THE STRATIGRAPHY OF THE AU TRAIN FORMATION AT AU TRAIN FALLS AND WAGNER FALLS, ALGER COUNTY NORTHERN MICHIGAN

Thesis for the Degree of M. S.

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ABSTRACT

THE STRATIGRAPHY OF THE AU TRAIN FORMATION AT AU TRAIN FALLS AND WAGNER FALLS, ALGER COUNTY, NORTHERN MICHIGAN

by Daniel B. Blake

The Au Train Formation of Northern Michigan occurs at the surface near the shore of Lake Superior. It displays an east-west trend in the eastern part of the peninsula. Southeast of Marquette, the outcrop changes to a southwestward trend. There are relatively few good exposures because of an overburden of glacial drift. The formation has been correlated with the Hermansville Formation by some workers but because of the lack of field evidence this correlation has been questioned. A distinct difference in lithology does exist between the typical Au Train lithology and the typical Hermansville lithology. This difference is responsible in part for the disagreement in correlation.

Field work was done during the summer of 1961. A detailed study was made of the rocks cropping out at Au Train Falls and Wagner Falls. Other smaller outcrops were visited. Rock samples, and, where possible, fossils, were collected for laboratory study.

In the laboratory, sedimentary analyses, including heavy mineral study, was performed on selected specimens. This work suggested to the

writer that the Au Train Formation was deposited in relatively quiet water at shallow depth possibly under slightly reducing conditions and under the partial influence of longshore currents.

The writer identified specimens of Lingulepsis exigua (Matthew). To the writer's knowledge, this is the first reported occurrence of this species in the Upper Mississippi River Valley area.

If the Au Train Formation proves to be Ordovician in age, then the species range should be extended.

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by

Daniel B. Blake

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Gratitude is expressed to David Cummings, graduate student in the department of Geology, for advice, suggestions, and criticism.

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INTRODUCTION

Purpose and Scope

The purpose of this thesis is a stratigraphic study of the Au Train Formation. An attempt is made to determine the formation's environment of deposition and geologic age. The formation is in Northern Michigan; the study is concentrated on the sections at Au Train Falls and Wagner Falls.

Stratigraphic sections at Au Train Falls and Wagner Falls were studied and samples were collected. Sedimentary analyses including heavy mineral identifications were made. Paleontological studies were made where possible. Fossil significance is noted.

Previous Work

Because of limited exposures, considerable disagreement has existed as to the age and correlation of this formation. Rominger (1873) suggested that these rocks were equivalent to the "chazy" and "calciferous" units of New York. After working in the Menominee area, Van Hise and Bailey (1900) applied the name Hermansville to the units described by Rominger. Van Hise and Bailey did not describe a distinct type locality. Because of this shortcoming, Grabau (1906), after studying the comparatively good exposures at Au Train Falls, proposed the term "Aux Trains." Bergquist (1937) retained the term "Hermansville" but later authors have preferred the term "Au Train", a slight modification of Grabau's proposal.

Location

The area is located in the Northern Peninsula of Michigan. It is in the north central portion of the peninsula along the south shore of Lake Superior, near the town of Munising (Fig. 1).

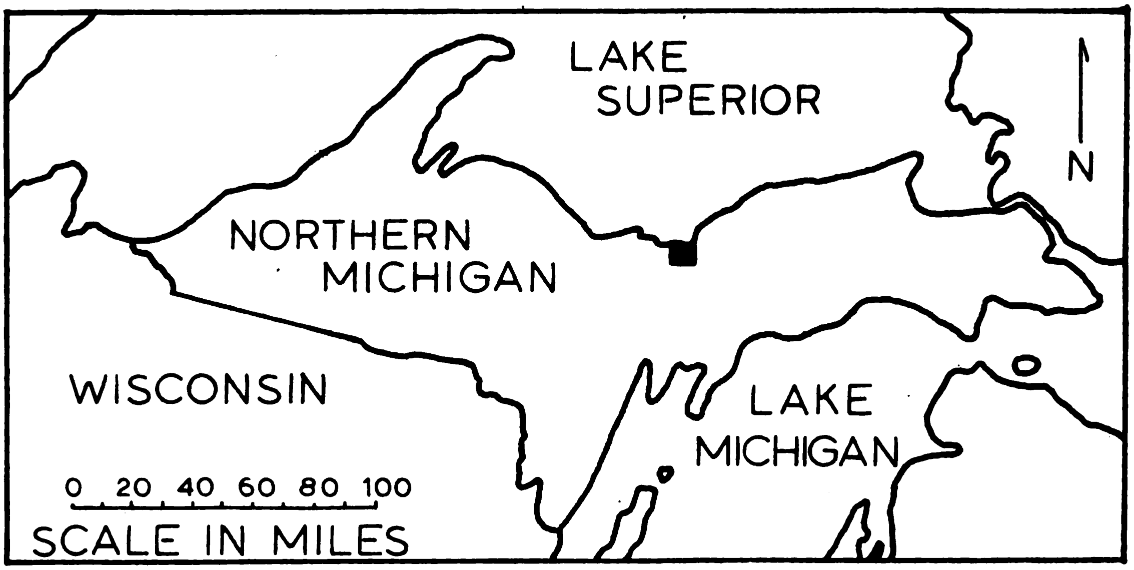
FIELD PROCEDURES

R. C. Hussey and E. O. Ulrich in the summer of 1927 and R. C. Hussey in the summer of 1928 studied outcrops of Lower Paleozoic rocks in Northern Michigan. The Michigan State Geological Survey possesses information on the locations of these outcrops. The survey permitted the writer to use this information. Many of the Hussey-Ulrich outcrops were small roadcuts which have apparently been overgrown with vegetation since Hussey's and Ulrich's field work. Nevertheless, these outcrops were visited and studied where possible. In addition, the writer looked for new exposures.

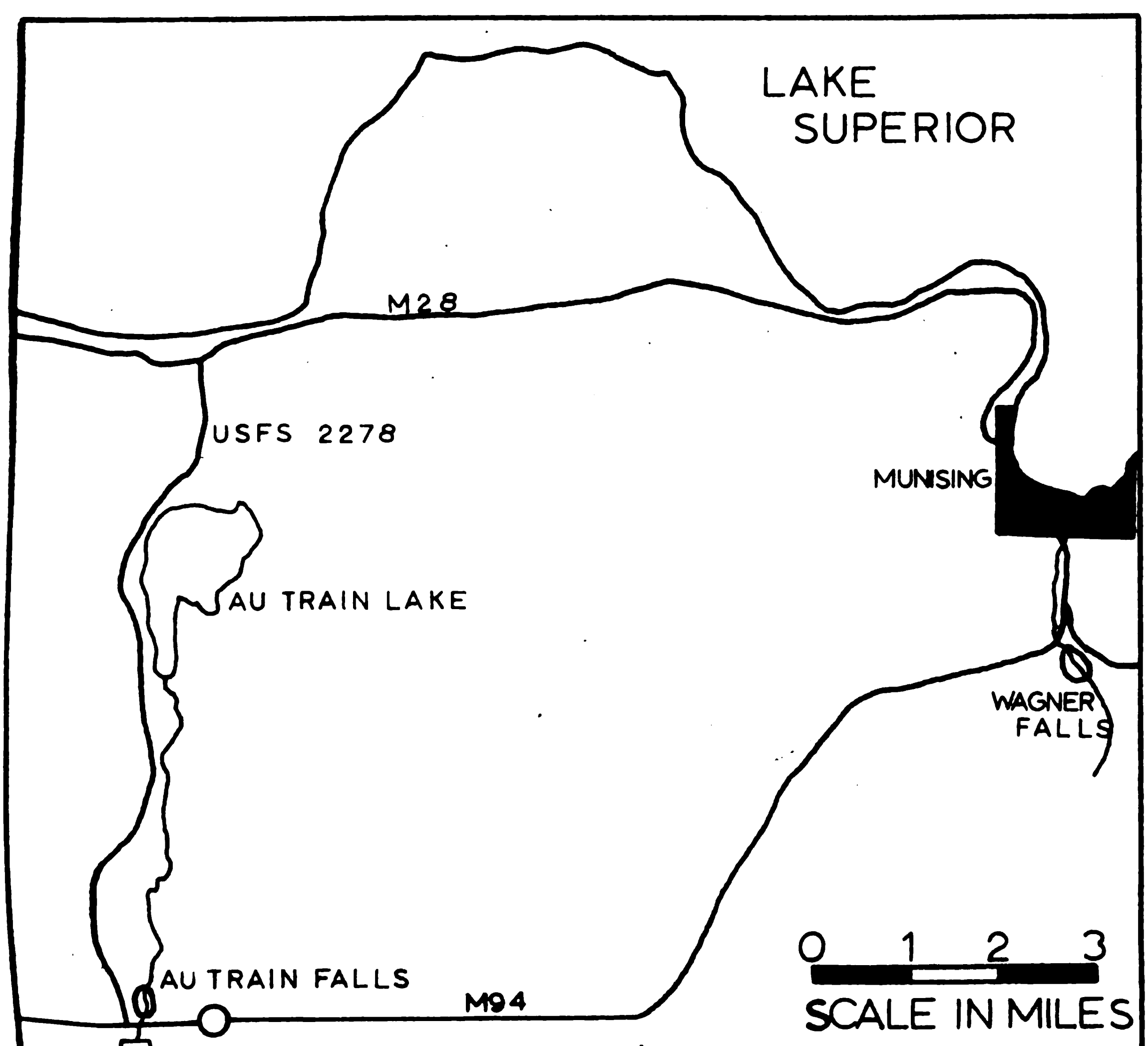
A sample or samples were collected at various locations. Lithology was observed and location relationships between typical Hermansville lithology and typical Au Train lithology were noted. Attempts were made to find paleontological evidence.

However, the major portion of the writer's effort was expended in the study of the sections at Au Train Falls and Wagner Falls. These two sections were measured in detail. Hand sample sized specimens were collected at every major lithic variation. If no variation was noted, random samples were collected at intervals not exceeding five feet.

FIGURE 1
LOCATION OF STUDIED AREAS IN NORTHERN MICHIGAN



LOCATION OF AU TRAIN FALLS AND WAGNER FALLS



STRATIGRAPHY

General Section

The rocks considered herein are underlain by the Munising Sandstone which has been correlated with the Dresbach and Franconia formations of Wisconsin on the basis of heavy minerals (Driscoll, 1956).

