A PETROGRAPHIC STUDY OF HEAVY MINERALS OF WISCONSIN IGNEOUS ROCKS, U.S.A.

BY

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(*The Geological Survey of China*)

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INTRODUCTION

The use of the heavy minerals in sedimentary rocks as a means for correlation of stratigraphic problem is becoming more and more widespread in recent years, especially in England and United States. Where the rock formations are scanty in fossils or can not be correlated by fossils alone, the study of the heavy minerals in such formations is quite important and often gives valuable informations not only regarding the stratigraphic correlation but also the source of the materials by which the rock formations are constituted.

No critical result to the source of the materials can be obtained unless a thorough study on the heavy minerals of the plutonic igneous rocks in the vicinity of the sedimentary rock formations under consideration is made at first. In ordinary thin rock sections these minerals easily escape detection due to their comparative scarcity with reference to the essential rock-forming minerals. Henry B. Milner said "It may be safely assumed that few investigators of igneous rocks according to strictly modern principles will be content to describe their fieldtypes merely from thin section in future, and acces-

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sary minerals will receive that degree of attention which their importance unquestionally merits. It is equally clear that detrital minerals, considered primarily as accessary constituents of igneous rocks, and thus studied "at the source" are made doubly potent in the solution of problems which seek to harmonize igneous and sedimentary activities at different geological epoches. Only such thorough investigation of parent-rock and contributed sediment, can the full significance of any particular cycle of sedimentation be grasped."

All these effects enable the writer in endeavour to undertake the study of the heavy minerals of the acid igneous rocks in the vicinity of Wisconsin, U. S. A.

The writer expresses his great indebtedness to Prof. A. N. Winchell, University of Wisconsin, who gave many suggestions and cristicisms. Acknowledgement is also due to Dr. W. P. Ramles who furnished several crushed rock samples.

Geological Ages and Distributions of the Rock Materials in the Vicinity of Wisconsin, U. S. A.

All the rock materials under study belong to acid igneous rocks and occur as isolated intrusions in the central and northern parts of the state of Wisconsin and in its adjacent regions. The geological age of these intrusions is Archaean according to the report of the Wisconsin Geological Survey. Except two among these intrusions all the others crop out as small mounds. Their distribution is shown in the accompanying map. In order to know the general characters of the rocks a brief account on each of them is stated in the following and is mostly based on the bulletin of the Wisconsin Geological Survey.

Berlin rhyolite. This occurs in two small mounds rising above the general level of the country. The rock is compact, dense and of uniform texture. The color is grayish black. Microscopic examination of the thin sections of the rock shows a fine crystalline groundmass of quartz and feldspar, through which numerous large prophyritic crystals of feldspar and small flecks of biotite are scattered.

Wausau granite. It crops out over an area of many square miles. Its color over this extensive area varies from gray through reddish brown to brilliant red. The mineralogical composition of the rock is composed of feldspar and quartz with a very little biotite and hornblende. The grains are of medium and comparatively uniform size. Iron oxide in the forms of hematite and magnetite is present in all the varieties. The geological age is considered to be pre-Cambrian.

Waushara and Lohrville granites. These occur as two small mounds not very far from each other. Their petrographic characters are so alike that they may be described together. The thin sections of these granites show that they are composed essentially of quartz and feldspar in about 90%. Hornblende, muscovite, zircon and iron oxide are the principle accessary minerals.

Mellen or High Bridge granite. It has a mixed pinkish gray color with porphyritic texture in which the groundmass is composed of feldspar, quartz, biotite and hornblende, and the phenocrysts are mostly feldspar.

Montello granite. It belongs to the Huronian of Archæan age and is situated near the village of Montello as an elliptical mound about one third of a mile in length and 40 ft. high. It has a medium grain with compact texture and a bright pinkish color. Its constituents consist predominantly of feldspar, quartz and mica.

Endeavor granite. This granite is much similar in petrographic character with Montello granite.

Athelstane granite. This is a coarse gray granite. Feldspar is the preponderant mineral constituent. Quartz is next in abundance, while biotite and hornblende, although present in relatively large quantities, are least abundant.

Pike River granite. It is a fine grained gray granite. Its mineralogical composition consists mainly of feldspar and quartz. Biotite is a much less abundant constituent than either above, but is scattered in small flakes quite uniformly through the entire rock. Zircon constitutes the accessory constituent.

St. Cloud and Marquette granites. The former occurs as a pre-Cambrian intrusion covering extensive area only next in size to Wausau granite while the latter is also in considerable dimensions.

Marquette rhyolite. This is situated a mile southwest of the village of Marquette in a group of knobs rising abruptly ₀o to 150 feet above the surrounding sandy and marshy plain. The mass of the rhyolite is dark reddish-purple or dark purplish on the fresh surface and dull reddish or grayish-red on the weathered surface. The rock is mainly porphyritic with pinkish feldspar phenocrysts scattered through the dense dark groundmass but in some localities it becomes largely felsitic.

Waterloo quartzite. This is a hard, gray quartzite of Archaean age.

General Discussion of the Problem under Study.

The problem under study consists of three questions.

1. Whether the heavy minerals of each igneous body is characteristic of that rock?

2. After the heavy minerals of one sample from an igneous body have been analyzed, can another sample from the same igneous body be recognized by the heavy minerals alone?

3. When the heavy minerals of a series of igneous bodies in one or two regions have been studied, do they show any relation to the magmatic provinces and any similarity agreeing with their geographical distributions?

To solve the first question it is necessary to separate the heavy minerals of different igneous bodies and to study them whether they are different for different rock bodies.

For the second question two samples from the same rock body are taken but they are distant apart, then heavy minerals of each are examined and compared.

As to the third question a comprehensive study regarding the heavy minerals of the igneous bodies in the vicinity of Wisconsin are carried out and an attempt is made to group such igneous bodies according to their characteristic heavy minerals or chemical elements.

Laboratory Processes

Sampling: The general rule of sampling in the field is in endeavor to collect the fresh outcrop and to avoid as far as possible the weathered materials.

In order to get a comprehensive sampling, the collection should be made at certain chosen intervals both along horizontal and vertical dimensions. The quantity of each sample should be large enough for laboratory work, for example, at least one kilogram. When a large number of samples is undertaken, careful systematic labelling is very important for avoiding confusion. The general rule is to put a label inside the sample-container as well as on the outside and to make the labelling as soon as the samples are collected.

Crushing of samples: It is desirable that before crushing the samples some thin sections should be prepared for microscopic examination. Under this head a careful record on the mineral composition, size and shape of the constituents, and texture etc. should be made as detailed as possible. All the samples used for study in this paper are mostly collected from those quarries where the Geological Survey of Wisconsin has published a series of papers regarding their rock character and composition. It is, therefore, not necessary to make thin slice examination under these special conditions.

To crush the rock sample the first step is to break it into small pieces with a heavy hammer. The size of these small fragments is usually less than half inch. After putting some of the broken material into a steel mortar, it is treated by pounding but never by grinding, with a steel pestle. The amount of material treated each time in the mortar should not be more than a few fragments to prevent the easy formation of rock-flour. When the pounding in the mortar has been carried out about ten to twenty sharp blows, the crushed material is first treated to pass a 30 mesh sieve to prevent overpounding. The left unpassed material is pounded again in just the same way until all the material once put in the mortar passes through the 30 mesh sieve. New fragments are then added into the mortar and the same process of pounding goes on.

When all the broken fragments have been in operation, the grain material which passed through 30 mesh sieve is pounded again in order to pass through a 65 or 80 mesh sieve. By the writer's experience the 80 mesh sieve is especially recommended in those cases in which the rock contains a large amount of biotite or hornlende. These minerals are usually nearly opaque under microscope when their grains pass through the 65 mesh sieve. An additional 200 mesh sieve is sometimes useful to eliminate the very fine material which is too small to identify under microscope. Such a sieve when used in operation is just placed under the 65 or 80 mesh as a receiver and thus worked at the same time. If the sieves when in operation get chocked up with fine material, some sharp taps upside down on the floor are necessary.

