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A Study of the Insoluble Residues of the Lower Traverse, Bell, and Upper Dundee Formations of Michigan

By

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A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in the University of Michigan.

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Approved

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A STUDY OF THE INSOLUBLE RESIDUES OF THE LOWER TRAVERSE, BELL, AND UPPER DUNDEE FORMATIONS OF MICHIGAN

Gerald E. Eddy

INTRODUCTION

The correlation of the Lower Traverse, Bell, and Upper Dundee formations of Michigan is one of the difficult problems encountered in the study of the subsurface geology of the state. This is especially true of the Dundee formation. Geologists are of varying opinions as to the age relationships of the quarry sections and the samples collected from wells drilled in the drift covered part of the state. In this paper the writer will attempt to show that there are definite characteristics by which the various formations may be recognized. Most of the 500 samples prepared and examined were furnished through the courtesy of the Michigan State Geological Survey. Additional samples were obtained from quarry sections, but there are but few localities in the state where good exposures of these formations may be found.

Certain characteristics have been found which indicate that correlations may be made over wide areas with a reasonable degree of accuracy. Enough work has not been done at present to be able to distinguish the lower Traverse and Dundee formations from either older or younger beds, hence no attempt is made to discuss these relationships. It is highly probable that similar results could be obtained from studies of the older and younger strata occurring in the Michigan Basin.

PREVIOUS STUDIES

The study of insoluble residues from calcareous well cuttings is not new. Methods for the examination of limestone samples have been used as far back as 1920. In 1920 Trager[1] proposed a method by which the sand, shale, and lime-

[1]Trager, Earl A., A Laboratory Method for the Examination of Well Cuttings, Econ. Geol. Vol. 15, pp. 170, 176, 1920.

stone fractions of a residue may be separated and analyzed. In this method the samples were first treated with hydrochloric acid and were then centrifuged to separate out the sand and shale portions. Lamar[2] has carried out experiments in which

[2]Lamar, J. E., Sedimentary Analysis of the Limestones of the Chester Series, Econ. Geol. Vol. XXL, pp. 578-585, 1926.

he examined residues from the Chester Series of Illinois. He obtained the residues by treating the cuttings with hydrochloric acid. The size of the particles, the textural features of the limestone, the heavy minerals, and the microfossils present were all considered in his paper. Claypool and Howard[3]

[3]Claypool, C.B. and Howard, W.V., Method of Examining Calcareous Well Cuttings. Bull. Amer. Assoc. Petrol. Geol., Vol. 12, pp. 1147-1152, 1928.

have prepared residues from limestones by dissolving them in hydrochloric acid, the heavy minerals being separated by means of a centrifuge. The principal work and the one upon which this paper is based was carried on by H. S. McQueen[4] under the

[4]McQueen, H.S., Insoluble Residues as a Guide in Stratigraphic Studies. Missouri Bureau of Geology and Mines - Appendix I, 56 Biennial Report, pp. 1-9, 1931.

direction of the Missouri Bureau of Geology and Mines in 1931. His method involves the treating the samples with dilute commercial hydrochloric acid and the examination of the residues thus prepared by means of a binocular microscope.

In so far as the writer is aware, there has been no attempt to correlate Michigan limestones by any of the above methods. All of the correlations to date have been based on drillers logs, logs compiled by the geologists of the various oil companies operating in the state, and from logs compiled by R. B. Newcombe and J. F. Poindexter under the direction of the Michigan Geological Survey, and have been based primarily upon their lithologic characteristics. Fossils found in the samples are practically valueless due to the fact that they have in most instances been destroyed in the drilling operations. Microfossils are significant and considerable work has been done in this field.

PURPOSE OF THE STUDY

The purpose of this investigation was to study the residues prepared and to see if there were any definite characteristics by which the lower Traverse, Bell and upper Dundee formations could be correlated across the State. The method used was the same as that used by McQueen,[5] described in his

[5] Op. cit. pp. 1-9.

paper on the Cambrian and Ordovician rocks of the Ozark region.

The topic was suggested by R. A. Smith, state geologist of Michigan as possessing potentialities as a new method of

correlating Michigan strata. The suggestion was made after he was convinced of its possibilities by H. A. Buehler, state geologist of Missouri, of its great value in naming formations very difficult to recognize by means of their paleontologic or lithologic content.

METHOD OF PROCEDURE

The reaction of hydrochloric acid with magnesium and calcium carbonates is a familiar one and has long been known, but its application to the study of limestones and dolomites is comparatively recent.