The Au Train and Hermansville lithologies rest on the Munising sandstone. The Au Train and Hermansville are considered to be a facies relationship by some workers (Hamblin, 1958). Other workers (Prouty, personal communication) consider the two units to be stratigraphically distinct in time because of a difference in lithology which exists between the Hermansville as described at Menominee and the rocks at Au Train Falls. He (Prouty) further compares the Hermansville lithology to the Prairie du Chien of Wisconsin and the Southern Michigan subsurface; and the Au Train to the typical Upper Cambrian Sandstones of Wisconsin. The Hermansville consists of a relatively pure dolomite whereas the Au Train at Au Train Falls is a dolomitic sandstone which contains abundant pyrite and glauconite. Hamblin (1958) believes a facies relation exists between the two lithologies. Oetking (1951), after studying the Hermansville-type lithology at the town of Eben, between Au Train Falls and Menominee, concluded that these rocks are twenty feet stratigraphically above the top of the exposed section at Au Train Falls. The writer knows of no

location where the contact between the typical Hermansville lithology and typical Au Train lithology can be observed. Therefore the relationship cannot be as yet conclusively determined.

On the basis of fossils, Oetking and Hamblin believe the Au Train to be lower Middle Ordovician (Black River). This interpretation has been questioned because of the poor quality of the preservation of the Au Train fossils which renders conclusive identification difficult (Prouty, personal communication).

The rocks overlying the Au Train Formation have been classified as Middle Ordovician (Cohee, 1948). These rocks are commonly fossiliferous. At the Van Meer quarry east of Munising the writer collected and identified specimens of the following forms.

Cephalopods

Actinoceras beloitense (Whitefield)
Endoceras proteiforme (Hall)
Murryoceras murrayi (Foerste)

Gastropod

Raphistoma sp.

Pelecypod

Vanuxemia sardesoni (Ulrich)

Brachiopod

Strophomena incurvata (Sheppard)

Au Train Formation

The Au Train Formation forms the cap rock of an escarpment of Munising Sandstone along Lake Superior. In Alger County, west of Munising, this escarpment has receded from the lake shore. In this county many waterfalls are developed on the Au Train Formation and a

considerable thickness of this unit may be exposed.

The best exposures known to the writer are at Au Train Falls and Wagner Falls, the two sections considered in this study.

The carbonate-clastic percentages (Table 3, appendix) show that the formation, in general, ranges from a dolomitic sandstone to a quartzose dolomite in its exposed thickness. However, the clastic content is locally variable.

Oetking (1951) believed the Munising-Au Train contact at Au Train Falls to be located slightly below the lowest of the series of falls. On the basis of heavy minerals, Driscoll (1956) suggested that this lowest portion of the falls is formed by the Munising Sandstone. On the basis of gross lithology, the writer concurs with Driscoll. The writer believes the first Au Train rock to be the four inch band of glauconite located at the top of the lower falls.

At Wagner Falls, the base of the Au Train Formation crops out at the top of a step-face well above the foot of the falls. The rock contains abundant glauconite and also pebbles of the friable coarse grained Munising Sandstone implying that the latter formation was partially reworked.

When fresh, the Au Train is light grey to light brown with glauconite commonly imparting a greenish hue. The rock weathers to a darker yellow brown.

In the lower portion of the formation the bedding is thin and irregular with numerous shale lenses. Glauconite is abundant in disseminated form as well as in concentrated bands which are up to several inches thick. Bands of concentrated quartz sand are common. Pyrite is present, being visible in the hand specimen. Cross bedding

and ripple marks occur.

In the stratigraphically higher, more dolomitic portions of the exposed section, the bedding is more massive. Glauconite is less important than in the lower portion of the formation. Quartz sand bands are common. Pyrite is apparent at many horizons forming nodules up to one inch long. Fossils, while extremely rare, are present. Because of the local variation in lithology, the writer was unable to make a detailed correlation between the two sections.

Hamblin (1958), from investigations of well cores, reports the Au Train Formation to be 300 feet thick. Only the lower portion of this thickness crops out at Au Train Falls. Good exposures of the upper portion of the formation have not been found.

Hamblin (1958) reported that a covered interval fifteen feet thick occurs at Au Train Falls. Because of subsequent erosion along the stream bank, the writer believes this thickness of rock is now exposed. At Wagner Falls, however, many thin covered intervals occur.

The measured sections of the Au Train Formation measured by the writer at Au Train Falls and Wagner Falls may be seen in Fig. 3.

**Comparison to a Core
from the Escanaba Area**

R. A. Dixon (1961) studied a well core from Delta County northwest of Escanaba, Northern Michigan. The writer compared his lithology to those lithologies reported by Dixon. The author recorded a zone of prominent pyrite, glauconite and garnet. This zone rests on a sandstone which contains well rounded sometimes frosted quartz. An increase in garnet is reported to occur higher in the section. Dixon considers this to be equivalent to the Dresbach and Franconia units of Wisconsin. It would therefore be comparable to the Munising Sandstone of the Lake Superior shore. Hence the overlying zone rich in pyrite, glauconite and garnet may be equivalent to the Au Train Formation of the lake shore because of the similar lithology and minerals. Dixon considers this zone of his well core to be Trempealeau in age. He bases this correlation on the lithologic similarity to the Trempealeau of Wisconsin. Because of Oetking's (1951) fauna, the writer considers the Au Train to be Middle Ordovician in age. There are two possible explanations for the conflict in time designations between Dixon and the writer.

1. The units, in spite of lithologic and stratigraphic continuity, may not be correlatives.

2. The lithologic correlation to Wisconsin may not be valid.

Dixon's study includes rocks designated as Middle Ordovician in age. The unit he considers to be Black River in age is rich in pyrite.

but is relatively pure dolomite, quartz and garnet being minor. Glauconite is not reported. Beneath this zone is a sandstone which contains abundant garnet and, in addition, some pyrite and glauconite. Dixon considers this zone to be the Glenwood equivalent.

The writer feels he does not possess sufficient information to formulate a valid correlation between the two areas.

Au Train Paleontology

The fossil content of the Au Train Formation is limited. Oetking (1951) and Hamblin (1958) collected in a road cut near Miners Castle. The writer, in an attempt to find new forms, concentrated his effort on other areas.

A new outcrop was found on a country road 1 1/3 miles due east of an outcrop described by Hussey in his field notes (see Fig. 2). The outcrop is in the form of a shallow drainage ditch along the north side of the road. The ditch was dug in the spring of 1961 exposing about eight feet of the Au Train Formation section. The material from the ditch was placed along the ditch's bank. Several fragments containing fossils were found in the trenched material about one vertical foot from the top of the outcrop. The freshness of the specimens that contain the fossils and the location of the three samples together in trenched material, all of the same lithology, has convinced the writer that the samples were derived from this location. However, the writer stresses that ultimately it cannot be proven that the samples were derived from bedrock at this location.

One of the three samples collected at this site contains only fragments impossible to identify. The other two samples contain

brachiopods. One brachiopod specimen is the exterior of a ventral valve and the other is the interior of a dorsal valve. Both were identified as Lingulepsis exigua (Matthews) by the writer. A shell fragment, believed to be of the same species was found in place at Au Train Falls. To the writer's knowledge, this species has not been described beyond the Cape Breton area. It also has been restricted to the Upper Cambrian. If the Au Train Formation is Black River, then the range of the species should be extended.

Another possibility concerning these specimens would be that they were reworked from an Upper Cambrian formation. If this were the case, then its stratigraphic range might be the same as at Cape Breton.

Lingulepsis exigua (Matthew)

> Ventral exterior: length 10 mm., width 8 mm., acuminate, very fine radiating straie, concentric growth lines forms a minutely irregular granulose surface at the anterior portion of the shell.
> Dorsal interior: anterior portion missing, fragment length 5 mm., width 7 mm., triangular outline; the vascular system left a central double groove with a slight ridge in between, lateral grooves are also present; rows of pits along the concentric growth lines partially obscure the vascular grooves.

In addition to the forms mentioned above, the writer found two inarticulate brachiopods and a low spired gastropod, none of which could be identifed.

The writer also found several small short cylindrical pyrite aggregates. It is suggested, on the basis of shape, that these are organic in origin, perhaps from worm burrows. The pyrite is presumed to have replaced the original organic material.

The University of Wisconsin permitted the writer to study Oetking's fauna. Oetking's fauna, as reported by him in his study,is listed below.

Cystoidea

Pleurocystites cf. *P. sqamosus* (Billings)

Brachiopoda

Lingula sp.

Gastropoda

Sinuites sp.
Sinuites sp.
Bucanella cf. *B. nana* (Meek)
Pterotheca cf. *P. expansa* (Emmons)
Raphistomina cf. *R. lapicida* (Salter)
Raphistoma sp.
Trochonema sp.
Liospira cf. *L. micula* (Hall)
Eotomaria suprecingulata (Billings)
Clathrospira subconia (Hall)
Helicotoma planulata (Selter)
Archinacella sp.

Scaphopoda

Hyolithes cf. *H. baconi* (Whitfield)
Prescochiton cf. *canadensis* (Billings)

Cephalopoda

Endoceras

Trilobita

Basiliella barrandi (Hall)

The writer concurs with Oetking's designation of the fauna as Middle Ordovician.

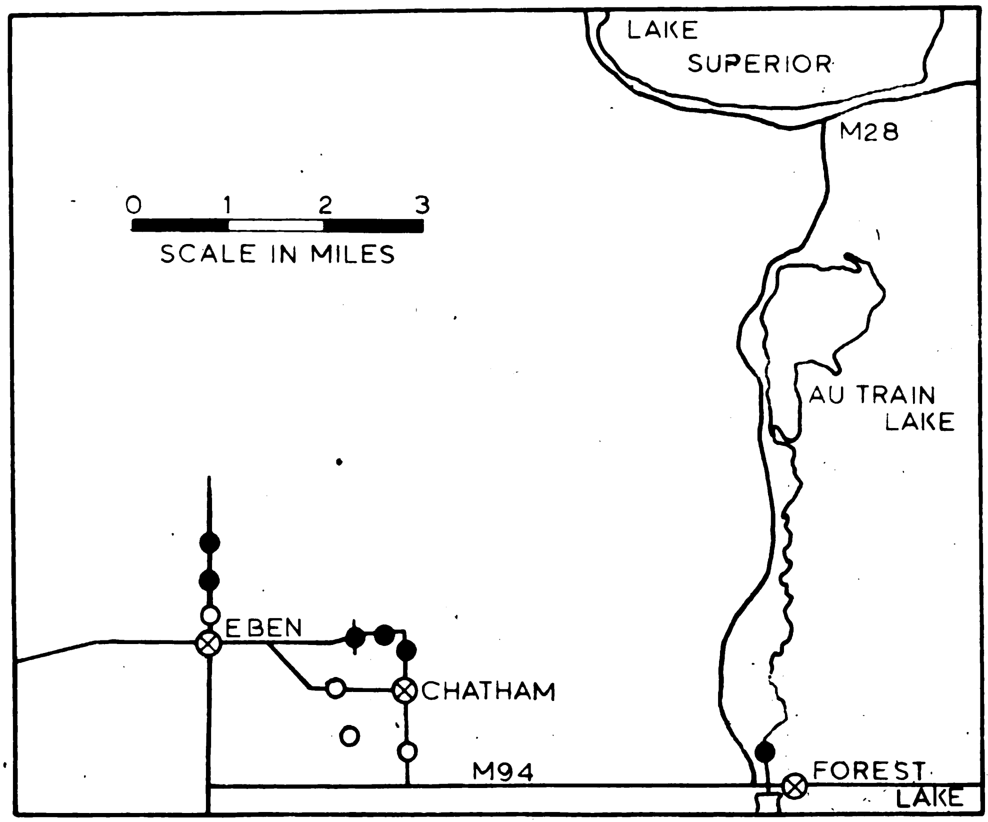
Hermansville Formation

Because the relationship between the Au Train lithology and the Hermansville lithology has not yet been fully established, the Hermansville is here considered separately.