Panning: It is desirable that the sample sifted as above is weighed with a balance. The most suitable quantity of sample for separating the heavy minerals from igneous rocks is from 300 to 500 grams. according as the rock is rich or poor in such minerals. The weighed material is now treated under panning. A little amount of the material is poured into a seven-inch evaporating dish. This dish is then filled with water which is stirred, allowed to settle the mineral grains and poured off. The process may be repeated until the liquid scanted is clear. The dish is next placed under a gentle running water and continually given a rotary and to-and-fro motion swirling the lighter constituents and alternative with scantation of such constituents until a desirable residue is left. The heavy residue is usually indicated by black grains. It is then moved on a piece of clean paper and another fresh material is now carried out. When all the material has been treated the concentrated residue is dried on a hot plate and weighed again. The suitable weight of residue is about 10 gr.

Heavy liquid separation: If the mineral grains in the concentrated residue are suspected to be contaminated by any authigenous material they may first be boiled in a 50 percent solution of hydrochloric acid, the heavy minerals being uneffected in practically all cases by this treatment. After boiling the material should be washed thoroughly and dried. For the samples of igneous rock this step is often unnecessary for the character of the minerals is generally not masked by secondary materials.

The heavy liquid most commonly used, is acetylene tetrabromoethane having a specific gravity of 3.0. One kilogram of this liquid is generally sufficient for common work. It can be obtained from Kodak photo Co., New York and is very expensive about $27 gold a kilogram. The first step of the separate process is to fill with the heavy liquid a tunnel equipped with rubber tubing and pinch clip. The concentrated residue is then poured off uniformly on the upper surface of the liquid which is afterwards frequently stirred with a glass rod and allowed to stay about one hour in order that a separation may be complete with all the grains whose specific gravity is greater than 3.0, sinking down into the stem of the funnel. The heavy grains will be collected on a filter paper below, when the pinch clip is loosened to make the attached rubber tube open. The liquid passing through the filter paper should be carefully kept for storage. The filter paper is usually folded into a fan shape before its putting on the funnel. The filtrate or heavy residue is thoroughly washed at least three times with carbon tetrachloride to remove all the traces of tetrabromoethane, subsequently dried on a steam basin and weighed.

Magnetic separation: In case there is a notable quantity of strongly magnetic minerals such as iron oxides in the heavy residue, they often give much trouble to the slides when mounted. They are thus expected to be separated out in advance. The process is usually accomplished with a horse-shoe magnet whose poles are enveloped with a thin sheet of paper in order to easily relieve the attracted mineral particles when the magnet poles are withdrawn from the envelope. Pour the heavy residue into a thin layer on a clean paper and then keep the enveloped magnet moving over it but not in contact. Relieve the strongly magnetic minerals on another paper from time to time until no more mineral is in attraction. In avoiding any non-magnetic heavy minerals brought by the strongly magnetic minerals on the last paper, repetition of the magnetic process is usually necessary and the final heavy minerals are then weighed again.

Sometimes it is, however, found that the separation with the above treatment is still imperfect and a certain amount of lighter minerals such as quartz and feldspar is mixed up with heavy grains especially when the concentrated residue is rich in iron oxides. In such case a repetition of separation with heavy liquid often gives a satisfactory result, but sometimes the repetition process can not be carried out readily unless the heavy iron oxides have been extracted in advance. As an illustration, in the sample of Wausau granite the heavy residue obtained from the first separation with heavy liquid weighs about 0.1504 gr. after extraction of the strong magnetic minerals and is reduced to 0.0916 gr. during a 2nd separation with about 0.0588 gr. of lighter minerals removed.

In case there is a great deal of pyrite in the heavy residue, which is of little diagnotic value for the research purpose and only tends to confuse the slide examination, the heavy residue should be treated with nitric acid and put into an evaporating dish which is covered with 75 percent solution of nitric acid. When there is difficulty in removing the pyrite, aqua regia may be used instead of nitric acid and often gives a clear result. After the nitric acid treatment care must be taken in washing the sample to keep the filter paper saturated with water to prevent its being eaten.

Mounting of heavy minerals on slides: The suitable size of the slide glass is 25 by 45 mm and that of the cover glass is 22 mm square. The convenient balsam is the balsam dissolved in xylol held in tubes. Before mounting, both the glass slide and cover glass must be made clean. Put a convenient amount of heavy grains on the slide glass which may be spreaded evenly with a mounted needle. Next a necessary quantity of balsam is poured over the heavy grains and the slide is then moved on a medium warm hot-plate adjusted on low heat. In case the balsam is being cooked on an over-heated hot plate, the heavy grains should be stirred in keeping their uniform distribution at the beginning time when the balsam becomes moving fluid and flows towards the edges of the slide. To test when the balsam will be cooked enough on the hot plate, a tiny drop of balsam from the heated slide is frequently taken with a mounted needle and tried on an iron plate until it becomes so brittle on cooling that the crushed particles may fly away when a pressure is engaged on such drops. Now remove the slide from the hot plate and place it on an iron plate. Put one edge of a cover glass into the outer portion of the cooked balsam, and then place the slide partly on the rim of the hot plate. As the balsam softens the cover glass will sink down and be gradually in contact with the balsam from one side to the other when the slide is at the same time gradually pushed into the inner part of the hot plate. In this way all air-bubbles may be expelled. Remove the slide on the iron plate again and press the cover glass down firmly and hold it until the balsam has hardened.

In cleaning the slides the major part of excess balsam can be removed with a knife, care being taken not to pry the cover glass off. The remainder of the balsam can be removed with acetene and a piece of white cloth.

In general four slides are mounted for each sample, in which three belong to the normal heavy minerals and one to the strongly magnetic minerals extracted by magnet.

DETAILED PETROGRAPHIC DESCRIPTIONS OF THE HEAVY-MINERAL SLIDES.

I. *Berlin rhyolite, Wis.*

Weight of crushed material passing sieve (65 wires to the linear inch)——— 231.4256 gr.

Rock-flour left after panning———8.4386 gr.

Weight of mineral grains with sp. gr. >2.90=0.8402 gr.

Percentage by weight of heavy minerals in rock=0.3 %.

Weight of mineral grains with sp. gr. >2.90 after the extraction of the strongly magnetic minerals by magnet=0.4042 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals =51.8 %.

Fluorite: This is identified by its negative relief, isometric character, and irregular angular shapes. The color is generally white with a few pinkish to yellowish fragments. Octahedral cleavage is sometimes distinct. Inclusions are plenty with a great diversity of anisotropic minerals.

Biotite: It is in yellow fragments or in lamellar plates. The optic plane normal to the basal cleavage is characteristic. The strong pleochroism from yellow to opaque is a useful datum for identification. The mineral is sometimes partially altered to chlorite.

Chlorite: This is represented by nearly opaque fragments which under cross nicols show distinct ultra blue interference color along their thin edges. The green color and pleochroism are also visible especially along the thin edges. No distinct interference figure is obtained to determine the optic sign. But from what the characters have been observed, the mineral most probably belongs to penninite. Besides penninite, some other varieties which show distinctly bright interference color, are probably due to the transition species from biotite to chlorite.

Generally speaking, there are two probable sources of deviation of chlorite. One is from the alteration of biotite as shown before, the other from feldspar. Some minute fragments of chlorite are visibly distributed in orthoclase in more or less parallel arrangement.

Iron oxides: Magnetite and hematite both occur in irregular fragments. In reflected light they are characterized by bluish gray and red colors.

