University of Minnesota

MINNESOTA GEOLOGICAL SURVEY

WILLIAM H. EMMONS, Director

Bulletin No. 21

THE GEOLOGY AND MAGNETITE DEPOSITS OF NORTHERN ST. LOUIS COUNTY, MINNESOTA

BY

FRANK F. GROUT

MINNEAPOLIS
The University of Minnesota
1926

Vermilion River, a few miles southwest of Crane Lake appears to cut its gorge through the mica schist following softer beds and avoiding the granite intrusives.

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PREFACE

This bulletin treats the geology and mineral deposits of a large area in northern St. Louis County, extending northward to the Canadian boundary. It lies north of the Mesabi iron range and includes most of the Vermilion iron range. It lies south of the Rainy Lake area of Canada. Because it adjoins the world's greatest iron-producing area it has been the subject of much interest to explorers and prospectors seeking new deposits of iron ore and parts of the area have been surveyed by the United States Geological Survey and the earlier Minnesota state surveys. Much of the area, however, had not been surveyed in detail.

The district for the most part is heavily forested or cut over timber land and much of it is not provided with roadways. The work was done mainly by canoe and many of the camps were necessarily at places where supplies had to be carried in pack sacks. With these conditions it is not surprising that certain parts of the area were little known. One who has not traveled the brush area of the north woods can hardly appreciate the amount of labor involved in mapping such an area.

The work was begun in 1919 with Dr. F. F. Grout in charge and Mr. Stanwood Johnston, chief assistant. Mr. Johnston served two seasons and on account of his industry, his willingness, and his clear understanding of the problem, contributed largely to the results of the survey. His sad death in 1922 at the threshold of his career is a distinct loss to the science of geology, as well as a deep felt personal loss to all who were associated with him in the field.

The report includes a general map of the area (Plate I) several detailed maps of small areas of economic interest and 88 township plats. These township plats are essentially outcrop maps and cover the entire area, approximately 2800 square miles. The officers of the survey regret that these maps could not be shown in colors, but the expense of printing so many maps in colors would have been prohibitive.

Although the district includes the important mining centers of the Vermilion Range, no attempt has been made to remap the geology of these centers except in a few places where the magnetic work has been extended. The surface formations or drift deposits have been mapped recently by Dr. F. Leverett and Dr. F. W. Sardeson and are described in Bulletin 13 of the Minnesota Geological Survey.

The chief scientific results of the survey are the study of the intrusives related to the great batholiths that invaded the schists and greenstones in Algomian time. These granites and their differentiation products are the central features of the district and although the ores connected with them, so far as they are discovered, seem to be relatively unimportant, the district offers one of the most attractive fields for petrographic study.

The chief economic resources of the district are the sedimentary iron ores of the Vermilion Range. Other deposits include the iron-bearing pegmatites, which are widespread in and near the roofs of the granitic batholiths and which have been explored at many places, thus far without much prospect of developing a mine. Still other mineral resources include the quarries for greenstone or slate used for surfacing tar paper roofing. There are also small prospects of mica and asbestos.

WILLIAM H. EMMONS

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THE GEOLOGY AND MAGNETITE DEPOSITS OF NORTHERN ST. LOUIS COUNTY

GENERAL STATEMENT

This bulletin describes an area in northern St. Louis County, northeast of Lake Superior, which heretofore has not been studied in detail, and of which only very general geologic maps are available. It lies between the better known areas of the Vermilion iron-bearing district and of Rainy Lake.

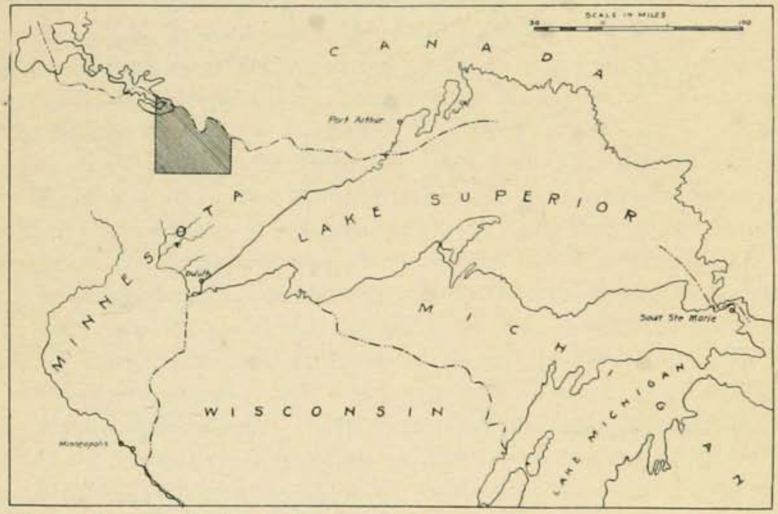


Fig. 1. Key map showing the location of the northern St. Louis County area, Minnesota, described in this report.

The major feature is the Vermilion batholith lying between the two districts mentioned. This mass of granite has certain unusual petrographic phases and has some economic interest on account of the occurrence of magnetite bodies which are widely exposed in the pegmatites near the roof. Slightly titaniferous magnetites also were segregated at an earlier stage near the south side of the batholith.

The main granite, formerly classed as Laurentian, is younger than the Lower-Middle Huronian slates and altered them to mica schists. It is here referred to the Algomian.

South of the Vermilion iron range, and near the southern limit of the area mapped, lies the Giants Range granite, another batholith.

The size, character, and origin of the magnetites are considered at length. The greenstones supply valuable material for felt roofing. Other deposits which possibly have economic value include those of asbestos, mica, and gold. There are also small masses of alkaline syenites, possibly related to the granites. One of them carries about 7 per cent potash in easily accessible locations.

ACKNOWLEDGMENTS

The first member of the staff to visit the magnetite pegmatite prospects was Dr. T. M. Broderick. During the following field seasons, the writer had the assistance of the following men, whose services are gratefully acknowledged. Work was begun with the able assistance of the late Mr. Stanwood Johnston, who was exceptionally efficient and well qualified for the work; his untimely death is deeply regretted by all of his associates. In the following seasons assistance has been given by Messrs. George A. Thiel, T. S. Lovering, and James D. Wheeler. The work of keeping camp and running compass has been done by Messrs. George Hezzelwood, V. T. Allen, Franklin Hanley, C. E. Erdmann, I. H. Cram, William Strunk, and John Searles. Certain maps and drawings have been made by Messrs. John Swart, John Nelimark, R. E. Sorenson, H. R. Kamb, W. C. Lawson, and C. R. Barthelemy.

The work both in the field and laboratory has been in charge of Dr. W. H. Emmons, director of the Minnesota Geological Survey, and his keen observations and helpful criticism have contributed largely to the success of the undertaking which he originally planned.

The survey has also had access to private reports with maps, which have been used to avoid the repetition of field work already done in standard form. The chief of these is a report by Professor C. K. Leith to the Virginia Rainy Lake Company, with maps by F. E. Williams and Edward Steidtmann. These were made available through the kindness of the company. Townships 61 North and Ranges 16 to 20 West have been mapped, so as to show the location of outcrops of granite and schist, by Mr. John Uno Sebenius and party, for the Oliver Iron Mining Company. Their assistance is here gratefully acknowledged and credit is given on the maps of the several townships to the geologist who did the field work. Mr. A. Grenager, of Buyck, showed the survey party a report by Charles Rees on the area recently explored in Sec. 3, T. 66 N., R. 17 W. Some early work by the Great Northern Railway seems to be hopelessly lost.

The assays of ore and tests involving magnetic concentration have been kindly furnished by the Minnesota School of Mines Experiment Station. There have been added to this report, several rock analyses, made in connection with petrographic studies by student chemists, working under a grant from the research funds of the Graduate School of the University of Minnesota.

PREVIOUS REPORTS

THE WORK OF THE MINNESOTA GEOLOGICAL SURVEY

In 1887 portions of the area were visited by Alexander Winchell, who showed in his report[1] that the granites were intruded into the older schists. N. H. Winchell in the same report described a transition from mica schist to granite which later led him to maintain that the granites were formed from melting of sediments. Active mining of iron ores began on the Vermilion Range in 1884, and the geologists of the Survey kept closely in touch with developments and prospects.[2]

In 1886 and 1888 the Survey geologists distinguished the "Vermilion schists" from the main Keewatin area, as the more highly crystalline group or series between the Keewatin and the underlying granites, which were supposed to be older.[3] The schists were thus equivalent to the series Lawson described as Coutchiching. Subsequently, in 1889, N. H. Winchell found that these schists were not definitely older than Keewatin; nor were they all of the same age. The granite had superinduced the crystallization on strata of different ages.[4] This conclusion is now generally accepted.

In 1889 N. H. Winchell reported granites of three different ages in the district, and suggested that the same stratigraphic term, Laurentian, should not be applied to the three.[5] Spurr in 1893 showed that the Giants Range granite is younger than the Lower Huronian and hence is to be distinguished from the area of Laurentian.[6] In 1895 a map of the Rainy Lake gold region by H. V. Winchell and U. S. Grant was issued showing Coutchiching schists, as described by Lawson.[7]

In the "Final Report," the work was summarized and restated with a few changes.[8] The Keewatin of the state survey included, even in the final reports, not only the Ely greenstone and Soudan formation, but the Ogishke (or Stuntz) conglomerate and the Knife Lake slate, classed as Upper Keewatin. The conglomerate was studied in detail.

[1] Winchell, Alexander. Minn. Geol. and Nat. Hist. Survey Ann. Rept. for 1886, vol. 15, p. 36 et seq., 1887.

[2] *Ibid.*, vol. 13, pp. 25, 35, 1885.

[3] *Ibid.*, vol. 17, p. 31, 1889.

[4] *Ibid.*, vol. 17, p. 67, 1889.

[5] *Ibid.*, vol. 17, pp. 27-31, 1889.

[6] *Ibid.*, vol. 22, 115-20, 1894.

[7] *Ibid.*, vol. 23, pp. 36-105, 1895.

[8] The reports which concern this area are: Minn. Geol. and Nat. Hist. Survey Final Report, vol. 4, chs. 10 and 29, and Plates 67 and 86; and many of the petrographic descriptions in volume 5.

The surface formations have recently been mapped by Leverett and Sardeson.[9]

THE WORK OF LAWSON AND CANADIAN GEOLOGISTS

Dr. A. C. Lawson, in 1885-86-87, studied the region around Rainy Lake and in 1889 published a report describing as the Coutchiching formation a mica schist of sedimentary origin, supposedly below the Keewatin which is of dominantly igneous origin.[10]

Barlow in 1890 showed that some Laurentian gneisses are truly igneous rocks, not sediments altered in place; also that they intrude the "Huronian."[11]

Lawson's work was questioned, and in 1913 he published a restudy of the area, maintaining that there are a few hundred feet of sedimentary schist below a green schist. In the Rice Bay area the evidence of the sequence of formations and their position is reinforced by the distribution of outcrops around a central granite dome, and the structure is probably correctly shown.[12] Since the base of the series, however, is lost in the intrusive granite, the present writer believes that the whole formation on Rice Bay may be assigned to a position within the greenstone, the sedimentary portion being perhaps 500 feet thick. (See page 9 and pages 26-27.)

Lawson also proposed to restrict the term Laurentian to the pre-Huronian granites and gneisses. Finding even more abundant granites of later age he proposed the term Algoman for granites following the "Seine series" of the Huronian.

THE WORK OF THE UNITED STATES GEOLOGICAL SURVEY

In 1903, after several seasons' work, the United States Geological Survey issued Monograph 45, on the Vermilion district.[13] This first gave the succession and correlation now used with only minor modifications. The formations were described in great detail as to their character and relations to each other. Only a few changes are necessary as a result of later work. In 1911 the summary monograph on the Lake Superior region[14] reviewed the work on both the Vermilion and Rainy Lake areas.

[9] Minnesota Geol. Survey Bull. 13, 1917.

[10] Lawson, A. C., On the geology of the Rainy Lake region: Geol. and Nat. Hist. Survey of Canada Ann. Rept., vol. 3, part 1-F, 1889.

[11] Barlow, A. E., On the contact of the Huronian and Laurentian: Amer. Geol., vol. 6, pp. 19-32, 1890.

[12] Lawson, A. C., The Archean geology of Rainy Lake restudied: Canada Dept. of Mines, Geological Survey, Memoir 40, 1913.

[13] Clements, J. M., The Vermilion iron-bearing district: U. S. Geol. Survey Mon. 45, 1903.

[14] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, 1911.

The United States Survey report recognized no Coutchiching formation in the sense in which Lawson named it; and did not give any prominence to the batholithic eruptions of Algomian time as compared to those of Laurentian time. They clearly showed the nature of the contact zone of schists near the granites and agreed that the alteration of the greenstone always gives an amphibole-bearing schist, while the biotite schists are characteristic of altered sediments and the mixed hornblende-biotite schists may result from either. The biotite schists on the northern side of the Vermilion Range, however, were mapped in their reports as Ely greenstone.

GEOGRAPHY AND DRAINAGE

The area in north St. Louis County is divided, after the manner of the early survey work, into two parts. Southwest from Vermilion and Pelican lakes the glacial drift is abundant and rock outcrops are few. The surface is gently rolling. Lakes are small and relatively few, but muskeg swamps are characteristic. North and east of this area the region is characterized by rock knobs, separated by lakes and swamps, with very little soil or drift. The topography of this region is very much influenced by the nature of bed rock. Hills are commonly found to consist of granite or greenstone, while valleys and elongated lakes mark the areas of slate and softer schists; but there are notable exceptions to the rule, for lakes are abundant everywhere. The whole is relatively plane, for the hills rarely rise much over 100 feet above the lakes. There are a few monadnocks above the general peneplain. Elevations above sea level range from nearly 1700 feet at the southeast, to about 1175 feet at the northwest. Very little of the area has been mapped topographically, but the State Drainage Commission has studied the water power sites (see Economic Geology section), and there are unpublished contour maps of the northern border, by the International Boundary Commission.

The whole area, except a few square miles southeast of Tower, drains northward into the boundary waters, thence through Rainy Lake and Rainy River toward Hudson Bay. The chief stream centrally placed in the area, is the Vermilion River, flowing north from Vermilion Lake to Crane Lake near the boundary. This receives tributaries from Pelican Lake and many smaller bodies. Along both the eastern and western sides the drainage is to the outside of the area, but there are no large lakes to be drained except Burntside and Long lakes on the east. This water flows northeast but ultimately follows the boundary back to Rainy Lake.

GENERAL GEOLOGY

(See Plate I.)

The stratigraphic succession of rocks in northern St. Louis County is as follows, in descending order:

Quaternary system		
Pleistocene series	Drift and lake beds	
(Unconformity)		
Algonkian system		
Keweenawan series	Duluth gabbro Diabase intrusives	
(Unconformity) Intrusive contact in this district		
Upper Huronian series (Animikian)	Virginia slate Biwabik formation, iron-bearing	
(Unconformity)		
Algomian series	Vermilion granite, Linden syenite, Acid and basic intrusives, Giants Range granite, etc.	
Lower-Middle Huronian series (Seine series)	Knife Lake slate Agawa formation, iron-bearing Ogishke conglomerate	Mica schists derived from the series
(Unconformity)		
Archean system		
Laurentian series	Small intrusions	
Keewatin series	Soudan formation, jaspilite Ely greenstone and green schists mostly derived from basic igneous surface rocks	

ARCHEAN SYSTEM

THE COUTCHICHING PROBLEM

Lawson gave the name Coutchiching to schists older than the Keewatin, and as such it may have been correctly applied in the Rice Bay area of Rainy Lake.[1]

Of the very extensive biotite schist areas in St. Louis County only a small part could possibly be assigned to pre-Keewatin age. The schist of these small areas is essentially like the biotite schist of Lower-Middle Huronian age. No formation in the state has been definitely proved older than the Ely greenstone, but there are a few mica schist pebbles in the basal Huronian conglomerate and a number of outcrops so isolated that their age may not be determined except by analogy. The formation is omitted from the tabular list because its existence is uncertain.[2]

KEEWATIN SERIES

THE ELY GREENSTONE

The Ely greenstone forms an irregular belt, about 5 to 10 miles wide, extending east and west across the southern part of the area shown, and many miles beyond in both directions. It is the chief formation of the Vermilion Range area, lying between two granite batholiths, and covered in part by infolded later sediments. In the eastern part of the county, outcrops are numerous and the belt can be easily traced. West of Tower, outcrops are less numerous and the boundaries more roughly estimated. The folds appear to plunge more deeply under Huronian slates and to reappear in smaller areas.

In the extreme northwest corner of the county, one of the islands in Rainy Lake consists of green schist forming part of another belt north of the granite, and extending into Koochiching County. The maps of the United States Geological Survey, as well as those of the state survey, show too much greenstone, because various other green formations were shown as Keewatin.

The structure of the belt of Ely greenstone has been determined at most places only in a rough way. A massive formation, rendered schistose by batholithic injection, contains little to guide one in determining the nature of folds. The associated beds of slate and jasper, and the occasional amygdaloidal bands may supply evidence of structures where

[1] Lawson, A. C. On the geology of the Rainy Lake region: Geol. and Nat. Hist. Survey of Canada. Ann. Rept. vol. 3, part 1 F., 1889.

[2] Grout, Frank F., The Coutchiching problem: Bull. Geol. Soc. Amer., vol. 36, pp. 351-64, 1925.

mapped with sufficient detail. These and the occurrence of the batholiths on each side indicate the general synclinal nature of the belt. In the granite there are a few small belts that may represent roof pendants of Ely greenstone—other synclines, now almost removed by erosion.

The formation has recently been described in detail by Dr. G. M. Schwartz, who reviews earlier descriptions.[3] As the name implies, the rocks are nearly everywhere green. The textural varieties, however, are numerous—massive, schistose, slaty, fragmental, spherulitic, porphyritic, amygdaloidal, and even granitoid and diabasic varieties occur. (See Plate II A, B, C, and D.) It is characteristic that nearly every large exposure or group of exposures, shows some trace of ellipsoidal or pillow structure; in the more schistose modifications the ellipsoids are of course obscure, but they may be recognized if sought for. This general ellipsoidal character is commonly taken as evidence that much of the greenstone solidified in bodies of water.

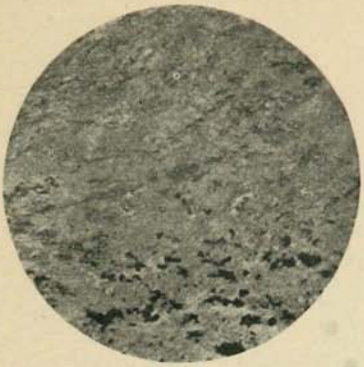
Parts of the area mapped as greenstone consist of basic intrusives of later age than the main mass. Even these, however, are altered much like the lava flows and can be distinguished only with difficulty. The possibility must be recognized that some Hurionian intrusions may have been mapped as Keewatin. Some later Keweenawan intrusives, however, are much less altered and more easily distinguished from Ely greenstone.

The original minerals of the greenstone were apparently those of intermediate and basic lava flows and tuffs, with possibly tuffaceous sediments: plagioclase, augite, hornblende, titaniferous magnetite, olivine, apatite, and possibly at some places quartz. Regional metamorphism has destroyed most of the primary material, leaving some plagioclase and the textural pseudomorphs that often indicate quite clearly the nature of the original minerals.

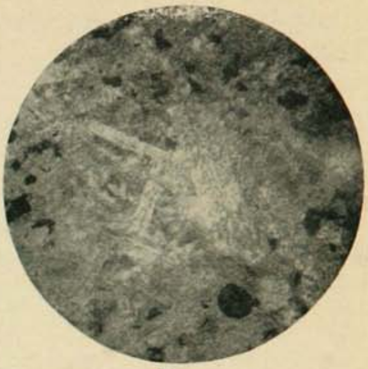
The minerals now present in the average and typical greenstone are largely secondary. In order of abundance they are: plagioclase, chlorite, hornblende, epidote, calcite, magnetite; of lesser importance are quartz, leucoxene, actinolite, augite, sericite, kaolin, pyrite, limonite; in places there are small amounts of zoisite, biotite, bronzite, talc, apatite, ilmenite, titanite, and perovskite. The various specimens differ a good deal but in most of them there are notable amounts of carbonate, quartz, and chlorite.

[3] Schwartz, G. M., Granite and gabbro intrusions on Ely greenstone: Jour. Geol., vol. 32, pp. 89-138, 1924.

Geologic Map of the Northern Part of St. Louis County, Minnesota, with Sections.



A



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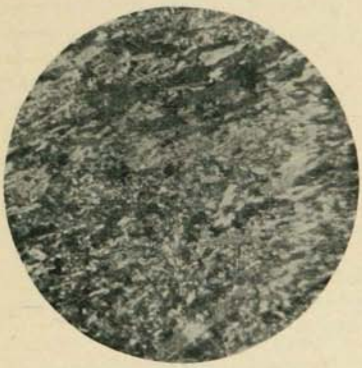

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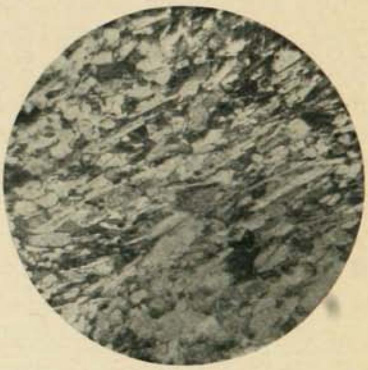

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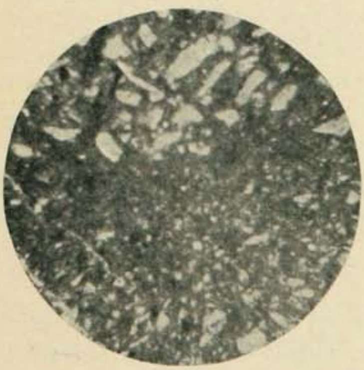
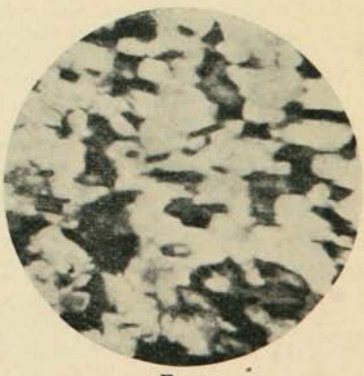


E



F

Microphotographs of Ely greenstone and Knife Lake slates. *A* and *B*. Ely greenstone with only regional metamorphism; magnification x 40. *C* and *D*. Ely greenstone altered by contact action of granite magma; magnification x 43. *E*. Knife Lake slate and graywacke; magnification x 43. *F*. Knife Lake biotite schist, altered by contact action of granite magma; magnification x 43.