The area in which the Hermansville occurs is a low drift-covered plain stretching southwestward from about the town of Eben. The occurrence farthest to the southwest is near Iron Mountain, Michigan. No good outcrop sections are known to the writer. Hussey (1936) described the rocks at Trenary as being somewhat siliceous argillaceous limestone. He reports irregular bedding varying from one inch to one foot. Oetking describes the rock at the town of Eben as a "fine-grained yellowish-grey dolomite evenly but sparsely scattered with frosted quartz grains."

Few fossils have been found. Rominger (1873) reported molluscan shell fragments. Van Hise and Bailey found further material, "a broken orthoceras, a fragment resembling a piece of cyrtoceras, a gastropod, and several other fragmentary forms..."

LOCATION OF OUTCROPS DISPLAYING DOMINANT LITHOLOGIES



LEGEND

● TYPICAL AU TRAIN LITHOLOGY
○ TYPICAL HERMANSVILLE LITHOLOGY
♦ LOCATION OF OUTCROP WITH L. EXIGUA

FIGURE 2

GENERALIZED GEOLOGIC COLUMNAR SECTIONS OF THE AU TRAIN FORMATION AT AU TRAIN FALLS AND WAGNER FALLS NORTHERN MICHIGAN

DOLOMITIC SANDSTONE
QUARTZOSE DOLOMITE
CONGLOMERATE
GLAUCONITE
PYRITE
COVERED INTERVAL

R5C2 SAMPLE ANALYZED IN THE LABORATORY

FIGURE 3

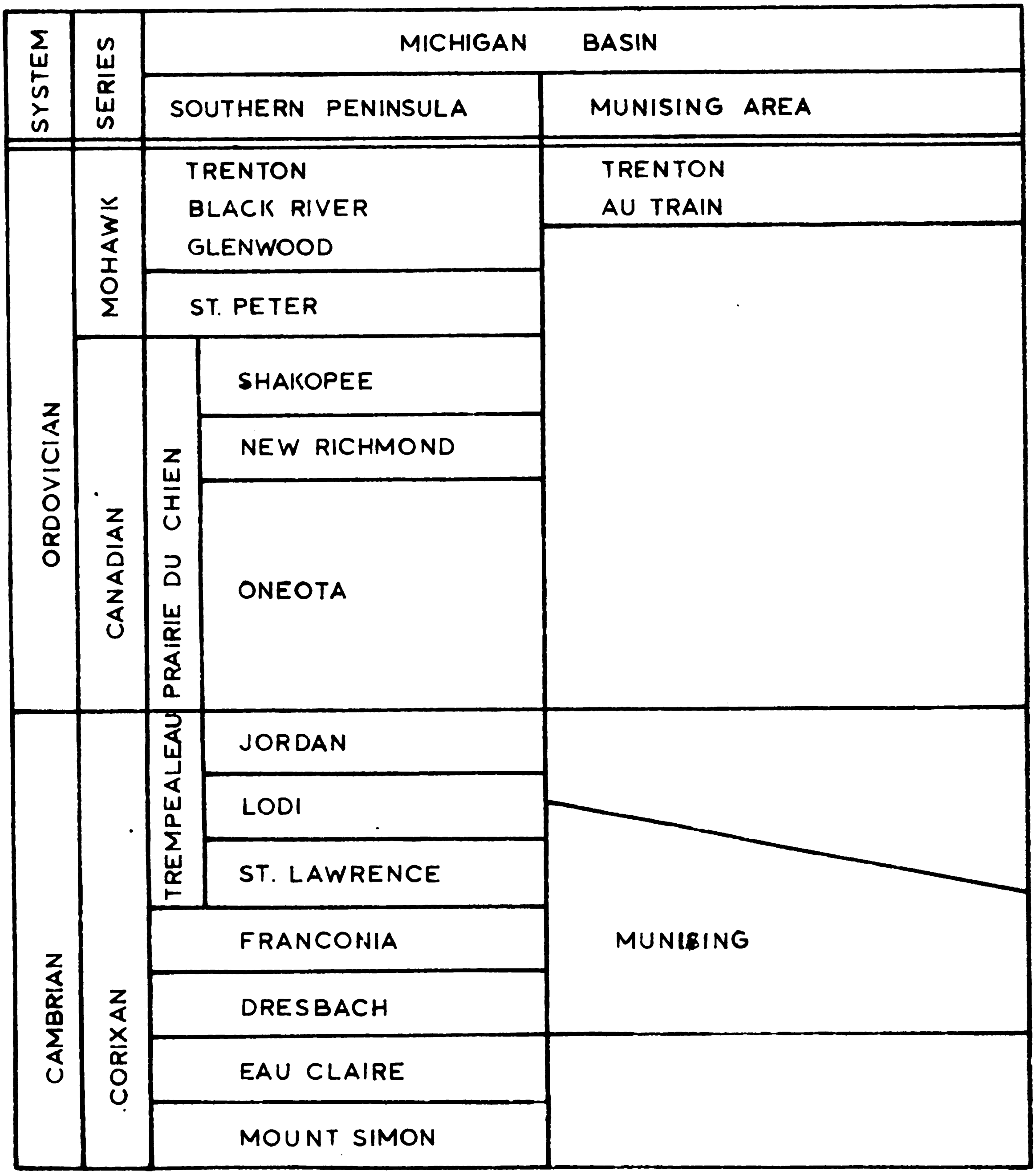


FIGURE 4

CORRELATION OF CAMBRIAN AND ORDOVICIAN FORMATIONS

(AFTER COHEE, DIXON, DRISCOLL, AND OETKING)

SEDIMENTATION

Laboratory Procedure

In the laboratory, the samples were crushed between boards. The samples were then weighed and placed in a 1:4 solution of hydrochloric acid where they remained until the carbonate fraction was dissolved. The acid was then siphoned. The sample was washed in water, filtered, dried and weighed. For the Wagner Falls section, every fourth field sample was run for heavy mineral analysis. For the Au Train Falls section, however, difficulty was encountered in adhering to this method. Therefore the intervals of selection are slightly irregular. The samples were sifted through U. S. standard sieves with openings of 710, 500, 350, 177, and 125 microns. The amount retained in each sieve size was weighed. The heavy minerals of the 125, 177, and 250 sieve sizes were separated in bromoform. The separations were restricted to this size range because the grain samples larger than 250 contain a paucity of heavy minerals. The size of the grains under 125 microns render them difficult to identify, hence they were also deleted. Some of the heavy mineral grains were placed in a mounting medium of index N = 1.67. They were identified and counted. The unmounted heavy mineral grains were studied with a binocular microscope. Table 2 (appendix) lists completely the mineral identifications and descriptions. Table 1 (p. 18) lists the results of the identifications and counts from the 125 sieve size in a more consice form.

TABLE 1

A LISTING AND COUNT OF HEAVY MINERALS FOUND IN THE 125 MICRON SIEVE SIZE SAMPLES

Au Train Falls

Sample No.	Pyrite	Glc.*	Garnet	Muscovite	Tourmaline	Hornblende	Leucoxene	Ilmenite	Gold
R5C - 2	203	c	1	0	0	0	0	u✓	0
9	117	c	11	0	4	0	6	1	0
17	85	m	27	0	6	2	5	u	0
34	3	a	0	25	0	0	2	u	u
R5D - 3	188	a	0	44	0	0	0	0	0
10	44	m	0	11	0	0	1	0	0
18	27	c	53	2	1	0	4	u	0
22	49	c	87	1	3	1	0	u	0
31	111	c	47	0	1	0	2	1	0

Wagner Falls

Sample No.	Pyrite	Glc.*	Garnet	Muscovite	Tourmaline	Hornblende	Leucoxene	Ilmenite	Gold
R7 - 2	85	c	11	11	0	1	3	3	0
6	33	c	8	23	1	0	4	u	0
10	8	i	177	0	0	1	5	u	0
14	118	i	10	5	0	1	0	u	0
18	87	c	14	2	3	0	10	0	0
22	245	a	0	11	0	0	0	u	0
26	134	a	36	40	0	0	3	u	0
30	7	m	344	1	4	0	1	1	1

*The quantity of glauconite present is listed using the following symbols: a: glauconite absent, m: glauconite minor, c: glauconite common, i: glauconite important

✓Samples in which ilmenite or gold was observed only in unmounted grains

Provenance

The heavy minerals imply that an ultimate source rock could have been a schist on the Shield. However, many of the heavy minerals display a high degree of rounding. This would suggest that the grains were either reworked or were subjected to a large amount of weathering and rounding prior to deposition. Driscoll (1956), on the basis of size, rounding and heavy mineral content thought the Au Train Formation to be either partially or wholly derived from the underlying Munising Sandstone. The writer found muscovite and gold in the Au Train Formation, neither of which have been reported from the Munising Sandstone. Hence, in addition to the Munising Sandstone, the writer suggests that another source rock is required.

Environment of Deposition

Glauconite is the most striking feature of the Au Train Formation occurring in concentrated bands up to four inches thick. It may be locally absent, but, in general, it occurs in disseminated form throughout the thickness of the exposed section. Glauconite is commonly dull green and ovaloid in shape.