The percentages by volume of the mentioned minerals are as the following:—

Iron oxides	Fluorite	Chlorite	Biotite
74.8%	14.5%	9.3%	1.2%

If only the percentages of those heavy minerals other than iron oxides are in consideration, they are as follows:—

Fluorite	Chlorite	Biotite
57.8%	37.2%	4.9%

II. *Wausau granite, Wis.*

No. 14

Weight of crushed rock material passing sieve (65)=312.6446 gr.

Weight of mineral grains after panning=4.9582 gr.

Weight of mineral grains with sp. gr. >2.90=0.7742 gr.

Percentage by weight of heavy minerals in rock=0.2%

Weight of mineral grains with sp. gr. >2.90 after extraction of strongly magnetic minerals and after the 2nd separation by heavy liquid=0.0916 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals=87.1%

Fluorite: This occurs as irregular angular fragments. The color varies from colorless to pinkish or yellowish shades. Some fragments unevenly distributed purple color is sometimes observed. Octahedral cleavage may be visible. Inclusions of iron oxide are very common. High negative relief and isotropic character are both characteristic.

Malacon: A few white to yellowish corroded anhedral crystals exhibit positive high relief with low interference color. Elongation is positive and extinction parallel. Prismatic forms with imperfect pyramidal faces are occasionally observed. This mineral is probably malacon derived from the alteration of zircon, but the alteration process is so complete that no primary zircon can be identified.

Biotite: This is in yellow brown or dark fragments. Pleochroism is strong. When the vibration direction of the polarized light is normal to the lamellar basal cleavage, the color is yellow brown and, while the vibration direction is parallel to the cleavage, it is dark. The shape of the fragments is both angular and irregular. Sometimes the mineral is hardly to be recognised due to its darkness.

Chlorite: The shape of the fragments of chlorite is nearly the same as that of biotite. It is probably an altered product both of hornblende and biotite. It can be identified by its predominant green color, low birefringence and weak pleochroism. The vibration direction of light normal to the cleavage gives yellowish green color and that parallel to the cleavage exhibits dark green shades.

Titanite: So far as observations go on in the slides in hand, there is one fragment of brown mineral with very high refringence and strong birefringence, which probably belongs to titanite. The optic character of the mineral can not be thoroughly identified.

Magnetite: This is the most abundant opaque mineral. The fragments are generally in irregular shapes.

Pyrite: The shape of the pyrite fragments is the same as that of magnetite. The mineral is usually partially altered to hematite. In reflected light the yellow spots of pyrite are generally mixed up with the red brown colors of hematite.

The percentages by volume of the above non-opaque minerals are as below:

Slide No. 1:—

Fluorite	Chlorite (hornblende)	Biotite	Malacon	Titanite
40.6%	42.7%	15.8%	0.8%	Little

Slide No. 2:—

Fluorite	Chlorite (hornblende)	Biotite	Malacon	Titanite
47.1%	49.1%	2.7%	0.9	

Slide No. 3:—

Fluorite	Chlorite (hornblende)	Biotite	Malacon	Titanite
54.9%	37.8%	%	2.1%	

Average:—

Fluorite	Chlorite (hornblende)	Biotite	Malacon	Titanite
47.5%	43.2%	7.8%	1.3%	little

If chlorite and biotite are counted as one unit, the percentages are:—

Fluorite	Chlorite & Biotite (Hornblende)	Malacon	Titanite
47.5%	51%	1.3%	Little

Wausau granite

Dr. Raule's sample.

Weight of crushed material passing sieve (-80) = 164.2856 gr.

Weight of mineral grains after panning = 5.1318 gr.

Weight of mineral grains with sp. gr. > 2.90 = 0.5506 gr.

Percentage by wieght of heavy mineral in rock = 0.3%

Weight of mineral grains with sp. gr. > 2.90 after extraction of strongly magnetic minerals=0.2174 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals =60.5%

Fluorite: It is colorless or shows irregularly distributed pinkish color. Iron oxide, probably hematite, is usually included as inclusions.

Hornblende: It mostly occurs as anhedral opaque crystals, though the thin edges of such fragments are often transparent and show distinct green color. It is sometimes altered into chlorite.

The pleochroism as shown by a few grains is:—Z=deep green;X=yellow.

Biotite: Brown biotite with strong pleochroism and showing parallel extinction is also recognised.

Zircon: This occurs as tabular crystals sometimes with perfect terminated pyramids, usually showing distinct yellow color or altered to malacon.

Slide No. 1:—

Fluorite	Hornblende & Chlorite	Biotite	Zircon	Titanite
40.6%	47.2%	9.4%	2.8%	

Slide No. 2:—

Fluorite	Hornblende & Chlorite	Biotite	Zircon
50%	40%	8%	2%

Slide No. 3:—

Fluorite	Hornblende & Chlorite	Biotite	Zircon
38.6%	49%	10.4%	1.8%

Average:—

Fluorite	Hornblende & Chlorite	Biotite	Zircon
43.1%	45.4%	9.3%	2.2%

If hornblende, chlorite and biotite are counted as one unit, the percentages are as below:—

Fluorite	Hornblende, Chlorite & Biotite	Zircon
43.1%	54.7%	2.2%

Wausau granite, Wis.

No. 16:—

Weight of crushed rock materials passing sieve (65) = 313.6636 gr.

Weight of mineral grains after panning = 10.1296 gr.

Weight of mineral grains with sp. g. > 2.90 = 0.5858 gr.

Percentage by weight of heavy minerals in rock = 0.18%

Weight of mineral grains with sp. g. > 2.90 after extraction of strongly magnetic minerals and after the 2nd separation by heavy liquid = 0.1092 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals=81 3%

Slide No. 1:—

Fluorite	Chlorite (hornblende)	Biotite	Malacon	Titanite
41.9%	53.1%	2.5%	1.8%	little

Slide No. 2:—

Fluorite	Chlorite (hornblende)	Biotite	Malacon	Titanite
42.6%	50.5%	4 9%	1.7%	

Slide No. 3:—

Fluorite	Chlorite (hornblende)	Biotite	Malacon	Titanite
41.7%	55.9%		2.3%	

Average:—

Fluorite	Chlorite (hornblende)	Biotite	Malacon	Titanite
42.1%	53.1%	2.5%	1.9%	little

If chlorite and biotite are counted as one unit, the percentages are as follows:—

Fluorite	Chlorite & biotite (hornblende)	Malacon	Titanite
42.1%	55.6%	1.9%	little

III. *Waushara granite.*

Weight of crushed rock material passing sieve (65)=331.1696 gr.

Weight of mineral grains after panning=11.1474 gr.

Weight of mineral grains with sp. gr. > 2.90 =1.0692 gr.

Percentage by weight of heavy minerals in rock=0.3%

Weight of mineral grains with sp. gr. > 2.90 after extraction of strongly magnetic minerals=0.3262 gr.

Weight of mineral grains with sp. gr. > 2.90 after the 2nd separation=0.2752 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals=72.9%

Fluorite: The color is purple or pinkish and usually not uniformly distributed. The shape of the fragments is irregular and angular. A notable amount of iron oxide, most hematite, usually occurs as inclusions in dendritic forms. Other inclusions of gaseous bubbles are not uncommon. Penetration twinning on (111) is present in some crystals. As in other slides the mineral is characterized by pronounced negative relief and isotropic character.

Biotite: The fragments of biotite are generally dark greenish yellow to pure yellow. Pseudo-uniaxial interference figure is obtained in some basal sections. Pleochroism is strong with X=yellow, Z=Y=dark greenish yellow, and X< Z=Y. Basal cleavage usually gives the lamellar appearance in some sections.

Chlorite: This occurs as green fragments. Pleochroism is very weak with X=pale yellowish green, Z = Y = green. The absorption is X<Z=Y Relief is positive low and birefringence weak. No distinct interference figure can be observed. The optic sign seems, however, to be negative as learned from some obscure interference figures.