Analyses of the greenstones of considerable variety are given in Table I.

TABLE I

Analyses of Ely Greenstone

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2	51.73	51.95	60.61	52.94	43.96	50.47	49.65	52.46	48.01
Al_2O_3	15.28	12.58	16.61	14.70	16.03	18.48	16.36	16.77	8.34
F_2O_3	3.41	.90	1.97	2.52	10.50	2.13	4.39	3.92	2.29
FeO	7.30	8.77	5.09	7.80	8.74	7.74	7.19	5.44	10.85
MgO	6.72	8.90	3.10	4.49	6.56	6.90	8.00	5.20	16.84
CaO	9.40	7.00	4.46	6.56	9.54	6.61	9.18	6.23	9.86
Na_2O	3.83	2.79	3.11	3.09	1.62	2.58	2.49	2.58	.98
K_2O	.76	1.38	.25	.04	.27	.30	1.17	1.39	.37
H_2O+	2.86	2.67	2.45	2.04	1.84	2.34	2.39	....	.40
H_2O-	.00	.14	....	....	....	....	....	3.28	.10
TiO_2	.78	1.03	....	....	....	....	....	.45	.46
P_2O_5	....	....	....	....	....	....	....	.16	.12
CO_2	....	1.02	1.57	4.86	....	....	....	2.14	none
Cr_2O_3	....	.17	....	....	....	....	....	....	.22
S	....	.11	....	....	....	....	....	....	*.02
MnO	.15	.15	....	....	....	....	....	....	.25
NiO	....	....	....	....	....	....	....	....	....
	102.22	99.22	99.22	99.04	99.06	97.52	100.82	100.00	99.11

I. Average of three phases of greenstone at Ely. Analyst, S. Darling.
II. Ely greenstone from Pine Island, Lake Vermilion. Analyst, S. Darling.
III. Interior of ellipsoid, Ely. *Minn. Geol. Survey, Twenty-third Annual Report,* p. 204. Analyst, C. F. Sidener.
IV. Tuffaceous greenstone, south shore Long Lake. *Minn. Geol. Survey, Twenty-third Annual Report,* p. 204. Analyst, C. F. Sidener.
V. Greenstone (Tuff), Kawasachong Falls. *Minn. Geol. Survey, Nineteenth Annual Report,* p. 126. Analyst, C. F. Sidener.
VI. Greenstone, NW. ¼ Sec. 4, T. 63 N., R. 9 W. *Minn. Geol. Survey, Nineteenth Annual Report,* p. 123. Analyst, C. F. Sidener.
VII. Greenstone, NW. ¼ SW. ¼ Sec. 17, T. 65 N., R. 5 W. *Minn. Geol. Survey, Final Report,* Vol. V, p. 519. Analysts, Dodge and Sidener.
VIII. Average of basic Keewatin rocks from Lake Superior region. Zapffe, *Econ. Geol.,* Vol. VII, p. 149. Sum is in error in original. Probably water is combined water.
IX. Greenstone altered by granite. Nearly all hornblende. Near ¼ Cor. Sec. 20 and 21, T. 65 N., R. 4 W. Analysts, F. F. Grout and R. W. Gannett.

* In Analysis IX FeS_2 (.02%) is reported instead of Sulphur.

The effect of large igneous intrusions on the greenstone has been noted by most of the geologists who have visited the region, but there has been no little confusion in the descriptions. The greenstone and later sediments both yield schistose and granular contact rocks, but certain clear exposures are available as a key to the origin of others. In this area there is no contact action of gabbro on the greenstone, but the effects of the Vermilion and Giants Range granites may be traced for many rods from the contact. Dr. G. M. Schwartz has recently made a careful study of this effect. A hornblende rock is found in each case replacing the chloritic original. In many cases the structure is schistose, but in others, the rocks are massive. Feldspars are freshened and clear of inclusions, and other constituents are little affected. Normally the contact rock fades out into typical chloritic greenstone, at a distance of a quarter to a half mile from the granite, but the extent of the alteration may be greater or less. An analysis (No. IX of Table I), of one of the altered rocks which contained only .55 per cent magnetite and the remainder of which was hornblende, shows that practically all the constituents of the normal greenstone can be combined to make hornblende.

Inclusions of the greenstone in the granite of both the Giants Range and the Vermilion batholith, are metamorphosed to form coarse hornblendites. A breccia of such inclusions in granite near White Iron Lake is described by Schwartz.[4] At places (for example at the outlet of Crane Lake, and northeast of Johnson Lake, and near Ash River Falls) numerous hornblendite inclusions in granite have been pervasively soaked with granite, showing a great change in composition, but retaining the forms of inclusions.

THE SOUDAN FORMATION

The Soudan formation is enclosed in, or lies near, the top of the Ely greenstone, and it furnishes the chief economic interest in the Vermilion Range. It is treated in detail in the monographs on the range, and may be passed over briefly here. The typical rock is a banded jasper and iron oxide, either black or red, called jaspilite. Recent work has shown that the chert contains structures resembling algae. This first discovery of fossils in the Archean was in a rock from north of Armstrong Lake.[5] The value of the formation as a source of iron is mentioned in the section on Economic Geology.

The area of the iron-bearing formation is small as compared with that of the Ely greenstone. It has much the same general distribution, but little is found west of the center of Vermilion Lake. In the synclines of greenstone, the center may be found to be jaspilite; or if the center is Huronian, the jaspilite may lie between the main greenstone and Huronian rocks. The folding, however, is very complex, and the formation in many places is broken. Probably it was not originally continuous; some of it was in lenses alternating with the greenstone.

[4] *Op. cit.*

[5] Gruner, J. W., Discovery of life in the Archean: Jour. Geol., vol. 33, p. 151, 1925.

The detailed mapping of the Soudan formation, largely done in connection with the *United States Geological Survey Monograph* 45, has been slightly extended in the present work. (See reports on T. 62 N., R. 14 W.; T. 62 N., R. 16 W.; and T. 63 N., R. 15 W.)

LAURENTIAN INTRUSIVES

There are probably several areas of Laurentian granite gneiss in the great area of Vermilion granite, as for example at Horse Lake a little east of the county line; and northwest of Burntside Lake. The outcrops at these places are highly gneissic, and are intruded by the Vermilion granite. They are so small, however, and so closely resemble the gneisses derived from *lit-par-lit* injection of sediments that no areas have been distinguished in mapping. The certainty that two granites occur in this area and that a considerable time interval elapsed between them was shown by some sketches by N. H. Winchell.[6] An area illustrating this relation even more clearly is exposed northeast of Avis Island of Vermilion Lake in Sec. 24, T. 63 N., R. 17 W. (See Fig. 3, page 31.) While the main mass of the schist is cut by granite and pegmatite of apparently Algomian age, there is an earlier basic dike that is itself younger than a granite that intrudes the schist *lit-par-lit* and in dikes. These granites might be assumed to be phases of one great batholith if it was not for the basic dike which shows a radical change of magma between the periods of the two granites. Possibly some of the older gneiss is Laurentian.

Many granite, rhyolite, porphyry, and felsite dikes are intruded into the Ely greenstone and into the Soudan formation. Some of these may be Huronian in age, since similar dikes intrude the Knife Lake slates; but it is certain that a large number are pre-Huronian, for they furnish abundant pebbles for the conglomerate at the base of the Huronian. Such a conglomerate outcrops around Stuntz Bay in Vermilion Lake.

Some of the smaller intrusives are dynamically metamorphosed to a sericite schist which forms a striking contrast with the chloritic and hornblende schists derived from the greenstone.

There is also in northern St. Louis County near Ely Island of Vermilion Lake the area made classic for the occurrence of a fractured porphyry, supposedly Laurentian, which may easily be mistaken for a metamorphosed conglomerate—in other words, a pseudoconglomerate.[7]

[6] Minnesota Geol. and Nat. Hist. Survey Final Report, vol. 4, p. 539.

[7] Smyth and Finlay. Trans. Amer. Inst. Min. Eng., Oct. 1895. See also Winchell, N. H., Minn. Survey Final Report, vol. 4, pp. 525-37. 1900.

ALGONKIAN SYSTEM

LOWER-MIDDLE HURONIAN SERIES

OGISHKE CONGLOMERATE

The Ogishke conglomerate has been mapped and described in detail in the Vermilion monograph. It need only be said here that the main areas are east of the county here mapped, and that in this county, all the outcrops seen are near the eastern side of Vermilion Lake where mapped by the United States Geological Survey. Few changes have been made in the maps as a result of further exploration. The "Seine" conglomerate described by Lawson from north and northwest of this county is apparently equivalent to the Ogishke, and is exposed in an altered green schistose condition on the islands in Rainy Lake at the northwest corner of the county. Petrographically the rock varies widely with the underlying formations. The alteration of the Ogishke conglomerate by the granite intrusions depends on the original nature of the pebbles, but large parts of the conglomerate have become mica schist with only faint lenses to show the outlines of the deformed pebbles.

One of the outcrops for which this region is celebrated is the conglomerate on Stuntz Bay of Vermilion Lake, where at one place most of the pebbles and matrix are of granite. Alteration has so far recrystallized the rock that it has become a "recomposed granite," and it is difficult to distinguish it from a primary granite.

Dynamic metamorphism has made sericite schist of parts of the conglomerate where the pebbles consisted of granite or of an acid porphyry.

AGAWA FORMATION

The Agawa formation is iron bearing, and hence distinguished from the conformable beds above and below it, though of itself it is small and not at all continuous. In the few places where discovered, it is a layer with abundant carbonate or jasper, or both, in the Knife Lake slate, at or near the bottom. It probably has no economic value in St. Louis County. The Agawa beds have not previously been mapped in St. Louis County, but beginning 10 miles east, have been followed by occasional outcrops into Canada. Small areas are exposed, however, at the northeast of Vermilion Lake, just east of Rice Bay. (See map of T. 63 N., R. 15 W.) Clements mentions a ferruginous belt in the slate near the east line of Sec. 4, T. 62 N., R. 13 W.[1] The manganiferous cherty carbonate rocks east of Cook, in Sec. 3, T. 62 N., R. 18 W., are also probably to be

[1] *Op. cit.*, p. 332.

assigned to the Agawa. North of the Vermilion granite, iron-bearing rocks appear at this horizon in Koochiching County and in Canada, but have not been seen in St. Louis County.

KNIFE LAKE SLATE AND MICA SCHIST

The Lower-Middle Huronian slates, and the schists which seem to be derived from them by the action of granite intrusions, are the most extensive sediments in north St. Louis County. They are named from Knife Lake, a few miles east of the county, where exposures are numerous, while the large areas in this county are partly concealed under heavier drift. The slates lie conformably on the Ogishke conglomerate, or Agawa formation, and in this area are in contact with no later rocks except the intrusives and glacial drift.

The slates and graywackes outcrop in the midst of the greenstone in narrow synclines extending from Ely to the eastern end of Vermilion Lake. The folding can be mapped at many good outcrops but very little of the area has been studied in such detail. (See Plate IV, B.) Structures are judged roughly from the relations to adjoining formations. South and west of Tower the slates spread widely and cover several townships. It is chiefly because of its wide extent without other infolded beds that it is assumed to be thousands of feet thick. Scattered outcrops farther west show the continuation of the belt practically across St. Louis and Koochiching counties.

The major part of the Knife Lake slate is made up of alternating layers of light and dark gray sediments; the dark parts consisting of argillaceous and graphitic slate, the lighter approaching graywacke. The bands vary in thickness from a fraction of an inch to several feet, and the average hand specimen shows several such bands, especially if weathered. (See Plate IV, A.) More rarely there are layers that are cherty, pebbly, or tuffaceous; and of intermediate varieties. Some broad zones near granite intrusives have been altered to biotite schists, still commonly retaining the appearance of alternating layers. Even the least altered slates show an orientation of grain by recrystallization, and the cleavage crosses the bedding. Most of the formation has a peculiarly complex network of silicified joints. (See Plate IV, C.)

The slates contain a few coarse quartz and feldspar grains, and the graywackes contain perhaps 50 per cent of grains about .3 mm. across, in a microscopically fine grained dark matrix, partly carbonaceous. The matrix is recrystallized, but the crystals are not larger than .02 mm. in typical slate, free from contact action. Judging partly by analogy with the associated graywackes, the matrix probably consists largely of quartz,

A. Knife Lake slate on Isle of Pines, Vermilion Lake. Cleavage follows the bluff, and bedding weathers into relief as grooves running up to the left.

B. Bedding in the biotite schist on Vermilion River. The uniformity of dip for long distances even where intruded by the granite suggests a structure developed before granite intrusion.

feldspar, chlorite, and sericite, with some zoisite, carbonate, pyrite, graphite, and leucoxene. Possibly some is so little altered that kaolin remains. Occasional accessories include zircon, apatite, and tourmaline. Biotite is practically absent except as a product of igneous metamorphism. The fragments in the graywackes suggest that most of the formation is derived from porphyries with acid feldspars. (See Plate II, E and F.) The chemical nature of the rocks is shown in Table II.

Metamorphism of the Knife Lake slate.—The Knife Lake slates have been much altered by igneous intrusion and the results vary with the nature of the igneous mass. In the area of north St. Louis County the granites are the only rocks that exerted much effect. The result of the granite intrusion is easily studied at several places, notably south of Tower along the Duluth and Iron Range Railway. Outcrops are not continuous, but the sequence is clear. Slate and graywacke bands alternate in each outcrop and there can be little doubt of the identity of the formation throughout.

The first Knife Lake slate, outcropping south of Tower, between mile posts 93 and 94, shows argillaceous dull surfaces. Within a mile south, the slate is more lustrous and may be classed as a phyllite, but still shows no mica to the naked eye. At mile post 89 the slaty phase has developed mica in recognizable flakes. At mile post 88 the flakes are coarser and the rock is a good example of biotite schist. Granite dikes appear in the schist near this post and increase in abundance to mile post 85 where the exposures show about equal parts of granite and schist. Most of the schist here is filled also with granite injections, *lit-par-lit*. At mile post 84, the crossing of Embarrass River exposes solid granite with few inclusions of any kind. The series thus extends over 10 miles, from unaltered slate to solid granite, and the micaceous contact zone is about five miles wide.

Other illustrations of the change from slate to biotite schist are found around the granite masses, east of this county, and Doctor Leith reports[2] that south of the Giants Range the granite has a similar effect on Huronian slates. The occurrence is closely analagous to that described as long ago as 1886 by Van Hise on the Gogebic Range.[3] He showed that the slate and thoroughly crystalline mica schists must have had the same origin and discusses the sources of the magnesia, iron oxide, and free silica that appear in the schists.

[2] Personal communication.

[3] Van Hise, C. R., Upon the origin of the mica schists and black mica slates of the Penkoee-Gogebic iron bearing series: Am. Jour. Sci., vol. 31, p. 455, 1886.

Metamorphic rock derived from the slates is rarely hornblendic in appearance. Not five per cent of this area of schist contains any amphibole. This is noteworthy in view of the fact that the Ely greenstone under similar circumstances becomes hornblendic, and the Huronian sediments are derived, at least in part, from the erosion of the greenstone. The Ogishke conglomerate in places consists almost wholly of greenstone pebbles with little alteration. Nevertheless the Knife Lake formation seems to have derived enough material from the aluminous phases of the Archean, to yield biotite, in amounts far in excess of hornblende.

An analysis of the schist formed from the Knife Lake slate is shown as IV in Table II beside analyses of the less altered slate. The changes are slight.

TABLE II

Analyses of the Knife Lake Formation in Minnesota

	I	II	III	IV
SiO_2	54.71	61.39	63.88	63.04
Al_2O_3	20.52	16.97	17.70	16.45
Fe_2O_3	1.72	.39	3.02	1.32
FeO	6.40	5.32	1.80	4.89
MgO	4.76	3.84	3.72	5.04
CaO	1.93	3.21	2.72	3.17
Na_2O	2.83	2.78	1.78	2.62
K_2O	2.68	1.25	3.34	2.14
H_2O+	3.25	2.44	.87	.66
H_2O-	.15	.06	.23	.03
CO_2	....	.88	....	....
TiO_2	.89	.62	.52	.54
ZrO_2	....	.07	trace	.26
P_2O_5	....	.19	.58	trace
S	....	.15	.19	....
MnO	....	.12	....	.22
BaO	....	.06	.26	....
Cr_2O_3	....	.01	....	....
	99.84	99.75	100.61	100.38
Specific Gravity	2.806	2.725		2.735

I. Knife Lake slate at Knife Lake. Analyst, Frank F. Grout.
II. Knife Lake graywacke at Knife Lake. Analyst, Frank F. Grout.
III. Knife Lake slate, south of Tower. Analyst, Douglas Manuel.
IV. Biotite schist near Vermilion Dam. Analysts, Frank F. Grout and S. Darling.

THE MICA SCHIST

General statement.—The mica schist of north St. Louis County is one of the most widespread formations in the area and has furnished the subject of much discussion. It outcrops in large areas along Rainy, Kabetogama, and Namekan lakes. Less extensive areas occur through the great area of Vermilion granite, and an almost continuous belt marks the southern boundary of that granite.

The problem of correlation of the schists is complicated by the general convergence of several different formations to certain metamorphic types as they are affected by the proximity of the granites. It is clear, for example, that on Rainy Lake there are biotite schists derived from the Keewatin series, from Huronian sediments, and from Laurentian granite. The biotite schists of several sources are scarcely distinguishable in the hand specimen or thin section. There are also several green schists—from the Keewatin, from the Huronian conglomerate, from basic dikes in the Huronian, and from the green beds of Huronian slate. There are at least three formations yielding sericite schists; the Laurentian porphyries, the Ogishke conglomerate, and the Algomian porphyries. It is evident that the several formations have each a variety of phases and that a certain petrographic type is rarely conclusive evidence of the age of a formation.

Field relations.—The field relations of the schists have already been stated for the Knife Lake slate formation south of Tower. The larger areas are yet to be considered.

The great mass of schist through Rainy, Kabetogama, and Namekan lakes is intruded on the south by the Vermilion granite and nearly everywhere by pegmatite dikes, probably related to the same granite. North of this large area the formation contacts are largely concealed beneath the waters of the lakes. To the east in Canada and to the west in Koochiching County, contacts are described by Lawson[4] as showing that the schist dips under the Ely greenstone, but no such structure has been found in Minnesota,[5] and the beds Lawson saw are probably overturned.

The schist south of the granite area is not as wide a belt, and many critical contacts are concealed under the waters of the lakes. The granite clearly intrudes the schist, and is filled with inclusions of it. Since many outcrops contain about equal amounts of granite and schist the mapping of the contact is somewhat arbitrary. The biotite schist forms an almost continuous belt between the less altered formations of the Vermilion Range and the granite. No doubt this is the reason it has previously been interpreted as altered greenstone.[6] There are places, however, where granite cuts through the belt of mica schist into the greenstone, and the

[4] Lawson, A. C., The geology of Rainy Lake restudied: Canada Dept. Mines, Geological Survey Memoir 40, 1913.

[5] Lawson's syncline on Dry Weed Island of Rainy Lake is not really synclinal. Grout, F. F., The Coutchiching problem: Geol. Soc. America Bull., 1925.

[6] Clements, J. M., The Vermilion iron-bearing district: U. S. Geol. Survey Mon. 45, Plate II, 1903.

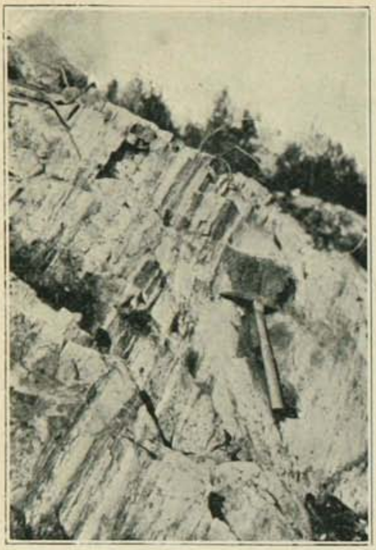
alteration of the greenstone does not yield any rocks closely approaching mica schist in appearance. A few outcrops are chloritic, and as green as the greenstone, with the micaceous structure of the mica schist. These have been mapped as greenstone, where they show no signs of sedimentary bedding.

In the midst of the granite area, schist inclusions are mapped as part of the granite, but roof pendants are considered schist *in place;* the distinction being based largely on the relative abundance of schist and the granite over considerable areas. Further than this, there was a strong tendency in the field to consider the outcrop as schist, with dikes in it, wherever a large area showed a uniformity in the strike and dip of the schist masses, even if the dikes constituted over 50 per cent of the whole. (See Plate III, B.) Notable schist masses, not formerly mapped, are those on Pelican River, on the south of Sand Point Lake, and on the channel by which Ash River reaches Kabetogama Lake.

The importance of the schist areas in the granite is much more strongly emphasized by detailed work than by a reconnaissance. It is found that many ridges of outcropping granite have outcrops of schist along their sides, near water level in the lakes and swamps. The conclusion is inevitable that schist areas occupy the topographic depressions, and are therefore largely concealed.

