt the case. The other source of the sand is considered to be the Winnipeg sandstone or a sandstone of similar age and position. This conclusion is drawn from the fact, that, the frosted and pitted grains of these sands are identical with the Winnipeg sandstone grains, and further, there is no sand of younger age than the Winnipeg that has frosting and pitting so well developed. The probability of the sand in question developing this character after being picked up by the ice is very unlikely. Even if conditions were suitable for the development of frosting and pitting during or after deposition by the ice, the factor of time comes in and as seen in the case of the Melbourne sand, time has not been long enough for these characters to become prominently developed. It seems quite probable that the ice in moving down from the north would incorporate in its load, part at least of any sands in its path; the Winnipeg sandstone or its equivalent being situated geographically north of the Pleistocene deposits in question would yield part of their sand to the ice. The well rounded, frosted and pitted grains of the Beausejour and the Smith Siding, although different types of glacial deposits can thus be explained as redeposited Winnipeg sandstone grains or an equivalent of that sand. The Grand Beach sand located near the south end of Lake Winnipeg, in which lake the Winnipeg sandstone outcrops could it is believed receive its frosted and pitted grains directly from the Winnipeg sandstone by water and wave transportation.

VII. Application of Heavy Minerals to Correlation.

A final survey of the heavy minerals described, is made in order to emphasize those species which are important for correlation purposes. For the most part, definite associations or suites of three or four minerals are the most important and most reliable. The minerals of little correlative value are also indicated.

The zircon, tourmaline, rutile suite is diagnostic of the Winnipeg sandstone.

Magnetite is never of value because it is present in similar amounts in all sands.

Hornblende is of great value in differentiating between the Dakota and later horizons; it is scarce in the Dakota and floods all later sands. The bleached variety is distinctive of Estevan.

Glauconite is indicative of certain parts of the Dakota.

Tourmaline varies so much in color that it has not as yet been found of particular value.

Apatite when clear, colorless and prismatic is characteristic of parts of the Dakota; while rounded, gray, pitted apatite is characteristic of the Melbourne sand.

Muscovite and Biotite are of little value.

Staurolite is found in small quantities in all horizons and is therefore of little correlative value, the same applies to Garnet.

Zircon is of little value except when colored. Rose and purple zircons are characteristic of Boissevain and Estevan sands.

Anatase is only recorded in the Boissevain and is therefore distinctive of that horizon.

Epidote is of little value except in helping to differentiate Dakota - where it has not been found - from later horizons.

Titanite when diamond shaped, as in the Dakota, is of value. It is very rare however and may easily be overlooked.

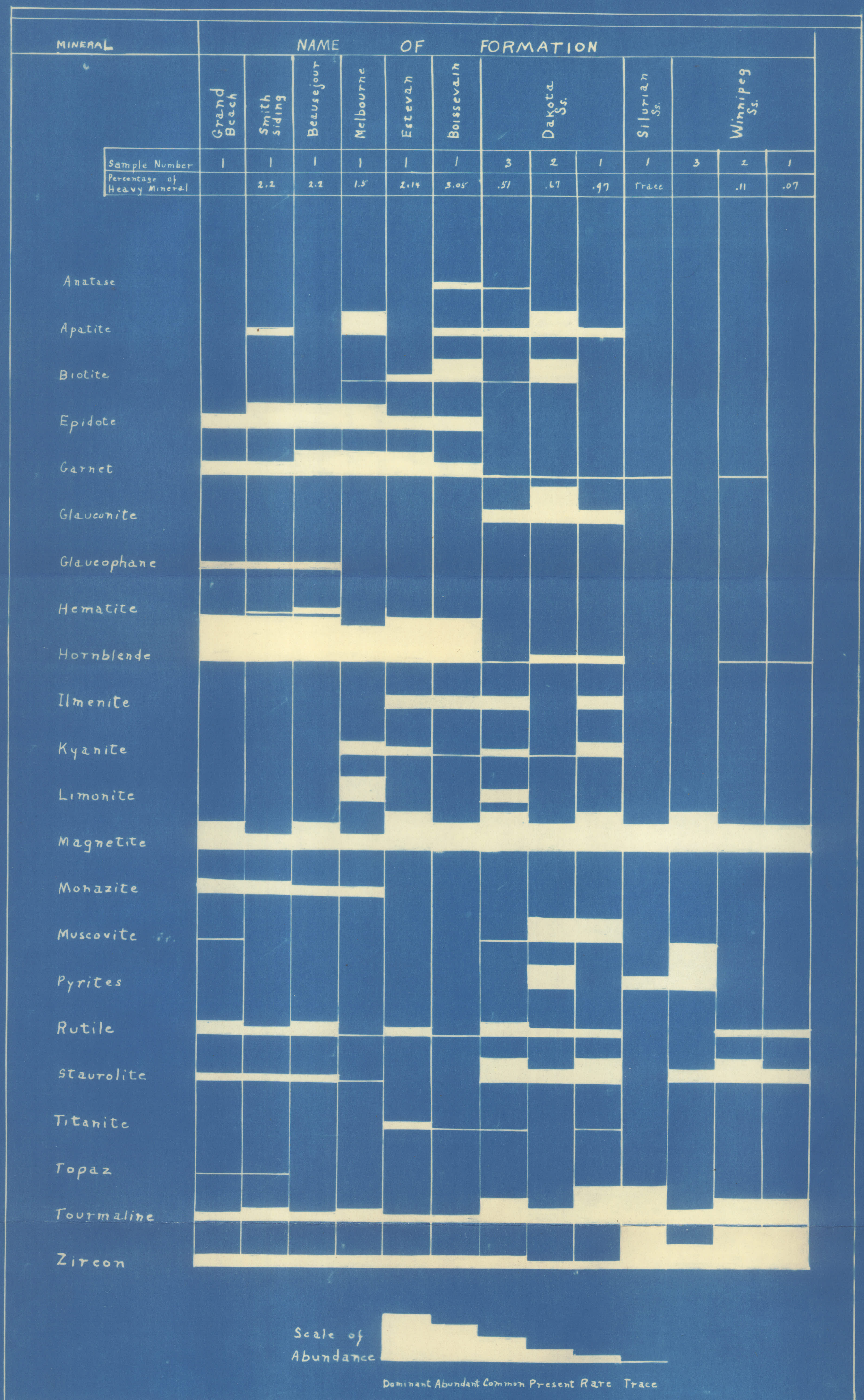
Monazite and Glaucophane are markers for the Pleistocene sands and can therefore be used in surface correlation of these deposits.