Zircon: It occurs in slender or square prisms usually terminated by unit pyramids. Corroded forms are also present. The color is white grayish or yellowish. Inclusions are not dominant, if any. The birefringence in some crystals is exceedingly weak, indicating the alteration of Zircon to malacon.

Pyrite: Angular fragments of pyrite are recognised by their brass yellow to brownish yellow color in reflected light.

Magnetite: This gives silver gray to bluish gray in reflected light. The shape of the fragments is very irregular without any outline of crystal forms.

The percentages by volume of the above minerals in excluding pyrite and magnetite are as follows:

Fluorite	Biotite	Chlorite	Zircon
29.7%	41.4%	17.9%	10.9%

IV. *Lohrville granite.*

Weight of crushed material passing sieve (—80) = 142.2886 gr.

Weight of mineral grains after panning=5.3876 gr.

Weight of mineral grains with sp. gr.>2 90=1.2036 gr.

Percentage by weight of heavy minerals in rock=0.8%

Weight of mineral grains with sp. gr.>2.90 after the extraction of strongly magnetic minerals=0.2572 gr.

Percentage of iron oxides in proportion to other heavy minerals=78.6%

Fluorite: This is mostly colorless though purple varieties are also present. The shape is very irregular, varying from triangular cleavage fragments to somewhat perfect dodecahedral crystals. Inclusions are common and sometimes a corroded zircon crystal is entirely enveloped in fluorite. The pronounced negative relief and isotropic character are characteristic for the latter mineral.

Apatite: It occurs as beautiful prismatic crystals and sometimes minute inclusions are arranged parallel to its vertical axis. The white color, parallel extinction and negative elongation are characteristic for this mineral. Further, the moderate relief and white gray interference color of the first order are also useful for determination under microscope. The length of crystals is generally about 0.12 mm.

Zircon: The prisms of zircon are all elongated parallel the C axis. Bipyramidal faces are sometimes well preserved but mostly more or less corroded. The color ranges from colorless to yellowish. Zoning is common. The special feature of this zircon is the abundance of inclusions which are sometimes hair-like and not definitely arranged though a tendency more or less parallel to the pyramidal faces, is obvious. Some bigger inclusions occasionally form the nuclei of zircon crystals and show somewhat parallelism to the vertical crystallographic axis. Partial alteration of the crystals into malacon is not uncommon and sometimes even the whole crystal is entirely transformed into the latter mineral. The size of the crystals is variable from 0.07 mm to 0.20 mm in length.

Muscovite: This mineral is identified by its moderate relief, strong birefringence, and optic plane normal to the distinct basal cleavage. It is in colorless fragments and the absorption is prominent with X<Z=Y. Inclusions of iron oxide are abundant in some fragments.

Penninite: In the basal cleavage flakes, indistinct pseudo-uniaxial interference figure is generally visible, indicating the optic negative character. All fragments are in green color and characterized by their very low interference color and moderate relief. Pleochroism is perceptible though weak.

Corundum: This is generally in colorless irregular angular fragments. Inclusions are plentiful and sometimes characterized by the dendritic form. Basal parting is distinct. The mineral can be determined by its high relief, low interference color (red of the 2nd order), parallel extinction, negative elongation and negative optic sign.

Biotite: The fragments of biotite are present in irregular forms. Its dark yellow color is generally useful for identification.

Garnet: It is characterized by yellow to black in color, very high relief, and isotropic character. The shape of the fragments is irregular.

Galena: This is in cubic fragments and characterized by the distinct cubic cleavages in two directions at right angles to each other. In reflected light the color is lead-gray.

Iron oxides: Magnetite and hematite are both present as shown by their gray and red colors and metallic luster in reflected light.

The percentages by volumes of the above minerals are as below:—

Iron oxides	Fluorite		Penninite	Zircon
34.9%	37.3%		13.9%	5.5%
Biotite	Galena	Garnet	Apatite	Corundum
4.1%	1.5%	1%	0.5%	0.5%
Muscovite				
0.5%				

If the percentages are calculated excluding iron oxides, then they are:—

Fluorite 57.3%	Penninite 21.4%	Zircon 8.5%	Biotite 6.3%
Galena 2.3%	Garnet 1.5%	Apatite 0.7%	Corundum 0.7%
Muscovite 0.7%			

V. *Mellen (High Bridge) granite, Wis.*

Weight of crushed rock material passing sieve (−65) = 279.378 gr.

Weight of mineral grains after panning = 10.724 gr.

Weight of mineral grains with sp. gr. > 2.90 = 3.6608 gr.

Percentage by weight of heavy minerals in rock = 1.3%

Weight of mineral grains with sp. gr. > 2.90 after extraction of strongly magnetic minerals = 3 6182 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals = 1.1%

Hornblende: This is the most abundant heavy mineral represented. It occurs in irregular angular fragments or occasionally in tabular form elongated parallel to C. Most fragments are nearly opaque due to their excess of thickness.

In a section normal to Y, $Z \wedge C = 15^{\circ}$. Pleochroism is distinct with Z=dark green, Y=pale green, and X=yellow, and the absorption formula is $Z > Y > X$.

Titanite: It shows a brownish yellow color with very weak pleochroism. Its angular fragments can be recognized by the high relief and very strong birefringence. In convergent light, a section nearly normal to one optic axis shows strongly rhombic dispersion with $P > V$, red color appearing on the convex side of the isogyre and blue on the concave side.

Zircon: It occurs as prismatic euhedral crystals yellowish to colorless and elongated parallel to C. Doubly terminated forms are fairly common; a

(100) predominant; m (110) subordinate; p (111) well developed. The peculiar feature of the crystals is distinct zoning, and inclusions are also commonly present.

Biotite: Tabular fragments of biotite can be distinguished from hornblende by its brown color, parallel extinction, and small optic angle.

Apatite: This occurs as prismatic fragments and can be identified by its uniaxial character and weak birefringence.

Most iron oxides were extracted from the above heavy minerals before mounting on the slide.

The percentage by volume of the heavy minerals mentioned, as calculated with Rosiwal method gives the following figures:—

Hornblende	Zircon	Titanite	Biotite	Apatite
89.5%	5.1%	3.8%	1%	0.4%

If the specific gravities of these minerals are assumed as follows:—Hornblende, 3.1; Zircon, 4.6; titanite, 3.4; biotite, 3.0; and apatite, 3.2; the percentage by weight of these minerals would be:—

Hornblende	Zircon	Titanite	Biotite	Apatite
80.2%	7.3%	4%	7.9%	0.4%

VI. *Montello granite.*

Weight of crushed rock material passing sieve (—65) 290.2616 gr.

Weight of mineral grains after panning = 8.658 gr.

Weight of mineral grains with sp. gr. >2.90=1.418 gr.

Percentage by weight of heavy minerals in rock=0.4%

Weight of mineral grains with sp. gr. >2.90 after extraction of strongly magnetic minerals=0.5164 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals = 63.5%

This granite is very poor in heavy minerals. The only known species except iron oxides belongs to fluorite and titanite.

Fluorite: Colorless to pinkish in color. Mostly occuring as angular anhedral fragments. Indeed, this is the only abundant heavy mineral in the rock besides iron oxides.

Titanite: Its color is yellow to brown. Pleochroism distinct. It can be recognised by its high relief and interference color of high orders. Uncentered interference figures obtained from some fragmental grains are usually sufficient to show the biaxial character.

If we count the number of mineral grains under microscope, we get 18 of fluorite in one slide and 20 in another while only one grain of titanite is represented in each. In general the grain of fluorite is bigger than that of titanite.

VII. *Endeavor granite.*

Weight of crushed rich material passing sieve (−65) = 339.2536 gr.

Weight of mineral grains after panning = 4.9842 gr.

Weight of mineral grains with sp. gr. > 2.90 = 1.3844 gr.