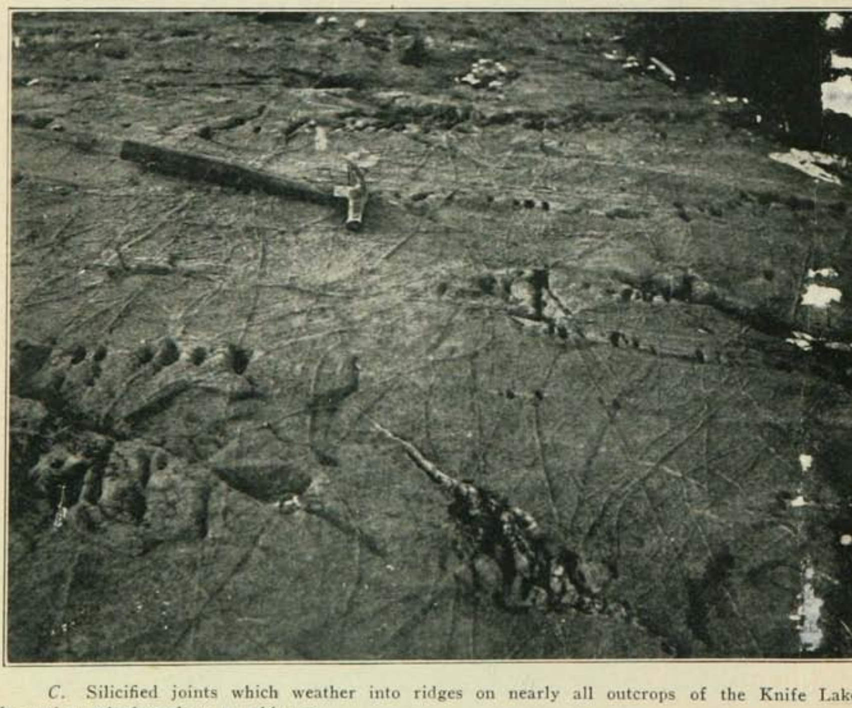
Petrography.—The mica schist is a medium grained, brownish gray, easily cleaved biotite rock. The graywackes develop microscopic augen. Some other minor variations occur in small quantities. All show prominent biotite in grains rarely over 1 mm. in diameter—average about .3 mm. across and .05 mm. thick—and most of the biotite is moderately well oriented in a mosaic consisting of quartz and feldspar grains less than .5 mm. across.

The schist shows a clearly sedimentary banding in nearly every large outcrop. The alternating beds from a fraction of an inch to several feet thick, vary mostly in the proportion of mica and quartz; the abundance of biotite in certain beds that must have been shale in the original, makes these beds darker than the graywacke bands. Bedding is also marked by the abundance and kind of metacrysts. Schistosity is more pronounced in the more biotitic bands, and can be seen to cross the bedding at many places at high angles. (See Plate III, A.) On the contrary, the most siliceous bands with little biotite show only the prominent bedding unless careful search is made for the position of the few biotite scales.



A. Sedimentary bedding in the biotite schist at the "Hoist" in the southwest corner of Burntside Lake.

B. Folds in the graywacke and biotite schist of the Knife Lake formation southeast of Burntside Lake.



C. Silicified joints which weather into ridges on nearly all outcrops of the Knife Lake formation, whether slaty or schistose.

In a large majority of outcrops the schist is composed of about 30 per cent each of biotite, quartz, and feldspar. (See Plate II, F.) Additional minerals include carbonate, muscovite, sericite, garnet; accessory zircon, apatite, pyrite, epidote, graphite; and in a few places magnetite, hornblende, cordierite, sillimanite, tourmaline, enstatite, staurolite, rutile, and chlorite. The rocks show very little weathering since scoured fresh by glaciation. By microscopic study the feldspars are found to be chiefly orthoclase and andesine, with some oligoclase. The biotite contains 17.60 per cent of FeO and .64 per cent Fe_2O_3 near Vermilion Lake, but the colors and indices of the several samples indicate different compositions. The rare hornblende has been seen in some cases to be altering to biotite. Late hydrothermal action may change the metamorphosed minerals partly to chlorite and sericite. The biotite is normally subhedral and includes only the rare accessories. Other constituents are dominantly in a mosaic of anhedral grains.

The differences in mineral content in the schist samples seem to be related largely to the nature of the original beds, rather than to differences in the intensity of metamorphism. Metacrysts of staurolite, garnet, and cordierite mark beds that alternate with more typical biotite schist. In one thin section, of fairly uniform grain, there are three beds, one characterized by biotite, another by chlorite, and a third by sericite. While these three beds were in a zone of relatively feeble contact action, they all in one thin section and it is unlikely that they were heated to different temperatures or received different emanations.

Certain portions of the schist are hornblendic. These, though small in proportion, were given special attention because the mica schists near the hornblendic green schist of the Ely greenstone were mapped by the United States Geological Survey as greenstone. Certain small inclusions of greenstone, or hornblende schist in granite, had narrow micaceous borders, but they did not look like the typical mica schist. The ordinary occurrence of hornblende schist, associated with the mica schist, was that of alternating beds or dikes. The presence of hornblende with or without biotite, appears to be a fairly definite sign of origin from a basic igneous rock or local sediment deriving its material from such a basic rock. The minor amounts of hornblende found in the mica schist areas are in agreement with similar occurrences in adjacent parts of Canada.[7]

The schist has been intruded by dikes and sheets of granite, pegmatite, and aplite, and many outcrops are only about half schist. The difficulty of deciding whether or not schist dominates in an exposure is

[7] Smith, W. H. C., Geology of Hunters Island: Geol. Survey of Canada Ann. Rept., vol. 5, G, pp. 48 G, 1892.

increased by the extensive *lit-par-lit* injections from these dikes and sheets. The outcrop at a distance may appear about half light and half dark, whereas on close inspection the dark part proves to be largely made of injected films of granite, leaving only about one fourth of the mass to be regarded as original schist.

Several exposures along bluffs in the mica schist area show a greenish modification resembling Ely greenstone. After detailed study it was concluded that they represented a chloritic alteration of the biotite along a fault plane. Certain brecciated materials associated with the green rock confirmed the conclusion.

Analyses of the biotite schist are given in Table II though it is clear that no uniformity of composition can be expected in a formation that varies so much in mineral nature. However, most outcrops of the schist show as principal phases, light and dark bands, which have the appearance of a fair degree of uniformity. The analyses show that even the graywacke and slate phases differ but slightly and are very much like the two main phases of the formation at Knife Lake.

Origin.—The appearance of sedimentary banding (Plate IV, A), is practically conclusive proof of sedimentary origin of most of the biotite schist. The banding has been obscured in considerable masses, however, by extreme metamorphism; and the microscopic study of the feldspars has led Steidtmann to suggest an igneous origin, possibly from a series of rhyolites.[8] His argument is based on the prevalent uniformity of the plagioclase in an igneous rock and the prevalent variability in the plagioclases of a sediment, even after metamorphism. In this schist he found the plagioclase uniformly oligoclase, and he therefore thinks the petrographic evidence might open the question of its origin for discussion, even if the field evidence does seem to indicate a sediment.

It seems probable that this feldspar criterion of origin is of great value in case of variation in the plagioclase in a schist; but that the contrary case, of uniform feldspars, leaves the matter wholly indeterminate. Many large shale deposits are so nearly uniform as to give uniform feldspars by metamorphism, and such uniform feldspars cannot be taken as evidence sufficient to contradict the positive structural evidence often found.

As another theory of origin, Winchell has suggested that the mica schist is formed from greenstone by the alteration of hornblende to biotite by the action of granite.[9] This of course ignores the sedimentary

[8] Steidtmann, Edward, Feldspars as indicators of origin: Bull. Geol. Soc. America, vol. 31 pp. 141-44, 1919.

Carlson, C. G., The feldspar method for the determination of the origin of metamorphic rocks: Jour. Geol., vol. 28, pp. 632.

[9] Winchell, N. H., Minn. Geol. and Nat. Hist. Survey 17th Ann. Rept., p. 32, 1889.

banding, but the banding can be attributed to peculiar metamorphism. The change from hornblende to biotite in metamorphism is well known,[10] but it seems wholly improbable that any great amount of mica schist formed that way in this region. In the first place banding is more extensively developed in the slate and mica schist than in the greenstone; even if banding could develop by *lit-par-lit* injection, it would not become so fused and obscured in character by later metamorphism. (See Fig. 3.) In the second place, if the hornblende, commonly formed from greenstone, can be changed to mica so extensively, it should have been changed in the little hornblende schist xenoliths which are at times associated with mica schist; they are in a perfectly analogous position and yet the hornblende schist xenoliths rarely show any tendency to alter to biotite schist even on the borders.[11] Finally when biotite and hornblende schist occur in the same inclusion, neither shows any sign of altering from the other, and neither has any different relation to the enclosing granite. It is therefore believed that the hornblendic phases represent beds of unusual composition in the original graywacke slate, or dikes of basic igneous rock, later metamorphosed.

The presence of staurolite in widely scattered outcrops of the schist may also be considered strong evidence that most of it was orginally a sediment.

Finally the chemical evidence confirms that seen in the minerals and field structures. (See Table II.) There is in the first place no resemblance to the greenstone in composition. Furthermore, the alkalies are low for a rhyolite, the alumina is high, the magnesia is greater than lime, and the potash nearly equal to soda. These are all relationships that indicate sedimentary origin,[12] and make the evidence conclusive, even where banding is not conspicuous. Analysis IV was of the less banded type. There may be, however, many rhyolites, and certainly there are some basic intrusives in the schist formation.

The schists that have been injected *lit-par-lit* by the granite, naturally show a composition intermediate between that of the granite and that of the sedimentary schist. They have not been analysed.

The thickness of mica schist.—The folding makes it almost impossible to estimate the thickness of the schist. Several geologists after reconnaissance trips across the northern schist belt, have noted the evident structure. The dips change along certain lines like anticlines and synclines.

[10] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47.

[11] I have seen zones of coarse biotite up to half an inch thick around a few inclusions of hornblendic rock, but the resulting biotite rock is coarse and not like the main mica schist.

[12] Trueman, J. D., Origin of foliated crystalline rocks: Jour. Geol., vol. 20, pp. 301-15, 1912.

On the basis of such appearances of folding, the thickness of the formation is estimated at nearly five miles.[13] A student of closely folded beds, however, will at once note that the supposedly uniformly dipping beds on one side of the supposed anticline, show folds and repetition of beds, so that the estimates made of thickness are wholly unreliable. It is the wide areal extent of the folded beds which is the strongest evidence that the formation attains great thickness—probably thousands of feet.

Age and correlation.—The progress of past opinions is briefly outlined here. The mica schist around Rainy Lake has been assigned to Coutchiching age by Dr. Lawson since 1888.[14] From his main contention in this, the special committee for the Lake Superior region (international) dissented in 1905, finding it more likely Lower-Middle Huronian.[15] Winchell in 1899 placed the schists below the Keewatin greenstone in some maps of the Final Reports of the Minnesota Survey.[16] He states, however,[17] that there is little probability that the Coutchiching schist at Rainy Lake is of the same age as the biotite schist at Vermilion Lake. Grant in the same volume uses the term Coutchiching with a note to say that its relation to the greenstone is not well known.[18] In the same volume H. V. Winchell and Grant give a tabular section showing Coutchiching schists below Keewatin.[19] The reports of the United State Geological Survey up to 1911 show the schists as Lower-Middle Huronian.[20] The granites which so clearly intrude the schists, however, are shown as Archean, Laurentian, without any explanatory phrase to show that it is a "Laurentian" of later age than the Huronian schist.[21] Lawson in 1913, remapped the region of Rainy Lake and again placed the greater part of the schist area in the Coutchiching.[22] Various private reports refer to the schists as Coutchiching to distinguish them petrographically, but not on the basis of any careful study of the case.

The southern belt of mica schist was mapped by Winchell in 1899 as Archean, in the map of north St. Louis County, but was shown above the greenstone in the detailed map of Vermilion Lake.[23] In the description

13 Lawson, A. C., Geol. Survey of Canada, vol. 2, pp. 101-2 F, 1889.

14 *Op. cit.*

15 Jour. Geology, vol. 13, p. 95, 1905.

16 Winchell, N. H., Final Report, vol. 4, Plates 65 and 67.

17 *Ibid.*, p. 541.

18 *Ibid.*, pp. 176-77.

19 *Ibid.*, p. 195 and Plate N.

20 Van Hise and Leith, Geology of the Lake Superior Region: U.S. Geol. Survey Mon. 52.

21 The "explanatory phrase" was preferred by the special committee wherever Laurentian was applied to Huronian granite: Jour. Geol., vol. 13, p. 103.

22 *Op. cit.*

23 Winchell, N. H., Minn. Geol. and Nat. Hist. Survey Final Report, vol. 4, Plates 67 and 86.

of the Vermilion Lake plate, on which the several members of the survey did intensive work, the schist is described as the result of granite contact action on the Huronian slates, then included in the Keewatin. The maps of the United States Geological Survey in 1903 ignore these areas of mica schist previously mapped by the state survey, showing only that the Ely greenstone near the granite is altered to schist; though admitting that the greenstone forms a hornblende schist nearly everywhere that granite affects it.

The schist areas in the midst of the granite have never been assigned to any stratigraphic position except by Seidtmann,[24] who assigns them to the Coutchiching. They should be assigned the same age as that of the main areas of schist on each side of the granite, but they have not, even in this report, been completely mapped. They have no evident economic significance and have therefore been passed over rapidly.

Every clear exposure studied in detail has indicated that the biotite schists here described are younger than Keewatin greenstone.[25] They are therefore classed as Knife Lake formation and correlated with the Seine series on Rainy Lake.

The evidence of the Huronian age of the mica schists makes the term Coutchiching inapplicable; and the term Vermilion as applied to a series of schists was abandoned because clearly not representing a single formation.[26] No new name is needed for the rocks altered near igneous contacts, since in this district they are as easily distinguished as the unaltered Knife Lake slate. The mica schists are therefore included in the Knife Lake formation.

ALGOMIAN SERIES

INTRODUCTORY STATEMENT

It is becoming every year more evident that the batholithic intrusion following some Huronian sedimentation was more widespread in area and involved greater volumes of magma in North America than that before Huronian time. This was clearly brought out in a paper by Coleman,[1] who thought that the two granites were too much alike to be separately mapped. Since the term Laurentian had been applied to granites of both periods, he argued that, if it was restricted at all, it should be retained for the larger masses of later age, and not for the less extensive earlier

[24] Steidtmann, Edward, Feldspars as indicators of origin of gneisses and schists, Bull. Geol. Soc. America, vol. 31, pp. 143-44, 1920.

[25] Grout, Frank F., The Coutchiching problem: Bull. Geol. Soc. Amer., vol. 36, pp. 351-64, 1925.

[26] Grant, U. S., Field work during 1893 in northeastern Minnesota: Minn. Geol. and Nat. Hist. Survey Ann. Rept. vol. 22, pp. 70-72, 1894.

[1] Coleman, A. P., The Sudbury series and its bearing on pre-Cambrian classification: 12th International Geologic Congress, pp. 387-98, 1910.

granites. The Special (international) Committee favored the use of "Laurentian" for the older granites, but decided it was necessary to use it for some granites of Huronian or unknown age, "with a qualifying phrase."[2] Van Hise and Leith have shown the need of separating the two granites in mapping,[3] and have so separated the Giants Range granite from the Laurentian, though they put it into the Huronian without assigning the period any name. Lawson proposes[4] for these granites the period name "Algoman," and as their importance deserves it, the name is here adopted.

In Minnesota the Giants Range granite is clearly intrusive into the Knife Lake slate and unconformably overlain by Animikie sediments.[5] This locates it definitely in the Algomian. The other intrusives believed to be of Algomian age are the Vermilion batholith with its border phases, and the satellites, stocks, and dikes in adjoining areas. The Burntside granite gneiss is earlier than the Vermilion, but probably also Algomian. These several intrusives are so prominent in the region that the question of assigning them to a particular age becomes of considerable importance. The matter is discussed at length in the description of the Vermilion granite, the largest of the masses.

The several intrusives, acid and basic, are not described here in the sequence of age, which is somewhat uncertain; but after a paragraph on the Giants Range and one on the Burntside granite gneiss, the remaining intrusives are discussed as parts of the Vermilion batholith or satellites related to it.

GIANTS RANGE GRANITE

The Giants Range granite is an extensive batholith that forms the nucleus of the Giants Range and is a logical southern limit for the area here considered. It is south of the main syncline of the Vermilion Range formations. Along the Mesabi Range there are also, in close areal relationship, some very small masses of younger granite that intrude the iron formation. The main mass is determined in age by its effect on the Knife Lake slates, and the unconformity between the granite and the Animikian beds of the Mesabi.

The mass has been described by Allison,[6] who gives analyses. It consists of a series of hornblende and biotite granites, mostly pink in color, but with some modifications in both texture, color, and proportions of minerals. The feldspars are largely oligoclase, but there are numerous

[2] Jour. Geol., vol. 13, p. 103, 1905.
[3] United States Geological Survey Bull., 360, p. 28.
[4] *Op. cit.*
[5] Spurr, J. E., Minn. Geol. and Nat. Hist. Survey Bull. 10, pp. 2-3, 1894.
[6] Allison, I. S., The Giants Range batholith of Minnesota: Jour. Geol., vol. 33, pp. 488-508, 1925.

phenocrysts of microcline in many of the eastern exposures. Xenoliths of amphibolite and xenocrysts of amphibole are conspicuous near the greenstone at places south of Ely. The northern border of the granite in places is less acid, grading into syenite, shonkinite, and hornblendite.

BURNTSIDE GRANITE GNEISS

On Burntside lake two granite intrusives are distinguishable one intruding the other. (See Plate VI, A.) Both, however, seem to be determined in age by the fact that they are later than Knife Lake schists and older than the black dikes of the Keweenawan. (See Fig. 2.) The schist dips under the greenstone in places, but seems to be overturned. The older, more gneissic granite is a relatively small mass and is intruded by the early phases of the Vermilion granite as well as by its pegmatites.

The texture of the older rock is notably granulated. The minerals, though much crushed and altered indicate a sodic granite, nearly 50 per cent oligoclase. Quartz and orthoclase each make up over 20 per cent of the rock, but microcline is rarely found. Some altered ferromagnesian mineral commonly makes 3 or 4 per cent of this rock. The following analysis was made on average material.

TABLE III

Analysis of Burntside Granite Gneiss

SiO_2	68.54	H_2O-	.18
Al_2O_3	17.89	TiO_2	.20
Fe_2O_3	1.77	ZrO_2	none
FeO	.52	P_2O_5	trace
MgO	1.22	S	.06
CaO	4.02	Cr_2O_2	none
Na_2O	5.14		
K_2O	1.05		101.05
H_2O+	.46		

Gneiss from the portage from Burntside Lake to Little Long Lake. Analyst, Douglas Manuel.

THE VERMILION GRANITE

General setting.—By far the largest area of granite in Minnesota is that extending from Vermilion and Burntside lakes to Namekan and Kabetogama lakes. It is the chief rock in about 50 townships. The western extension of this area into Koochiching County is obscured by drift, but appears to be short. To the east of St. Louis County, however, granite (probably in several distinct masses) appears to extend far into Ontario. As an east-west belt the granite separates the two synclinal belts of the Vermilion and Rainy Lake districts. It intrudes the older formations on each side, and alters them to crystalline schists. (See Fig. 6.)

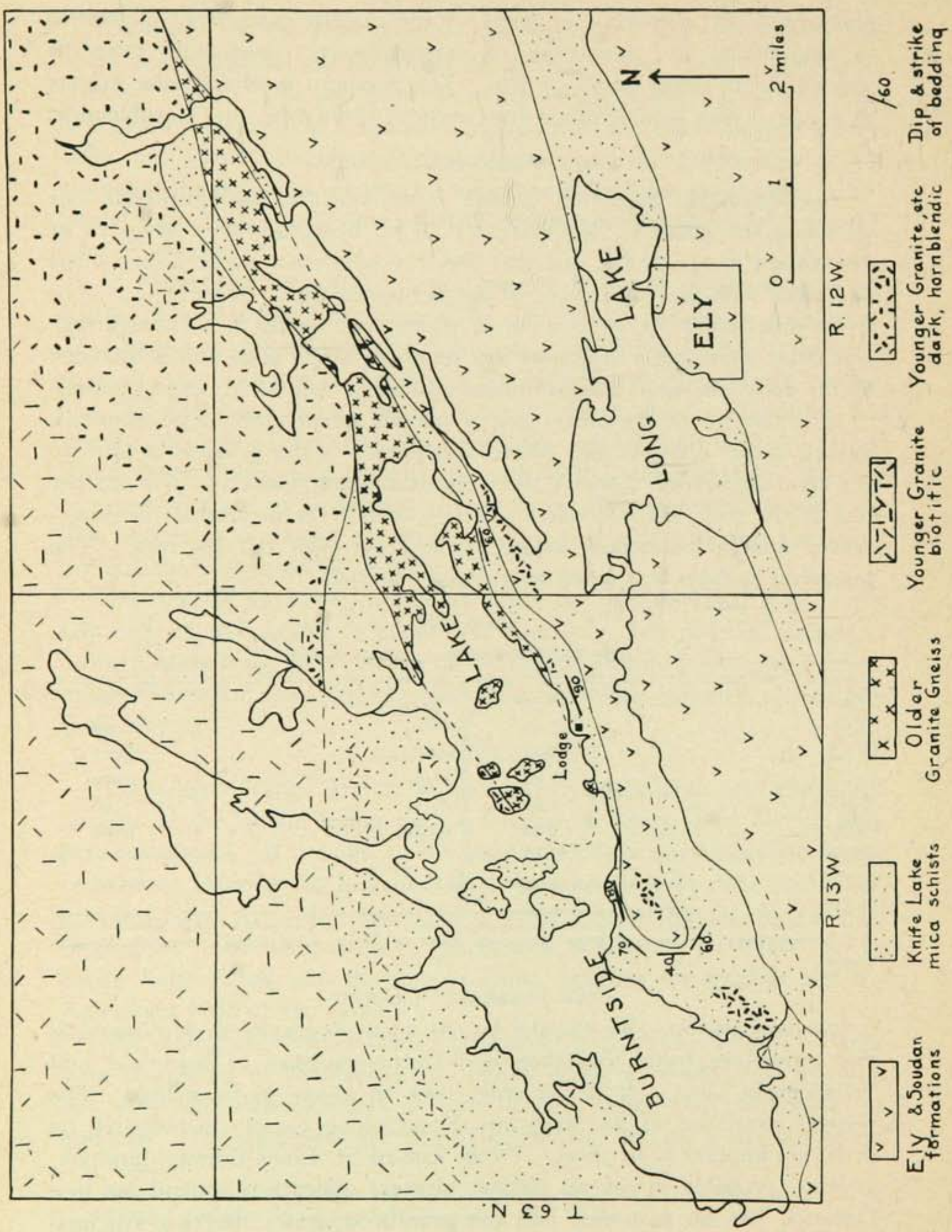


Fig. 2. Map of an area on Burntside Lake, showing granite of two ages, both later than biotite schist. The schist overlies greenstone in an anticlinal fold in T. 63 N., R. 13 W.