Kyanite - Staurolite - Garnet suite is typical of Dakota sands.

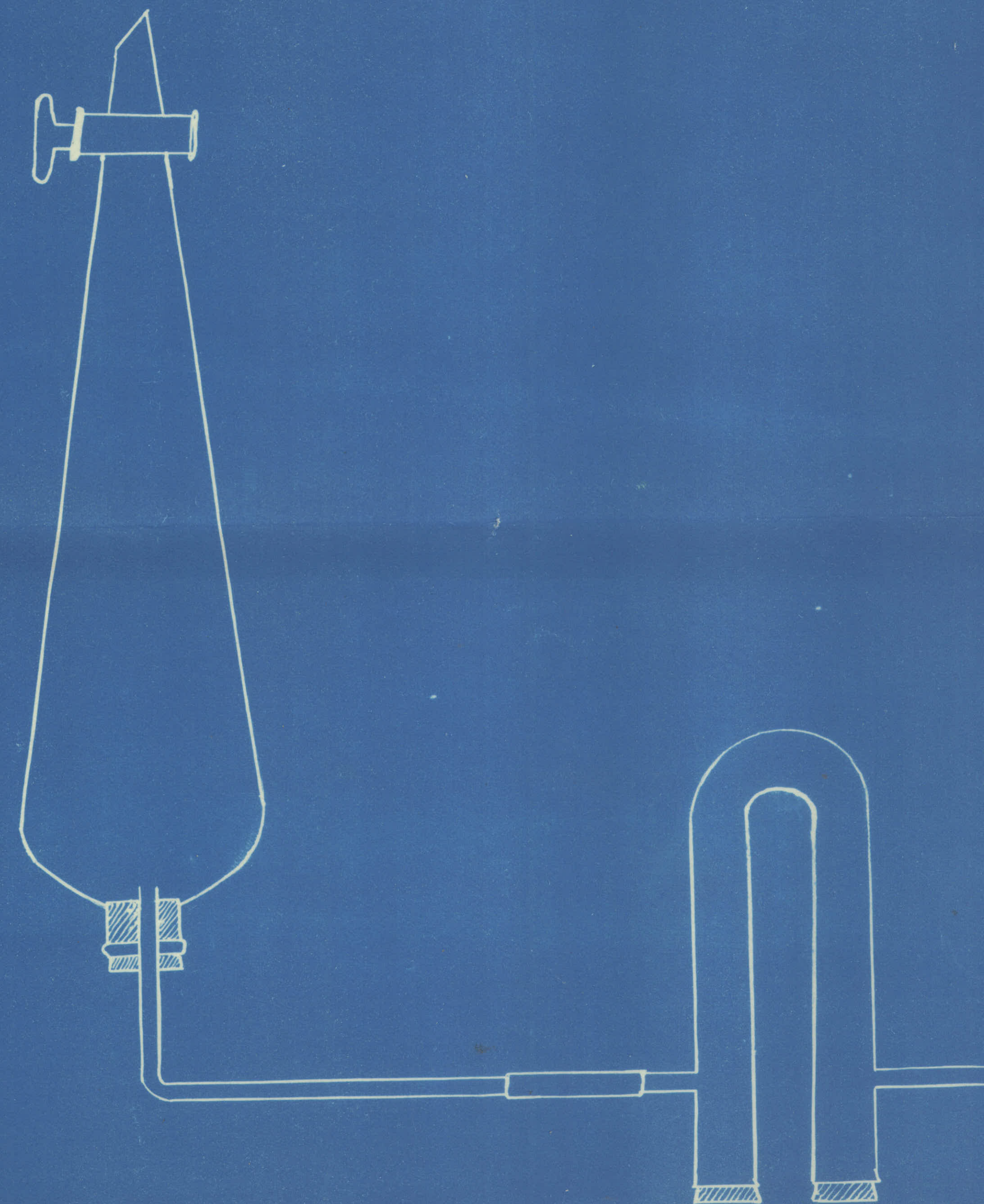
Feldspar and Calcite when very abundant in the light residue is diagnostic of Boissevain sands.

Ilmenite - Anatase - Rutile suite is characteristic of Boissevain.

Topaz is found only in some of the Pleistocene deposits; it may be of correlative value.



Block Diagram Showing Relative Abundance Of Heavy Minerals In Each Formation.