Percentage by weight of heavy minerals in rock = 0.4%

Weight of mineral grains with sp. gr. > 2.90 after the extraction of strongly magnetic minerals = 0.1412 gr..

Percentage of strongly magnetic minerals in proportion to other heavy minerals = 89.8%

Fluorite: It occurs as angular fragments and sometimes with distinct octahedral cleavages. Its color varies from colorless to pinkish, but is here especially characteristic by some irregularly distributed purple shades. Inclusions are abundant with a great diversity of mineral varieties and those in the pinkish or purple fragments usually belong to iron oxide, probably hematite. The dimensions of the fragments range from 0.105 mm by 0.135 mm, to 0.345 mm by 0.225 mm.

Zircon: This consists both of euhedral crystals and anhedral fragments. Its color is yellowish or colorless and some fragment is nearly opaque. The special feature is that most crystals are more or less corroded after their formation and perfect doubly terminated pyramidal crystals as often observed in other rocks, are rare. Inclusions are plentiful. The lengths of the crystals are generally from 0.075 mm. to 0.180 mm.

Chlorite: There are some green minerals usually opaque near the central parts of the fragments with distinct pleochroism from dark green to yellowish green. These minerals probably belong to chlorite as the relief is moderate and the birefringence is weak. No distinct interference figure is obtained so far as we go,

Titanite: Only one fragment identified as titanite, is present in the slides under study. It is recognised by its high relief, very strong birefringence, and its positive uncentered biaxial interference figure. Axial dispersion is distinct and the optic angle as estimated from the curvature of the isogyre of the partial centered figure, is about 30°.

Iron oxides: Some opaque minerals occurring as angular fragments and showing distinct metallic luster and bluish black to silver gray color in reflected light, are determined as magnetite, while others which exhibit gray white color in reflected light, are treated as ilmenite and leucoxene. Still others giving red-brown color in reflected light, are considered to be hematite.

Iron sulphide: The angular fragments of pyrite are recognised by their brass yellow color in reflected light. The presence of this mineral with a certain amount of chlorite indicates that the rock under study has suffered some influence of hydrothermal solution, though the pyrite may also be taken as a primary mineral crystallized just as the other mineral constituents during the normal course of the consolidation of the rock.

The percentages by volume of the minerals mentioned, are shown below:—

Fluorite	Iron oxides & sulphide	Chlorite	Zircon	Titanite
36.8%	51.8%	7.7%	3.2%	0.4%

If we exclude the iron oxides and sulphide into the percentage, we get the following figures:—

Fluorite	Chlorite	Zircon	Titanite
76.4%	15.9%	6.6%	0.9%

VIII. *Athelstane granite:*

Weight of crushed rock material passing sieve (—80) = 193.16 gr.

Weight of mineral grains after panning = 10.8176 gr.

Weight of mineral grains with sp. g. > 2.90 = 2.3344 gr.

Percentage by weight of heavy minerals in rock = 6.1%

Weight of mineral grains with sp. g. > 2.90 after extraction of strongly magnetic minerals by magnet = 2.1322 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals = 8.6%

Apatite: This is in prismatic crystals but the terminated faces are not well developed. The crystals are generally colorless or partially yellow due to the inclusions of iron oxide and mostly bigger than those as usually observed in other slides. Inclusions are common and usually arranged parallel to or along the vertical crystallographic axis. The high relief, low interference colo and prismatic crystal forms are useful for recognition under microscope. The lengths of the crystals vary from 0.33 mm. to 0.15 mm.

Titanite: It occurs in irregularly angular shapes and is generally colorless or yellowish brown. The relief is very high and the interference colors rise up to white of the higher orders. Most fragments give partial optic axial interference figures. When a section normal to the acute bisectrix is found, the positive biaxial character is well shown and the optic angle is estimated about 30°. Rhombic dispersion with red color on the convex side of the isogyre and blue on the concave side is very distinct. In plane polarized light with crossed nicols a perfect extinction is not obtained and the lowest interference color is bluish gray. Cleavage is sometimes visible, but pleochroism is imperceptible.

Zircon: The color of zircon is grayish yellow to brown and its shapes vary from perfect prismatic crystals with bipyramidal terminations to longitudinal crystals with irregular ends. Zoning is common. Inclusions are abundant or form networks in the crystals. The high relief and strong birefringence with distinct crystal habit make zircon to be easily identified. Alteration of zircon to malacon is occasionally present. The length of the crystals is from 0.38 mm to 0.15 mm.

Fluorite: It shows distinct negative relief and remains dark under crossed nicols. The shape of the fragments is angular and very irregular. The color is generally pinkish and the occasional presence of irregularly distributed purple color is characteristic. Inclusions of anisotropic mineral grains are sometimes present.

Hornblende: This is mostly in green and yellowish fragments which are irregular and angular. The relief is moderate and the interferenee color is high. Prismatic cleavage is distinct. Pleochroism is distinct with $X =$ yellow, $Z =$ dark green, $y =$ pale green and $X < Y < Z$.

Biotite: This is generally in yellow and dark fragments. The shape is the same as chlorite but the interferenc color is exceedingly high and the pleochroism is strong with $X =$ yellow, $Z = Y =$ dark, and $X < Z = Y$. The cleavage fragments show parallel extinction and the basal flakes give pseudo-uniaxial negative interference figures.

The percentages by volume of the minerals mentioned are as below.—

Apatite	Titanite	Zircon	Fluorite	Hornblende	Biotite
4.1%	6.4%	9.8%	1.1%	66.4%	11.9%

IX. *Pike River granite.*

Weight of crushed rock material passing through (—65) sieve = 260.4624 gr.

Weight of mineral grains after panning = 12.6478 gr.

Weight of mineral grains with sp. g. > 2.90 = 0.7910 gr.

Percentage by weight of heavy minerals in rock = 0.3%

Weight of mineral grains with sp. g. > 2.90 after extraction of strongly magnetic minerals = 0.7422 gr.

Percentage of strongly magnetic minerals in proportion to other heavy minerals = 6.1%

Biotite: This is the most abundant heavy mineral in the slice. Its identification depends upon its brown color, strong absorption, parallel extinction and small extinction angle, the last being only about 3° by estimation. When the fragments are so thick that they nearly become opaque, only their thin edges, if any, are used for recognization.

Hornblende: This mineral is distinguished from biotite by its predominant green color. Prismatic cleavages are usually well represented. An extinction angle measured from these cleavages on one fragment is about 22°, but this is not the maximum one for no centered interference figure is obtained. The pleochroism in the prismatic section is generally ranged from green to yellow.

Epidote: Occurring as eubedral crystals, it can be recognised by its high relief, strong birefringence and distinct pleochroism generally colorless to greenish yellow. So far as the mineral grains are examined in the slices under study, no centered interference figure is obtained but there is one uncentered interference figure with its centre at the edge of the field of view which seems sufficiently to show the negative biaxial character of the mineral. Learned from the straightness of the isogyre, the optic angle is probably larger than 70°. Dispersion is obscure due to the wanting of centered figure.

Zircon: Euhedral crystals with doubly terminated pyramids are common. Color is yellowish. Zoning is predominant. It is a striking fact that the interference color in these crystals seems especially low, though every other aspect is all like zircon. Lengths of crystals are measured as from 0.12 mm to 0.225 mm.

Garnet: This is represented as angular fragments colorless to yellow in color. Its identification depends upon its positive high relief, vitreous luster and isometric character. Inclusions are common. A few fragments sometimes show more or less gray interference color of the 1st. order.

Apatite: The prismatic crystals usually give well centered flash interference figure for recognising their negative optic character. The high refringence and low birefringence not giving the interference color above white of the 1st. order, are characteristic of this mineral. Lengths of crystals are usually from 0.12 mm to 0.195 mm.