Outcrops are numerous over an area 30 by 80 miles across, and the main rock is a normal granite with only about two per cent of biotite. Many outcrops show special phases, inclusions or differentiates. The main granite is exposed on Lac la Croix, and southeast of Namekan Lake

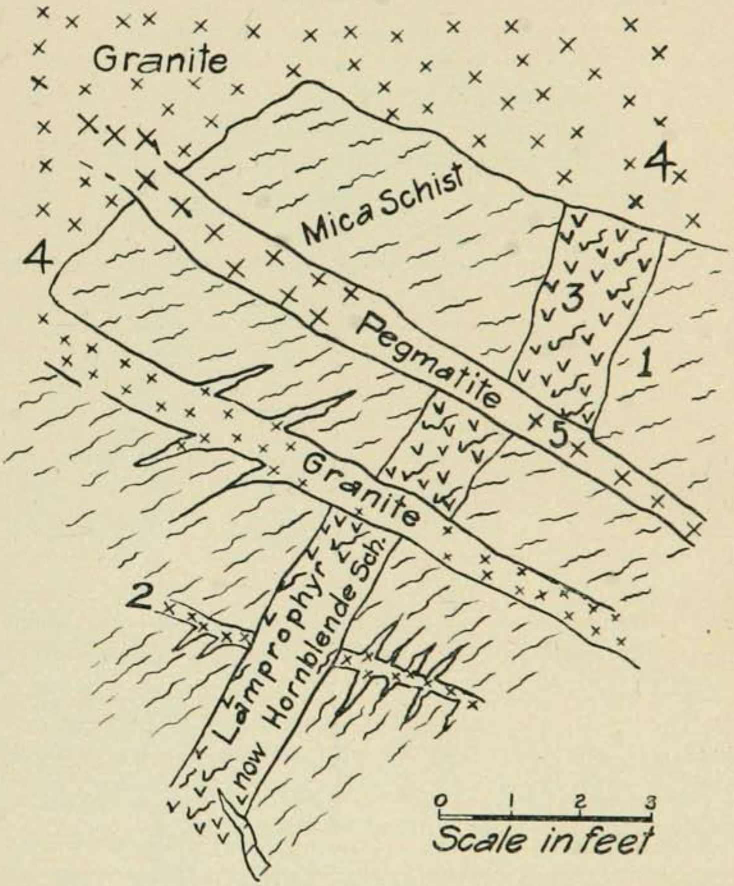


Fig. 3. Igneous intrusives 2000 paces northwest of the south quarter-corner of Sec. 24, T. 63 N., R. 17 W. Surface about 10 feet square.

The sequence of rocks is as follows. 1, Schist; 2, Granite injecting *lit-par-lit*; 3, Lamprophyr; 4, Granite; 5, Pegmatite. The occurrence of lamprophyr between the granites indicates a considerable change in magmatic character and probably a long time between the granite intrusions. Note also that *lit-par-lit* banding is not obliterated by two later intrusives.

in a zone about 10 miles wide with hardly a pegmatite to break its uniformity. Elsewhere the granite is mostly filled with inclusions and crossed by pegmatites and aplites; in short all the modifications characteristic of the upper portions of batholiths. About nine tenths of the inclusions are mica schist of sedimentary origin, but there are small areas of amphibole rocks and other minor varieties of schist. Along the borders, especially on the south and east of the batholith, there are hornblendic differentiates, some of them more basic than the average of the mass. These make up only about 5 per cent of the area.

The contact action of the granite on Knife Lake slate and Ely greenstone is described under the head of these formations.

Mode of intrusion.—Many investigators agree that batholiths reach their places by two distinguishable modes of intrusion.[7] In great depths the roof and walls may be crowded aside, moving by rock flowage as the magma rises. In the zone of fracture the roof and walls have a chance to yield by stoping and slight doming up at the surface.

The Vermilion batholith shows abundant *lit-par-lit* injections of its walls and the strike of the structure in the walls is roughly parallel to the contact. These suggest a crowding action at considerable depth. There is also, however, such a remarkable abundance of schist inclusions in much of the granite area that it is evident that the magma was working its way upward by stoping. Probably it had reached a moderate depth and both processes here acted at the same time.

One feature may be considered as a limit to the amount of stoping accomplished. A relatively basic hornblendic rock on the borders of the batholith seems to be a relic of an early stage of the magma. It is largely syenite, but has in places even more basic phases. If, as it seems, this rock solidified from the magma early, the stoping done during the long process of differentiation to granitic composition was not sufficient to remove all the early basic separates. Probably during the differentiation little stoping was done except to form the inclusions now indicated by the outcrops.

Age.—The granite both on the north and south sides clearly intrudes mica schists which are equivalent to the Knife Lake slates, Lower-Middle Huronian.[8]

The other limit to the age of the granite is less accurately determined. No sediments later than the Knife Lake slates have been found in contact with the granite, except the drift. The granite is without doubt as old as early Keweenawan, for fresh basalt and diabase dikes cut across it in several places,[9] and such dikes in Minnesota are not known to be later

[7] Paige, Sidney, Intrusion of Black Hills granite: Bull. Geol. Soc. Am., vol. 27, pp. 104-5 (1916), and discussion by Joseph Barrell.

[8] Grout, Frank F., The Coutchiching problem: Bull. Geol. Soc. Am., vol. 36, pp. 351-64, 1925.

[9] Sec. 23, T. 63 N., R. 18 W. Specimens 2000 to 2004 of the Survey are from basalt dikes. See 24th Ann. Rept., pp. 7-9. See also Final Report, vol. 4, pp. 539-40 and 243. A basalt dike cuts across pegmatite in the channel from Sand Point to Namekan lakes.

than Keweenawan. Whether it is early Keweenawan,[10] or Algomian is not easily settled; but the petrographic series resembling, even in minute detail[11] that of the Algomian granite of the Giants Range and that of the Kekequabic and Snowbank stocks which are supposed to be Algomian, indicates that Vermilion mass is also Algomian.[12]

This assignment of the greatest of Minnesota granites to Algomian leaves very little Laurentian as commonly understood. A small dike of granite gneiss on Rainy Lake and the Saganaga granite (largely in Canada) are the only clear cases in the state, of granite old enough to supply pebbles to the Lower-Middle Huronian conglomerates. See Fig. 3.

Name.—The name Vermilion is applied to this granite from the abundant exposures along the Vermilion River, flowing north practically across the center of the batholith. Exposures are also clear along the north shore of Vermilion Lake, which is the source of the river.[13]

Petrography of the main granite.—The mineral composition of the granite varies but little from the following: quartz, 25 per cent; orthoclase, 30 per cent; microcline, 20 per cent; oligoclase, 20 per cent; and biotite 2 per cent. The analyses indicate that the measured orthoclase and microcline must contain some soda. There are accessory apatite, zircon, and allanite, with traces of magnetite and muscovite in a few places. (See Fig. 4.) Epidote, chlorite and kaolinite are common secondary products in small amounts. Biotite as the essential mineral of variable composition was separated, purified and tested. Its specific gravity is 3.107; gamma $= 1.640 \pm 2$; alpha $= 1.597 \pm 5$. It has a medium brown color.

TABLE IV

Partial Analysis of Biotite from Vermilion Granite

SiO_2	37.12	K_2O	5.40
Al_2O_3	17.06	H_2O+	3.10
Fe_2O_3	4.05	H_2O-	.30
FeO	14.80	TiO_2	2.23
MgO	10.21	MnO	.48
CaO	2.36		
Na_2O	.68		97.79

[10] To be correlated with Killarnean; see T. T. Quirke, Correlation of Huronian and Grenville rocks: Jour. Geol., vol. 32, p. 332, 1924.

[11] Grout, Frank F., A peculiar shonkinite related to granite: Am. Jour. Sci. vol. 9, pp. 472-80, 1925.

[12] Spelled in accordance with nomenclature of other periods.

[13] The name "Vermilion" was used before 1890 by Minnesota geologists for a schist, a series, or a group, in this same district. The men who proposed it soon found that the schist was not a single formation, but included the metamorphosed phases of several formations. They dropped the term and it is therefore available for other use.

The use of the term Vermilion for some western formations has always included a compound, as Vermilion Cliff formation, Vermilion beds, Vermilion creek, which will not be confused.

A. A pegmatite dike in Vermilion granite. This dike is straighter than most of the pegmatites and shows no sharp contact with granite.

B. Platy parting in the hornblende syenite near High Lake, north of Ely. A border phase of the Vermilion batholith. The joints are not related to the surface.

A fair degree of uniformity in the large mass is indicated by the following partial analyses from widely scattered points:

TABLE V

Partial Analyses of Normal Vermilion Granite

	I	II	III	IV	V	VI	VII
Fe_2O_3	.58	.46	2.25	.93	1.31	...	1.67
FeO	1.35	.72					
Na_2O	3.58	4.56	3.90	3.73	3.77	3.01	3.79
K_2O	4.63	3.54	4.72	5.36	5.06	5.70	4.83
Spec. Grav.	2.615	2.637	...	2.611	2.618	...	2.644

I. From the northwest part of Sand Point Lake, Sec. 12, T. 68 N., R. 17 W.
II. From southeast of Pelican Lake, T. 64 N., R. 19 W.
III. From Sec. 23, T. 65 N., R. 15 W.
IV. From Sec. 10, T. 66 N., R. 17 W., near the chief prospect hole in magnetite pegmatite.
V. From Sec. 24, T. 66 N., R. 18 W.
VI. From Sec. 10, T. 66 N., R. 15 W.
VII. From Sec. 21, T. 66 N., R. 13 W.

Variations.—Mineralogic variation in the granite mass is suggested by N. H. Winchell, in his references to "granite, syenite and diorite," as belonging in the area.[14] Considerable time was therefore given to a search for the gradations. For the most part, the granite is notably uniform except in the matter of inclusions and pegmatite and aplite dikes. In a few places, e.g., in Sec. 25, T. 64 N., R. 16 W., Trout Lake; in Sec. 2, T. 64 N., R. 17 W.; and in a low outcrop on the road from Buyck to Harding, feldspar phenocrysts develop, as they do in the eastern part of the Giants Range granite. Some phases are slightly gneissic as a primary structure. The color is commonly pink, but is gray or brown in some small areas. Rarely there are local dark rocks resembling diorite, such as may be seen along the road toward Vermilion Dam in the southern part of T. 65 N., R. 17 W. Beyond these minor changes certain other variations in the granite are noteworthy. (See Plate IX.)

Gneissic border phase.—On the shores of Namekan Lake, from Sec. 18, T. 69 N., R. 18 W. east nearly to Sand Point Lake the granite is gneissic. The exposures near shore might lead one to suppose that the gneiss was a distinct formation. In the bay, in Section 36, however, there are within a mile, all gradations from gneissic to massive granite and there can be no doubt that the gneiss is related to the Vermilion granite. If older granite occurs, it is only as small inclusions. On the islands in

[14] Winchell, N. H., Geology of the north part of St. Louis County: Minn. Geol. and Nat. Hist. Survey Final Report, vol. 4, p. 251, 1899.

Sec. 18 and Sec. 19, T. 69 N., R. 18 W., there is a complex of gneiss, granite, and pegmatite of great irregularity. Several successive intrusions are clearly shown, but it is believed that all are related to a long period of alternating injection and mashing connected with a single batholith.[15]

The connection of this gneiss with Algomian granite is also indicated by its composition. It contains 2.76 per cent soda and 5.37 per cent potash closely resembling the granites, analyses of which are given in Table V.

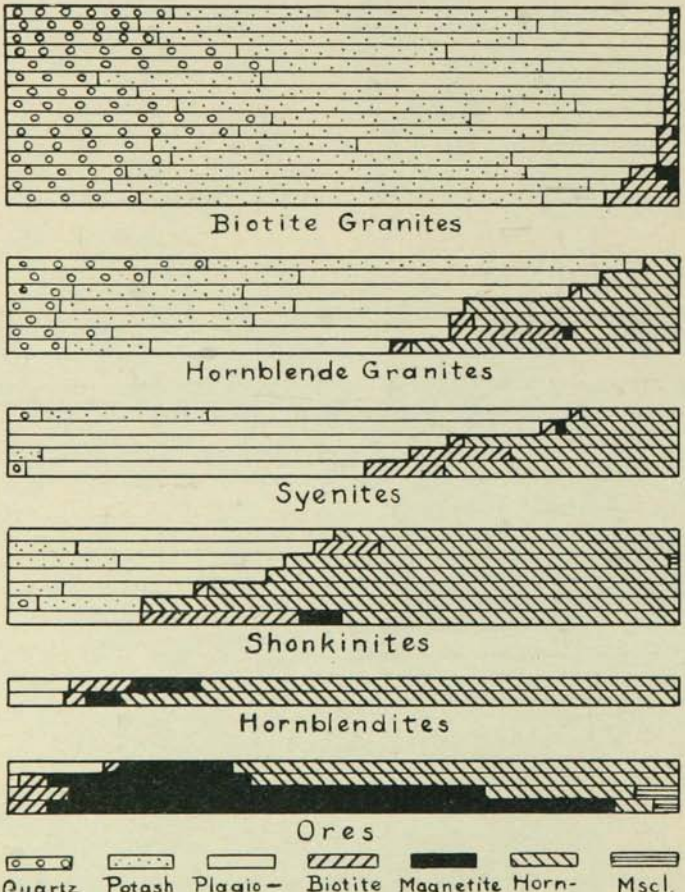
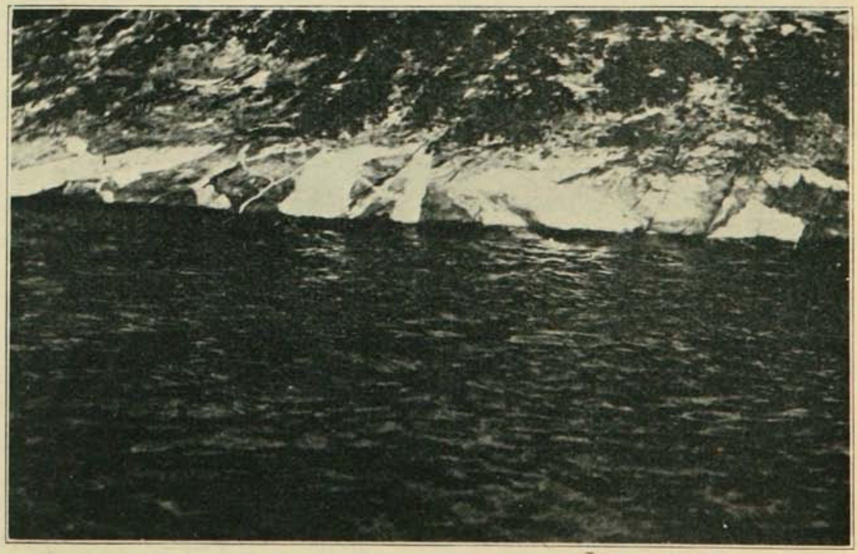


Fig. 4. Diagram of the modes of the several phases of the Vermilion batholith. Each horizontal bar represents one rock measured. The biotite granites of the upper set make up nine tenths of the exposures. The plagioclase is andesine in one rock, but more acid in all the others.

[15] Barrell, Joseph, Relations of subjacent igneous invasion to regional metamorphism: Am. Jour. Sci., vol. 1, pp. 1-19, and 174-86, and 255-67, 1921.

A. Breccia of fragments of older Algomian gneiss in a matrix of dark border phase of Vermilion granite, on Burntside Lake.



B. Vermilion granite on Ash River, containing many biotite schist inclusions.

Microscopically the gneisses show only a slight granulation and scarcely any augen structure. (See Plate IX, B.) None of the minerals of the granite is wholly obliterated, but the biotite has largely altered to muscovite and both micas are commonly bent. There is rather more of graphic and perthitic intergrowth than in the average granite.

Such dynamically altered rocks have not been found in the southern part of the granite, though an older granite on Burntside Lake is even more altered. Probably the deformation following the intrusion of the granite was more intense on the north side of the area, for the conglomerates on Rainy Lake are more distorted than those on Vermilion Lake.

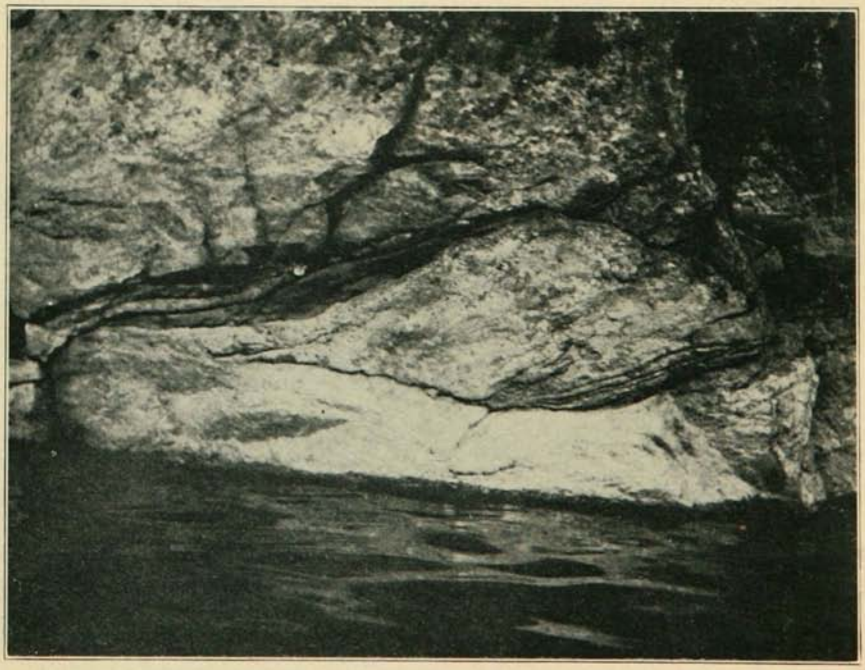
Early border phases and iron ores.—The second type of variation is that to a dark basic border phase. This suggests, according to the prevailing hypothesis, that the magma as first intruded was basic, and at least portions of it cooled to basic rocks; while the main central liquid differentiated to granite by the settling of basic minerals.

Such border phases of the Vermilion granite were found along both sides. The darker rock is not a continuous belt and might have been mistaken for some other small intrusion, except for its peculiar petrographic character—some of it conspicuously spotted, (Plate VIII, B.)—and its occurrence at widely distributed points, all of the large masses being along the border of the granite. Again, since it is a basic phase and adjacent to the Vermilion Range, it might have been assumed to be a product resulting from greenstone assimilation exactly analagous to the biotitic phase of granite from the mica schist, described below. (See page 42.) The dark rock, however, is found not only adjacent to greenstone, but at other places adjacent to mica schist and even, on Burntside Lake, beside an older granite. No assimilation of granite could possibly produce a basic border phase in the Vermilion granite.

Finally, when the whole area was studied, it was found that many outcrops are of intermediate rocks (Plate IX, C and D). While there is evidently a sequence in the solidification of the rocks—dark syenite intruded by light syenite and both intruded by granite—a series of rocks can be selected showing scarcely a break from granite to hornblendite. No single outcrop showed a complete gradation but the relation of all the rocks to a single batholith can scarcely be doubted.

The most accessible belt of this border rock is along the bluff on the north side of Frazer Bay in Vermilion Lake in Sec. 3, T. 62 N., R. 17 W. It can be seen in less regular but large exposures, north of Pine Island in the same lake. At the latter place the rock forms cognate xenoliths—it apparently crystallized while the main granite magma was still fluid, and by later movement was stoped into the granite in blocks both large

A. Vermilion granite near the magnetite prospect southwest of Crane Lake. Note the numerous schist inclusions.



B. Vermilion granite on Ash River showing biotite schist inclusions much injected and apparently partly assimilated, developing schlieren.

and small. One or two small blocks of spotted rock were noted far in the granite and away from the contact. In Burntside Lake some islands in the SE¼ Sec. 15, T. 63 N., R. 13 W., show the same sort of rock at the edge of a great area of Vermilion granite.

The largest areas of the border differentiate are around Basswood Lake, but these are syenites intermediate between granite and darker shonkinites. Some especially instructive exposures occur north of High Lake.

The variation in mineral content of this series is indicated by a few measurements shown in Figure 4. The syenite, making up a larger mass east of St. Louis County than inside it, is normally made up of about 40 per cent oligoclase, 20 per cent orthoclase, 30 per cent hornblende, 5 per cent quartz, and 3 per cent biotite. It shows a platy parting where weathered, (Plate V, B), and a slightly trachitoid structure in hand specimens.