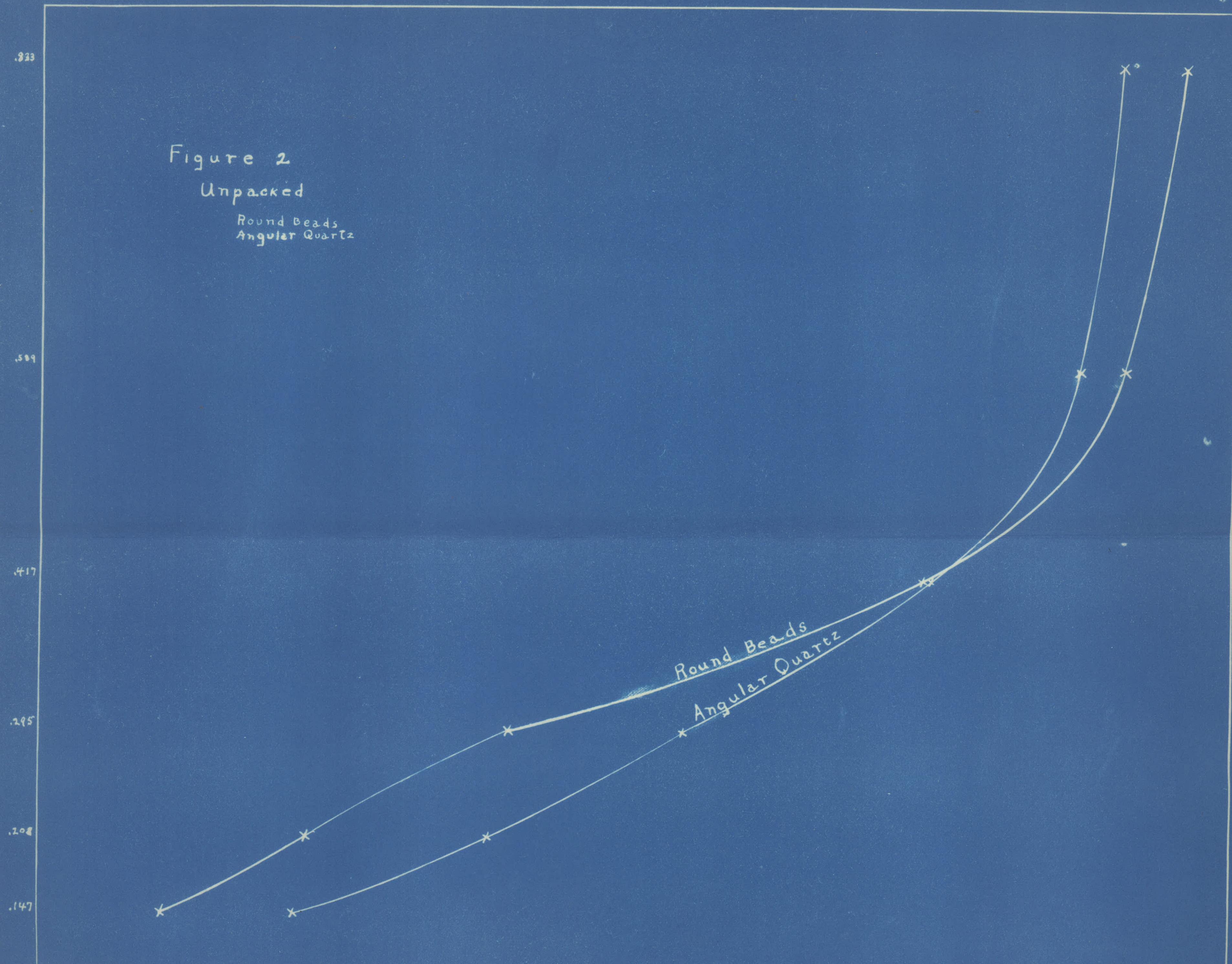


Figure 2
Unpacked
Round Beads
Angular Quartz
.833
.589
.417
.295
.208
.147
Round Beads
Angular Quartz