The samples prepared were taken from limestone quarries or were obtained from the state survey files. Any size sample varying from 2 to 30 grams may be used, depending upon the amount available. About 10 to 15 gram samples were found to be the most convenient. The cuttings were ground to pass a 10 mesh screen and placed in a 250 or 500 cc beaker. They were then covered with 50 cc of commercial hydrochloric acid diluted to half strength with distilled water. In some of the more strongly effervescing limestones the acid must be added very slowly in order to decrease the strong immediate reaction. It was discovered good practice to add water to the sample first and then add the acid to make up the 50% solution. In the case of the more slowly effervescing limestones, shales, and dolomites, heating on a sand bath was necessary in order to be sure of complete digestion of the carbonates. Care must be taken not to leave the samples in the sand bath too long because the mixture may become thick and gelatinous, producing small crystals

of gypsum. The gypsum is formed by the reaction between the sulphuric acid in commercial hydrochloric acid and the limestone or dolomite. After all reaction has ceased, the residues are washed by decanting off the clay and silt fractions. These clay and silt fractions were not saved for examination due to their fine state of subdivision which renders them too small for study. They also tend to obscure the nature of the larger, recognisable fragments. After washing, the samples were placed on a sand bath or in an oven and thoroughly dried. They were then placed in glass vials for future study. In some cases it was found necessary to treat the samples with the acid a second time in order to have complete digestion and to remove the siliceous film on the grains of the siliceous carbonate rocks.

The equipment required varies, depending upon the number of samples to be run. The writer has been able to run as many as 75 samples in 5 hours, but this number could be greatly increased with more efficient equipment. It was found most convenient to run the samples in groups of 20 or 25 at one time. In actual field work, samples can be prepared with a simple field kit and the examinations can be made with the ordinary hand lens.

The residues were examined with a binocular microscope. Low to medium power magnification was used in order to obtain a fairly large field and still have a high enough magnification to be able to recognize the various types of residues. Small, black cardboard trays were used to hold the specimens for examination. They measured about 2x3 inches by $\frac{1}{2}$ inch deep. One corner was cut off to facilitate the pouring back of the samples

into their respective vials.

About 60 photographs were taken of definite horizons. The photographs of the finer residues have a magnification of 12 diameters while those of the larger ones have a magnification of about 8 diameters. Comparing photographs was found to be much more reliable for correlation purposes than examination with the microscope as the student has nothing to carry over from one slide to the next.

CHARACTERISTICS OF THE RESIDUES

The characteristics of the residues of the lower Traverse, Bell and upper Dundee formations are quite variable, but they show enough contrast so that they are of value in indicating formational units as well as the larger stratigraphic divisions.

Shale is the predominant insoluble constituent of all of the residues. The shales vary from very fine, thin bedded, micaceous shales to massive, coarse bedded shales, which are shown in the residues as well rounded particles or angular fragments.

Next in importance to the shales is the sand content. The sand grains vary from very fine, angular, and poorly rounded grains to large and well rounded grains. Some of the grains are frosted and others are not grains at all, but are well developed crystals of quartz.

Other insoluble materials found in the residues are chert and secondary quartz in the form of irregular masses and the very small fragments making up the siliceous shales. Other minerals occurring are pyrite, hematite, limonite, and magnetite.

The writer did not study these minerals in detail as the study of the mass characteristics of the residues was the object of the investigation.

Another, and perhaps the most outstanding feature of the residues, was the occurrence of what McQueen[6] calls dolocasts.

[6]Op. cit. pp. 10-32.

He proposes the name "dolocast" because they are the impressions of the dolomite crystals in the insoluble chert, shale, or pyrite. To like structures found in the Michigan limestones, the name "cast" is applied, because these features were found, not only in residues from dolomite, but in residues from limestones as well. These casts are formed by the deposition of silica and other insoluble materials in the interstices between the crystals of dolomite and calcite. The casts are of two types. To the first type the name "spongy" is given, in which the intervening walls are thick and the openings caused by the dissolving out of the calcite are relatively small. The second type is one in which the openings are large and the intervening walls are relatively thin. These are called "lacy" casts. The occurrence of these casts seems to be more or less limited to zones close to unconformities, which the writer thinks indicates a tendency toward their development where there is extensive circulation of ground water and deposition of silica and pyrite.

FORMATIONS STUDIED

The formations studied in this paper are of Middle Devonian age, ranging from the upper Dundee, through the Bell shale,

to the top of the Long Lake series at the base of the Traverse formation. The investigation did not extend up further into the Traverse because the object was to distinguish between formations and not between the groups or series within a formation. The Bell shale at the base of the Traverse presents an interesting problem because of its great variation in thickness and its total absence in some parts of the state. A map showing the Middle Devonian Unconformity of Western Michigan is shown in Fig. 2.[7] The study of the Dundee formation is also

[7] Newcombe, R.B., Middle Devonian Unconformity in Michigan. Bull. Geol. Society of America, Vol. 41, p. 734, 1930.

very interesting because of the occurrence of oil in the formation. The prominent erosion surface at the top and the irregular deposition of the formation in parts of the state make a study of this nature of considerable importance in the field of Economic Geology. A summary of the characteristics of the residues follows on the succeeding pages.