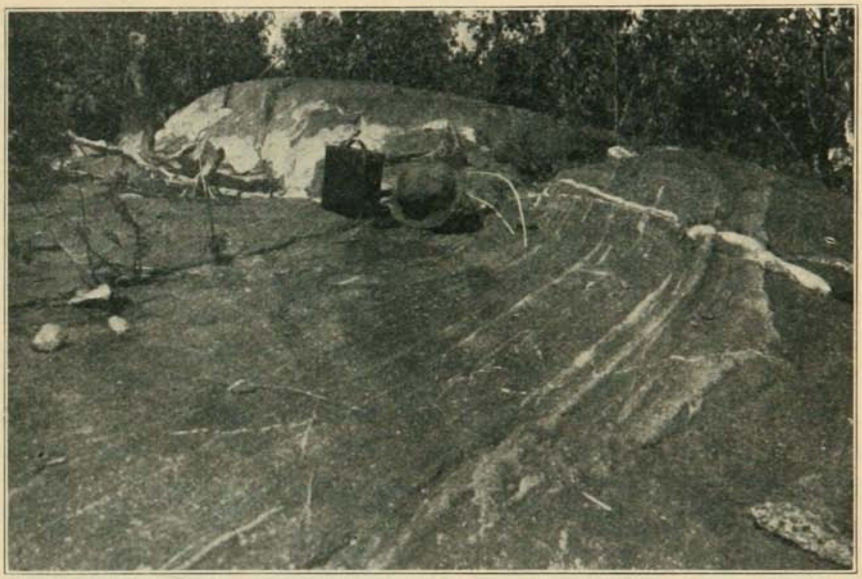
From High Lake to Vermilion Lake most of the early border phase shows a banding of darker differentiates (Plate VIII, A), some of which are conspicuously spotted with large poikilitic feldspars in a hornblendic matrix. (Plate VIII, B.) This is distinguished as shonkinite (Basswood type).[16] There is a group of black bands also, in the syenite at High Lake, including hornblendite and magnetite ore. (See section on Economic Geology and the report on T. 63 N., R. 12 W., pages 74 and 91.) Analyses are given in Table VIII, and the appearance of the thin sections is indicated in Plate X.

Assimilation phases.—Two of the rocks intruded by the Vermilion granite differ from it so notably that included fragments are very conspicuous. The Knife Lake slate forms dark biotite schist, and the Ely greenstone dark hornblende schist fragments in light pink granite. The two rocks, however, reacted differently with the granite magma.

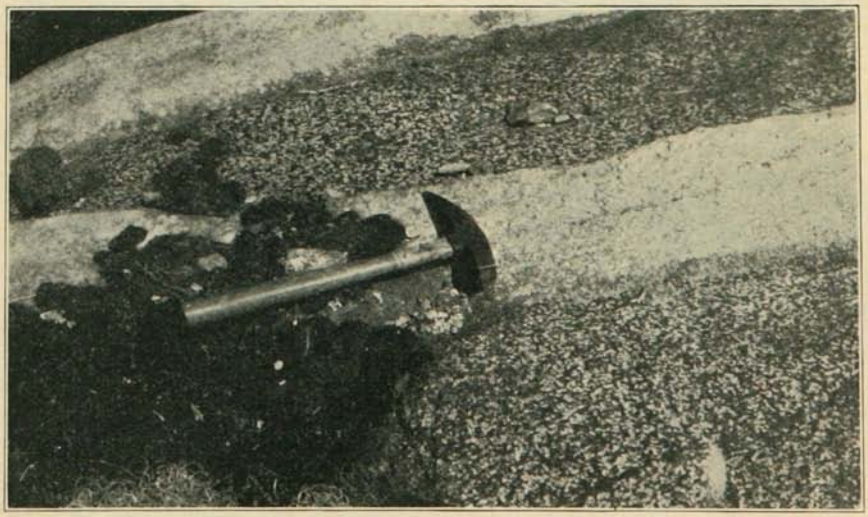
In a few small areas, hornblendite inclusions possibly derived from Ely greenstone are more abundant than mica schist. The reaction of granite and hornblendite is evident in the soaking of the granite juices into the outer parts of the inclusion, making a gneiss. It is not a typical *lit-par-lit* injection, for the hornblendite has only an imperfect cleavage; the soaking is pervasive. Neither is there a complete gradation to the granite; the soaked inclusions still commonly retain the outlines of inclusions surrounded by a granite that shows no excess of ferromagnesian mineral. The altered part of the inclusion shows a progressive change from hornblende to biotite[17] and outside the inclusion there are

[16] Grout, Frank F., A peculiar shonkinite related to granite: Am. Jour. Sci., vol. 9, pp. 472-80, 1925.

[17] Schwartz, G. M. The effect of granite and gabbro intrusions on Ely greenstone: Jour. Geol., vol. 32, pp. 89-138, 1924.



A. Banded differentiates north of High Lake in the dark border phases, shonkinites, of the Vermilion batholith. Magnetite ore forms one such band, four feet wide.



B. Banded differentiates north of High Lake. The bands are wide and the darker bands are the spotted shonkinite (Basswood type).

a few biotitic schlieren. (Plate VII, B.) These schlieren probably indicate about the extent of real assimilation. The biotite granite has not been found to become hornblendic near the hornblendic inclusions anywhere in the batholith.

Most of the granite area is characterized by an abundance of biotite schist inclusions. There is only a little evidence of solution of fragments. The schist has 10 to 20 per cent of biotite and most of the granite only 2 or 3 per cent; but in a few places the granite near inclusions is slightly darker than average. (Compare Plate IX, A and F.) Such rocks are exposed on Gun Lake and Murphy Lake in the eastern part of the area mapped. These are quite apart from those mixed rocks that show traces of schist structures, and they cannot be considered extreme phases of injected schist; they are granite. Several features combine to indicate, however, that the granite has been affected by the digestion of some schist. The fragments of schist are rounded at the corners, and the cleavage plates on the sides are injected *lit-par-lit* until they float off into the granite as schlieren more and more indistinct. Finally, not only biotite but other constituents, show that the darkened granite is intermediate between normal granite and biotite schist. It may be noted that a 20 per cent addition of schist would produce this much modification of the granite, and since the dark granite is not common, assimilation was probably not of great importance at that stage of magma history. The complete analysis of the modified granite is No. 15 in Table VIII.

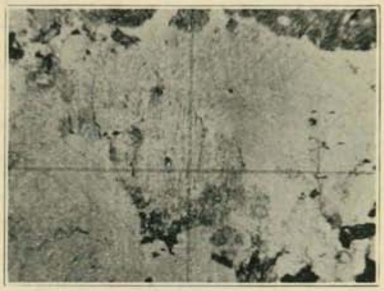
TABLE VI

Parts of Analyses Suggesting Assimilation

	Vermilion Granite No. 1	Biotite Schist Near Vermilion Lake	Calculated Mixture 4 Parts No. 1 and 1 Part Schist	Supposed Assimilation Phase of Granite No. 15
SiO_2	71.73	63.04	69.99	69.01
Al_2O_3	14.76	16.45	15.10	16.92
MgO	.62	5.04	1.50	1.28
CaO	1.18	3.17	1.58	2.67

Pegmatitic phases and iron ores.—Pegmatites and aplites occur abundantly through most of the area of the batholith and in the schist walls and inclusions. North of the granite a number of large dikes follow approximately the structure of the schist and form great ridges, 40 to 50 feet wide. These have been noted for their coarse muscovite, but the quality of this mineral is not promising. Much more abundant but usually smaller masses of pegmatite occur within the area mapped as granite. They form segregations and dikes in the granite and dikes of

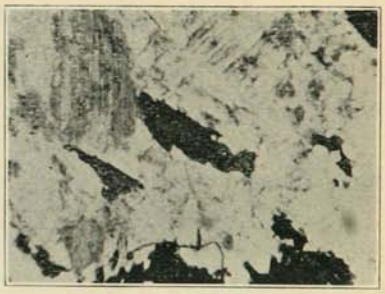
MICROPHOTOGRAPHS OF VERMILION GRANITE AND ITS PHASES



A. Normal granite showing feldspar, quartz, and a little biotite.

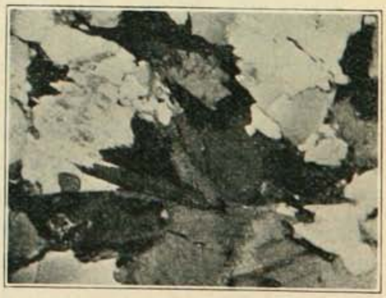
B. Gneissic granite on Namekan Lake.

C. Rare hornblendic biotite granite.



D. Hornblende syenite on the south-east side of the batholith.

E. Hornblendite.



F. Biotitic phase showing signs of assimilated schist. Magnifications X 40.

great complexity in the fractured schist of the roof pendants and inclusions. In a large way many outcrops may be considered as breccias of biotite schist with an abundant pegmatite matrix (Plate VI, B and VII, A). Most of the pegmatite is pink like the granite but some is nearly white. There may have been a series of pegmatite developments related to the granite, for in several exposures pink pegmatite crosses the white pegmatite as if distinctly later. These later pegmatites have at places some accumulations of coarse magnetite which roused the interest of prospectors, and they are given detailed study in a later section of this report. Note has been made also of some ladder veins crossing the pegmatites[18] (Plate XI, A).

The chief minerals of the pegmatite are pink microcline, or its graphic intergrowths with quartz, white to greenish albite (or oligoclase), and quartz. Biotite is the chief dark mineral but there are locally magnetite, muscovite, garnet, and tourmaline and commonly all dark minerals are absent. Pyrite and chalcopyrite cross the early minerals in some of the magnetite deposits. Quartz in the average pegmatite is probably less than 20 per cent. The extreme compositions noted are (1) those with almost 100 per cent quartz, (2) those nearly all acid feldspars, and (3) those with about 50 per cent magnetite.

The texture of the pegmatites shows the usual variation (Plate V, A), and aplites are associated in many places, even occurring in the same dike in rudely banded structures. Banded pegmatites are not common, however, though many show a central zone more quartzose than the borders.

The chemical composition is naturally variable. Analysis No. 16 of Table VIII was made on the average magnetite rock at a prospect hole. No other analyses have been made, but it is clear from the minerals that the ratio of soda to potash is variable, and silica may rise to the practical exclusion of all other constituents.

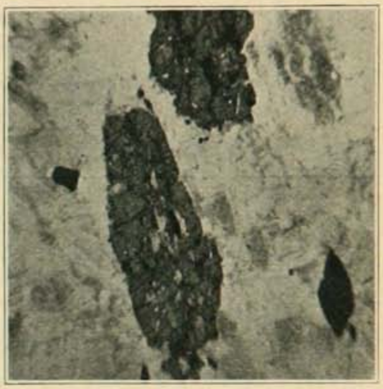
Dikes and satellites.—Igneous rocks of small surface outcrop, near the Vermilion granite, may be related to the granite. The pegmatites north of the main area have been mentioned above. South and east along Vermilion and Burntside lakes, the granite fades into the schists in a series of irregularly diminishing dikes and *lit-par-lit* injections, so that its boundary can hardly be mapped. Several masses of granite lie far out between the Vermilion and Giants Range areas, suggesting a possible relationship between the two batholiths. Some of the larger are petrographically like the biotitic Vermilion granite; others are hornblendic like the border rock on Basswood Lake.

[18] Grout, Frank F., Occurrences of ladder veins in Minnesota: Econ. Geol., vol. 18, pp. 494-505, 1923.

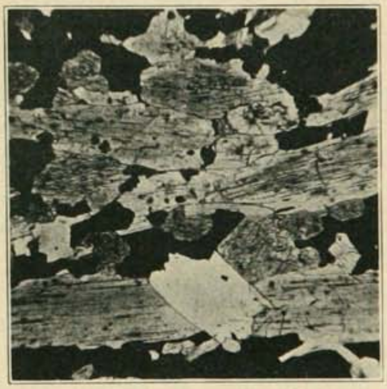
PLATE X

MICROPHOTOGRAPHS OF SOME IGNEOUS ROCKS OF ST. LOUIS COUNTY

A. Shonkinite (Basswood type) near High Lake. The hornblende is poikilitically scattered in coarse feldspar.



B. Linden syenite showing green pyroxene and titanite in a field of feldspars.



C. Magnetite segregation near High Lake. The gray grains are hornblende and the light grains phlogopite.

D. Magnetite segregation near High Lake. The gray rounded grain is green spinel. Various other minerals in small amounts.

Several dikes intrusive into the rocks of the Vermilion district are also closely similar in age and composition to Vermilion granite. Since they are most abundant near the granite, they should be considered as apophyses unless they can be shown to be older than the Huronian sediments of the district. Their textures range from granitoid to porphyritic, and some of the granite dikes, a few yards across, grade into porphyry near the walls.[19] In some of the porphyries quartz is found only in the groundmass. Several such intrusives cut the ore bodies of the Vermilion Range.

[19] Seen in a clear outcrop on the line between Sec. 12 and Sec. 13, T. 62 N., R. 13 W.

Many intrusives of more basic composition than the granite, also cut the Huronian sediments. The dark dikes of fresh rock are considered Keweenawan, but the more altered rocks may possibly be apophyses from the border phase magmas of the Vermilion batholith. Some show the peculiar and almost distinctive petrography of the border phase. Furthermore the location of some dark dikes close south of the southern border phase on Burntside Lake shows that such dikes are to be expected in other places. Examples are found along the shores in the eastern part of Vermilion Lake, and on Stuntz Island of that lake.

Two masses of alkaline syenite lying between the Vermilion and Giants Range granites have less certain connections. One lies along the southwest side of Vermilion Lake, and the other, here called Linden syenite, in Townships 62 and 63 N. along the west side of St. Louis County. (See Plate I.) They are not noticeably altered and the one on Vermilion Lake is intrusive into the Knife Lake slates. Possibly they may be as young as Keweenawan, but there is little petrographic similarity to the Keweenawan diabases or their differentiates. They are here tentatively correlated with the Vermilion granite, and this is made the more probable by a similar satellite north of the granite, at Pooh Bah Lake, Ontario. (See northeasterly area in Fig. 6.) With almost identical field relations to the same granite, the rock at Pooh Bah Lake is even more alkalic—a malignite, as Lawson called it.[20] To some degree, also, the syenites of Snowbank and Kekequabic lakes may be considered similar satellites and suggest the generalization that alkalic differentiates are widely characteristic of Algomian granites in Minnesota.

Both of these alkalic syenites southwest of the batholith are characterized by a trachitoid structure based on lathlike alkalic feldspars with interstitial dark minerals. (See Plate X, B.) This structure trends a little north of east. The rocks are a purplish pink but certain phases weather nearly white.

The feldspar in the Linden syenite is a light purplish microcline-microperthite, and makes up about 80 per cent of the rock. The dark mineral is a green pyroxene in subhedral grains slightly elongated in the same direction as the feldspars. Quartz and titanite are present in smaller amounts.

The pyroxene, as the variable mineral of the rock, has been separated and tested. Its indices of refraction are, gamma $= 1.740 \pm 4$, beta $= 1.728 \pm 6$, and alpha $= 1.720 \pm 4$. Its optic angle is large. It has altered in places to pale brown biotite with low index of refraction,[21] and to

[20] Lawson, A. C., On malignite; Univ. of Calif., Dept. of Geol. Bull. 1, p. 343, 1896.

[21] Probably less than 15 per cent iron oxides in the biotite. See American Mineralogist, vol. 9, p. 163.

glaucophane. These characters have been seen in no other pyroxene in Minnesota, but somewhat resemble those of the augites of the porphyry at Kekequabic Lake and of the malignite of Pooh Bah Lake, in Ontario. An analysis (A) of this new pyroxene by the writer is given below, beside that of the Kekequabic mineral (B) by Dr. Grant. The material analysed may have had as much as 5 per cent of impurities, mostly titanite and the products mentioned as derived by alteration of the pyroxene. Its specific gravity is 3.361.

TABLE VII

Analyses of Pyroxenes from Minnesota Syenite

	A	B*		A	B
SiO_2	46.85	53.19	K_2O	.50	.38
Al_2O_3	2.50	2.38	H_2O+	.92	.01
Fe_2O_3	11.40	9.25	H_2O-	none	....
FeO	6.72	5.15	TiO_2	2.13	n. d.
MgO	8.17	9.43	MnO	.31	n. d.
CaO	17.85	17.81			
Na_2O	2.49	2.63		99.84	100.23

* Minn. Geol. and Nat. Hist. Survey Ann. Rept., vol. 21, p. 48, 1893.

The analysis (A) shows the pyroxene in the Linden syenite to be largely diopside with both acmite and hedenbergite in notable amounts. It contains soda enough to show the alkalic nature of the syenite as a whole.

The analysis of the Linden syenite is given as No. 17 of Table VIII. Its high potash content, 6.32 per cent, is noteworthy. This is greater than the potash content of average glauconite deposits and as great as some that have aroused interest as possible potash producers.

It is also noteworthy that these satellitic syenites are in several ways strikingly different from the early syenites of the border phase of the Vermilion granite. Possibly the alkalic syenites are late differentiates in contrast with the early, more hornblendic, syenites.

The processes of differentiation.—The rock series exhibited by the outcrops of the Vermilion batholith is shown in Figures 4 and 5. Some rock series in other parts of the world have similar compositions in their end members, as may be seen by the descriptions of the Isle of Skye, Nordingrå, Carrock Fell, Garabal Hill, and others.[22] None of these, however, are of batholithic proportions, and it is chiefly in the Cordilleran region of North America that Mesozoic batholiths have been well studied

[22] Grout, Frank F., A graphic study of igneous rock series: Bull. Geol. Soc. Am., vol. 33, pp. 617-38, 1922.

and found to grade from granite through diorite to gabbro.[23] The Vermilion mass then adds to the list of batholiths that give an indication of their primary magmatic nature, one of the pre-Cambrian masses of the Canadian shield.

TABLE VIII

Analyses of Phases of the Vermilion Batholith and Supposedly Related Rocks in Minnesota

	1	2	16	8	9	13	14	15	17
SiO_2	71.73	72.06	58.72	57.12	58.55	38.13	5.69	69.01	60.21
Al_2O_3	14.76	16.00	10.81	16.68	12.56	12.26	7.23	16.92	16.28
Fe_2O_3	.58	.46	12.84	1.96	1.72	8.86	46.92	.55	2.49
FeO	1.35	.72	6.80	4.60	5.05	11.68	27.87	1.43	1.62
MgO	.62	.97	.94	4.60	8.63	11.55	3.70	1.28	2.21
CaO	1.18	.86	.82	8.73	7.34	10.35	1.03	2.67	4.76
Na_2O	3.58	4.56	3.59	4.03	3.09	1.39	.28	4.59	3.78
K_2O	4.63	3.54	4.89	1.36	2.01	.43	.24	2.55	6.32
H_2O+	.64	.39	.34	.57	.50	2.36	1.17	.41	.10
H_2O-	.20	.05	.16	.01	.12	trace	....	trace	.19
CO_2	n. d.	.10	n. d.	trace	.00	trace	.26	n. d.	.47
TiO_2	.53	.12	.42	.29	.51	2.49	5.97	.23	.56
ZrO_2	.06	.03	.02	....	.03	trace	....	.04	.12
P_2O_5	.14	.09	.20	.33	.14	.19	.02	.11	.23
FeS_2	.06	.09	trace	.08	.04	.33	....	....	....
Cr_2O_3	.02	.02	none	.02	.09	.02	.03	.01	.01
MnO	.03	.06	.08	.14	.17	.30	.26	.03	.08
SrO	n. d.	none	none	....	.02	....	....	n. d.	n. d.
BaO	.14	.12	.07	.02	.08	.05	....	.03	.30
	100.25	100.24	100.70	100.54	100.65	100.39	101.44*	99.90†	99.76‡
Sp. G.	2.615	2.637	2.793	2.820	2.820	3.174	4.425	2.670	2.739

* Includes .49 V_2O_5; .12 S; .09 NiO; and .07 CoO.
† Includes .04 S.
‡ Includes .03 S.

1. Vermilion granite from northwest part of Sand Point Lake, Sec. 12, T. 68 N., R. 17 W.
2. Vermilion granite from southeast of Pelican Lake, T. 64 N., R. 19 W.
16. Magnetite pegmatite from the dump of a shaft in Sec. 3, T. 66 N., R. 17 W.
8. Syenite, abundant around Basswood Lake.
9. Border phase of granite, near shore of Vermilion Lake, Sec. 30, T. 63 N., R. 16 W.
13. Hornblendite north of High Lake.
14. Magnetite ore north of High Lake, J. H. McCarthy, analyst. Recalculated from "Total Fe = 55.39, Magnetic Fe = 49.28."
15. Biotitic phase of granite, that probably assimilated some biotite schist, Gun Lake, Sec. 14, T. 65 N., R. 12 W.
17. Syenite (possibly related to the granite), Linden township, Sec. 7, T. 62 N., R. 20 W.

Analyses by Frank F. Grout, except No. 14.

[23] Daly, R. A., Igneous rocks and their origin. Appendix B. McGraw Hill Book Co., 1914; Lindgren, Waldemar, See U. S. Geol. Survey Folios 29, 31, 39, 66, 129, etc.