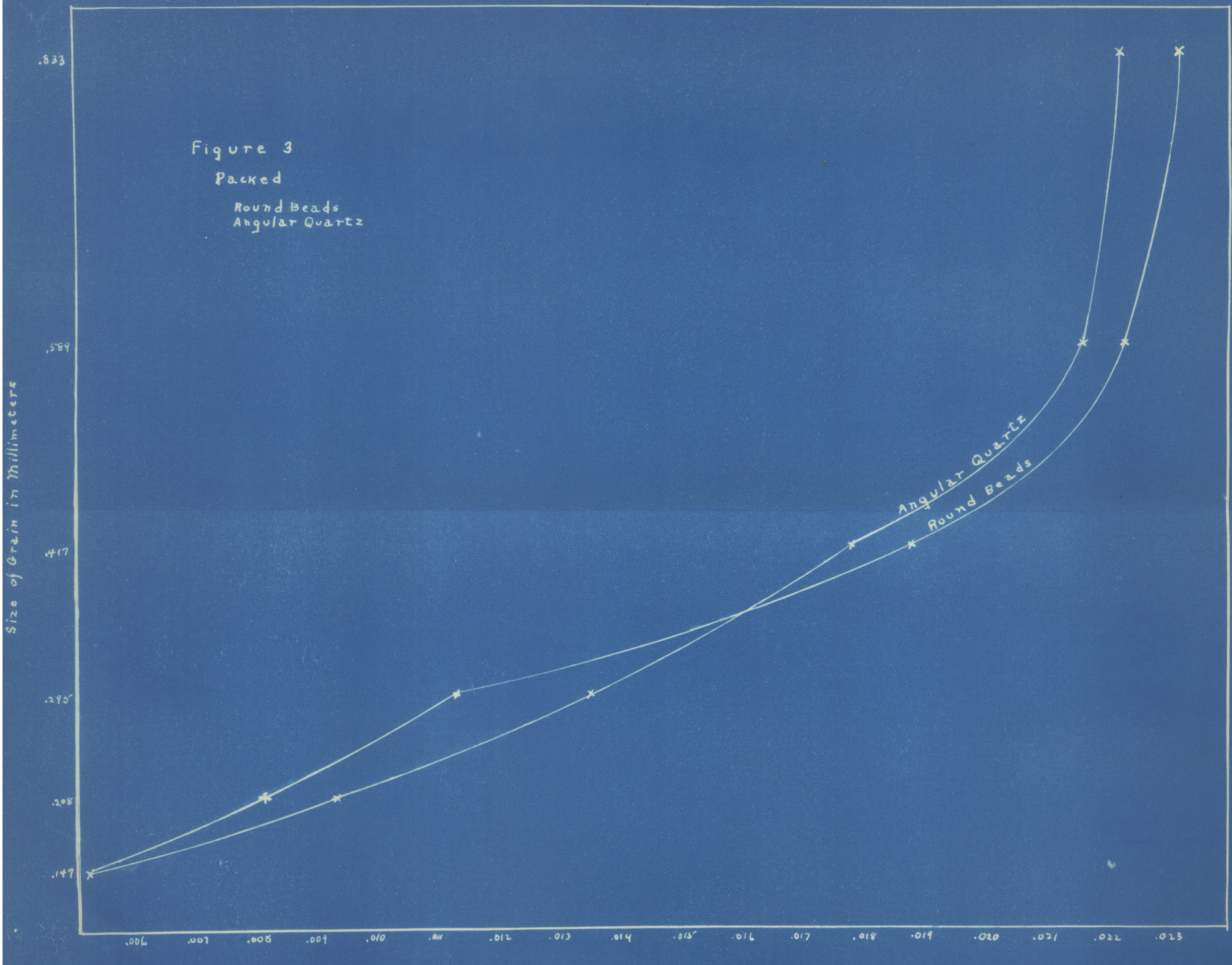


Figure 3
Packed
Round Beads
Angular Quartz
Size of Grain in Millimeters
.833
.589
.417
.295
.208
.147
Angular Quartz
Round Beads
.006
.007
.008
.009
.010
.011
.012
.013
.014
.015
.016
.017
.018
.019
.020
.021
.022
.023

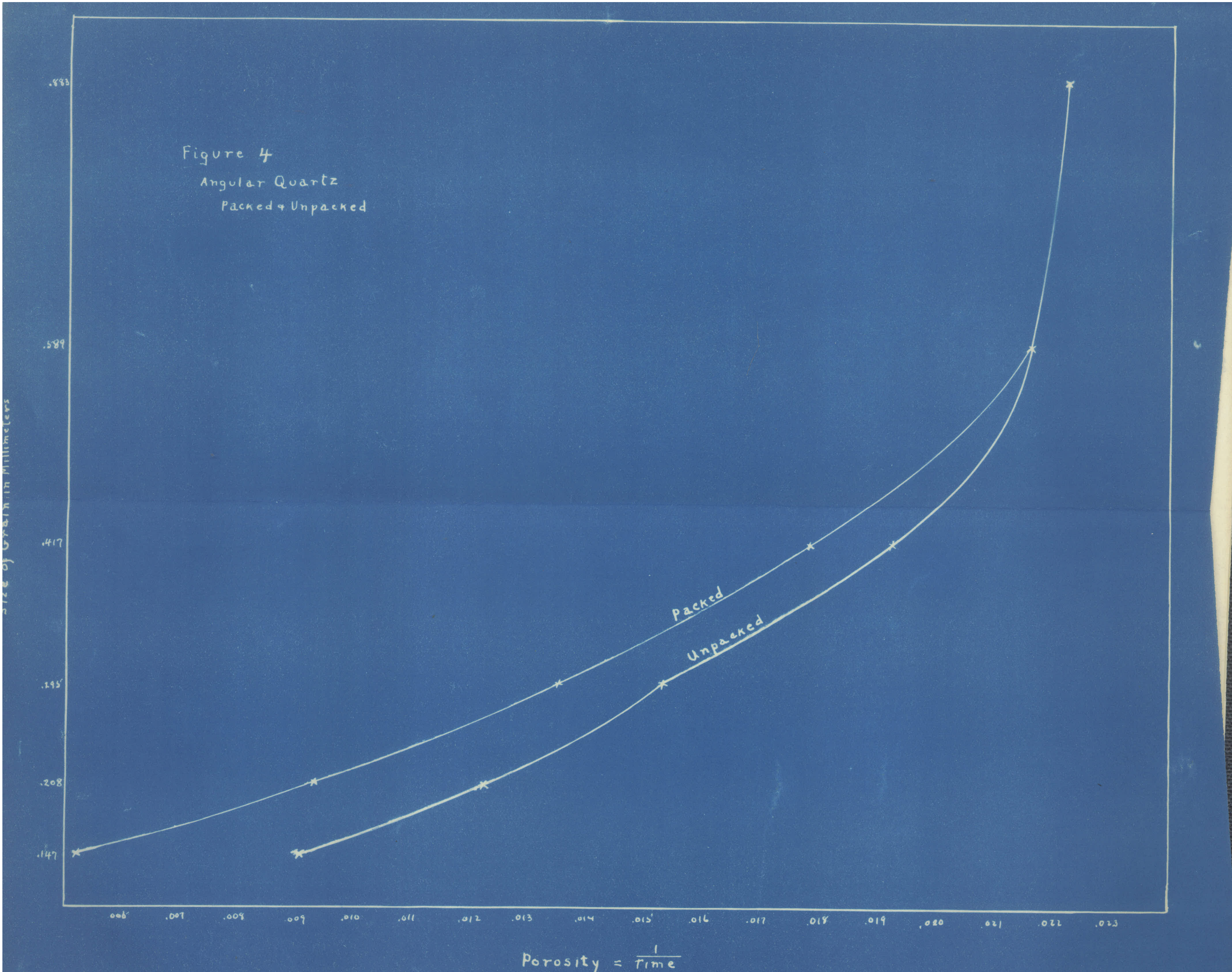


Figure 4
Angular Quartz
Packed & Unpacked
Packed
Unpacked
.883
.589
.417
.295
.208
.147
.006
.007
.008
.009
.010
.011
.012
.013
.014
.015
.016
.017
.018
.019
.020
.021
.022
.023
Size of Grain in Millimeters
Porosity = 1/Time