Topaz: It is colorless with abundant fluid or gas cavities. Only one anhedral fragment is recognised in the slices under study. It is determined by its high relief, low interference color scarcely rising over yellow of the 1st. order and biaxial character.

The percentage by volume of the above minerals as calculated with Rosiwal method is as the following:—

Biotite	Garnet	Hornblende	Epidote
93%	1%	2.1%	1.9%
Zircon	Apatite	Topaz	Chlorite?
1.4%	0.4%	0.2%	

X. *St. Cloud granite.*

Fluorite: This occurs mostly as colorless (a little pinkish) fragments, though irregularly distributed purple fragments are also present. Inclusions are generally few, but in certain crystals they are notably plentiful. In the latter case the nature of the inclusions varies greatly and sometimes they are minute iron oxide, probably hematite, or bigger grains of transparent anisotropic minerals. Cleavage is not very distinct.

Topaz: The fragment of topaz is colorless and in parallel polarized light much like fluorite in certain physical features. The basal cleavage is generally invisible, but the mineral can be recognised by its low interference color and positive biaxial character. The optic angle is about 60° as estimated from the curvature of the isogyre of the optic axis figure. Dispersion and pleochroism are both imperceptible. Colorless inclusions of anisotropic minerals are common.

Muscovite: Being colorless to a little pale colored, it is somewhat difficult to be distinguished from topaz in the same slide. The most common fragments of muscovite are the basal cleavage flakes in which the difference of Nm and Ng is only about 0.006 while the birefringence of topaz is about 0.0095. Fortunately, the basal flake of the former generally gives well centered acute bisectrix interference figure and as such the nature of muscovite can be determined by the much smaller optic angle of about 40° and the negative optic character. In addition, the relief of muscovite is a little lower than that of topaz and the interference color of those sections other than the basal flakes is higher. No dispersion is recognisable and pleochroism is weak from colorless to yellowish. Inclusions are sometimes abundant and in a great diversity of mineral varieties.

Titanite: It occurs as yellow fragments. As the shape of the fragment is irregular and centered interference figure is generally not observed, this mineral may fail to be distinguished from xenotimite in ordinary mounted slides. But if a few grains of both minerals are immersed in a liquid whose index is about 1.74, xenotimite will have one index higher than 1.74 and the other lower, while the indices of titanite are all higher.

Xenotimite: It occurs as colorless or yellowish fragments ranging from corroded grains to irregular angular shapes. Prismatic crystals with perfect (110) faces and terminated pyramids are also present. The mineral can be identified by its high relief, very strong birefringence, and positive uniaxial character. The occasionally distinct (110) cleavage is the only fact with which it is characteristic from cassiterite. Another different optic character between xenotimite and cassiterite lies on the lower refringence of the former, but this is not always available for differentiation in common mounted slides, unless a high refringence melt is specially prepared. Inclusions are common and sometimes belong to a lot of minute dots of iron oxide.

Zircon: Colorless to yellow in well vertically elongated prisms. Prismatic cleavage sometimes very distinct; which is a special feature for this zircon.

Malacon: Most zircon crystals are altered into the hydrous mineral malacon, which usually gives much lower interference color of brown of the 1st. order in the slides. The refringence is also much lower, but the crystal form of zircon is still well preserved. Inclusions are abundant but their nature is mostly obscure due to the advanced process of alteration. The lengths of the crystals range from 0.1 mm. 0.3 mm.

Chlorite: The fragment of chlorite is grass green in color and pleochroism is imperceptible. The refringence is notably high but the birefringence is very weak, the interference color being nearly dark in crossed nicols. No interference figure is visible due to the exceedingly low birefringence.

Biotite: The (001) cleavage flakes of biotite show a general dark yellow color and often give a well centered negative acute bisectrix interference figure. Pleochroism is strong: X=light yellow, Z=Y=dark yellow. The absorption formula is Z=Y>X. Basal cleavage is very distinct in the sections parallel to X.

Apatite: It is in colorless prismatic euhedral crystals. Its moderate relief and negative elongation are characteristic, but the interference color generally gives yellow of the 1st. order and is thus somewhat higher than usual as observed in other rock slides. There are some inclusions of xenotimite arranged parallel to the vertical axis.

Chloritoid: This occurs as blue crystals. Pleochroism is distinctly blue to light yellowish blue. Relief is high and birefringence strong. Though no centered interference figure is obtained in the slides, the biaxial character of the mineral is well shown in some partial interference figure.

The abundance of chlorite with Chloritoid which is only notably generated in metamorphic rocks, indicates that the rock under study has suffered intense hydrothermal alteration either during or after its consolidation. Most crystals of Zircon are changed into malacon probably due to the same effect and as such the process of alteration from zircon to malacon is here well proved.

The percentages by volume of the mentioned minerals are shown below:—

Fluorite	Topaz	Muscovite	Xenotimite & titanite	Zircon
12.4%	3.1%	6.2%	12.6%	0.6%
Malacon	Chlorite	Biotite	Apatite	Chloritoid
5.2%	6.9%	52%	0.5%	0.3%

Cyanite: This is recognised by its high relief, and two directions of cleavage about at 90° to each other. In a section normal to x, the biaxial negative character is distinctly shown and the opte angle is large.

XI. *St. Cloud granite, No. 18.*

Weight of crushed rock materials passing sieve (—65) = 332.8676 gr.
Weight of minerals grains after panning = 10.5392 gr.

Weight of mineral grains with sp. gr. $> 2.90 = 1.3108$ gr.
Percentage by weight of heavy minerals in rock $= 0.3\%$
Weight of mineral grains with sp. gr. > 2.90 after extraction of strongly magnetic minerals $= 1.0826$ gr.
Percentage of strongly magnetic minerals in proportion to other heavy minerals $= 17.4\%$

Fluorite: It is mostly colorless though pinkish fragments are also present. Inclusions are not uncommon. The shape of the fragments is generally angular and irregular. Octahedral cleavage is sometimes distinct. Negative relief is high. No anomalous polarization is shown under crossed nicols.

Zircon: The fragments of zircon vary from euhedral to subhedral crystals. The color is usually white or yellowish. Zoning is often observed. Inclusions are sometimes present. The partial or entire alteration of zircon to malacon with a great reduction of birefringence is a common feature. The length of the crystals is averagely about 0.15 mm.

Biotite: This occurs as lamellar fragments with yellow brown to dark greenish yellow color. Absorption is strong. Most fragments are nearly opaque under microscope. Their optic character is generally much difficult to be determined, though the optic plane normal to the basal cleavage is occasionally visible.

Hornblende: The fragments of hornblende are generally in greenish yellow color. Pleochroism is moderate with Y= pale green, X = greenish yellow, and Z = dark green. The absorption formular is $X < Y < Z$. In a section nearly normal to one optic axis, the optic sign is determined as negative and the optic angle seems not less than 80°

Pyrite: The presence of pyrite is indicated by the yellow color in reflected light, though a large amount of it seems altered to brown limonite.

Magnetite: Angular fragments of magnetite are commonly observed as shown by their white gray color in reflected light.

The percentages by volume of those minerals other than pyrite and magnetite are as the following:—

Fluorite	Zircon	Biotite	Hornblende
2.3%	1.3%	79.6%	16.6%

As biotite and hornblende are both nearly opaque in thick sections, their differentiation is sometimes impossible under microscope. It is, thus, rather safe to consider the two minerals together in percentage as below:—

Fluorite	Zircon	Biotite & Hornblende
2.3%	1.3%	96.2%

XII. *Marquette granite.*

Andalusite: Being colorless and water-clean, it looks much like topaz as the refringence is moderate and just nearly the same for both minerals. The birefringence of the former is, however, evidently a little lower and not above yellow of the first order in interference color in the slides. When a section normal to one optic axis is obtained, a negative biaxial character is distinctly shown. The optic angle as estimated from the curvature of the isogyre is also much larger than that of topaz. Prismatic cleavage is sometimes visible, but pleochroism is too weak to be recognisable. Inclusions are abundant with various anisotropic minerals.