Norms

	1	2	16	8	9	13	14	15	17
Quartz	29.40	28.32	16.80	3.60	5.88	....	....	24.24	4.08
Orthoclase ...	27.24	21.13	28.91	10.01	11.68	2.22	Kp.80±	15.57	37.25
Albite	30.39	38.77	28.30	34.06	26.20	8.38	....	38.77	31.96
Anorthite	5.28	3.61	....	22.24	14.73	26.13	5.28	12.51	8.90
Nephelite ...	....	....	....	....	....	1.99	1.40±	....	....
Corundum ...	1.94	3.26	....	....	....	....	4.59	1.94	....
Diopside	....	....	2.09	15.76	16.90	19.59	....	....	10.37
Hypersthene .	2.69	3.32	1.83	10.33	20.65	....	....	4.78	.70
Olivine	....	....	....	....	....	21.25	6.82	....	....
Acmite	....	....	1.85	....	....	....	......	....	....
Magnetite ...	.93	.70	17.63	3.02	2.55	12.99	68.22	.93	3.71
Ilmenite	.91	.15	.76	.61	.91	4.71	11.40	.46	1.06
Chromite	....	....	....	....	.91	....	....	....	....
Apatite	.34	.34	.34	.67	.34	.34	....	.34	.67
Zircon	.18	....	....	....	....	....	....	....	.18
Pyrite	.06	.09	....	.08	.04	.33	....	....	....
MgO	....	....	....	....	....	....	1.20	....	....
	Toscanose	Kallerudose	Grorudose	Andose	Camptonose	Auvergnose	Ore V.5.1.4	Toscanose	Monzonose

The primary magma of the Vermilion batholith may have been approximately basaltic in composition, but if so, no specimen collected represents that magma without a good deal of differentiation. The shonkinite (Basswood type) is probably closest to the composition of primitive basalt,[24] but it has so little alumina that lime is combined in hornblende, leaving the feldspars alkalic in character. On the other hand, the abundant syenite represented by rock No. 8 is half way on the course of differentiation to granite. The late stage of magmatic evolution suggested by the abundance of syenite, is also indicated by the moderate titanium content of the magnetite segregation—much lower than in common gabbro magnetites, but higher than in the late pegmatitic magnetites of this same magma. See page 48.

Whatever the primary magma may have been, the rocks formed here near the top and sides of the batholith do not range from peridotite and normal gabbro to granite as in the Cordilleran batholiths. They range from hornblendite and magnetite rock through shonkinite and syenite to granite, with only rare traces of moderately calcic feldspar. The main portion of the batholith now exposed clearly evolved from its primary composition to a magma of normal granitic nature.

[24] Daly, R. A., *op. cit.*, p. 315.

This evolution could not have resulted from syntexis, or melting, dissolving, and mixing with the invaded rock for the rocks available were not of suitable composition. This conclusion seems certain because there are now available analyses of all the main phases of the older rocks. When the magma reached the position where this evolution occurred, the Keewatin greenstone and the Knife Lake slate were the only abundant formations in its roof and walls; there were very subordinate amounts of Soudan iron-bearing formation, Ogishke conglomerate, and Laurentian intrusives. One of the two major formations, the greenstone, must have had a composition about like that of the primary magma of the batholith. It could therefore not cause much change. The other formation is the Knife Lake slate; and a study of its composition shows that no mixture of schist and basalt magma could produce a granitic composition. The evidence given above also indicates that assimilation of slate did not cause differentiation of the magma to produce a granite; the granite which has assimilated some schist is so modified that alkalies and silica are reduced and lime and magnesia increased. Clearly the schist has made the granite magma change in a direction toward basalt, rather than changing some other magma to granite. Note the location of point *G*, in Figure 5.

Since the change in the magma is not logically explained by assimilation or syntexis, differentiation during crystallization may be the most acceptable theory for its evolution. The several border phases then constitute a portion solidified at an early stage while differentiation was in progress.

The banded trachitoid condition of much of this early phase indicates some movement during crystallization. The nearly vertical position of the bands roughly parallel to the walls of the batholith, is also noteworthy. It can hardly be assumed that this portion of the batholith had a floor, on which layers of banded rock accumulated by settling, and that these were later tilted to vertical positions; for batholiths in other regions are not known to have such floors. It is much more reasonable to assume that the bands and wall of the magma chamber are still approximately in their original positions.

The question remains as to what kind of a movement produced the bands and fluxion structure. A batholithic mass, 30 by 80 miles across, stoping its way upward cannot be supposed to develop bands by movements of injection; it could not have been passing through this chamber as magma passes upward in a volcanic plug[25] though it may

[25] The vertical banding of Mt. Johnson in the Monteregian Hills is so explained by F. D. Adams, Jour. Geol., vol. 11, pp. 278-82.

have been stirred a little by the settling of stoped blocks. Neither can it be maintained that rhythmic earth movements after the mass was partly crystalline produced a "bridging" or filter pressing that would explain the banding.[26] It is much more likely that a gentle convection circulation was in progress.[27] Any mass of rock crystallized along the walls of a batholith during convection would be in vertical bands as here found, and would show variations in the mineral compositions of the bands, depending on the progress and conditions of cooling—in this case ranging from granite and syenite to shonkinite, hornblendite, and iron ore.

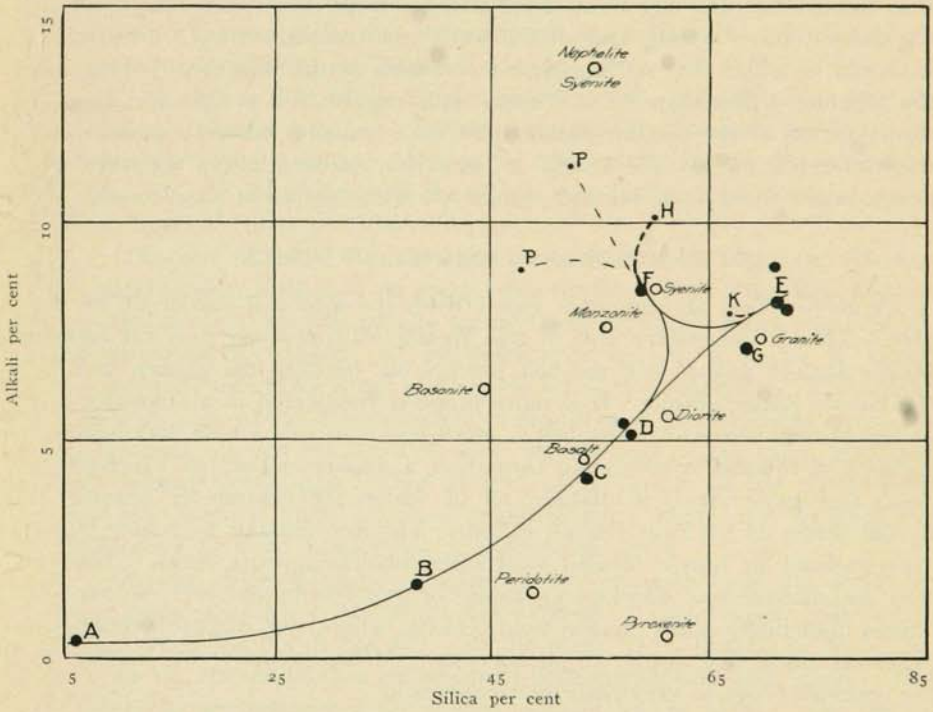


Fig. 5. A diagram of the rock series of the Vermilion batholith. The black spots show rocks analyzed; the circles show the average compositions of several standard rock families for comparison. The curve marks the general trend of the series; broken lines connect the rocks of the batholith with smaller spots representing satellites which are probably related. *A*, segregated ore; *B*, hornblendite; *C*, shonkinite; *D*, syenites; *E*, main granite of great extent; *F*, magnetite pegmatite; *G*, granite with assimilated schist; *H*, Linden syenite stock; *K*, Kekequabic granite stock; *P*, Pooh Bah malignite stock.

[26] Bowen, N. L., Crystallization-differentiation in igneous magmas: Jour. Geol., vol. 27, p. 411, 1919.

[27] Grout, Frank F., Internal structures of igneous rocks: Jour. Geol., vol. 26, pp. 439 and 458, 1918; and Two phase convection in igneous magmas: Jour. Geol., vol. 26, pp. 481-99, 1918.

Very little that is definite can be said about the evolution of the alkaline rocks in the five satellitic stocks scattered around the batholith. The location of the stocks about equally distant from the main mass, the development of a sodic pyroxene of about the same nature in three of them, and the occurrence in two of them of shonkinite (Basswood type) like that in the granite batholith, all suggest very strongly a consanguinity with the batholith.

It is noteworthy that while the alkaline bodies, according to theory[28] are marginal and satellitic, they are not light differentiates which occupy higher positions on account of low specific gravity. Nor is there evidence that the granite was any more deeply eroded than the stocks. None of the masses shows a roof, and all the walls seem nearly vertical. Finally it should be added that no limestone is available in the region, to explain the alkaline differentiate.[29] All these data suggest the probability that the evolution of the alkaline masses may be a primary feature related to the differentiation of the stocks as satellites, rather than a universal development which is accidentally preserved at the points of least erosion.

UPPER HURONIAN (ANIMIKIAN) SERIES

A narrow belt of Animikian rock crosses the southeast corner of the area. This is the eastern end of the Mesabi Range where it is cut off by the Duluth gabbro and the belt pinches out between the gabbro and the Giants Range granite. It is more properly considered in a discussion of the Mesabi district.[30] The belt is much less than half a mile wide and consists of Biwabik iron-bearing formation, a smaller amount of Virginia slate, and some intrusive diabase, all of which are profoundly altered by the action of the later Duluth gabbro. The iron-bearing formation is recrystallized to coarse banded quartz-amphibole-magnetite rocks. The slate and diabase have developed granular or granoblastic textures and are almost indistinguishable in the field, except where the diabase retains remnants of a few scattered phenocrysts. Microscopically, of course, the minerals prove to vary with the composition.

The generally low dip of Mesabi Range formations to the south, is here disturbed by the gabbro. Dips are high to the southeast, and at the northeast end the beds are broken and contorted.

[28] Bowen, N. L., Later stages in the evolution of igneous rocks: Jour. Geol., vol. 23, supplement, Nov.-Dec. 1915, p. 65.

[29] As suggested for most alkaline rocks by R. A. Daly; Origin of alkaline rocks: Bull. Geol. Soc. America, vol. 21, pp. 87-118, 1910.

[30] See Grout, Frank F. and Broderick, T. M., Magnetite deposits of the eastern Mesabi Range, Minnesota: Minn. Geol. Survey, Bull. 17, 1919.

KEWEENAWAN SERIES

The Duluth gabbro represents the Keweenawan in this area, but the sills in the Animikian sediments may belong to the same period, and there are numerous fresh basic dikes in other parts of the district which are probably Keweenawan. The Duluth gabbro extends both south and east from this area so far that the area shown is a very small portion of the formation. The gabbro in this area shows no unusual features. It is banded with slightly variable bands of olivine gabbro, troctolite, and normal gabbro. It has several inclusions of iron formation and slate, highly metamorphosed. Nevertheless the general impression of the series of outcrops is that of monotonous uniformity. No large or peculiar segregations are reported near this area.

The diabase sills in the Animikian rocks are definitely older than the gabbro, and some may be older than Keweenawan; no doubt the Keweenawan extrusives were accompanied by some intrusives of the same type. The sills are correlated with the Logan sills farther east, some of which can be shown to be pre-Keweenawan.

The few dikes of the trap rock which at various places cut Archean and Huronian rock need no special description. They are black, basaltic to diabasic and microscopically fresher than any other basic rocks in this area except the gabbro. At one outcrop in Sec. 26, T. 62 N., R. 14 W. a group of thin black dikes have glassy selvages of tachylite. This freshness of glass of pre-Cambrian age is rare even in the Keweenawan. The dikes and sills are too small to show on the scale of the maps, and have no special significance. They extend as far north as the north limits of the area, a good example being exposed along the international boundary between Sand Point and Namekan lakes.

Several ridges of gabbro southwest of Vermilion Lake are shown in the maps, but their relations are not exposed. Granite aplite cuts one in Sec. 36, T. 63 N., R. 20 W. On the other hand, in Sec. 9, T. 61 N., R. 20 W., the gabbro has inclusions of both granite and mica schist. This leaves the age relation of the gabbro more or less in doubt. Their petrographic resemblance to Keweenawan intrusives is the chief basis for classing them as Keweenawan.

CENOZOIC SYSTEM

PLEISTOCENE SERIES[1]

The northern portion of St. Louis County was probably glaciated early in Pleistocene time, and was deeply scoured by the "Rainy Lake lobe" of the Labrador ice moving from the northeast. Later the ice from the northwest moved in far enough to deposit drift from another region over the western boundary of the county. A large part of this deposit was reworked by the waters of a glacial lake which occupied the Red River Valley; this is known as Lake Agassiz.

[1] For details refer to Leverett, Frank, and Sardeson, F. W., Surface formations and agricultural conditions of northeastern Minnesota: Minnesota Geol. Survey Bull. 13, 1917.

GEOLOGIC STRUCTURES

The major structure of north St. Louis County is apparently determined by the two great Algomian batholithic masses, the Vermilion and Giants Range granites. These trend a little north of east, and may have followed some earlier structure in this direction, but there is relatively little evidence of any such previous structure.

Between the batholiths of the Algomian lies the Vermilion Range. North of the northern batholith is the similar trough of Rainy Lake. Both are closely folded with much of the rock in nearly vertical attitudes. Overturned folds are common and the present position of the bedding and schistosity must be noted in great detail in order to determine the structure. These two belts have been regarded as synclinoria, not because the formations rise definitely on either side but because the beds are closely folded and lie in troughs between two batholiths. If any of the Vermilion formations remained above the intruded granites, they must have been at high levels and have produced a syncline; but they may all have been stoped in without much elevation.

Several geologists, after observations made in reconnaissances across the granite area and north into the schists have suggested a major folding which may be related to the granite intrusion. In a broad way the schistosity changes its dip and strike from vertical to small northerly dips in passing from the northwest corner of the county to the south side of Saginaw Bay; and south of that it becomes steeply inclined to the south. The bedding at many places coincides with the schistosity, giving the appearance of an anticline of huge proportions. Similar changes may be seen near Crane Lake and elsewhere. The Vermilion River follows some conspicuous folds in the schist in the southeast part of T. 67 N., R. 17 W. (See frontispiece.) Most of the surroundings are granite, but the schist forms a large part of the river banks and its structure is that of a drag fold of large size modifying the general easterly strike.

The close folding, however, seen in nearly every outcrop makes the existence of these major folds uncertain until more detailed work can be done. Close observation at practically any outcrop along the south side of Rainy Lake shows that the bedding crosses the schistosity, and that in several cases stratigraphically higher beds dip under lower beds at places that were not discovered in the reconnaissance work mentioned.

A somewhat similar uncertainty exists as to the structural significance of the position of the schists on Sand Point Lake near T. 68 N., R. 17 W. Mica schists dip north on the north side of the lake; hornblende schists dip north on the south side of the lake, and the main jointing in the granite between dips north. These observations might suggest that the granite was intruded between schist roof and floor; but the contacts are not clear and the structure is more probably a remnant of some antecedent structure, for the schists show changes of dip in short distances, and elsewhere give no sign of such a mode of intrusion.

Thus it is seen that there are folds of several orders of magnitude. The major structure seems to be dominated by the batholith, but folds of a second order are mapped by a study of contacts of rocks of the different formations; a third order of folds is recognized by detailed study of bedding and schistosity; and there are finally the minute crenulations seen in even smaller outcrops.[1] (See Plate IV, B.) The bedding planes have not yet been mapped in detail over much of the area.

Faults are not conspicuous in the area, most of the deformation having occurred under conditions of rock flowage and recrystallization. Nevertheless the occurrence of some breccias and the appearance of slickensides and "gouge" along certain bluffs, indicate at least some displacement of later date. Possibly the movement was not great, as the rocks on the two sides do not appear to be different formations, where faults are suspected. One such "reibungs" breccia occurs on the south side of Shaft's Point in Outlet Bay of Vermilion Lake; another on the point northeast of Avis Island (or Hinsdale Island) in that lake. At certain places the south border of granite may mark a fault, especially where there is little contact effect.

Joints in the metamorphic rocks seem to be controlled largely by the schistosity, many joints following the structure and a few crossing nearly at right angles. At a few places joints follow bedding rather than schistosity; or both bedding and schistosity. (See Plate III, B.)

In general the schistosity which controls the joints strikes nearly east and west following the granite border, and the dips are steep. Locally, even in the midst of the granite area, the strike turns considerably to the northeast, and at a great many places the dip changes to low angles either to the north or south. It has not been practicable on the basis of the field work done so far, to show any broad structure on the basis of such areas in the midst of the granite.

The granite that followed the schistosity as it was intruded, has a few joints in the same system as that found in the schist. A noteworthy feature, probably related to some joints formed by cooling contraction, is a series of ladder veins of quartz crossing pegmatites and granite.[2]

[1] Minn. Geol. and Nat. Hist. Survey Final Rept., vol. 4, pp. 249-250, gives sketches of this crumpling.

[2] Grout, Frank F. Occurrences of ladder veins in Minnesota: Econ. Geol., vol. 18, pp. 494-505, 1923.

No regularity could be found in the joints of the main granite areas. Nearly all the prominent joints curved and joined other joints at variable angles. In the excellent exposures along Sand Point Lake a slight suggestion appears of a sheet-like jointing with a dip of 10° or 15° to the north. Even this is variable and is not seen in all outcrops.

Two major unconformities are well shown in the district, one representing the erosion after the Laurentian and another after the Algomian mountain-making periods. A third unconformity in the series, between the Animikian and the Keweenawan in this district is obscured by an intrusive contact.

The contact effects—orientation and recrystallization—extend several hundred feet from the granite intrusions, and with the prevailing dip spread over a belt nearly half a mile wide. These intense effects are oriented with the regional schistosity and cleavage which appear in all the rocks older than the granite.

SUMMARY OF GEOLOGICAL HISTORY

Without attempting to go back of the record in the rocks now found, the history of northern St. Louis County begins with a great outburst of volcanic flows and eruptions. At least a part of the lava was probably poured out below the sea, and another part was originally fragmental. Nearly all was of basic material. The basement on which these rocks were deposited is not seen because later batholithic invasion has stoped away earlier beds. The jaspilite of the Soudan iron-bearing formation was developed near the close of the period. Then occurred the batholithic invasion of magma yielding Laurentian granites. These undoubtedly deformed and metamorphosed the earlier rocks. There were both contact and regional metamorphic effects. Either at once or later the greenstones were left exposed to erosion.

During Lower-Middle Huronian time, the advancing sea found exposures of all the earlier rocks including the batholiths of Laurentian age, but the sea probably did not reach as far north as St. Louis County. The sediments seem to be delta and river deposits rather than marine sediments. Upon the Archean rocks there are immense conglomerates, graywackes, and slates alternating with pebbly beds.

In Algomian time there were intrusions of batholiths far greater than any others in this district. The Vermilion and Giants Range granites and related magmas intruded all the earlier rocks, deformed and recrystallized them, many almost beyond recognition. The elevation was great enough, so that the following period of erosion cut deeply into the batholiths and left the metamorphic older formations as synclinal remnants, in a fairly flat country.

Over the southeast corner of the area here mapped and extending an unknown distance into the area, there were deposited some Animikian sediments, including iron formation and slate. The history of these is given in more detail in studies of the Mesabi Range to the south. There was a period of erosion and a period of diabase sill intrusion before the final intrusive activity affecting this district. Then the great Duluth gabbro lopolith, probably in late middle Keweenawan time, spread into the district to an unknown distance, greatly altering the Animikian rocks at the southeast, but probably not greatly affecting the other formations except to tilt them a little to the south.

At the end of the Keweenawan period the district was again eroded and with minor episodes this continues to the present time. No further deposition is recorded except that of the glacial drift, much of which covers the southwest townships, and much of which is reworked by glacial lake waters.

ECONOMIC GEOLOGY

GENERAL STATEMENT

The area here mapped includes the productive ore bodies of the Vermilion iron-bearing range, and most of the smaller mines and prospects are within northern St. Louis County. No detailed study of recent developments on that range is given here, although a small amount of detailed mapping has been done. For most of the Vermilion iron range detailed maps are available in the atlas accompanying *Monograph* 45 of the United States Geological Survey.

Probably second in actual value of mineral production is the greenstone used for roofing. There are also prospects of asbestos, mica, gold, and potash rock, but none have shown great promise. Water powers in considerable number await development.

The immense value of the iron production in the Vermilion and Mesabi districts has no doubt been the reason for considerable interest manifested in a series of lean iron deposits. These have been investigated with care and the results are here compiled, but the prospect of finding ore of commercial value is not promising.

THE MAGNETITE PEGMATITES

INTRODUCTION

Beginning about 1905 considerable attention has been given and a good deal of money spent in exploration of magnetite prospects in northern St. Louis County. Companies have been organized, prospectuses have been printed with all the misleading suggestions common to certain mine promotion enterprises, and considerable work has actually been done by both shafts and diamond drill holes. Up to 1923 the inaccurate methods of sampling and caring for the material have made the results of little value. The statements here made as to the nature of the deposits are therefore based almost wholly on surface observations. Whatever information from the drilling and shaft sinking appears trustworthy, confirms the idea that the deposits underground are similar to those exposed. The location of the drill holes indicates that if any magnetite was found in the drilling, as rumored, it probably was the extension at depths of several hundred feet of the deposits seen in outcrop.

It is reported that on the strength of exposures of some magnetite pegmatite, the price of land has been raised from the usual \$5 or \$10 per acre, commonly asked for rocky land after timber has been cut, to \$500 or more per acre. Companies have purchased several hundred acres at such exaggerated prices. This has been done with very little evidence as to the quantity and quality of magnetite. It is to give such data as may be available that this section has been compiled. While it cannot be supposed that the parties of the Survey saw all the magnetite in the district, they visited and mapped all the properties of the main prospecting companies and many others, including all rumored deposits and many deposits which seemed to be unknown to prospectors and settlers.