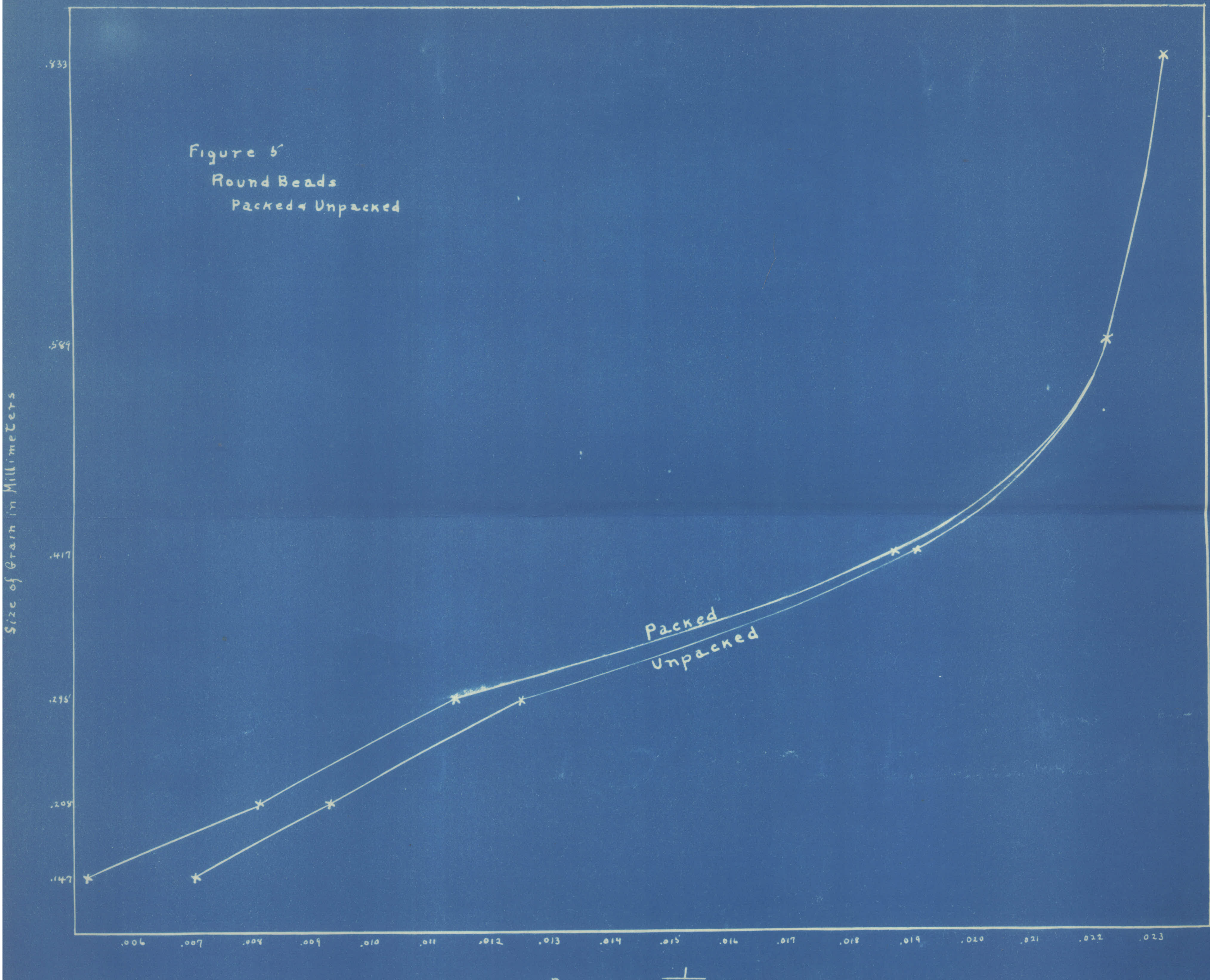


Figure 5
Round Beads
Packed & Unpacked
Size of Grain in Millimeters
.833
.589
.417
.295
.208
.147
Packed
Unpacked
.006
.007
.008
.009
.010
.011
.012
.013
.014
.015
.016
.017
.018
.019
.020
.021
.022
.023