Pyrite is also very common, although it is usually not obvious in the hand speciman. Nodules up to one inch in length occur at some horizons. Microscopic crystals (cubes and octahedra) commonly retain excellent crystal form. Some of the cubes are striated. Pyrite is commonly imbedded in glauconite. Several pyrite aggregates, short and cylindrical in shape were observed. It is suggested that these represent worm burrows. Because of the euhedral form of the pyrite, its occurence imbedded in glauconite and its occurrence as worm

burrows, it may be at least in part authigenic. Driscoll (1956) reports pyrite in the Munising Sandstone, which is considered, at least in part, to be the Au Train Formation source rock. Also, pyrite veins occur in the Au Train Formation. Hence part of the pyrite was introduced following the rock's deposition. The glauconite may also be in part authigenic. The morphological features of the glauconite as listed above has been cited as evidence for authigenic origin of this mineral (Light, 1952).

The above observations would imply certain conditions of deposition. Cloud (1955) lists physical limits of glauconite formation, some of which are summarized below as it would apply to the sections studied by the writer.

1. The present areal distribution of glauconite deposition is mainly on continental shelves away from large streams.

2. As far as is known, glauconite originates only in marine waters of normal salinity.

3. Its formation requires slightly reducing conditions.

4. Glauconite formation may be cyclic.

5. The depth of formation is usually neritic.

6. Temperature tolerance is wide, although formation is not favored by water of excessive warmth.

7. The water may be somewhat turbulent.

8. The source material may be micacous minerals or bottom muds of high organic content.

9. Sedimentary influx is probably slight, preferably only enough to supply the needed elements. By-passing of the very fine fraction could accomplish the same result as minor sedimentary influx.

There is another possible explanation for the origin of the glauconite and pyrite; this is an epigenetic one. The weakness of the proposed syngenetic origin is related to the oxygen content of the water. The Au Train Formation appears to be of shallow water origin. This is suggested by the intraformational conglomerates which imply that the bottom was at least occasionally above wave base. The presence of coarse sand grains implies proximity to the shore. The fauna, although limited, is sufficient to suggest a relatively shallow environment.

The turbulence, the streams, and the hypothesized longshore currents (see below) could all serve to introduce oxygen to the environment no matter how restricted the environment. In order to maintain reducing conditions, a greater amount of organic material is necessary than might reasonably be expected. The glauconite and pyrite could therefore have been formed slightly beneath the depositional interface under reducing conditions away from the influence of oxygenated waters. A reducing environment is considered necessary for glauconite formation. This requirement is absent above the depositional interface.

Pyrite is an important constituent of the muscovite-rich suite, but glauconite is minor or absent. Garrels (1960) states that glauconite and pyrite form in a similar pH range but that pyrite forms under conditions of lower oxidation potential. This would suggest that the currents in some manner reduced the oxidation potential.

The above argument is based on the theory that at least slightly reducing conditions are required for glauconite formation.

Teodorovich (1961) states "The mineral is the product of a special marine mineralogical-geochemical facies, namely the glauconite facies, characterized by repeated microfluctuations in the oxidation-reduction boundary, i.e. characterized by repeated microfluctuations in the oxidation-reduction boundary, (sic) i.e. characterized by a struggle between oxidizing and reducing conditions, oxidizing conditions generally dominating." He cites several Russian publications to support his hypothesis. Teodorovich mentions other factors believed necessary for glauconite formation. He states the mineral is formed in the shelf zone along a shore of magmatic rocks away from river mouths in areas of strong bottom currents where sedimentation is retarded or "reversed." Transgressions and regressions leading to movements of marine waters which in turn disturbs the equilibrium favors glauconite formation. Because of the presence of glauconite in carbonates, the temperature of formation cannot have been too low. He further states that optimum temperatures and depth of glauconite formation has not been consistent throughout geologic time but that "they (the conditions) have depended on the salinity of the marine waters, on the mineralization, and on other factors." Teodorovich does, however, believe that glauconite may be of diagenetic origin.

The writer does not feel qualified to draw conclusions concerning the conditions under which the Au Train glauconite was formed.

Table 1 (p.18) reveals a division in the occurrence of heavy minerals. The Au Train Falls section more clearly displays this division. Muscovite occurs either as the predominant non-authegenic heavy mineral or as a minor-to-absent constituent. Where muscovite is minor or absent, garnet is the predominant mineral. Thus two

suites are discernable, a muscovite suite and a garnet suite. If the heavy minerals were derived solely from the Munising Formation, then no muscovite should be present, for muscovite has not been reported in this rock by previous authors. Therefore, another source rock is required.

If it were assumed that streams entering the area of deposition contained all the heavy minerals, then, because of differential settling rates, muscovite should not be found in significant quantities associated with other heavy minerals.

The muscovite occurs in relatively large quantities and is rounded and largely unaltered. Krynine (1940) states that, "Rounding of the micas indicates a specialized set of sluggishly moving currents with a gentle to-and-fro motion." It is therefore suggested that the muscovite was introduced by longshore currents independent of the other heavy minerals. If these conditons did exist, then these currents would carry relatively minor amounts of coarse material and relatively large amounts of fine material. Therefore sediments deposited under the influence of these currents should contain a high percentage of fine material and a relatively minor percentage of coarse material.

Histograms of weight percentages were prepared (appendix, Table 3). The histograms are also discussed in the appendix.

At Au Train Falls, over 80% by weight of the muscovite rich samples is found to be less than 125 microns in size. In those samples in which garnet is dominant, the percent of fines ranges from about 15% to 50%.

The section at Wagner Falls does not display as uniform a division as does the section at Au Train Falls. Two samples (R7-10,

R7-30) also contain relatively large quantites of quartz in the coarser sieve sizes.

Another possible cause for the combined suite exists. As a result of the highly interbedded nature of the formation, some of the individual samples studied consisted of a comparatively coarse quartz sand glauconitic rock in contact with a fine grained clay rich relatively quartz free rock. The writer believes the garnet may occur in the quartz rich glauconitic layer while muscovite occurs in the finer grained layers.

SUMMARY AND CONCLUSIONS

The Au Train Formation of Northern Michigan, as it appears in outcrop at Au Train Falls and Wagner Falls, is primarily a dolomitic sandstone. The rock is rich in glauconite which occurs disseminated as well as in concentrated bands. Nearly pure quartz bands are also present. Pyrite is common. The lower portion of the formation is more highly glauconitic and contains more quartz than is in the upper portion.

Much of the pyrite and glauconite may be authigenic. This suggests that the formation was deposited in relatively shallow quiet water under slightly reducing conditions. It is also possible that the glauconite and pyrite were formed penicontemporaneous below the depositional interface. On the basis of heavy minerals and the appearance of the quartz grains, previous authors have suggested that the source rock for the Au Train Formation consists in part or in whole of the underlying Munising Sandstone. The presence of gold and muscovite, not previously reported, suggests to the writer that another source rock is necessary. Where muscovite occurs, there is, in general, a paucity of other minerals. Because of this the writer suggests that longshore currents were present which introduced muscovite independent of the other minerals.

Fossils are rare in the Au Train Formation. Previous authors have found material which leads them to believe the formation to be Black River. This age has been questioned by some workers. The

writer found a specimen of Lingulepsis exigua (Matthew) which has not, to the writer's knowledge, previously been reported outside of the Cape Breton area. In addition it has not been reported to range beyond the Upper Cambrian. The geographic range of this species must be extended. Its temporal range may also need to be extended.

The writer was permitted to study P. E. Oetking's fauna. The writer believes the fauna to be Middle Ordovician. Hence, the Au Train Formation would also be of this age. This would imply a facies relationship between the Au Train - Black River rocks and the relatively pure carbonate Black River units found elsewhere in the area. The writer considers the term Au Train to be valid if restricted to the quartzitic glauconitic rock as it occurs at Au Train Falls. No study was made of the Hermansville lithology nor of the relationship between the Hermansville and Au Train Formation.

SUGGESTIONS FOR FUTURE WORK

More information on the environment of deposition and the possibility of the influence of longshore currents may be gained by a more detailed lithologic study of the Au Train Formation at Au Train Falls and Wagner Falls. In addition, other outcrops should be studied to determine local variation of heavy mineral content. The relationship between Hermansville lithology and Au Train lithology has not yet been determined and needs further work.

More detailed paleontological work remains to be done. The promising new outcrop described by the writer should be further investigated.

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APPENDIX

TABLE 2

A COMPLETE LISTING OF HEAVY MINERAL GRAINS IN THE STUDIED SAMPLES

Au Train Falls

Sample Number	Number of Grains in Sample
R5C2- 250*	
pyrite, occurs with glauconite	125
R5C2- 177	
pyrite, occurs with glauconite	106
R5C2- 125	
pyrite, occurs with glauconite	203
garnet	1
ilmenite observed in unmounted heavy fraction	
R5C9- 250	
pyrite, occurs with glauconite	50
leucoxene	1
R5C9- 177	
pyrite, occurs with glauconite	51
leucoxene	5
R5C9- 125	
pyrite on glauconite	117
leucoxene	6
garnet	11
tourmaline	4
ilmenite	1

*Sieve size in microns

TABLE 2-- Continued

Sample Number	Number of Grains in Sample
R5C17 - 250	
Pyrite, glauconite rare	29
R5C17- 177	
pyrite, glauconite rare	61
garnet	1
R5C17- 125	
pyrite, little glauconite	85
garnet	27
tourmaline	6
leucoxene	5
hornblende	2
ilmenite observed in unmounted sands	
R5C34- 250	
pyrite, no glauconite	2
R5C34- 177	
-- --	
R5C34- 125	
pyrite, no glauconite	3
leucoxene	2
muscovite	25
ilmenite, garnet and gold, all rare, occur in unmounted sands	
R5D3- 250	
pyrite, no glauconite	52
R5D3- 177	
pyrite, no glauconite	78
muscovite	2
R5D3- 125	
pyrite, no glauconite (assoc. w. qtz.)	188
muscovite	44
R5D10- 250	
-- --	
R5D10- 177	
pyrite, no glauconite	24
muscovite	5
R5D10- 125	
pyrite, glauconite rare	44
muscovite	11
leucoxene	1

TABLE 2-- Continued

Sample Number	Number of Grains in Sample
R5D18- 250	
pyrite, with glauconite	3
leucoxene	1
R5D18- 177	
pyrite, with glauconite	10
muscovite	4
leucoxene	2
R5D18- 125	
pyrite, with glauconite	27
garnet	53
leucoxene	4
tourmaline	1
muscovite	2
ilmenite occurs in unmounted grains	
R5D22- 250	
pyrite with glauconite	16
R5D22- 177	
pyrite with glauconite	58
garnet	3
leucoxene	1
R5D22- 125	
pyrite with glauconite	49
garnet	87
tourmaline	3
hornblende	1
muscovite	1
ilmenite in unmounted grains	
R5D31- 250	
pyrite in glauconite	28
R5D31- 177	
pyrite with glauconite	67
garnet	1
R5D31- 125	
pyrite with glaucónite	111
garnet	47
tourmaline	1
leucoxene	2
ilmenite	1