Muscovite: It occurs as colorless fragments and can, under microscope, be distinguished from andalusite by its lower relief, small optic angle in cleavage flakes, and higher interference colors in those sections parallel to X. In addition, (001) cleavage is distinct and the same is for the absorption with $X<Z=Y$.

Zircon: This is mostly in corroded prismatic forms and pale colored. Its refringence and birefringence are generally both much reduced especially in the latter and thus the mineral is probably mostly changed into malacon. The length of the crystals is averagely about 0.15 mm.

Penninite: Occurring as green fragments, it is characterized by the ultra blue interference color in the cleavage flakes. Optic sign is negative. In a section normal to X, a pseudo-uniaxial optic axial interference figure is obtained. Basal cleavage and pleochroism are both distinct though the latter is weak with X = yellowish green, Z = Y = green. The absorption formula is $X<Z=Y$.

Biotite: It is generally dark brown in color. The basal cleavage plates usually give the pseudo-uniaxial interference figure showing the negative character of the mineral. Pleochroism is strong as shown by the sections other than those parallel to the basal cleavage plates. The formula is: X = light yellow, Z = Y = dark brown, and X < Z = Y.

Garnet: The color of garnet is pinkish gray and thus it is easily recognisable from the above nearly colorless minerals. The very high relief combined with the isotropic character is characteristic. The shape of the fragments is irregular and the mineral is very rare in the slides.

The percentages by volume of the heavy minerals mentioned are as follows:—

Biotite	Penninite	Andalusite	Muscovite	Garnet	Zircon
86.4%	8.2%	2.7%	1%	0.4%	1%

XIII. *Marquette rhyolite.*

Weight of crushed rock material passing sieve (—65) = 175.9086 gr.
Weight of mineral grains after panning = 6.4562 gr.
Weight of mineral grains with sp. gr. > 2.90 = 0.3154 gr.
Percentage by weight of heavy minerals in rock = 0.17%
Weight of mineral grains with sp. gr. > 2.90 after extraction of strongly magnetic minerals = 0.175 gr.
Percentage of strongly magnetic minerals in proportion to other heavy minerals = 44.5%

Diopside: It is colorless with distinct (110) cleavage. In an angular fragment parallel to b, an uncentered optic axis interference figure is clearly shown and as such the positive biaxial character of the mineral is readily determined. This combined with the characters of high refringence and very strong birefringence, leads to the identification of the mineral as diopside.

Apatite: Occurring as prismatic colorless crystals, it usually includes inclusions arranged parallel to the vertical crystallographic axis. Its moderate relief, low interference color, parallel extinction, and negative elongation aid to its recognition.

Chlorite: The angular fragments of chlorite show distinct grass-green color and basal cleavage. Pleochroism is imperceptible. Relief is high with weak birefringence. The optic sign is negative as determined from a section normal to one optic axis and the optic angle estimated from the cruvature of the isogyre is near 30°. Dispersion is not strong enough to be noticeable.

Garnet: It occurs as angular fragments and contains numerous inclusions both of iron oxides and of other colorless anisotropic minerals. The high relief and isotropic character sufficiently determine its nature.

Iron oxides: Hematite is represented in a notable quantity, and gives a reddish-brown color in reflected light. Ilmenite is present and usually partially transformed into leucoxene by alteration. Sometimes even the whole fragment of the former is entirely changed into the latter mineral and as such gives a distinct white cloudy feature in reflected light.

Except iron oxide minerals, all the other heavy minerals are only represented in one or two fragments in the slides. As Arthur Holmes indicated that with Rosiwal method of micrometric analysis the total length measured must be at least a hundred times that of the average diameter of the constituents measured, so in this case the percentage by volume of the heavy minerals other than iron oxides can not be correctly calculated. But it is safe to say that according to the order of decreasing abundance they are chlorite, diopside, garnet and apatite.

XIV. *Waterloo quartzite.*

Weight of crushed rock material passing sieve (—65) = 352.2986 gr.
Weight of mineral grains after panning. = 5.6574 gr.
Weight of mineral grains with sp. gr. > 2. 90 = 0.1828 gr.
Percentage by weight of heavy minerals in rock = 0.05%
Weight of mineral grains with sp. gr. > 2.90 after extraction of strongly magnetic minerals = 0.0524 gr.
Percentage of strongly magnetic minerals in proportion to other heavy minerals = 71.3%

Zircon: Colorless to yellowish brown. Zonal crystals are fairly common with numerous inclusions. Most grains are rounded but euhedral crystals with perfect prismatic crystal faces are also present, and the faces are usually pitted or grooved. The lengths of crystals range from 0.075 mm—0.225 mm.

Ilmenite and leucoxene: The opaque minerals, when examined by reflected light, mostly show white and gray colors and thus probably belong to ilmenite and leucoxene. These are the most abundant heavy minerals in the rock under study.

Muscovite: It is colorless with high relief and very strong birefringence. In a section normal to the acute bisectrix, the optic angle is estimated as about 40°. Horizontal dispersion is strong with P<V. Iron inclusions are usually abundant. Most muscovite occurs as angular fragments.

Apatite: Crystals of apatite are generally rounded with some iron inclusions.

The percentage by volume as calculated with Rosiwal method is as follows:

Ilmenite with leucoxene	Zircon	Muscovite	Apatite
81.2%	9.3%	6.9%	2.4%

The light mineral most belongs to quartz. The grains are usually rounded. Their special feature is the abundance of irregular mineral inclusions and fluid or gas cavities. This combined with the absence of metamorphic heavy minerals so far as we know now, indicates that the heavy mineral constituents of the quartzite under study were derived from igneous rocks, probably acidic.

CONCLUSION.

The heavy minerals of individual igneous intrusions are characteristic both in quality and in quantity and may be used for identification of each intrusion if suitably manipulated. The alteration of the minerals may, however, sometimes lead to misinterpretation. As, for example, in Wausau granite if one fails to detect the chlorite of samples No. 14 and 15, altered from hornblende and biotite, he would be unable to make comparison of samples No. 14 and 16 with the sample furnished by Mr. Raules

Further, the heavy minerals of igneous rocks are not only characteristic for individual intrusion itself but also seem to be characteristic for a series of intrusions derived from the same magma reservoir and intruded during the same period. In other words, each magma province seems to have its own peculiar heavy mineral assemblage and a well established heavy mineral assemblage is likely to be reasonably used for recognition or division of magma provinces.

As an illustration, the heavy minerals of the rock samples under study may be distinguished into two distinct assemblages. One is characteristic by the abundance of fluorite from 75%-30%, a little quantity of zircon 10%-2% and moderate amount of hornblende (or altered to chlorite) and biotite 50%-15%. If the physical characters of the individual minerals are carefully compared, they should give other similarities.

The localities of the intrusions characterised by this assemblage are Wausau, Waushara, Lohrville, Berlin, Montello, and Endeavor which are all geographically distributed in adjacent districts. This assemblage may be called Wausau heavy mineral assemblage which indicates a magma rich in fluorine or consolidated in a condition suitable for the crystallization of fluorite.

The other heavy mineral assemblage is characterised by the abundance of biotite and hornblende 80%-95%, absence of fluorite, and often a little amount of apatite and titanite. The physical characters of the individual minerals may have their special similarities.

The intrusions characterised by this assemblage are at Mellen, Pike River, Athelstane and Marquette Range which are all also distributed in adjacent regions. This assemblage may be called Pike River heavy mineral assemblage which shows a magma wanting or very poor in fluorine and on the other hand comparatively rich in phosphorous.