Long Lake Series

The Long Lake Series is a grey or dark grey shaly, thin bedded shale and limestone, locally fossiliferous, cherty, or bituminous. The bituminous property is distinctly observed in the preparation of the samples, the acid taking on an oily appearance and the mixture giving off a strong odor of crude petroleum. Near the base of the formation are beds of chert and dolomite which have been instrumental in furnishing well developed casts.

The residues from wells in Muskegon, Newaygo, Midland,

Crawford, Cass, Missaukee, and Livingston Counties show a definite development of casts in the brown and grey shale members in the lower part of the series. On plate I, fig. 3 is shown the type of casts found in well No. 631 in Oceana County in a bed about 100 feet above the top of the Bell-Traverse contact. The residue here is a light brown shale, and the shape of the openings in the shale indicates that the dissolved mineral was probably dolomite. On plate I, fig. 2 is shown casts in a grey shale. The openings are not as large or as well developed as those in the brown shale beds. These casts come from a bed 50 feet above the top of the Bell-Traverse contact, and are from well #1177 in Missaukee County. On plate I, figs. 3 and 4 are shown residues from beds 100 and 50 feet above the Bell-Traverse contact respectively. Fig. 3 is from well #1020 in Livingston County and Fig. 4 is from well # 1177 in Wexford County. Another important difference in the residues from these two zones is in the nature of the shape of the shale fragments. The fragments from the bed 100 feet above the contact are very angular while those from the bed 50 feet above the contact are rounded. This seems to indicate that the particles have been transported and also that it is possible that they have been eroded from the Bell surface.

The casts in the brown shale are the best developed of the types found and the occurrence of this type together with casts in grey shale and chert seems to point quite definitely to the beds in which they occur as belonging to the Lower Long

Lake Series. The only areas where these casts do not occur are in two wells in Newaygo County. Here the residues consist of irregular, secondary quartz fragments showing iron staining, which gives a brown color to the residue as a whole.

Bell Shale

The Bell (Marcellus) shale is a blue or black to dark grey shale, locally fossiliferous. The thickness varies from 0 to 80 feet.

The insoluble residues consist principally of a massive shale. Massive, in this sense, means a coarse bedded shale and also a lack of casts. The shale fragments are light to dark grey in color. In shape they are either well rounded or sharply angular. While some of the shale fragments have the same shape as those found in the bed 50 feet above the Bell in the Traverse, they differ in that they are massive. There are some very fine, well developed casts in a brown shale but it is probable that they have had their origin in the Long Lake Series above and have become mixed with the Bell cuttings as a result of caving or slumping in the hole. They are almost identical with those described under the above heading. Care must be taken in order not to misinterpret these apparent results. It was concluded that they belong to the Long Lake Series because of their striking similarity and also because they occurred in only two out of the twelve wells sampled. There are a few casts in a brown shale that are not like the ones mentioned. They are coarser and possess what might be called a drusy structure. They also resemble very fine solution channels.

The residues in the eastern part of the state are fairly consistent, but the samples from wells in the western part of the state show a wide variation which seems to indicate varying conditions of erosion or non-deposition of the Bell shale. They vary from grey, massive shale, black well rounded shales, angular grey shale, to very fine angular silt. See plate II, figs. 1 and 2.

Dundee Limestone

The Dundee limestone is a grey and buff crystalline limestone, locally cherty, fossiliferous, and bituminous. Sulphate waters and highly mineralized brines occur in the lower beds while oil is found in commercial quantities in the upper beds. The thickness varies from 65 (?) to 250 feet.

Samples of the formation were taken from 19 wells and from 2 quarries. It was found that the residues from the Dundee are the most variable of any of those studied. The first ones to be examined were of rock specimens from the Rogers City quarry in Alpena County and from the Calcite quarry in Presque Isle County in the northeastern part of the state, and from the Sibley quarry in Wayne County in the southeastern part of the state. These localities were selected with the idea of correlating the horizons from these areas with the beds occurring in the Mount Pleasant field and also with the "Dundee" occurring in the Muskegon field in the western part of the state. There are but few complete sections of the Dundee available in the oil fields because the drilling usually has ceased as soon as oil is struck in the upper beds of the Dundee.

Only 6 of the 19 wells sampled penetrated through the Dundee into the Detroit River group.

The residues from the rock quarries in Alpena and Presque Isle Counties were found to be quite different from those from the Sibley quarry in Wayne County. Sand is the predominant constituent in the residues from both areas, but the sands differ in size and shape. The residues from the northern area show an angular to subangular type of grain which is, in general, larger than the angular grain found in the southeastern area. The residues from several beds from the Sibley quarry show a well rounded type of grain. The grains are also often frosted. (See plate III, fig. 4.) This rounding of grains may be due to a greater amount of transportation or to the action of solutions. J. J. Galloway[8] says that the

[8]Galloway, J. J., The Rounding of Sand Grains by Solution, Amer. Jour. Science, 4th Series, Vol. 47, pp. 270-280. April, 1919.

rounding of the grains may be done by solutions in a manner similar to the process of exfoliation. The largest grain that may be formed by this process is given as 0.1 millimeter, so it seems more likely that the grains found in the Sibley section are caused by abrasion and not by solution. There are, in addition to the rounded grains, several beds containing very fine angular grains of sand. These grains are very small and hence their angularity does not mean that they have been subjected to less mechanical transportation and abrasion than the rounded type of grain. It is much more probable that their

angularity is due to the fact that they are below the theoretical size limit for mechanical abrasion. That is, they are so small and their mass is so slight that the water film between the particles is sufficient to hold them apart. (See plate fig. 3.)