GEOGRAPHIC OCCURRENCE

The magnetite pegmatites, shown in Figure 6, occur widely scattered over the northern part of the county and extend slightly beyond the county lines both east and west. The formation cannot be classed as an "iron range," in the topographic sense, nor in the sense that it is extended into a belt like most Lake Superior ranges.[1] The magnetite is found locally over almost the whole area of the Vermilion granite. Details regarding the prospects are given in the later descriptions of the area by townships. See especially the reports on T. 66 N., R. 17 W., and T. 68 N., R. 19 W. An easily accessible locality is the northern slope of the hill about 300 paces northeast of the south end of the railway siding at Kinmount, in T. 67 N., R. 20 W. A similar, but perhaps leaner outcrop occurs on the road between Orr and the "halfway house" at Buyck, near the northwest corner of Sec. 16, T. 65 N., R. 17 W. It is noteworthy that all the prospects lie 20 to 50 miles north of the producing ranges of the state, so that the freight-haul would be longer than for the ores now being produced.

GEOLOGICAL OCCURRENCE AND ASSOCIATED ROCKS

The occurrences of magnetite are so definitely restricted to the area of the Vermilion granite (see Fig. 6) and so widely scattered all over that area, that the genetic relation between the two is not to be doubted. Magnetite is found in a few places in the granite itself, but no conspicuous concentration occurs except in the pegmatites. No granite was found with more than 10 per cent magnetite, and only a few pounds of such rock could be seen. The pegmatites, though present in nearly every outcrop in the granite area, are much more abundant in the roof phases of the batholith, mixed with biotite schist, aplite, other schists, gneisses, etc. Magnetite is much more abundant in the mixtures of schist, granite, and pegmatite in about equal parts, than where either rock largely dominates.

Magnetite is a primary mineral in some of the pegmatites. It appears to have formed early in the series of minerals, but shows very imperfect crystal forms. Its most intimate associate is biotite; in some pegmatites

[1] The most active promoter of the prospects in recent years called his properties the "Namekan Range."

biotite is the only dark mineral, in others, magnetite, and in a few, magnetite is surrounded by biotite, all in apparently similar positions in the pegmatites. Where the pegmatite is coarse grained, the magnetite also shows coarse crystals, up to several inches across, and these coarse magnetite masses furnish specimens that readily arouse interest in the prospects of a mine. Most commonly there are variations in the richness of the pegmatite that seem to follow no law or regularity. One place has magnetite and another has none, and it has not been found possible to predict a foot ahead of actual exposure, where the magnetite will be found. No law has been discovered governing the occurrence of ore

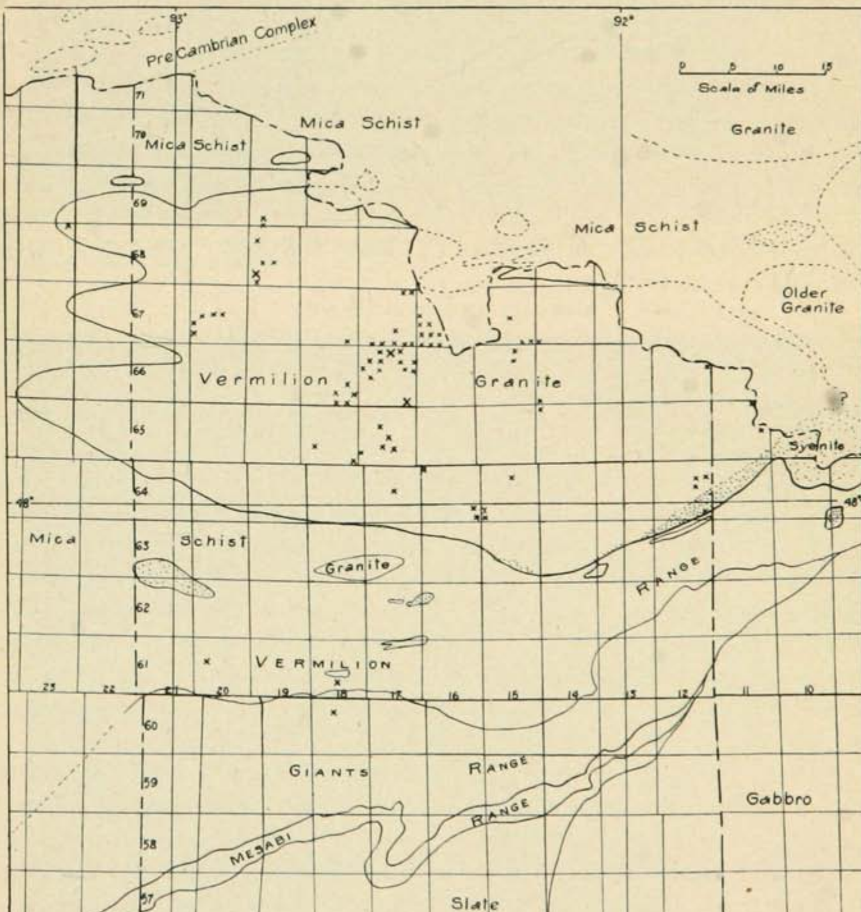


Fig. 6. Showing by crosses the occurrences of magnetite in and near the Vermilion batholith. Stippled areas are syenite. The magnetite of the Soudan iron-bearing formation is omitted. Details of the locations are shown in the outcrop maps of the individual townships. The area of the batholith coincides so closely to the area of magnetite that the genetic connection is certain.

which might be used in determining favorable or unfavorable conditions for an iron district or for good deposits in a known district, aside from the bare statement that the best ores are in late pegmatites related to the Vermilion granite. This erratic concentration of magnetite in the pegmatites, combined with the equally erratic occurrence and form of the pegmatite in its association of schist and granite, would make careful drilling imperative before making large investments in development of such a prospect.

Most of the magnetite-bearing pegmatites are pink in color from pink microcline, and most of them seem to be the latest phase of a complex igneous history; they cross all earlier structures and dikes, as commonly as they conform to them. The large white muscovite-bearing pegmatite dikes of Rainy and Kabetogama lakes have not shown any magnetite.

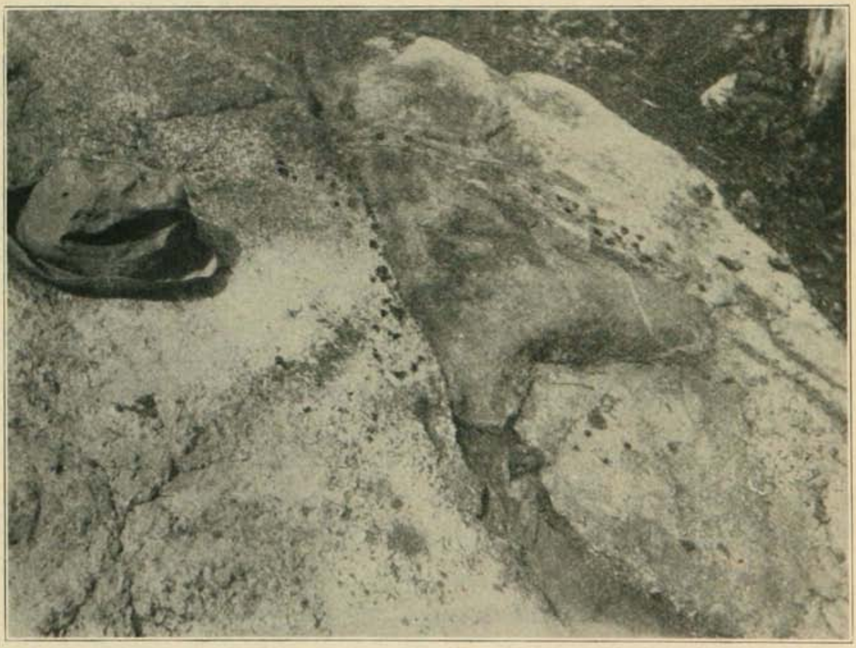
Magnetite has been seen in a few places, in special association. The gradation of pegmatite to quartz veins is common in the district and magnetite is present in a few small quartz masses that seem to be pegmatitic in origin. Again the common pink variety of pegmatite has both pink microcline and white albite feldspar, and the magnetite in a few places increases with an increase of white feldspar. (See also Plate XI, B.)

FORMS AND STRUCTURES

The magnetite deposits, considered in a large way as material that might be mined, are probably to be classed as "stock-works." (See Plate VII, A.) The magnetite is in a network of veins or dikes in shattered schist and granite, striking in all directions and curving in and out around numerous inclusions of the wall. Some dikes follow the schistose structure, but rather more of them cross the structure at high angles. Most of the ore-bearing dikes have not sharply defined walls, but grade along their length into lean pegmatite or granite. Many are so small and irregular that they are to be classed as stringers rather than dikes. The dikes in contact with schist have in places injected the schist *lit-par-lit,* but only rarely has any magnetite been seen in the schist or smaller injections. Some magnetite pegmatite occurs in segregations up to three feet in diameter in granite.

The network of dikes bearing magnetite is in a few places extended into a belt, constituting a roof phase of the granite, between more massive granite and the earlier schist. Such belts may extend more or less continuously for some miles. No such belt, however, is continuously exposed. The scattered outcrops at Kinmount and for a few miles east strongly suggest such a belt with schist on the south and granite on the north. Magnetite occurs in a belt about 100 paces wide.

A. Ladder veins of quartz crossing pegmatite dikes in biotite schist, near Buyck. The pegmatites contain some magnetite.



B. Magnetite concentrated in pegmatite near an inclusion of mica schist. In Section 4, T. 66 N., R. 17 W.

As a rule the magnetite occurs in the pegmatites as scattered grains among other minerals, without regularity (Plate XII, A and B). A number of pegmatite dikes show some banding of minerals, or differentiation; such as a band of quartz in the center and more feldspathic material at the sides; or bands of aplite alternating with pegmatite. These structures are more common in the older pegmatites than in the late ore-bearing pegmatites, but banding of constituents occurs in some of the ore also. When magnetite forms a band parallel to the sides of a dike or sheet, it has not apparently formed as a crustified banded vein; for no case of symmetrical banding by magnetite has been discovered. In a few cases magnetite grains are especially abundant in a pegmatite along the borders of a schist inclusion. (See Plate XI, B.) The aplitic dikes and phases of dikes have nowhere been found to contain more than 2 per cent magnetite.

CHARACTER OF THE MAGNETITE ROCK

The magnetite rock selected from any opening in the deposits is pinkish to greenish gray and shows coarse feldspar, quartz, and biotite intergrown with magnetite. Biotite seems to be best developed as crystal plates, but none of the minerals is characteristically euhedral. The feldspars are pink microcline and greenish albite or oligoclase which weathers white. Both are commonly present. Quartz is not abundant but can be seen in nearly every specimen. For general appearance see Plate XII, B. With such coarse material thin sections scarcely show more than a single grain. Laboratory separations with a hand magnet show 10 to 20 per cent magnetite in a number of selected specimens.

The pegmatite is too variable to afford wholly satisfactory samples for analysis. A general average of the magnetite-bearing rock from the dump of a deep shaft in Sec. 3, T. 66 N., R. 17 W., was analyzed by the writer, and found to contain 12.84 per cent ferric oxide and 6.80 per cent ferrous oxide. For a complete analysis, see Table VIII, page 48 which has also analyses of some related rocks.

A private report made by Charles Rees to Mr. Grenager of Duluth quotes the following analysis of selected magnetite grains from the same property.

	Per Cent
Iron	68.25
Sulphur	.055
Phosphorus	.025
Titanium	1.60

The concentration tests given below are also significant of the chemical nature of the ore. Since most of the iron is present in magnetite, only magnetic concentration has been attempted. In 1919, about 1,100 pounds of the best magnetite rock was sent from Sec. 3, T. 66 N., R. 17 W., to the Minnesota School of Mines Experiment Station for mill tests. The whole sample contained 35.80 per cent iron. Half a ton was magnetically concentrated at several stages of grinding.

One-inch feed

	Concentrates Per cent	Middlings Per cent	Tailings Per cent
By weight	47.58	25.50	26.92
Iron	60.91	24.32	2.30
Silica	9.96		
Phosphorus	.006		
Titanium	2.72		

Middlings crushed to ½ inch

	Concentrates Per cent	Middlings Per cent	Tailings Per cent
By weight	8.37	6.17	10.97
Iron	60.83	13.78	2.37

Middlings crushed to 4 mesh and 10 mesh gave small concentrates containing about 50 per cent iron. Without crushing finer than half-inch size, nearly all the iron gets into the concentrates.

Summary of Magnetic Separation Test

	Per Cent by Weight	Per Cent Iron	Per Cent Silica	Per Cent Phosphorus	Per Cent Titanium
Feed	100.00	35.80	....	....	....
Total concentrate	57.21	60.73	9.72	.010	2.61
Total tailings ...	42.79	2.48	....	....	....

The iron in the concentrate is high and phosphorus very low. The average of three good deposits shows .006 per cent phosphorus in the concentrate at 100 mesh. The titanium is not high enough to be objectionable, and the milling process could be managed without fine grinding, so that the concentrate would not need sintering.

Assays have also been made by the experiment station on many samples taken at other places in the district by the Survey parties. Sample 2367X contained 0.23 per cent titanium oxide; the concentrate derived from it had 0.35 per cent.

Survey No.	Location	Per Cent Soluble Iron	Per Cent Magnetic Iron[a]
2337A	Ash River	2.44	1.54
2367X	Kinmount (estimated average)	4.80	3.80
2381	Kinmount (selected)	10.80	9.60
2410	Sec. 29, Ash River (selected)	17.13	15.81
2369	Sec. 3, T. 66 N., R. 17 W. (ore dikes)	9.34	8.11
2370	Sec. 3, T. 66 N., R. 17 W. (gangue and walls)	4.55	.26

[a] Magnetic iron is the per cent of iron in form for magnetic recovery.

MAGNETISM

The ore in hand specimens affects the compass very notably. It was hoped for a time that the ore bodies could be found and traced underground by their effects on the dip needle and dial compass. After detailed work in several properties it was found that the effects are slight and erratic. (See Fig. 11, page 152.) The areas outlined show outcrops. In these areas, estimates were made of the per cent of "magnetic iron," [2] and the data plotted beside readings of dip needle and dial compass. While some abnormal dip and dial readings occur in the same forty acres with the ore, the richest outcrop did not always give the abnormal reading; and some abnormal readings were obtained on bare granite outcrops. The correlation is very rough, to say the least. No belt could be followed magnetically, to indicate an extension of this deposit underground.

SIZE AND QUALITY OF MAGNETITE PROSPECTS

Any discussion of the tonnage of such a deposit must be made with a clear understanding of the conditions just stated; briefly, the admixture of barren schist and an erratic concentration in an erratic rock. Nevertheless, with all these handicaps, the showing of magnetite has been sufficient in several places to stimulate extensive prospecting. The Survey parties have therefore taken a number of careful samples and made detailed maps of several areas. The geologists made estimates of the per cent of magnetite in the several outcrops, and their estimates were checked by assays.

The magnetite pegmatites are nowhere of large size. The largest of such dikes noted was not over 15 feet wide and could not be followed over 50 yards. Few are over 5 feet wide and most of them are very crooked (see Plate VI, B), winding in and out among inclusions. The mining of the pegmatite without handling the inclusions seems wholly impossible. The zones in which magnetite pegmatites are abundant may be a few hundred feet wide and several thousand feet long, but no such

[2] Per cent of iron in form for magnetic recovery.

belt has been well explored to prove its continuity. A series of such zones may cover an area of several townships, but the richer parts make a very small fraction of such an area.

It is easily possible in several places to pick out a few pounds of magnetite that will assay about 70 per cent iron. These masses are of course too small to be considered ore bodies. It is also possible to select from prospect holes, or with a small amount of blasting, samples of half a ton of ore which will assay 35 per cent iron. No exposure of 40 acres, however, with over 5 per cent iron has been sampled or seen by the Survey parties.

The most noteworthy areas are listed below, with the per cent of iron estimated from surface outcrops by men of long experience in magnetite ores—men whose estimates have been repeatedly checked by sampling. In some, separate estimates were made of the richness of the pegmatite and its amount in the outcrop. These also were checked by assays. These are the best estimates available at the present time, since the drill cores, used for promoting, have been made useless for accurate estimates of quality and quantity. The outcrops in the region are so numerous and geologic conditions are so uniform that further work would probably only confirm these estimates.

TABLE IX

Areas and Roughly Estimated Per Cent of "Magnetic Iron" of the Better Looking Exposures in Northern St. Louis County

Per Cent of Magnetic Iron[a]	Area in Acres	Location
10	10	NE¼ NE¼ Sec. 29, T. 68 N., R. 19 W.
5	40	NE¼ NE¼ Sec. 29, T. 68 N., R. 19 W.
5	10	NE¼ SW¼ Sec. 3, T. 66 N., R. 17 W.
5	10	N½ SW¼ Sec. 36, T. 66 N., R. 17 W.
5	20	SW¼ SE¼ Sec. 33, T. 67 N., R. 17 W.
5—	100	East-west belt through centers of Sec. 15, 16, 17, T. 67 N., R. 20 W.
4	40	SW¼ NW¼ Sec. 32, T. 68 N., R. 19 W. and NW¼ SW¼ Sec. 32, T. 68 N., R. 19 W.
4	20	E½ SE¼ Sec. 4, T. 66 N., R. 17 W.
3	20	SW¼ SE¼ Sec. 33, T. 67 N., R. 16 W.
3	10	N½ NE¼ Sec. 20, T. 66 N., R. 17 W.

[a] Iron in such mineral forms that it can be concentrated magnetically.

In general the profit to be made per ton in handling of low grade iron ore will be small. A study of operating costs of plants where iron ores are concentrated magnetically also shows that most of them could not operate profitably if they used the expensive methods of underground mining.[3] The search for ore in such a belt as this should therefore be directed first to the material within 200 or 300 feet of the surface. Deep drilling is wasteful. If the grade of some considerable body of ore is found to be much better than that of the whole belt, a careful calculation of costs should be undertaken before any further operations are justified. A difference of a few cents in the price of ore may change a profit into a loss in the case of these low grade ores.

THE PROBABLE EXTENT OF MAGNETITE BODIES WHERE CONCEALED

No prediction can be made ahead of actual exploration of the extent or form of such an ore body as a hill of schist, shot through with irregular dikes of magnetite pegmatite. Several of the areas, however, have a slight elongation in one direction, as if a belt or tabular mass was to be indicated. It may be suggested, where granite appears to dominate on one side and schist on the other side of the prospect, that the deposit is in a roof phase of the batholith; the schist representing a roof pendant. Such is the belt running east from Kinmount. The magnetite rock mixture in such a case might be expected to follow around the contact of the two. The suggestion, however, has not made it possible to find or trace any ore bodies. It is simply to be noted that most of the good magnetite is in a mixed rock; other mixed rocks with apparently as favorable conditions are wholly barren.

ORIGIN OF THE MAGNETITE BODIES

The first and most evident fact is that these magnetites are primary minerals of the pegmatites related to the Vermilion granite.[4]

Second, the granite itself has in several places some magnetite, showing that the magma was not an improbable source for the derivation of iron-bearing differentiates. See later township reports for T. 67 N., R. 17 W., and T. 67 N., R. 16 W.

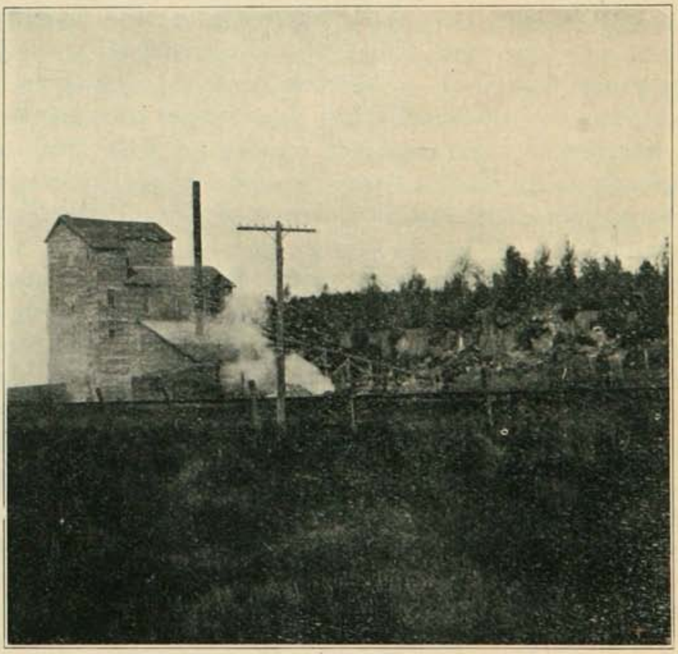
The third fact evident is that the magnetite-bearing pegmatites are most notably developed in a zone of fragments and inclusions between massive granite and large bodies of metamorphic rocks. It cannot be maintained, however, that the nature of the older rock of the fragments and roof of the batholith had any essential part in the origin of the ore. The pegmatites may be rich in one place and lean in another with similar schist in similar relations. And the magnetite concentrations are partly

[3] Davis, E. W. Magnetic concentration of iron ore: Minnesota School of Mines Experiment Station Bull. 9, p. 135, 1921.

[4] Winchell, H. V., once suggested that iron formations may have been included in material melted up to form the granite but the idea is no longer favored. See Geologic age of the Saganaga granite: Am. Jour. Sci., vol. 41, p. 390, 1891.

A. Magnetite pegmatite block.

B. Hand specimen of magnetite pegmatite about one third natural size.



C. Mill and quarry of the Emeralite Surfacing Products Company, three miles west of Ely.

in mica schist and partly in hornblendite areas, though the two rocks differ widely in their iron content—about 5 per cent in the mica schist, and about 10 per cent in the hornblendite. This is most clearly shown north of the falls of Ash River where an area of practically continuous (though very lean) magnetite rock covers perhaps 80 acres. The southwestern half shows mica schist with less than 5 per cent hornblende schist; the northeastern half shows, on the contrary, practically no rock but hornblende schist and magnetitic pegmatite. The magnetite in the pegmatite, therefore, seems to be a result of processes inherent in the granite and not of processes of assimilation of the country or roof rock.