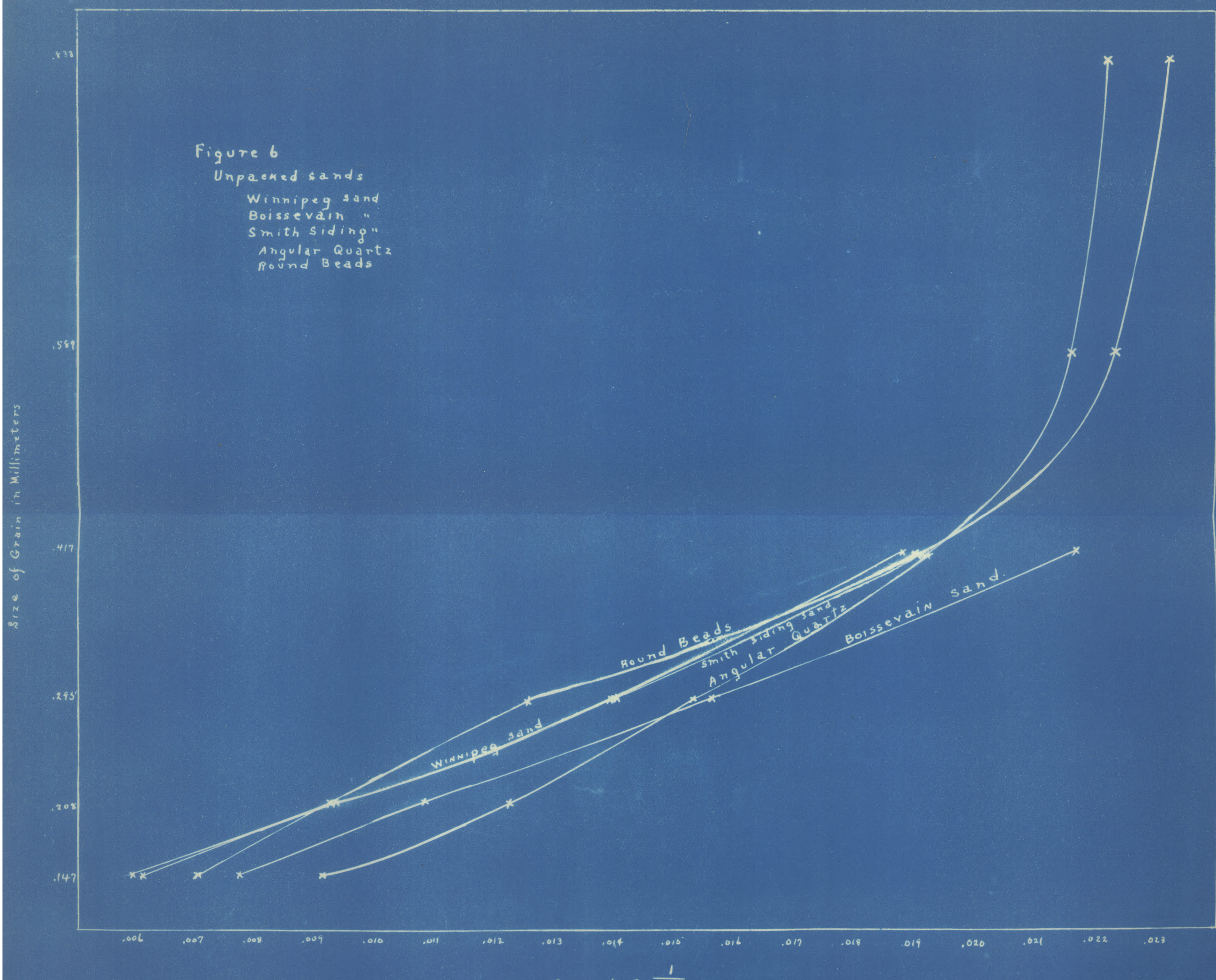


Figure 6
Unpacked sands
Winnipeg sand
Boissevain "
Smith Siding"
Angular Quartz
Round Beads
Size of Grain in Millimeters
.833
.589
.417
.295
.208
.147
.006
.007
.008
.009
.010
.011
.012
.013
.014
.015
.016
.017
.018
.019
.020
.021
.022
.023
Round Beads
Smith Siding sand
Angular Quartz
Boissevain sand.
Winnipeg sand

VIII. Heavy Minerals as Indicators of Continental or Marine Origin of Sands.

A study of the heavy minerals of the various sands described in this investigation leads to a very important conclusion in regard to the origin of the deposits; the dominance of hornblende occurs only in those horizons which are considered to be continental in orgin. This fact indicates that this mineral may be a very important criterion for diferentiating between continental and marine deposits. The deposits which are undoubtly marine are either very low in hornblende or it is absent altogether, e.g. the Dakota and the Winnipeg sandstones. The Boissevain and the Estevan sandstones contain coal and lignite beds, very suggestive of continental deposition, probably in shallow water; these sands are flooded with hornblende. The Pleistocene sands which are ice deposited are also flooded with hornblende; this feature further substantiates a continental origin for these sands.

The accompanying block diagram of the heavy minerals shows very clearly the flooding of hornblende in the Boissevain and all younger deposits; it also shows other minerals which, though not so abundant are also characteristic of the continental deposits. The most important of which is epidote; this mineral has not been found in the marine but it is a very characteristic feature of the continental deposits. The mineral garnet may be mentioned although its value as an indicator for either continental or marine conditions is doubtful; it occurs more abundantly in the continental deposits and is generally pink in color. Glauconite is found only in the Dakota; this helps to verify the marine origin of this sand.

IX. The Determination of a Rapid Method for Quantitatively Measuring the Roundness of Sand Grains.

The degree of rounding of sand grains, produced through mechanical wear during transportation is an important feature in interpreting the geological history of sand. It is important from an economic standpoint since the degree of rounding determines to a certain extent, the porosity of the sand, which in turn determines whether or not the horizon could possibly carry oil or gas.

A microscopic examination of the grains is helpful in determining their roundness but it is deficient in two respects. First, the grains can only be studied in one dimension and second, only a few grains can be examined. The object of this part of the work is to determine another means of measuring the roundness of sand grains.

Two methods have been employed, the first of which involved the use of a jig-table. The jig-table consisted of an inclined plane, 3' x 14", adjustable to any angle, supported on a mechanical shaker. The surface of the table was made as smooth as possible in order to lessen the friction. The sand grains to be tested were placed in a row on the higher end of the board. The shaker was then started and allowed to run for a definite period; the speed of the shaker being reduced until the grains ceased to jump when placed on the table. The purpose in this method was that with grains of like size, the rounder the grain the farther it would roll in a given time of shaking.

This method did not prove to be satisfactory in the fine grade sizes of the sand on account of the friction between the sand and the table, which caused the grains to remain at the top instead of jigging down. The method could probably be made applicable in the coarse grade sizes i.e. in the 35 mesh size and larger, where the force of gravity overcomes the friction between the grains and the table. Since the greatest part of all the sands studied have an average size much smaller than 35 mesh, the method could not advantageously be applied.

The second method depended upon the permeability of sand. The object was first, to find out whether angular material or round material is the more porous, and second, to find out whether or not porosity changes with change in size of grain.

The apparatus consisted of a conical dropping funnel, a suitable stand, and a "U" tube. The sand to be experimented with was first screened in order to obtain grains of a uniform size. The screened material was placed into the "U" tube up to the level of the arms. Each branch of the tube was then closed with a rubber stopper. The conical dropping funnel, used as an aspirator was filled with water and connected by a piece of rubber tubing to one arm of the "U" tube. The apparatus used is shown in Fig. 1.