At a level about 25 feet below the top of the section are found two chert beds about 6 feet apart. These cherts are massive, showing but a poor development of casts. Residues from these cherts are shown on plate III, fig. 2.

The top 7 feet of the section show a good development of casts in a very thin bedded brown shale. The casts are of the lacy type with very thin walls between the openings.

The predominant constituent from well #130 in Macomb County is a rounded type of sand grain. In addition to these grains there are a few beds containing grains of the very fine angular variety of quartz (see plate V, fig. 1) and one bed about 50 feet from the top of the formation containing abundant pyrite masses and one bed of slightly castic chert at about the same horizon. There was also found one horizon in which casts occurred. The casts occur in brown shale and are very fine and poorly developed. They are very similar to those found in the upper seven feet of the section at Sibley quarry.

The predominant constituent of the residue from well #130 in Lenawee County is pyrite. This mineral is of the crystalline variety principally. In addition to the pyrite there are several samples showing the typical rounded grains of sand as described above. The same massive chert beds as

those noted at Sibley quarry were also found. There were several fragments of black shale but it is most probable that they are cavings from the overlying Bell shale.

Rounded grains of quartz are the most characteristic features found in the residues from well #1020 in Livingston County. The grains vary from white through brown, to a deep reddish-brown. This coloring is due to limonitic staining, which gives a brownish color or cast to the residue as a whole.

In the above six paragraphs is given a summary of the characteristics of the residues from wells in the southeastern part of the state. It will be noted that large, well rounded sand grains seem to occur in every section sampled. The writer did not find grains of this type in any other section studied with the possible exception of a few grains in the hand specimens from the Rogers City quarry in Alpena County.

In the northeastern part of the state, samples were obtained from four wells and from the Calcite quarry in Presque Isle County and from the Rogers City quarry in Alpena county. The wells are located in Presque Isle, Alpena, Crawford, and Ogemaw Counties. For an exact location of the wells sampled, consult Fig. 1.

The samples from the quarries were given to the writer by G. M. Ehlers and were obtained from the University Museum collection. While their geographical location is known, their stratigraphic location was not knowndefinitely. As stated at another place, the sand grains are angular and differ from the residues from the southeast part of the state only in their

size. The grains in the northern area are much larger and seem to indicate less abrasion and hence a smaller distance from the source to the point of deposition. There is one sample showing a non-castic chert and two containing abundant pyrite and hematite which have no counterpart at Sibley quarry.

The residues from well #830 in Alpena County show an angular quartz grain, a few beds of siliceous shale, and a mixed residue of pyrite, brown and black shale about 100 feet from the base of the formation. There are a few good casts found in a bed about 45 feet from the top of the formation.

In cuttings from Campbell #1 well in Alpena County, the residues from the top 75 feet consist of an impure cherty quartz, all the fragments of which are very angular or are irregular crystalline masses. An increase of pyrite up to 40% in amount was noted. The cherty quartz also changes to an impure chert. The lower 60 feet has a residue of angular crystalline quartz and cherty quartz.

In well #1143 in Ogemaw County the top 75 feet have a residue consisting of a light grey, thin bedded shale. The particles of shale are massive and are well rounded. Below this there is a bed of irregular, smoky quartz and chert which is a decided change from the overlying beds. These are followed by 40 feet of brown to grey shale, containing casts in the brown shale and considerable amounts of pyrite and hematite. Below these beds is 10 feet of grey shale and very fine sand grains cemented together to form features resembling casts. The fine sands persist downward for an additional 10 feet and then this

gives way to a few feet of impure chert which is slightly castic. This is followed by massive shale containing abundant hematite. The hematite is especially abundant in the last 20 feet of the section.

The residues from Grayling #1 well in Crawford County are principally fine bedded, siliceous grey shales plus a few rounded, frosted quartz grains. Crystalline pyrite is quite common and there are also a few particles of blue, irregular, massive quartz.

All of the above samples are from the northeastern part of the state. Summarizing, the outstanding characteristics of the residues from this area are the angular, large sand grains and a greater abundance of either crystalline or massive pyrite. The percentage of pyrite in some of the cuttings runs as high as 60% in one well. The residue from the Grayling well differs from all the rest in that the principal constituent is siliceous shale, thin bedded and entirely lacking in casts.

Cuttings from wells in Newaygo, Oceana, and Muskegon Counties were studied and the following things noted.