Wagner Falls

Sample Number	Number of Grains in Sample
R7-2- 250	
pyrite with glauconite	10
R7-2- 177	
pyrite with glauconite	45
muscovite	2
R7-2- 125	
pyrite, with glauconite	85
muscovite	11
garnet	11
hornblende	1
leucoxene	3
ilmenite	3
R7-6- 250	
pyrite and glauconite	2
R7-6- 177	
pyrite and glauconite	18
R7-6- 125	
pyrite with glauconite	33
muscovite	23
garnet	8
leucoxene	14
tourmaline	1
ilmenite in unmounted sands	
R7-10- 250	
pyrite minor, much glauconite	18
R7-10- 177	
pyrite minor, much glauconite	55
hornblende	1
leucoxene	1
R7-10- 125	
pyrite minor, principally glauconite	8
garnet	177
leucoxene	5
horneblende	1
R7-14- 250	
pyrite minor, principally glauconite	27

TABLE 2— Continued

Sample Number	Number of Grains in Sample
R7-14- 177	
Pyrite minor, principally gluconite	92
muscovite	1
R7-14- 125	
pyrite minor, principally glauconite	118
garnet	10
muscovite	5
hornblende	1
ilmenite in unmounted sands	
R7-18- 250	
pyrite with glauconite	8
R7-18- 177	
pyrite with glauconite	100
R7-18- 125	
pyrite with glauconite	87
garnet	14
leucoxene	10
tourmaline	3
muscovite	2
R7-22- 250	
pyrite, glauconite absent	110
R7-22- 177	
pyrite, glauconite absent	275
R7-22- 125	
pyrite, glauconite absent	245
muscovite	11
ilmenite occurs in unmounted sands	
R7-26- 250	
pyrite, glauconite absent	5
R7-26- 177	
pyrite, glauconite absent	49
muscovite	2
R7-26- 125	
pyrite, glauconite absent	134
garnet	36
leucoxene	3
muscovite	40
ilmenite in unmounted sands	

Sample Number	Number of Grains in Sample
R7-30- 250	
pyrite with glauconite	12
garnet	8
R7-30- 177	
pyrite with glauconite	14
garnet	249
tourmaline	3
R7-30- 125	
pyrite with some glauconite	7
garnet	344
tourmaline	4
gold	1
ilmenite	1
muscovite	1
leucoxene	1

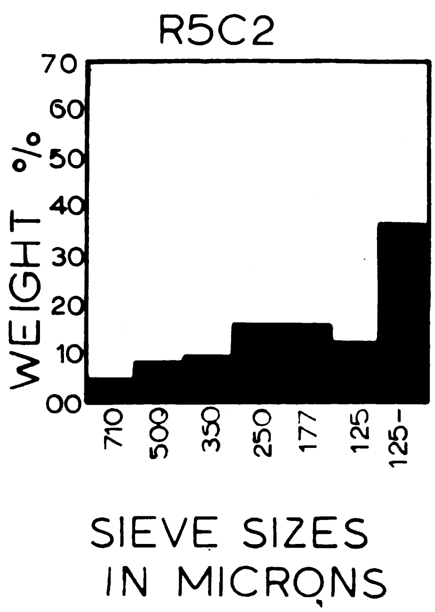
MINERAL DESCRIPTIONS

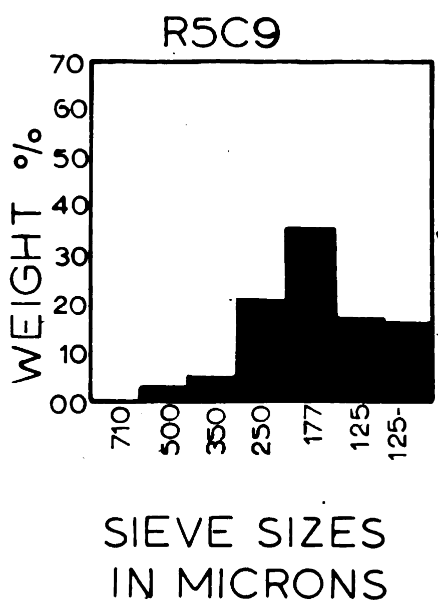
Pyrite	The dominant heavy mineral. Generally occurs as an aggregate with either galuconite or quartz. Pyrite is commonly surrounded by glauconite. It displays excellent cubes and less commonly, octahedra.
Glauconite	The presence of glauconite in the heavy mineral assemblages is explained primarily on the basis of its association with pyrite. Teodorovich does report glauconites maximum specific gravity as being between 2.85 and 2.90 which is in excess of the 2.86 specific gravity of bromoform. The glauconite varies in color from pale to dark green. It is usually present as an aggregate. No good optic figures were seen. Hardness about 2, indices near to 1.61. Pyrite is commonly imbedded in it.
Almandine garnet	Isotropic red, index over 1.67. Grains vary from well rounded to grains with good crystal faces. Some grains with re-entrant angles. Proximity of garnets index to the index of the mounting medium imparts a distinct bluish tint to some grains. The variation in roundness and the variation in indices as indicated by the blue tint are both graduated, hence differentiation of garnets is not possible.
Muscovite	Translucent colorless tabular crystals with vitreous luster, minor alteration. Excellent cleavage flakes yield excellent biaxial negative optic figures. $2V = 40^{o}$. Index under 1.67.
Leucoxene	A pitted dull white opaque mineral, commonly on ilmenite grains.
Tourmaline	Well rounded brown pleochroic length fast uniaxial negative grains.
Hornblende	Rounded and fractured green pleochroic unaltered grains, oblique extinction, biaxial positive.
Gold	Very thin, very soft metallic gold colored flakes. Although uncommon in slides, it is found in unbroken rocks.
Ilmenite	Opaque dark submettalic rounded grains; partial alteration to leucoxene common.

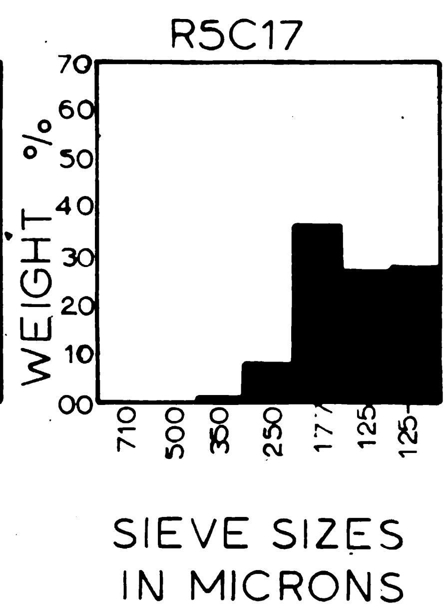
LIGHT MINERALS

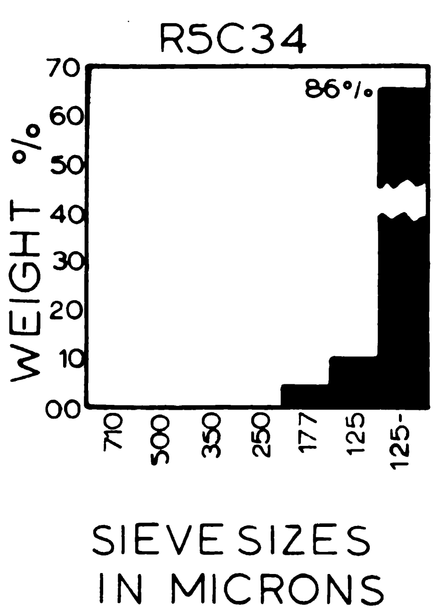
Several slides of light minerals were prepared. The principal constituent is well rounded quartz grains, frosted either by wind action or solution. The second major constituent is feldspar, identified by its biaxial negative interference figures and on the basis of twinning. Measurements on combined-carlsbad twins places the composition of one grain in the andesine plagioclase range. Good crystal development is common. There is some alteration and decompositon of the crystals. No secondary overgrowths were observed. It is not known if the feldspar is derived from igneous or metamorphic rocks or if it is authigenic; however, the presence of the andesine suggests it is at least in part primary. The other principal lights are glauconite and calcite, dissolved either partially or wholly in the preparation of the material for study.

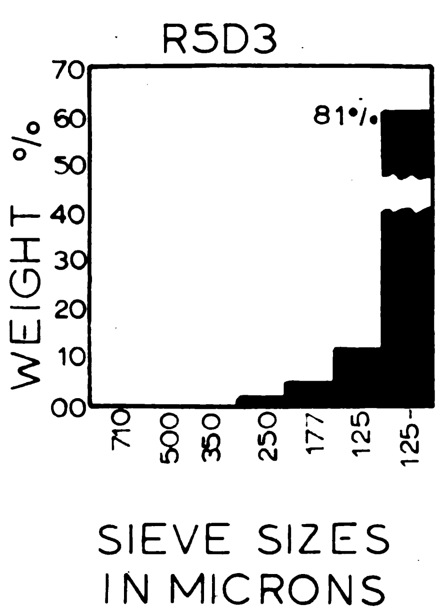
HISTOGRAMS OF THE AU TRAIN FORMATION
AU TRAIN FALLS