Before each test care was taken to see that the water was at a definite level in the dropping funnel; a finger was placed over the free end of the "U" tube and the stop-cock of the dropping funnel opened to make sure that no air was leaking into the apparatus.

The length of time taken by the water to run out of the dropping funnel was noted by means of a stop-watch. From the time measurements the relative porosity of each sample was computed since the porosity varies inversely as the time.

The dropping funnel was filled again and another reading obtained. The "U" tube was emptied and refilled with sand and two more readings taken. This was repeated a third time in order that a fair average might be obtained.

Experiments were carried out with two types of material; the first type used was crushed quartz, representing a high degree of angularity; the second type used was solid glass beads, representing a high degree of rounding. A series of tests was made with the two materials; each test being made with a different grade size. The grade sizes experimented with included the following 20, 28, 35, 48, 65, and 100 mesh.

It was found that the results varied if care was not taken in pouring the sand into the "U" tube. The slightest packing of the sand decreased the porosity considerably; for this reason the sand was poured into the "U" tube through a funnel held at a uniform height in order that any packing caused in pouring the sand would be as nearly as possible the same in all tests.

The results were plotted on graph paper using the abscissa to represent the porosity and the ordinate to represent the size of grain. Fig. 2, shows the curves representing the porosity results of angular quartz and round beads when no packing agent is used in putting the sand into the "U" tube. The curves show that in the case of both angular and round material there is a moderately steady increase of porosity with increase in size of grain up to a size between .417 and .589 millimeters. From this grade size to the largest experimented with, the increase in porosity compared with increase in size of grain is very small. In the coarse grades i.e. the .833 and .589 mm. sizes the round beads show a slightly greater porosity than does the angular quartz. At the .417 mm. size the two materials have an equal porosity. From this size to the smallest tested i.e. .147 mm. size the round beads are considerably less porous than the angular quartz.

A similar series of tests was performed a second time, with the exception, that a definite amount of packing of the sand in the "U" tube was undertaken. To accomplish this the "U" tube filled with sand was attached to an upright suspended from above. The upright when released above allowed the "U" tube to drop through a vertical distance of one inch and a half on to a surface covered with felt to produce a dead fall. The tube filled with sand was dropped in this way ten times before each porosity test.

Fig. 3, represents the results of this series of experiments. Again it is evident there is an increase in porosity with increase in size of grain. The three coarsest grades i.e. .833, .589 and .417 mm. sizes show a slightly greater porosity in the round condition. Between the

.417 and .295 mm. sizes the porosity of the two comes to be the same at one point. The following two smaller sizes show, the round beads to be less porous than the angular quartz but the finest grade size i.e. the .147 mm. size shows the porosity of the two materials to be equal again. The proximity of the two curves indicates that under packed conditions the two kinds of material when of uniform size have very nearly the same porosity.

Fig. 4 & 5, show respectively angular quartz and round beads plotted to show the relation between like materials tested under both unpacked and packed conditions. In both cases the curves show that under packed conditions the porosity is less. They also show that the same amount of packing decreases the porosity to a greater extent in angular material than it does in round material. In both cases the effect of packing on porosity in the two coarsest grades is negligible.

X. Results and Conclusions of the Porosity Method.

Theoretically, for perfectly round grains in a definite space with the number of grains increasing in proportion with the decrease in size, the actual pore space is the same for groups of grains of any one size. In actual practice, these conditions are never met with; all the curves in the accompanying graphs show that by the means of measurement employed, the porosity is not the same for each grade size but instead it increases definitely with increase in size of grain. The change in rate of flow of air through the sand is greater in the fine grade sizes than in the coaser.

"One of the reasons for this great difference in time of flow is found in the fact that, while the total area of cross section through which the flow may take place is very nearly the same in all cases, the number of tubes through which the air must move is very different and at the same time their diameters are extremely unlike in size, the pores being very many, but small, where the flow is slow, and much fewer and relatively larger where the flow is faster. If, then, there is the same absolute amount of friction per each equal unit area of sliding surface, it is evident that where the pore space has been most divided there must be the largest loss of energy per unit of time, and hence the smallest flow, just as has been observed." Ref. (15).

This explains not only the great difference in the porosity of the different grade sizes in the materials used in this investigation but also it explains the relatively greater change i.e. a greater decrease in porosity with decrease in size of grain in the smaller grade sizes than in the coarser.

The application of the porosity results to the shape of sand grains with which this part of the work is primarily concerned yields some fairly definite conclusions. In the finer grade sizes (See Fig.2) i.e. from the .417 mm. size to the .147 the round beads are less porous than the crushed quartz. This is the result one would expect since the angular nature of the crushed quartz would tend to prevent the grains from fitting against one another in as compact a manner as possible; the grains tend to hold one another apart rather than to fit in together. The result of this is to create a greater amount of pore space which in turn causes a higher porosity value. As the size of grain increases past the .417 mm. size this property of the angular grains being more efficient in creating pore space does not seem to hold.

Little significance is attached to the fact that the curves show a greater porosity for the round beads than the angular quartz in the coarsest grades examined. This really represents only a difference in actual time reading of about 2 seconds whereas, the difference in time reading of the three smaller grade sizes varies from 15 seconds in the .295 mm. size, 25 seconds in the .208 mm. size to 28 seconds in the .147 mm. size.

When a definite amount of packing of the materials is undertaken the porosity of similar grade sizes of the two materials is much nearer the same than in unpacked conditions Fig. 3. Fig. 4 and 5 show that the packing has a greater effect ~~than~~ on the angular than on the round material.