It was discovered that the residues from this area were the most variable of any of those examined. There seemed to be a wider variation over a much smaller area than from any wells in other sections of the state. In other areas, the residues seem to show a distinct similarity, as the above descriptions indicate.

In well #631 in Oceana County the residues consist of fine, poorly rounded to angular quartz grains. In well #346

in Muskegon County, the residue is a light grey shale whose fragments are well rounded. This feature was only found elsewhere in wells in the central part of the state. The residue from well #788 in Newaygo County is a brown sand. The grains are chiefly rounded and frosted with a few grading over into the angular type. All of the grains are iron stained and are very similar to the ones found in well #654 in Newaygo County. In addition to these features, there was also found clear, crystalline quartz and a few fragments of magnetite partially altered to limonite. In well #696 in Newaygo County, the residue consists of grey shaly fragments, some angular quartz and a few grains of the rounded type.

In the central part of the state, residues from four wells were prepared and examined. The residues from this area were found to differ widely from any other Dundee samples with the exception of well #346 in Muskegon County. A description of the residues will be given in the succeeding paragraphs.

In well #73 in Midland County the residue consists chiefly of a grey to brown shale, the fragments of which are well rounded. This feature is shown on plate IV, fig. 2. There are also some thin walled casts in chert and a fairly abundant occurrence of pyrite. In well #982 in Mecosta County the residue is also chiefly a shale. The particles are well rounded. The shale varies in color from grey, through brown, to black. The next most common feature was the great abundance of pyrite. This mineral occurs in all but 20 feet of the 120 foot section and is of both the massive and the crystalline

variety. Limonite is also present in beds near the base of the section. The residues from well #1149 in Isabella County are much the same as those in well #982 in Mecosta County, grey, brown, and black shales predominating. One horizon was found containing the rounded quartz grains found at Sibley quarry. This is shown on plate V, fig. 2. Near the base of the section, the residues grade into a much darker shale, some of them being almost coal black. In well #8 in the Saginaw field, the residues of the entire Dundee section consist of shale fragments, all of which are well rounded. (See plate V, fig. 4.) A few casts in pyrite and chert were found but occur in such small quantities that they are not significant. A few beds of brown shale occur in which there are what appears to be casts, but it is more probable they are the result of solution from ground water.

SUMMARY AND CONCLUSIONS

The depositional features of the Michigan Basin are found to be much different from those in any other part of the country. Sediments have been laid down in fluctuating basins and between the structural ridges. These ridges have acted as natural barriers to the migration of the various types of fauna. The seas entering the Michigan basin have come from several different directions and the barriers have kept the seas from intermingling.[9] G. M. Ehlers[10] is of the opinion that the

[9] Newcombe, R. B., Depositional and Structural Features of the Michigan Synclinal Basin, pp. 94-97. June 1931 (In print).

[10]Oral Communication.

Dundee section at Calcite quarry is of a different age than that of the Sibley quarry. He basis his opinion on the difference in the faunal life. Some species that occur in the northern section are not represented in the southeastern part of the state, and vice versa. R. A. Smith[11] is also of a similar

[11]Oral Communication.

opinion. In the study of the residues, no features were found in the residues which the writer could be sure occurred in both areas. It was found, however, that the residues were consistent over small areas. This fact seems to bear out the idea of R. B. Newcombe[12] that at the end of Dundee time there was a long period

[12]Op. cit., pp. 161-164.

of erosion or non-deposition of marine sediments. This is also shown by the fact that the Dundee varies in thickness from 200 feet to total absence over comparatively short distances.

The residues from the Dundee formation in the Mount Pleasant field were found to be much different from any found elsewhere in the state. They do not conform to typical Dundee "purity" due to the fact that the principal constituent of the residues is shale, grey to brown in color. It was first thought that they were cavings from the overlying Bell shale because the fragments were all well rounded. They occur much too consistently for this to be the case. The presence of this shale would seem to indicate that the Dundee in this locality is a

shaly facies, having been laid down in close proximity to some land mass.

In the western part of the state, the residues are not at all consistent. The area studied includes Oceana, Newaygo, and Muskegon Counties. Even in such a small area the residues from the different wells do not correspond as well as the residues from samples from other parts of the state. This is probably due to erosion or non-deposition of the Dundee beds. Newcombe[13] says that there is a east-west area across Oceana,

[13] Op. cit., p. 163.

Newaygo, and Muskegon Counties with smaller basins paralleling the area on either side. This structural feature, no doubt, accounts for the lack of similarity in the residues. With one exception, the residues from all of the wells are characteristically "Dundee" in that they consist of sand grains. The grains are usually brown due to limonite staining.

The Bell formation has a residue consisting entirely of shale fragments. The fragments may be either well rounded or sub-angular in shape. This feature is most prominent in wells from the central and from the eastern parts of the state. The residues from wells in the Muskegon area do not seem to be as consistent. This is not surprising as the Bell shale was laid down in a sea progressively overlapping to the west.[14] The Bell

[14] Newcombe, R.B., Middle Devonian Unconformity in Michigan. Bull. Geol. Soc. of Amer., Vol. 41, pp. 725-738, 1930.

has never been found in wells in the southwestern part of the state. The oscillatory nature of the sea bottom caused the

alternating beds of shale, limestone, and calcareous shale.[15]

[15] Newcombe, R. B., Depositional and Structural Features of the Michigan Synclinal Basin. P. 258. June, 1931. (In print).