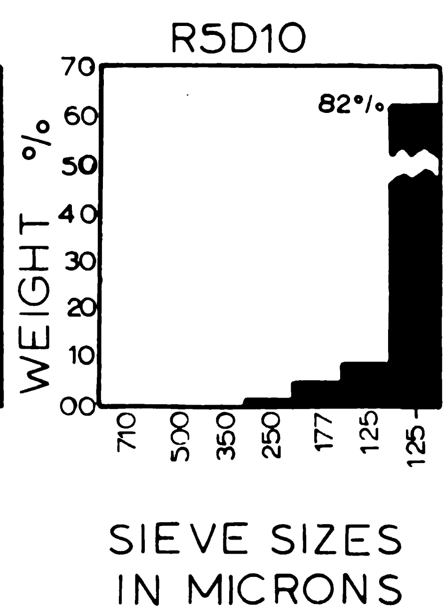


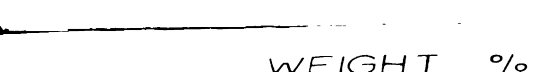








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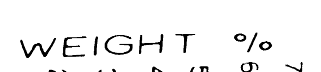
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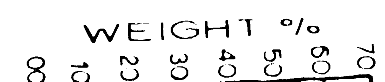
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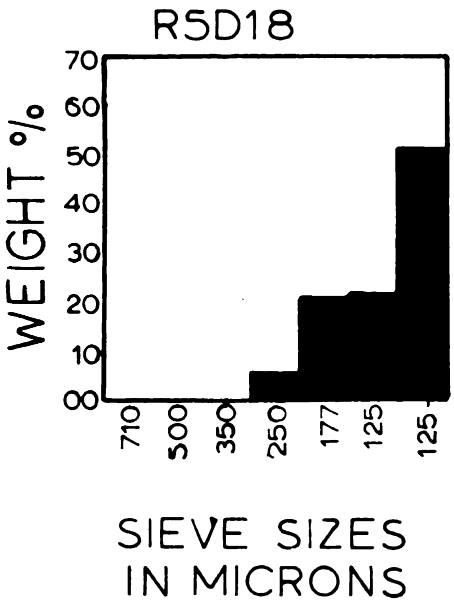
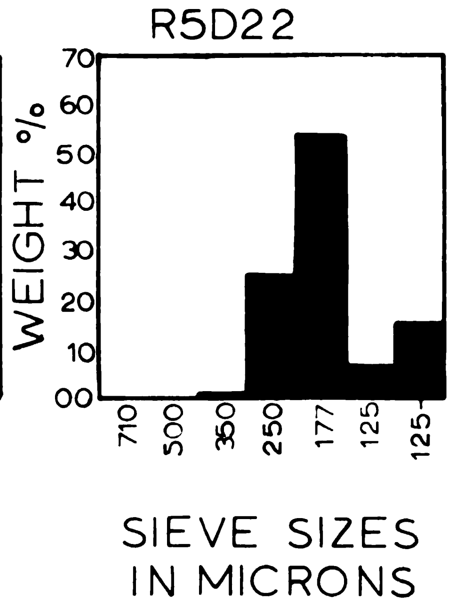
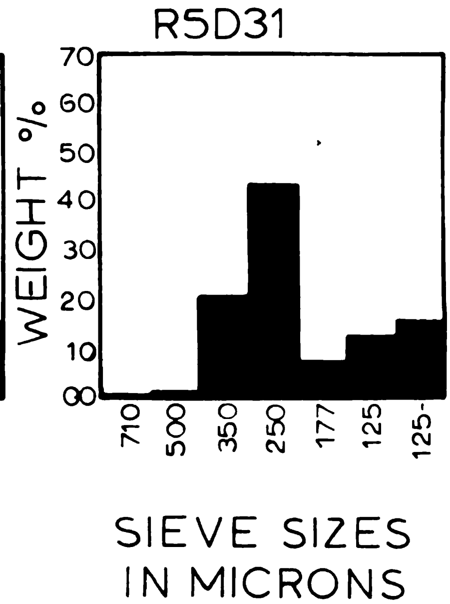
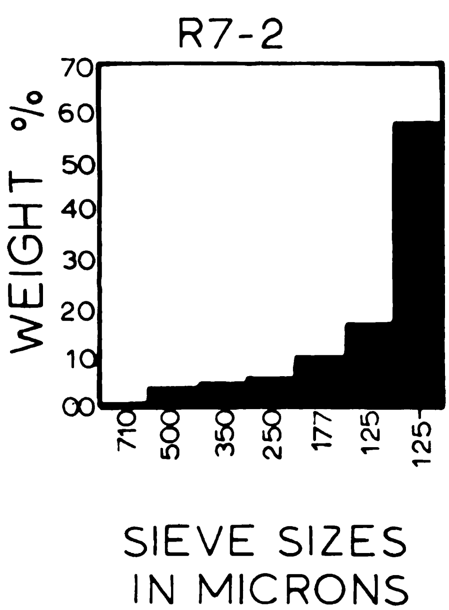
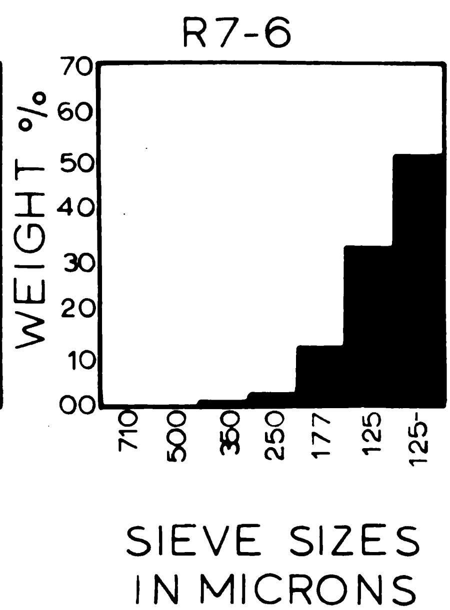