This further substantiates the theory advanced to explain the first graph i.e. the angular material instead of occupying a small a space as possible tends to create a large pore space, the result being that when packed these grains are rearranged and come to occupy a much smaller space. Consequently, the effect of packing while it is a better method of ensuring similar treatment of material before each test, yet it causes the angular material to approach the round material in porosity reading so closely that the difference in the nature of the grains cannot correctly be interpreted. Fig. 5 shows the small effect packing has on round material. The round glass beads which are very nearly perfect spheres tend to occupy as small a space as possible even without being packed and the tendency seems to be to fit in together rather than to hold one another apart.

XI. Application of Method to Particular Sands.

Three sands representing different types of deposit and of different age were experimented with, the sands used being the 35, 48, 65 & 100 grade sizes of the following:

Winnipeg Sand
Boissevain Sand
Smith Siding Sand

The porosity tests were made with unpacked material. Fig. 6 shows the results of these tests with the curves representing angular quartz and round beads also shown.

The proximity of the Winnipeg sandstone and the Smith Siding curves is very noticeable; the curves are also very close to the round glass beads curve. The Winnipeg and the Smith Siding as mentioned in the first part of this investigation are exceedingly well rounded sands. The close similarity in the porosity results of these two sands indicates the practicability of this method in determining the shape of sand grains. The Boissevain sand curve shows it to be a more porous sand, even more porous than the crushed quartz in the coarser grades. The great irregularity in the shape of the Boissevain grains is considered to be the cause of this sand giving such high porosity values.

At first it was thought that crushed quartz would represent the highest degree of angularity possible in a sand. This view is now known to be erroneous since for the most part the crushed quartz is only angular in three dimensions and is comparatively flat in the fourth; this is due to the way in which this mineral fractures. The Boissevain sand with its very irregular development is really a more angular sand because it is angular in every dimension. This is especially the case in the coarser grades and thus the sand gives a greater porosity reading than does crushed quartz.

The porosity method of determining the shape of sand grains is deficient in one respect, that is, the slightest change in conditions in carrying out the experiment, especially any packing effects must be guarded against as this always has the effect of decreasing the porosity values much below normal.

BIBLIOGRAPHY

1 Bailey, J.P. — "Sedimentation Studies by Oil Companies" Researches in Sedimentation 1925-26 (Nat. Res. Council)

2 Boswell, P.G.H. — "The Distribution of Heavy Minerals in British Sediments" L.G.S. Oct. 1923.

3 Boswell, P.G.H. — "The Petrography of the Sands of the Upper Lias and Lower Inferior Oolite in the West of England" Geol. Mag. Vol. LXI pp. 246 - 64, June 1924.

4 Boswell, P.G.H. — "Some Recent Work on the Petography of Sedimentary Rocks" L.G.S. part lv, Vol. XIV 1927.

5 Boswell, P.G.H. — "On the Distribution of Purple Zircon in British Sedimentary Rocks" Mineralogical Magazine, Sept. 1927, Vol. XXI pp. 310 - 317.

6 Boswell, P.G.H. — "The Rarer Detrital Minerals of British Sedimentary Rocks" Trans. Geol. Soc. of Glasgow. Vol. XVIII part I,1926-27

7 Dake, C.L. — "The Problem of the St. Peter Sandstone" School of Mines and Metallurgy, Vol. VI August 1921.

8 Dowling, D.B. — "The Coal Field of the Souris River" Part F. Vol. XV G.S.C. Annual Report.

9 Edson, Fanny Carter — "Criteria for the Recognition of Heavy Minerals Occurring in the Mid-Continent Field" Okla. Geol. Survey Bull. No. 31.

10 Fleming, G.M. — "Field Methods in Sedimentary Petrography," Trans. Inst. Min. and Met. Vol. XXXIII 1924.

11 Galloway, J.J. — "Value of the Physical Characters of Sand Grains" G.S.A. Vol. XXXIII p.104.

12 Holmes, Arthur — "Petrographic Methods & Calculations"

13 Iddings, J.P. — "Rock Minerals"

14 Johannsen, Albert — "Determination of Rock-Forming Minerals"

15 King, F.H. — "Principles and Conditions of the Movements of Ground Water" U.S.G.S. XIX Annual Report.

16 Larsen, E.S. — "The Microscopic Determination of the Nonopaque Minerals" U.S.G.S. Bulletin 679, 1921.

17 Milner, H.B. — "An Introduction to Sedimentary Petrography"

18 Milner, H.B. — "A Study and Correlation of Sediments by Petrographic Methods" Mining Mag. Feb. 1923.

19 Parks, W.A. — "Report on the Building & Ornamental Stones of Canada" Canada Dept. of Mines Vol. IV.

20 Reed, R.D. "Some Methods of Heavy Mineral Investigation" Econ. Geol. Vol. XIX 1924.

21 Reed, R.D. "Heavy Mineral Investigations in California" Researches in Sedimentation 1926-27. National Research Council.

22 Reed, R.D. "Role of Heavy Minerals in California Tertiary Formations" Econ. Geol. Vol. XIX 1924.

23 Ross, Clarence C. "Methods of Preparation of Sedimentary Materials for Study" Econ. Geol. Vol. XXI 1926.

24 Shannon, W.G. "The Petrography & Correlation of the Surface Deposits of South East Devon" Geol. Mag. Vol. LXIV April 1927.

25 Sherzer, W.H. "Criteria for the Recognition of Various Types of Sand Grains" G.S.A. 1910, Vol.XXI pp.625-662.

26 Slichter, C.S. "Theoretical Investigation of the Motion of Ground Waters" U.S.G.S. 19th Annual Report.

27 Trowbridge, A.C. & Mortimore, M.E. "Correlation of Oil Sands by Sedimentary Analysis" Econ. Geol. Vol. XX p.409, 1925.

28 Upham, W. "The Glacial Lake Agassiz" U.S.G.S. Monograph XXV.

29 Wallace, R.C. "The Geological Formations of Manitoba"