The residues of the Long Lake Series appear to be the most consistent of any of those examined. Two horizons were found which have the same characteristic type of residue. It was in the Long Lake Series that the good casts were discovered. There were two zones in which these casts were especially common. These zones are located 50 and 100 feet above the top of the Bell shale. The casts from the two zones differ in the shape of the shale fragments in which the residues occurred. The casts from the lower horizon are in pieces of rounded shale while those from the upper beds are in fragments of angular shale.

It is true that not all residues from the same horizon are identical. There are minor differences, the addition of new material, or the loss of others. These variations are of minor importance as the main and characteristic features of the residues are the significant things by which the zones may be recognized.

Erosion surfaces may be located by this method. A good circulation of ground water is conducive to the formation of good casts by furnishing abundant insoluble material.

It is very probable that further work would shed much more light on the problem, and this paper is written with the purpose in mind of stimulating further investigations in the study of insoluble residues.

FIG. 1. MAP SHOWING LOCATION OF WELL AND QUARRY SAMPLES.

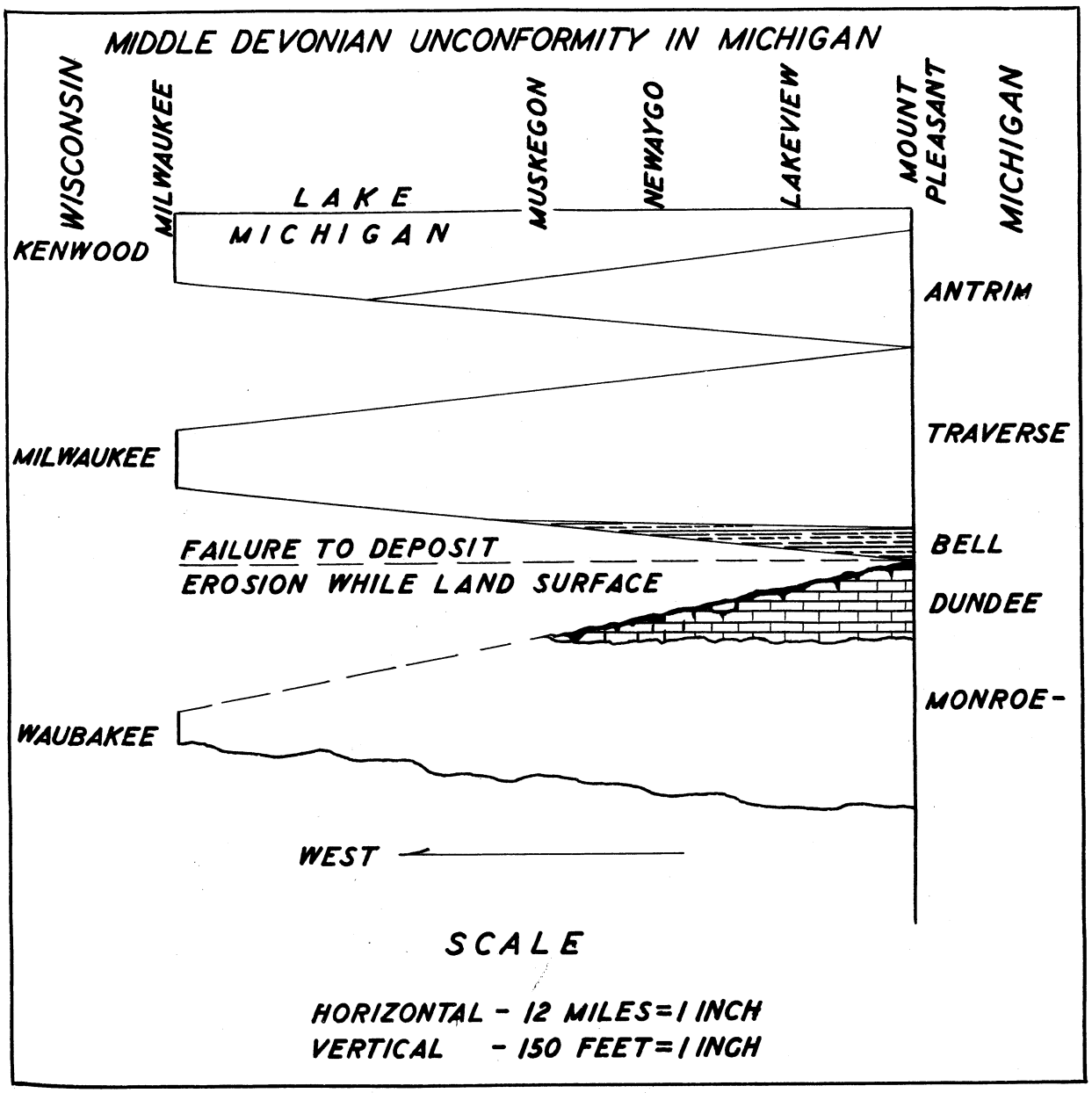

FIG. 2. DIAGRAMMATIC SKETCH OF THE MIDDLE DEVONIAN UNCONFONFORMITY IN WESTERN MICHIGAN. (AFTER R.B. NEWCOMBE)