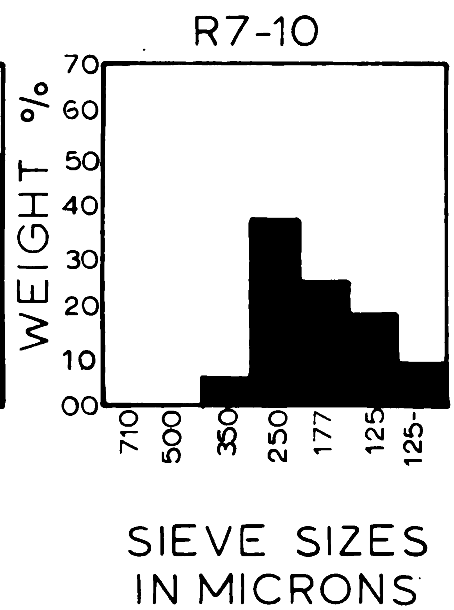


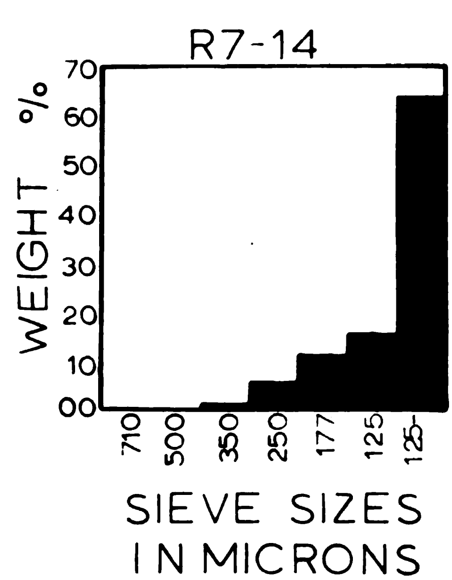


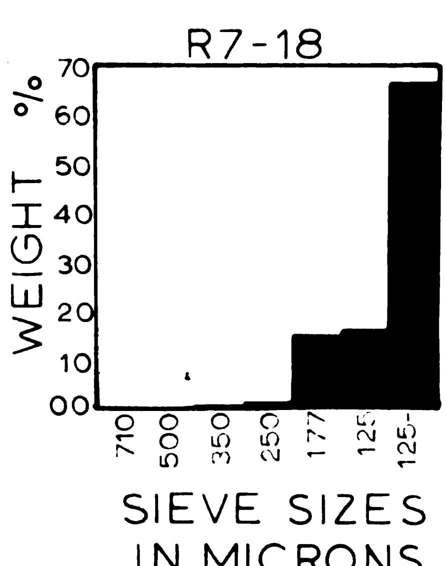
WAGNER FALLS

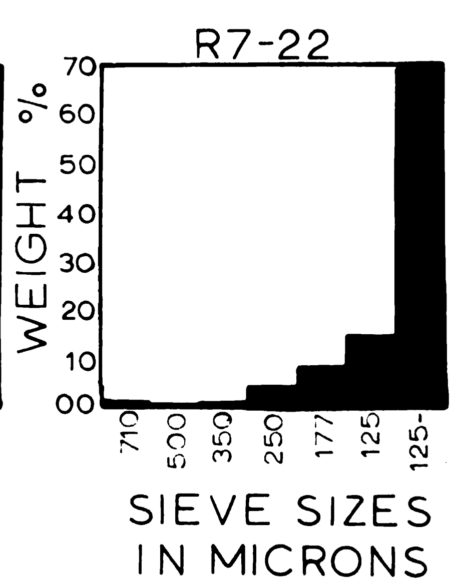


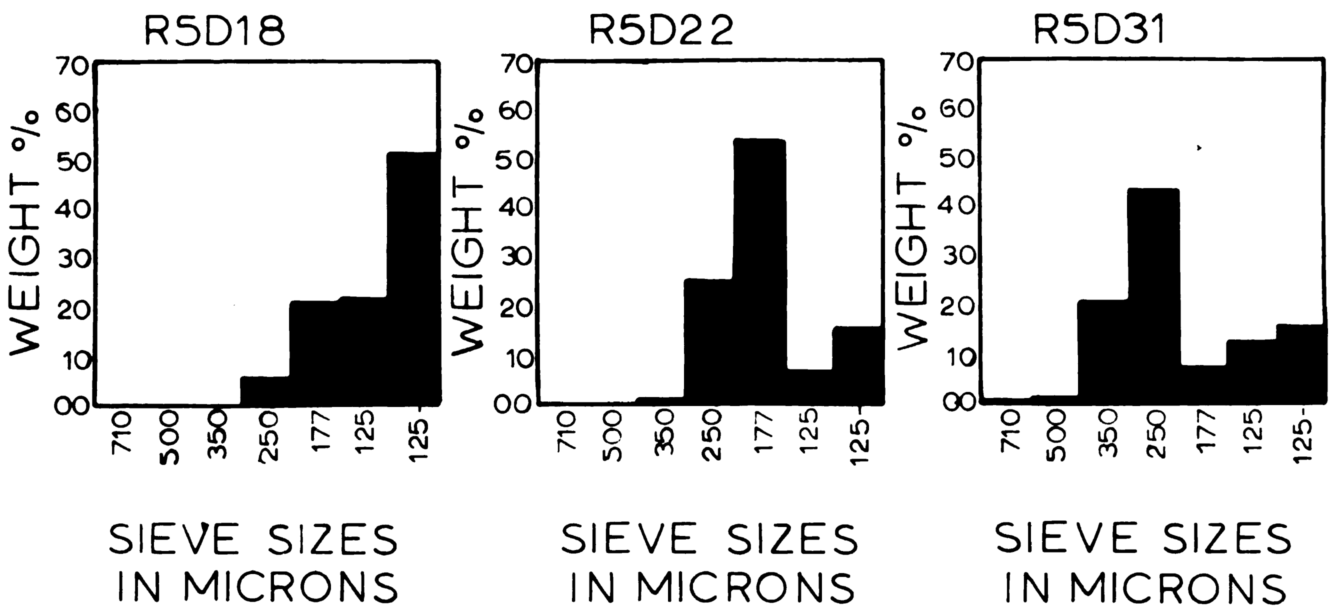












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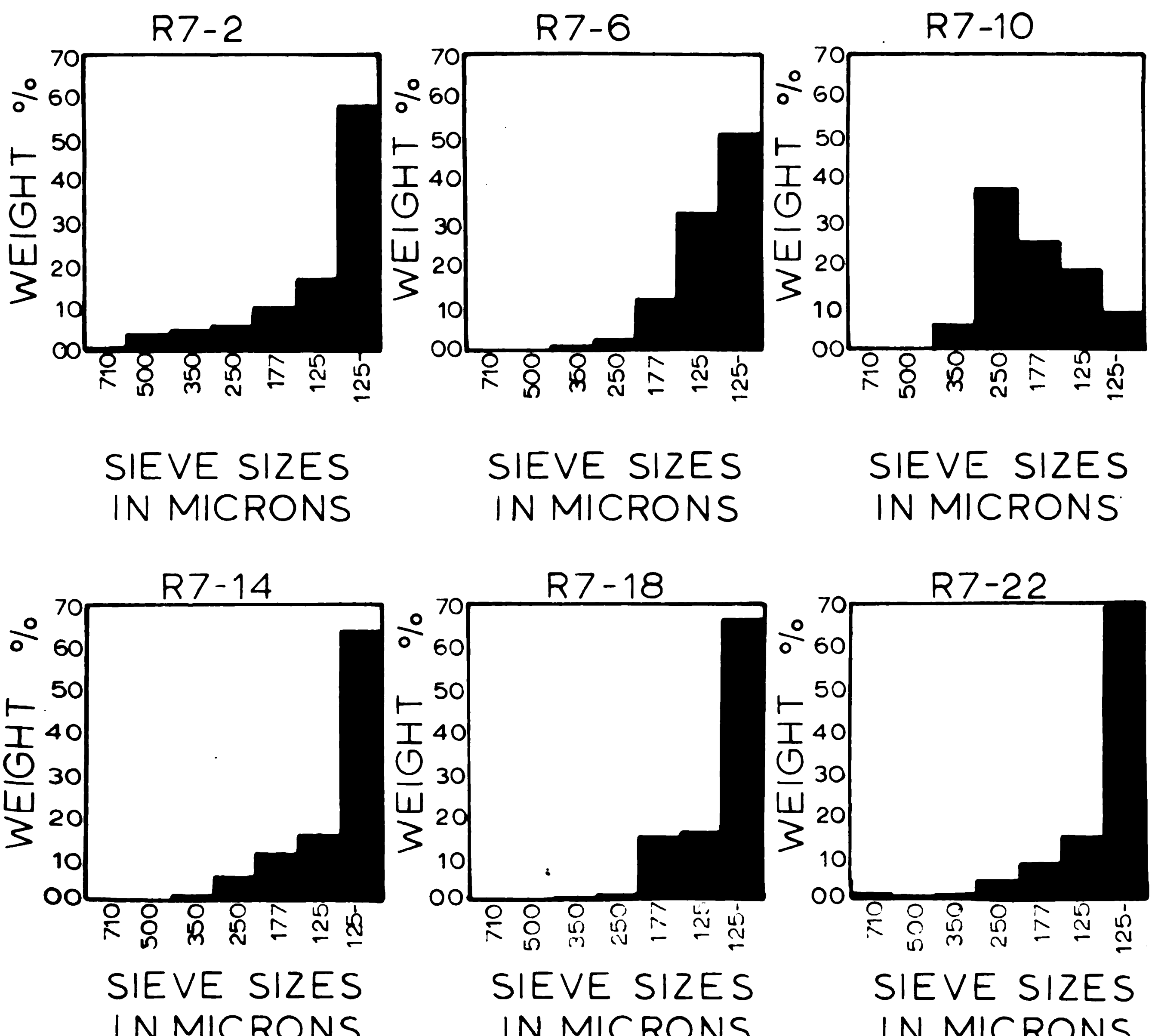

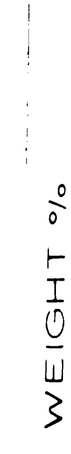
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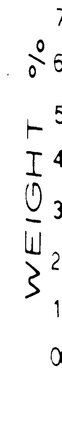
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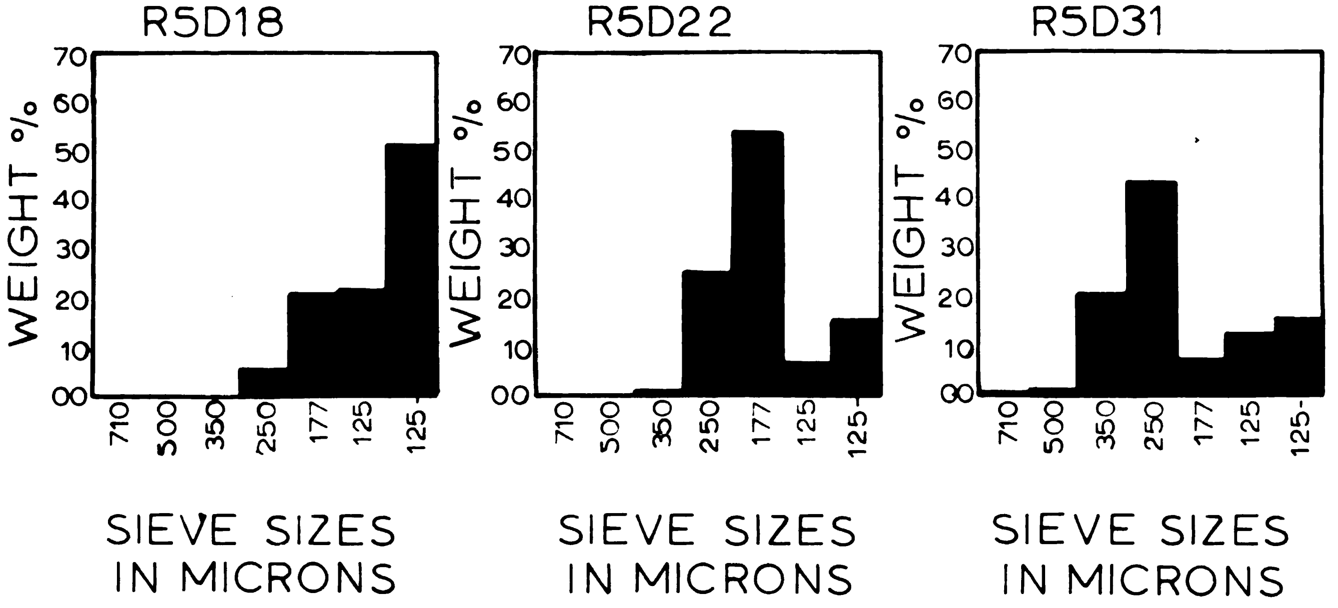

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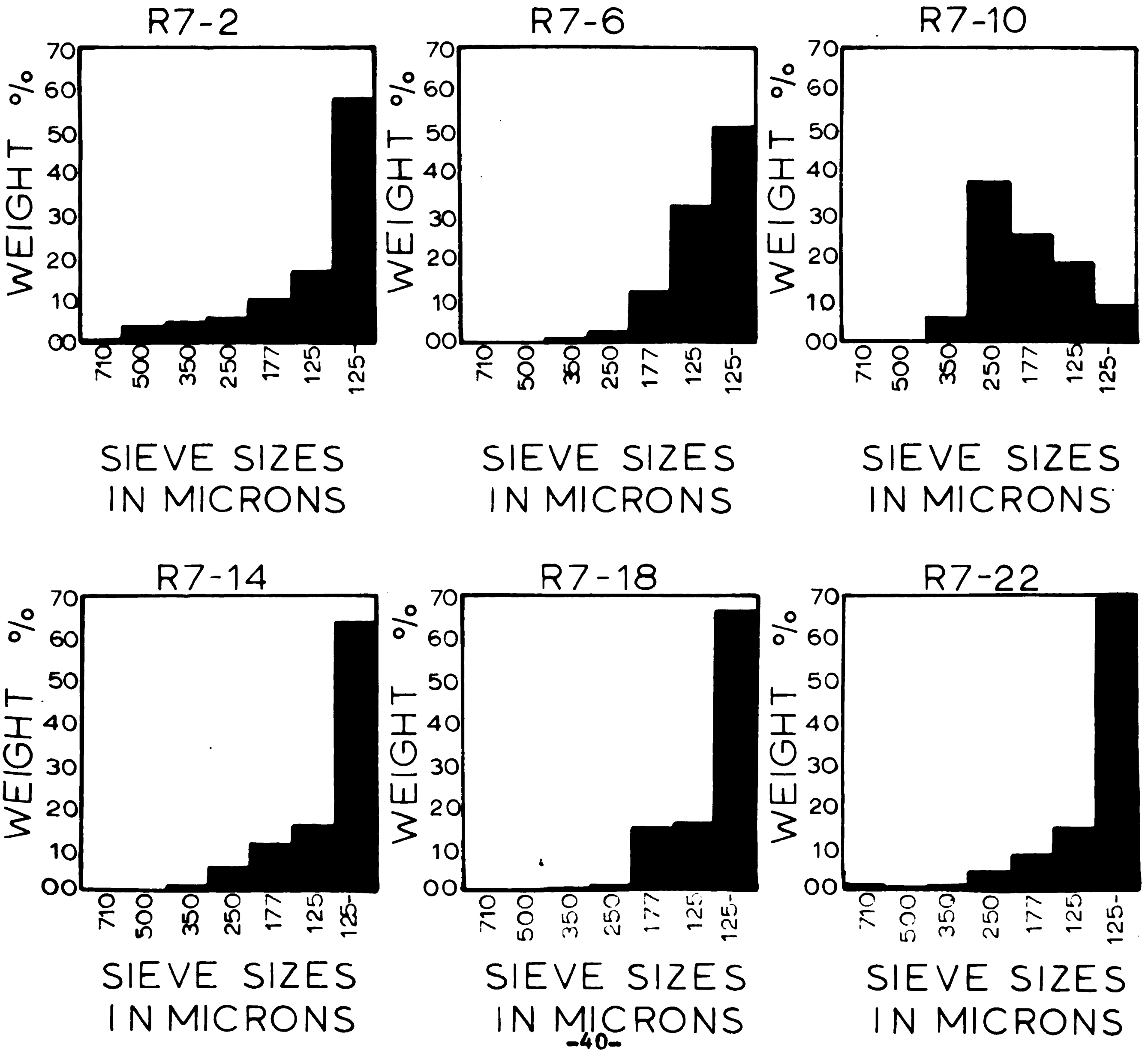