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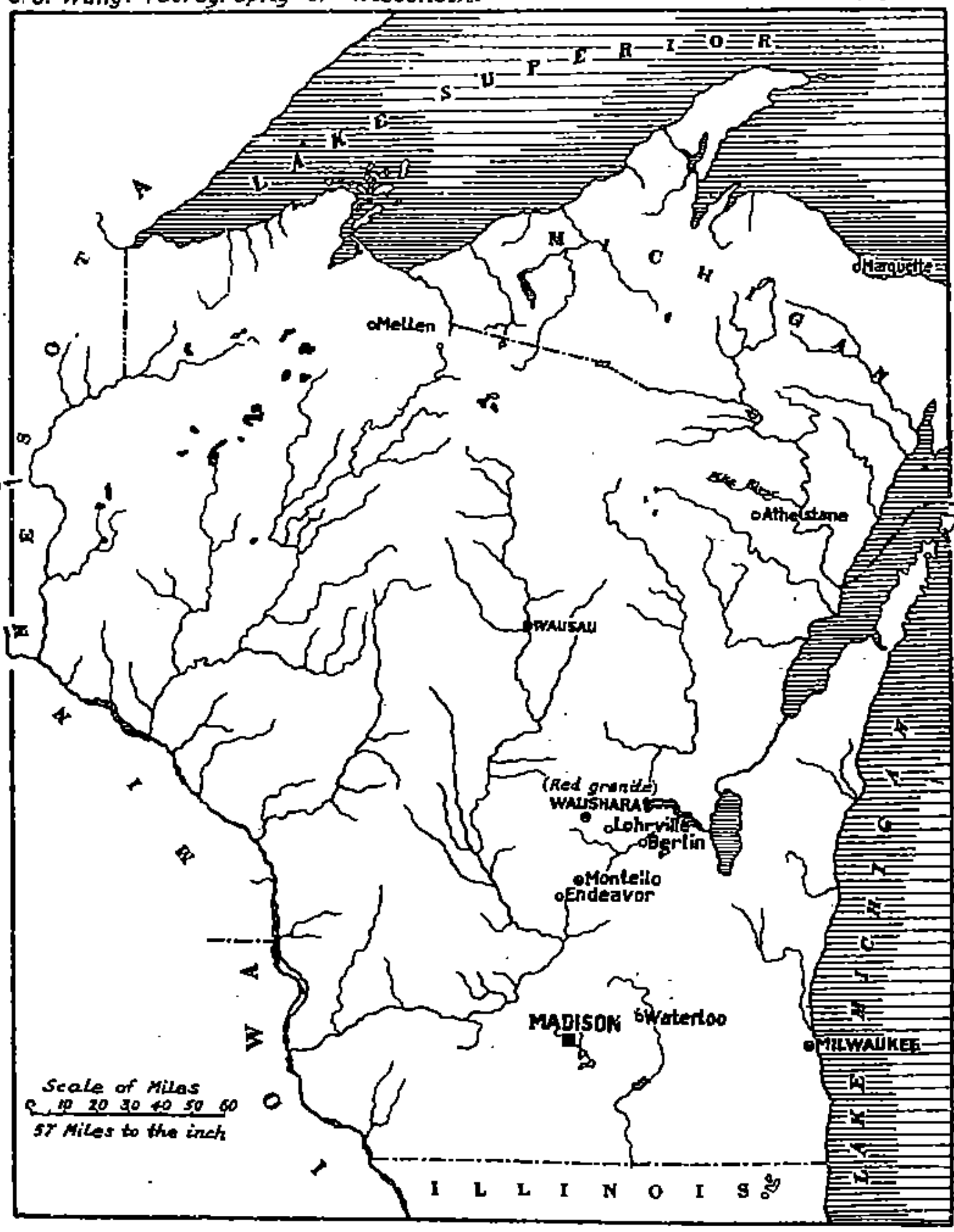


Explanation of Plate II

PLATE II

Fig. 1. Fluorite fragments from Wausau granite showing their irregular angular forms. × 57.

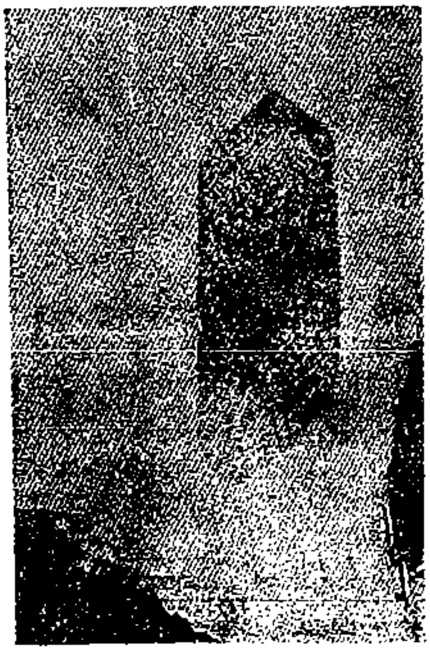
Fig. 2. Fragments of penninite (black) from Lohrville granite. White gray mineral belonging to fluorite. × 80.

Fig. 3. Crystal of Zircon from Athelstane granite showing perfect prismatic faces and bipyramidal terminations. × 340.

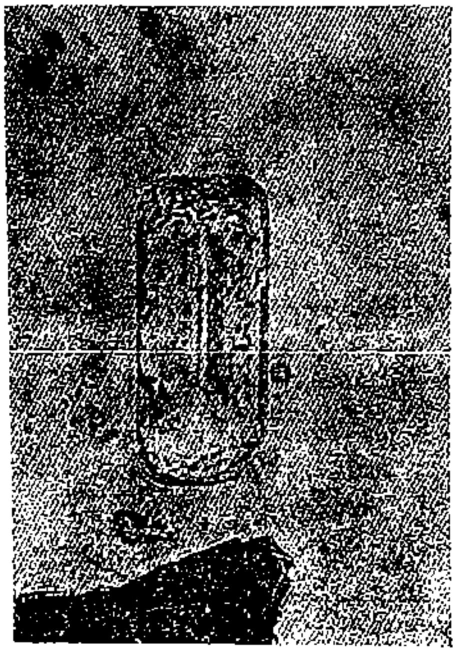
Fig. 4. Crystal of apatite from Athelstane granite with well-defined prismatic faces and basal pinacoids. × 360.

1 ×57

2 ×80



3 ×340



4 ×360

Explanation of Plate III

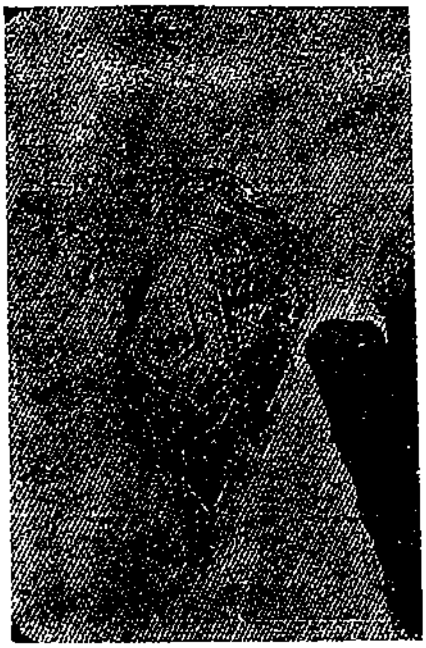
PLATE III

Fig. 1. Muscovite from St. Cloud granite showing distinct basal cleavage plates. × 210.

Fig. 2. Fragment of topaz normal to z giving distinct positive optic character in convergent polarized light. From St. Cloud granite. × 120.

Fig. 3. Crystal of Malacon showing well preserved prismatic form of zircon. From St. Cloud granite. × 160.

Fig. 4. Crystal of xenotimite showing its prismatic form with terminated pyramids. From St. Cloud granite. × 130.



1 × 210

2 × 120

3 × 160

4 × 130