PLATE I

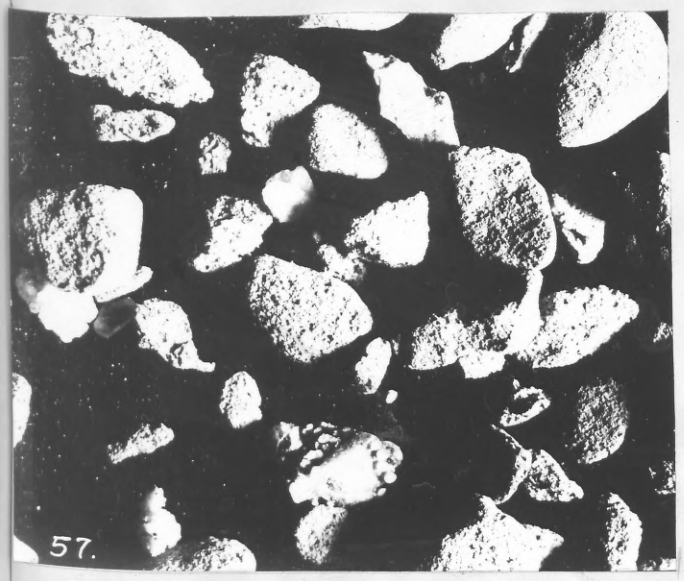

Fig. 1. x8

Fig. 2. x8

Figures 1 and 2 are from beds 50 feet above the top of the Bell Shale in the Traverse Formation

Fig. 3. x8

Fig. 4. x8

Figures 3 and 4 are from beds 100 feet above the top of the Bell shale in the Traverse Formation