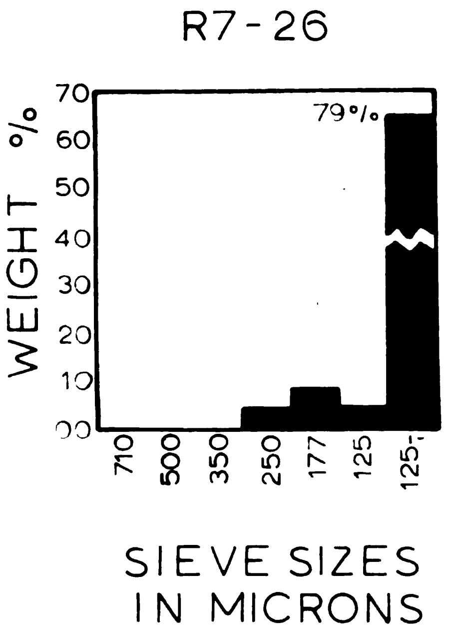
R7-26
WEIGHT %
70
60
50
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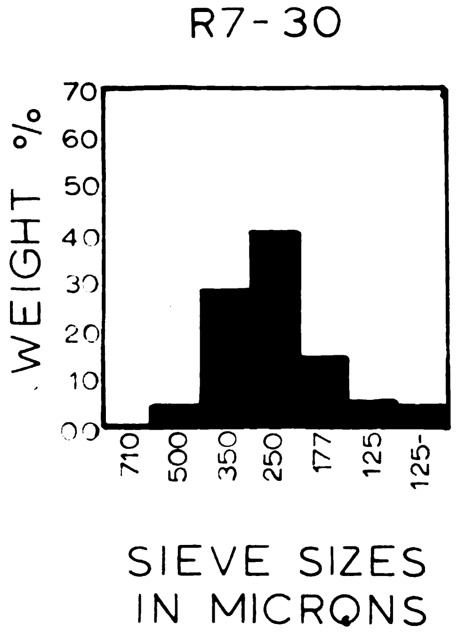
20
10
00
79%
710
500
350
250
177
125
125-
SIEVE SIZES
IN MICRONS


R7-30
WEIGHT %
70
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125
125-
SIEVE SIZES
IN MICRONS

DESCRIPTION OF HISTOGRAMS

Au Train Falls

R5C2	No significant amount of heavy minerals. Samples largely glauconite, some quartz.
R5C9	Garnet suit, 177 sieve size forms about 35% of the sample, fines (those grains under 125 microns) form under 20% of the sample.
R5C17	Garnet suite 177 sieve size forms about 35% of the sample, fines are under 30%.
R5C34 R5D3 R5D10	Because of similarity, these three muscovite-rich samples are considered together. In all samples, the fines exceed 80%. The larger the sieve sizes, the smaller the weight percentage. This was not true in previous samples.
R5D18	Primarily garnet, although 2 of the 86 counted grains were muscovite. Fines less important than in previous 3 samples while the 177 and 125 sieve sizes both exceed 20%.
R5D22	Primarily garnet, although 1 of the 147 counted grains was muscovite. The 177 micron sieve size forms over 50% while the fines form about 15%.
R5D31	A garnet suite with no muscovite being observed. The 250 sieve size is the principal component, forming over 40% of the suite. Fines again form about 15%.

WAGNER FALLS

R7-2 R7-6	Combinations of both suites, in which the fines are dominant.
R7-10	A garnet dominant sample, the fines are under 10%.

R7-14
R7-18 Combinations, although fines are dominant.
R7-26

R7-22 Muscovite suite

R7-30 Sample with quantities of garnet, muscovite very minor, fines very minor.

TABLE 3

CARBONATE PERCENTAGES AT AU TRAIN FALLS
AND WAGNER FALLS

Au Train Falls

	%		%		%
R5B		25	14.8	10	57.1
1	78.5	26	54.1	11	58.8
2	55.0	27	79.8	12	39.2
R5C		28	33.5	13	38.7
2	71.2	29	25.2	14	30.8
3	50.3	30	75.7	15	67.3
4	47.5	31	65.3	16	43.4
5	35.1	32	27.6	18	33.4
6	35.6	33	75.8	19	48.5
7	38.6	34	50.8	20	42.8
8	40.2	35	70.2	21	67.6
9	27.1	36	27.4	22	59.6
10	24.3	37	33.1	23	46.2
11	26.6	38	51.8	24	53.9
12	41.0			25	61.9
13	38.6	R5D		26	52.4
14	34.0	1	42.8	27	75.2
15	42.6	2	43.5	28	39.2
16	36.3	3	56.9	29	57.6
17	46.6	4	44.0	30	10.4
18	44.9	4*	3.8	31	70.2
19	19.3	5	45.7	32	83.3
20	31.6	6	52.3	33	80.4
21	36.4	7	19.7	34	61.2
22	15.4	8	58.0	35	87.2
24	6.6	9	57.5	36	70.3
				37	79.1

Note: The lowest exposed rock is R5B-1, the highest is R5D37. Positions of selected samples may be seen in Fig. 3.

TABLE 3 -- Continued

Wagner Falls

	%		%		%
R7		R7		R7	
- 1	55.6	-13	45.4	-24	67.9
- 2	30.1	-14	32.7	-25	59.6
- 3	29.8	-15	27.7	-26	52.4
- 4	35.4	-16	53.7	-27	49.8
- 5	27.0	-17	38.4	-28	43.5
- 6	39.0	-18	46.3	-29	35.2
- 8	59.8	-19	38.7	-30	52.2
- 9	41.0	-20	14.9	-31	40.0
-10	16.6	-21	43.6	-32	9.0
-11	75.2	-22	47.1	-33	24.8
-12	54.9	-23	80.6		

SECTION DESCRIPTIONS

Au Train Falls

Unit No.		Unit Thickness	Cumulative Thickness
	Munising Sandstone		
1	Bedding 1" to 4", coarse grained rounded frosted grains, minor glauconite, vugs, some gastropods, some horizons conglomeratic	6'	6'
	Au Train Formation		
2	Quartzose dolomite, quartz sand is fine grained, disseminated glauconite gives greenish gray color, clay blebs, intraformational conglomerate	½'	6½'
3	Dolomitic sandstone interbedded with layers of high glauconite content, glauconite usually occurs disseminated, bedding under two inches, pyrite present but minor, partially cross-bedded	1'	7½'
4	Dolomitic sandstone containing disseminated glauconite and clay blebs, some pyrite, quartz, sand is fine grained, cross-laminated, glauconite bands under 1" thick, intraformational conglomerate	8½'	16'
5	Dolomitic sandstones similar to #4, except laminae are more regular, fewer clay blebs are present, carbonate vugs, local glauconite bands	8'	24'
6	Principally quartzose dolomite with dolomite being locally subordinate, some clay blebs, local pyrite nodules up to ¼ inch in diameter, some		

SECTION DESCRIPTIONS-- Continued

Unit No.		Unit Thickness	Cumulative Thickness
	intraformational conglomerates, gray to brown color glauconite is subordinate, bedding thicker than in previous units	10'	34'
7	Dolomitic sandstone, similar to #4, irregular laminae, intraformational conglomerate, locally friable sand layers, local clay bleb concentrations, generally fine quartz sand, conglomeratic glauconite layer occurs at the top of this interval	14'	48'
8	Quartzose dolomite, contains a pyrite rich horizon near the base of the interval, veins and nodules up to 1" long occur, local conglomerates and carbonate vugs, glauconite is minor, occurs disseminated	8'	56'
9	A sequence of rocks similar to #7 and #8 with clastic and carbonate material alternating as the dominant feature, local pyrite, disseminated glauconite, quartz sand is locally coarse, friable quartz sand layers several inches thick occur	20'	76'
10	The remainder of the section is a quartz sand dolomite with the carbonate percentage increasing upward in the section, glauconite is locally absent, but occurs disseminated in quantity at local horizons, pyrite occurs locally, local sand horizons, fresh rock is, in general, gray, it weathers buff, the top of the interval contains an intraformational conglomerate	16'	92'

SECTION DESCRIPTIONS-- Continued

Wagner Falls

Bottom unit

Unit No.		Unit Thickness	Cumulative Thickness
	Au Train Formation		
1	Quartzose dolomite, glauconite, conglomeratic, pebbles of Munising-type lithology up to two inches in diameter, pebbles are partially cemented by carbonate, quartz sand is rounded and frosted, similar to the Munising type sand	1'	1'
2	Covered interval	1½'	2½'
3	Dolomitic sandstone, layers of material rich in clay, glauconite rich bands occur, alternate with bands of rounded quartz sand, sand is finer grained than at the contact, thin bedded 1"	1'	2½'
4	Covered interval		
5	Rock similar to #3	1'	6'
6	Covered interval	2'	8'
7	Dolomitic sandstone, thinly bedded, contains clay blebs, color is light buff, glauconite is scattered in the matrix, numerous fine grained friable quartz sand bands are present, glauconite is present disseminated and in thin bands	10½'	18½'
8	Quartzose dolomite, glauconite and quartz-rich bands alternate with clay-rich bands, rock is more massive and thicker bedded than in the lower intervals, several distinct sand bonds are present, the sand being coarser grained in the bands than in the dolomitic rock, cross bedded, pale buff color	9½'	28'
9	Covered interval	2'	30'

SECTION DESCRIPTIONS__ Continued

Unit No.		Unit Thickness	Cumulative Thickness
10	A largely covered interval, rock is, in general, similar to the material described under #3, dolomitic sandstone, clay blebs and glauconite scattered irregularly throughout, quartz sand is relatively fine grained	14'	44'
11	Similar to #10 except no part of the interval is covered, contains two thin bedded friable glauconite rich bands	12'	56'
12	Quartzose dolomite, gray in color, variable quartz sand content, fine grained, glauconite is sparsely scattered throughout, pyrite occurs disseminated and in vugs,some intraformational conglomerate, pebbles are flat, dolomitic	9'	65'
13	Remainder of section quartzose dolomite to dolomitic sandstone, light buff clay blebs and pyrite is present with the pyrite being commonly concentrated, glauconite is unimportant, bedding is more massive than it is lower in the section, contains bands of friable coarse grained quartz sand	18'	83'

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