INSOLUBLE RESIDUES OF THE LONG LAKE SERIES

PLATE II

Fig. 1. x8

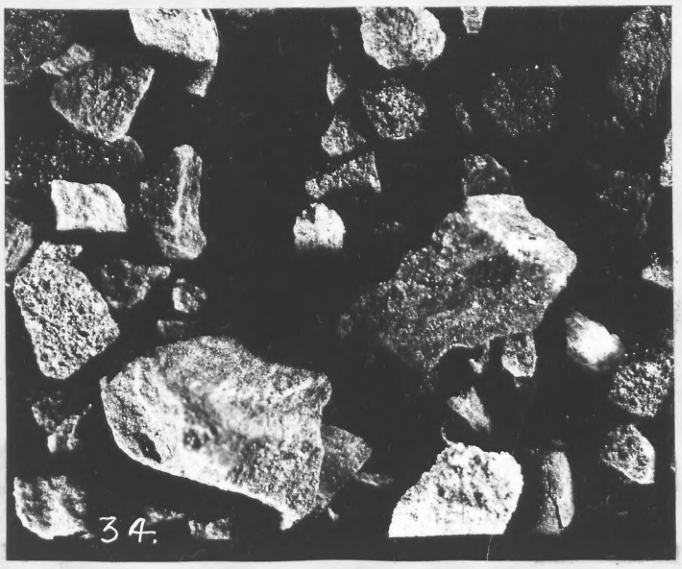

Fig. 2. x8

RESIDUES OF THE BELL SHALE

PLATE III

Fig. 1. x8

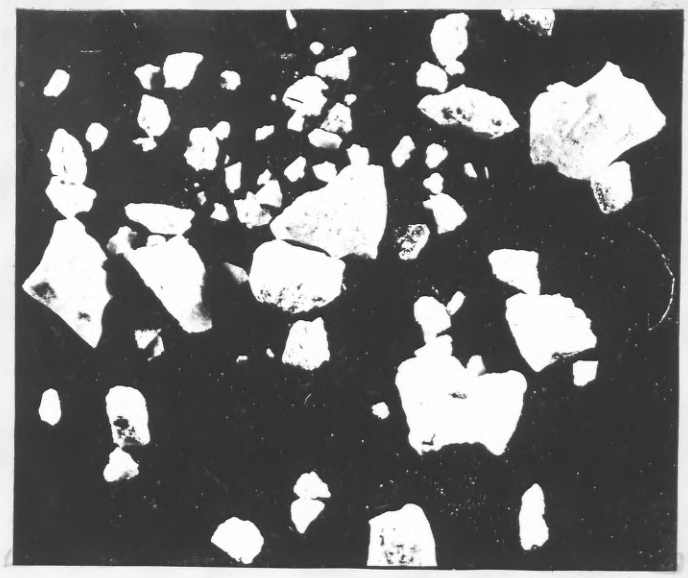

Fig. 2. x8

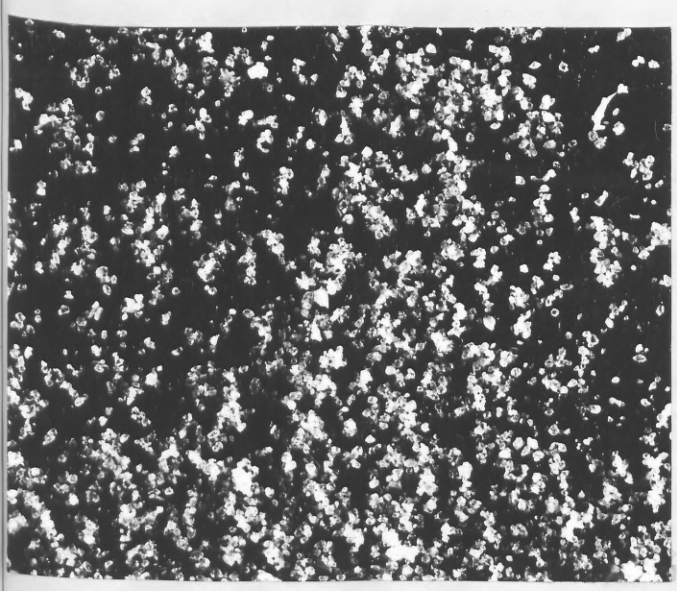

Fig. 3. x18

Fig. 4. x18

RESIDUES CHARACTERISTIC OF THE DUNDEE FORMATION

SAMPLES ARE FROM A BED 50 FEET BELOW THE TOP

PLATE IV

Fig. 1. x8

Fig. 2. x8

CHARACTERISTIC RESIDUES OF THE DUNDEE FORMATION FROM A BED 50 FEET BELOW THE TOP OF THE FORMATION

PLATE V

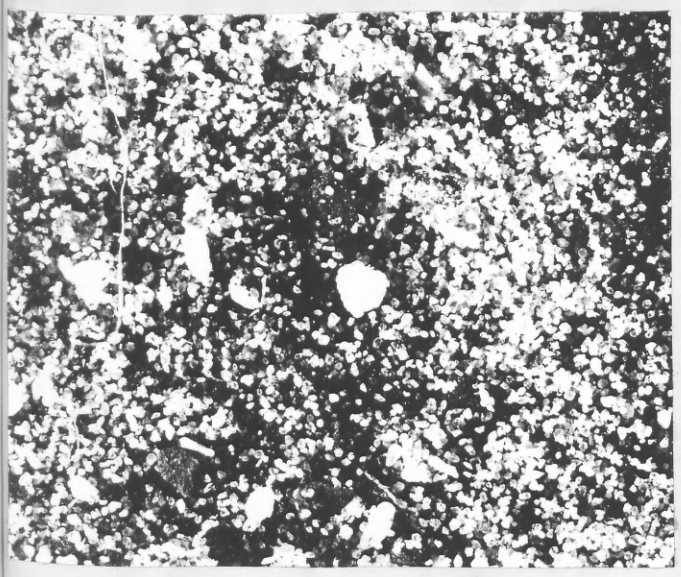

Fig. 1. x12

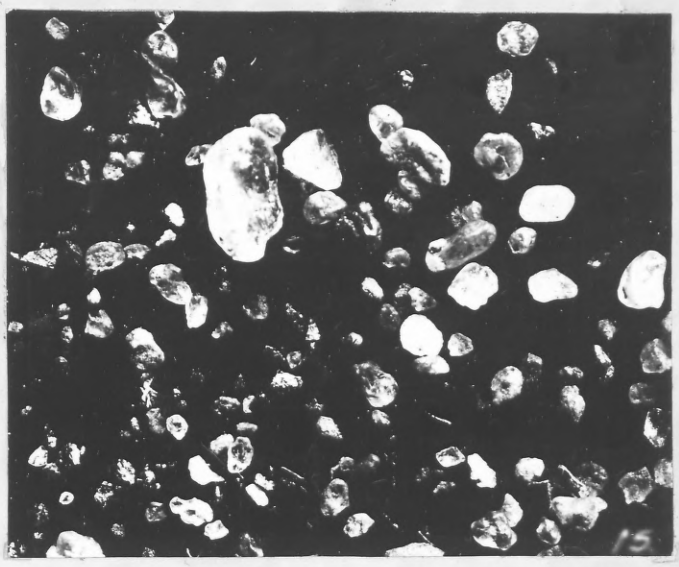

Fig. 2. x12

Fig. 3. x8

Fig. 4. x8

RESIDUES CHARACTERISTIC OF THE DUNDEE FORMATION FROM A BED 100 FEET BELOW THE TOP OF THE FORMATION

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