This point may require further discussion. The similar pegmatitic magnetites of the eastern United States have been attributed to the iron of the silicates in the older rocks.[5] The arguments there used, however, do not apply to the Minnesota conditions. The altered basic rocks that form the walls of the ore in Clinton County, New York, have a good deal of magnetite and other iron-bearing minerals. In the mica schist, that is the most abundant wall rock of Minnesota ores, not one fifth of the mass has any magnetite whatever. A little pyrite is more common, but is not likely a source of ore. The granite of Minnesota also has much less magnetite than that in New York. The less abundant hornblende schists near these ores have rarely any magnetite and none have been found with over 5 per cent. The total iron contents of the several rocks may also be significant. The mica schist has an average content of about 5 per cent iron, the hornblende schist about 10 per cent, and the normal granite has hardly 1 per cent; in contrast to these, the magnetite-pegmatite may carry about 15 per cent iron and the basic segregations in the border phases of batholith over 50 per cent. See Table VIII, analysis 14.

Certain features of Minnesota rocks, however, do suggest a good deal of reaction between the igneous rock and its walls or roof. Most of the walls are biotite schist, about 30 per cent biotite; and it was noted in the description of the granite that where schist is abundant the granite seems unusually biotitic; biotite increasing from 2 per cent to 6 or 8 per cent, as if it had been absorbed and crystallized out again, becoming indistinguishable from primary biotite. The case is equally clear for the assimilation of some biotite in the pegmatites; the biotite, spalled off from inclusions of biotite schist, is recrystallized so thoroughly as to become indistinguishable from primary biotite in the pegmatite. Now the increase in biotite content by assimilation is evidence of the increase in iron content,

[5] Miller, W. J., Magnetic iron ores of Clinton County, New York: Econ. Geol., vol. 14, p. 509-35, 1919.

and might strongly suggest that magnetite was also a result of assimilation. The two minerals occur in similar relations to pegmatite—they even occur together in a number of cases. Two other facts, however, seem to be opposed to any such theory of the origin of the magnetite; the mica schists show hardly a trace of magnetite, and the alteration of the schist inclusions does not seem to have produced magnetite in any of them.

It is therefore believed that the iron was first concentrated from a granite low in iron, into the pegmatites by the segregation of those pegmatites; and locally concentrated in some of the late pegmatites (rather uniformly in all), near the upper phase of the batholith where the schistose roof was shattered and broken. The conditions which determined that magnetite developed in some pegmatites and not in others may have been accidental, but are so far unknown.

The degree of concentration may be judged from the analyses, showing about 2 per cent of iron oxides in the granite and 19.64 per cent in the selected ore. The titanium oxide shows no such concentration. The granite carries .29 per cent and the selected ore .42 per cent of titanium oxide.

COMPARISON WITH DISTRICTS HAVING SIMILAR ORES

Lyon Mountain, New York, produces magnetite from a series of pre-Cambrian pegmatite dikes, intruding gabbro and amphibolite. The normal granite of Lyon Mountain contains from one to three per cent magnetite, and the gabbro much more. Both are therefore richer in iron than the country rocks in St. Louis County, Minnesota. Relatively little concentration was necessary in the magma to make the Lyon Mountain ore. The magnetite pegmatites are mineralogically similar to those in Minnesota, but are larger and form much more continuous belts than have been discovered in Minnesota. Miller concludes[6] from the constant association that the pegmatites derived much of their iron from the gabbro and amphibolite. Colony and Newland consider the iron more directly magmatic, the assimilation not necessary.[7]

Magnetite ores in the Highlands of New Jersey are partly in pre-Cambrian pegmatite. Bayley concludes[8] that after the cooling of the granite (gneiss), which had little magnetite, a more ferruginous portion of the magma intruded the gneiss as magnetite pegmatite; and still later the iron-bearing solutions emanating from deep magmatic sources enriched the ore somewhat. In this later enrichment the New Jersey pegmatites

[6] Miller, W. J., Magnetic iron ores of Clinton County, New York: Econ. Geol., vol. 14, pp. 509-35, 1919. See also Econ. Geol. vol. 18, pp. 268-69, 1923.

[7] Colony, R. J., Magnetite iron deposits of southeast New York: N. Y. State Museum Bull. 249-50, pp. 69-73, 1923.

[8] Bayley, W. S., Iron mines and mining in New Jersey: New Jersey Geol. Survey, vol. 7, Final Rept., pp. 147-93, 1910.

seem to differ from those in Minnesota. No vein-like masses seem to cross the Minnesota ores except a few small sulphide veinlets. Much more of the New Jersey magnetite ore is outside the pegmatite in the country rocks than is in the pegmatite. In this respect no comparable deposits are found in Minnesota.

In North Carolina, pre-Cambrian magnetite pegmatites occur, which Bayley[9] finds closely similar to those in New Jersey. The main ore is a magnetite-hornblende rock with or without quartz and epidote; but this is crossed and in places enriched by dikes of pegmatite, magnetite pegmatite, and even pure magnetite.

Outside of the Appalachian Mountain region few magnetite deposits have been described as being so definitely related to pegmatite. Ball has described a deposit of lean iron ore closely resembling the Minnesota deposits, from the pegmatites of the Georgetown quadrangle, Colorado,[10] and Lovering has found such pegmatites near Cooke City, Montana.[11] Van Hise and Leith mention briefly, also, a deposit in the Atikokan district of the Lake Superior region[12] which seems pegmatitic, but consists largely of amphibole and magnetite, related to a diorite, thus differing greatly from the pegmatites here described.

THE SEGREGATED MAGNETITE

GENERAL SETTING

An earlier report[13] has briefly noted an iron prospect in the southwest quarter of the northwest quarter of Sec. 4, T. 63 N., R. 12 W., north of Ely, Minnesota. Several test pits were opened many years ago, but the ore was then supposed to be a phase of the Keewatin. Since the timber was cut a dense growth of brush has sprung up and the outcrop is not easily found. It is best reached from High Lake by following the sketch map, Figure 7.

The country rock for about a mile each way is banded and syenitic, the border phase of the Vermilion batholith. The general setting in the

9 Bayley, W. S., Magnetic ores of North Carolina—their origin: Econ. Geol., vol. 16, pp. 142-52, 1921.

10 Ball, S. H., General geology of the Georgetown quadrangle. In U. S. Geol. Survey, Prof. Paper 63, pp. 61-63, 1908.

11 Lovering, T. S., The New World Mining District, Montana; Thesis, University of Minnesota, 1924.

12 Van Hise, C. R., and Leith, C. K., Geology of the Lake Superior region: U. S. Geol. Survey, Mon. 52, p. 562, 1911.

13 Winchell, N. H., and H. V., Minn. Geol. and Nat. Hist. Survey Bull. 6, pp. 7-24, 1891. The magnetite rock is described as having "supposed igneous characters, but these are found sometimes to fade out, and a sedimentary lamination to supervene."

surrounding region is shown in Plate I. The Keewatin greenstone and its included iron formation are more than a mile away to the south. The Knife Lake slates occur in and near the areas of greenstone as synclinal belts. Igneous intrusive magmas have turned much of the slate to mica schist. Just south of the syenite in which the ore band occurs is a narrow belt of granite gneiss which is intruded by the syenite. Just north of the syenite is the great Vermilion granite batholith which in places intrudes the syenite. In other places the syenite seems to grade into the granite; and this, in connection with its position along the borders of the granite, makes it evident that the syenite is an early differentiate of the granite magma.

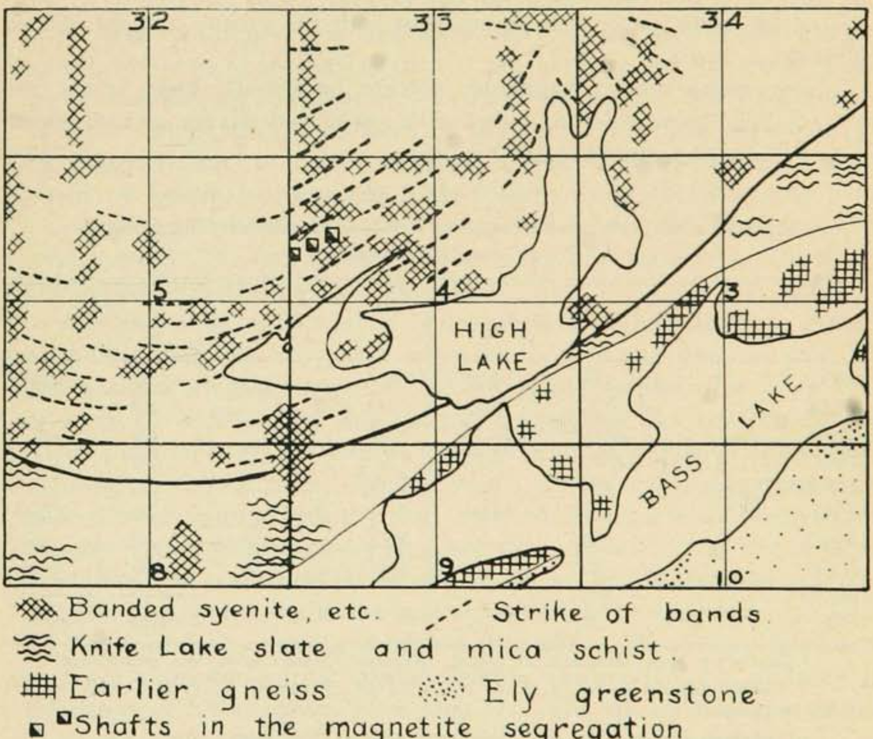


Fig. 7. Map of outcrops in and near Sec. 4, T. 63 N., R. 12 W., showing the test pits in segregated magnetite.

The largest development of syenite around the granite batholith is found on Basswood Lake, along the international boundary. A relatively narrow belt extends westward to High Lake, and intermittently for many miles farther west. Near High Lake the syenite is more banded, and has a greater proportion of dark minerals than in most places. The bands include some rare petrographic types such as the shonkinite (Basswood type). See page 40. Near the ore, several bands of the rock are especially rich in dark minerals, but those tested were found to contain less than 10 per cent magnetite. Most of the feldspar in the bands is orthoclase and oligoclase; but a few bands contain andesine and should be classed as diorite.

THE ORE

The band of ore is about 4 feet wide and has been traced by test pits for perhaps 100 yards. It is banded, like its wall rocks, with varying amounts of magnetite and silicates in the several bands. The elongated crystals are partly oriented in the direction of the bands. Both crystals and bands strike N. 60° E. and dip nearly 90°. In one test pit the ore is cut by aplite, such as is common in both the syenite and the related granite.

The ore consists of magnetite, ilmenite, hornblende, green spinel, and a very light brown biotite, with a little pyrite and allanite as accessories. (See Plate X, C and D.)

TABLE X

Analyses of Segregated Magnetite Bands in the Border Phase of the Vermilion Batholith

	1	2		1	2
SiO_2	5.69	10.90	TiO_2	5.97	none
Al_2O_3	7.23	5.83	CoO	.07	....
Fe_2O_3	46.92[a]	70.39	NiO	.09	....
FeO	27.87[a]	8.75	Cr_2O_3	.03	....
MgO	3.70	1.50	V_2O_5	.49	....
CaO	1.03	1.20	S	.12	.47
Na_2O	.28	....	P_2O_5	.02	.02+
K_2O	.24	....	MnO	.26	none
H_2O+	1.17	....			
CO_2	.26	....		101.44	99.06

[a] Total Fe = 55.39, Magnetic Fe, 49.28. Tabulated results have been recalculated.

1. Sample collected in Sec. 4, T. 63 N., R. 12 W., Minnesota, by F. F. Grout. Analyst, J. H. McCarthy.

2. Specimen obtained from Mr. Mallman. Analyst, J. A. Dodge.

Note should be made of the titanium content. This was not found in the older work, and its absence led to a suspicion that the ore was not strictly igneous.

The magnetite is partly, if not wholly of late crystallization. It surrounds, and in places cuts across, the silicates. Ilmenite is in subhedral grains of about the same size as the grains of magnetite—not intimately intergrown with the magnetite along crystallographic planes, as it commonly is in gabbro ores. The hornblende is of the common green variety, with a mean index of refraction about 1.672.[14] Biotite in the ore is very light colored and has an index of refraction gamma about 1.610. These features indicate that the iron of the magma was in some way concentrated into the magnetite leaving relatively little in the mica.[15] Green spinel is abundant only in a few of the richer ore bands. The composition of the ore is approximately shown by the analysis in Table X, made for the Survey by the Minnesota School of Mines Experiment Station. An older analysis on material of less certain origin is added for comparison.

ORIGIN OF THE ORE

It is believed that the bands of magnetite 5 miles north of Ely are not of pegmatitic origin because the pegmatites of the same batholith have some non-titaniferous magnetite deposits, of very different character from these. (See pages 64 to 70.) Furthermore, hydrothermal effects are not conspicuous and some of the richest ore is associated with igneous minerals with practically no signs of alteration. The field occurrence of the magnetite band in banded syenite is almost conclusive evidence of its origin by igneous segregation. The occurrence of the magnetite band where most of the other bands are especially dark and ferruginous, is confirmatory. The process by which it segregated and attained its present vertical position still requires discussion.

The degree of concentration is noteworthy. While the main granite of the batholith has only about 2 per cent of iron, the ore was probably segregated at an early stage represented by the syenite with 5 per cent or more of iron. From this magma, segregation has produced bands which show 20 to 65 per cent of magnetic iron, as estimated from measurements of thin sections. Evidently at a certain stage, magnetite crystallized much more abundantly than it did before or after. The evidence appears in the thin sections, showing that magnetite was not first to crystallize, and in the field occurrence of the ore which lies between layers of other rock types—not at the base or border of the igneous rock.

The trachitoid texture and banded structure of the ore are conclusive evidence of motion during crystallization. The motion was probably in the nature of a convection. (See page 51.) The ore crystals accumulated along the cooling wall of the batholith at the particular time when conditions especially favored the formation of magnetite in the circulating magma.

[14] Winchell, A. N., Studies in the amphibole group: Am. Jour. Sci., vol. 7, pp. 287-310, 1924.

[15] Grout, Frank F., Notes on biotite: Amer. Mineralogist, vol. 9, pp. 159-65, 1924.

Several other districts are known to have magnetite deposits in banded syenite, so that this theory of origin is not at all unique. The magnetites of Lapland in northern Sweden, at Gellivare and Kiruna are associated with syenites. Some of those in New York and New Jersey may also be in this class.

ECONOMIC FEATURES

The ore body now known is too small to be of much interest, and the exploration conducted years ago probably proved that no greater volume is to be expected here. Other bands of the same sort, however, may exist in the region. Rumors have come to the Survey of some iron ore in sections 33 and 34, T. 64 N., R. 12 W., north of this deposit; but no ore has been seen there by Survey parties. Some dark bands of pyroxenite are known to cross the area and there may be others.

The magnetism of the ore makes it possible to concentrate even the leaner portions to a rich product. The injurious impurities are easily removed in the process, chiefly because ilmenite is in coarse grains. The magnetite grains, however, range about 0.5 mm. in diameter, with some rather smaller, so that fine grinding would be necessary for a high recovery. A test made by the Minnesota School of Mines Experiment Station, using a magnetic washer, and ore ground to 100 mesh, gave 71.6 per cent of concentrate, which contained 68.83 per cent iron, .92 per cent titanium oxide, and .010 per cent phosphorus.

The search for tonnage, then, is the first step in any further consideration of these ores. This search, if attempted, should be directed to the area of the syenite of Basswood Lake and other such syenites near the Vermilion granite.[16]

THE VERMILION IRON-BEARING DISTRICT

GENERAL STATEMENT

The Vermilion district has been treated in the Final Reports of the State Survey and in monographic reports of the United States Geological Survey. No attempt has been made to review that work in detail. A few notes are here given as additions to mapping and records of recent activities on the range. The ores are a part of the Soudan formation of the Archean, and are commonly folded into areas of Ely greenstone. "It is significant that notwithstanding the enormous sums of money spent in exploration of the district, no ore deposit of magnitude has been developed outside of the two principal series of deposits at Tower and Ely which

[16] Not to the greenstone and other *inclusions* in the granite, as suggested by Winchell. Minn. Geol. and Nat. Hist. Survey Bull. 6, p. 24, 1891.

were the first discoveries in the district."[17] The explorations in Sec. 30, T. 63 N., R. 11 W., just east of the county here mapped, resulted in the development of some small bodies of ore which have been mined and shipped. There are also two or three incomplete explorations, which may result in a certain production of ore, but none which promise large results in comparison with those already mentioned. Drilling and underground workings have been undertaken in recent years, at Armstrong Bay, at Robinson, and east of Rice Bay on Vermilion Lake.

The monographic treatment of the Vermilion Range[18] was not extended west of Vermilion Lake, but it is well known that the Ely greenstone and Soudan formation are widely distributed under the drift, with a few outcrops west of St. Louis County. Some magnetic lines mapped in Plate I of Monograph 52 of the United States Geological Survey are known to be caused by Soudan formation. Most of the area from Vermilion Lake to the west side of the county, however, is not promising as an area for prospecting.

The large ore bodies that are the foundation of activity in the Vermilion district are those at Soudan and at Ely. Nearly a million tons were shipped from the Vermilion Range in 1924, mostly of bessemer grade. There has been little tendency to conduct exploration, however, because the prices of iron ore were low.

The Soudan mine in 1924 was improved by concrete work and electric equipment, using newly developed power from a dam at Fall Lake. The mine is opened to the twentieth level at 1650 feet.

The group of mines at Ely, the Pioneer-Chandler, the Zenith, and the Sibley, were all working in 1924 at depths around 1100 feet. A branch ore body discovered in relatively recent work has been followed back up within 200 feet of the surface.

The Armstrong Bay prospect, (the La Rue mine), in Secs. 7 and 8, T. 62 N., R. 14 W. has a railroad, and the development work includes two adits into the hill. The ore includes a hard hematite and a soft brecciated type, both of which have been stock piled. The wall rocks seem to be intrusive porphyry, at least on the south side.

At the principal mines considerable progress has been made in the understanding of the structure and relations of the ore bodies. The Oliver Iron Mining Company has had its staff of geologists and engineers at work on the detailed geology, both at Soudan Hill and at the Ely trough. Dr. C. K. Leith has been directing some exploration also at Ely. At the Zenith mine the wall rock north of the ore seems to be

[17] Van Hise, C. R., Leith, C. K., and Mead, W. J., Geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, p. 137, 1911.

[18] Clements, J. M., The Vermilion iron-bearing district: U. S. Geol. Survey Mon. 45, 1903.

different from that on the south which is more normal greenstone. These several studies are yet incomplete, but a most important feature has been the realization that intrusive porphyries, later than the Soudan formation, cut the rocks and ores at a much larger number of places than was formerly supposed. Two samples taken by the Survey parties from the eighth level of the North Chandler mine have the microscopic character of later intrusives rather than those of the Ely greenstone.

"The iron ore formation or jasper is found in pitching synclines and anticlines, or in steeply dipping lenses, having greenstone foot wall and in many places apparently overlaid by greenstone also. Both jasper and greenstone are intruded most irregularly and intricately by basic igneous rocks, chiefly porphyries. During the past year, considerable geologic knowledge has been added to that previously assembled regarding Vermilion orebodies, particularly in recognizing great quantities of intrusives in both Ely and Soudan mine areas and in interpreting accurately the structure of these orebodies This additional information is of much importance in estimating ore tonnages.

"No fixed practice is followed in estimating probable ore except that 100 feet vertically below a bottom level is the maximum depth to which ore is assumed to extend. This limit is warranted because of the presence of large quantities of igneous intrusive rocks in both Ely and Soudan orebodies and the uncertainty as to where the orebodies may be cut off entirely in depth by these intrusives.

"The Soudan ore is very hard, dense and high grade and 10 cubic feet per long ton is used in estimating it. Some of the Ely ore along the foot wall is hard and dense but much of the orebody is relatively soft and some is even granular and fine; 12 cubic feet per long ton is used for it. The Ely orebody lies in a syncline, of which one limb extends eastward between greenstone foot and hanging walls. The orebody in the synclinal area occurs at the base of the jasper on the greenstone foot wall. At one place practically the entire width of the syncline is ore. The bottom part of the eastward extension of this jasper syncline is ore, having greenstone on either side of it. Ore is developed in the Ely trough to a vertical depth of 1460 feet.

"The Soudan mine is in a combined anticlinal and synclinal area cut by many intrusives so as to form pitching troughs in the jasper. The ore has been localized by leaching and concentration of the jasper in these troughs."[19]

The detailed work done by the state and federal surveys on the Vermilion made it clear that all the ore bodies were to be expected in close association with Ely greenstone.[20] It was therefore a natural tendency in the first work done, to class several formations as greenstone if there was any doubt of their nature. This left the doubtful area still a subject for prospecting; and it was desirable to have it so until the deposits were all discovered. Detailed work shows not only that some of the green

[19] Wolff, J. F., Derby, E. L., and Cole, W. A. Sampling and estimating Lake Superior iron ores: Mining and Metallurgy, Sept. 1922, pp. 43-44.

[20] Minn. Geol. and Nat. Hist. Survey. Final Rept., vol. 4, p. 547.

rocks are intrusives, but also that some are greenish phases of later sediments. Few such areas have been found, however, and none require special mention.

While the main ore of the Vermilion Range is said to be hard ore, there is a variety in its hardness, and different bodies evidently have had different histories. Ores enriched by leaching of the jaspilite of the Soudan formation may be, at first, soft hematite. This may be hardened by recrystallization under pressure, or by cementation. Some specimens show hematite, and a few show siderite, as the cement; but rather more are hard blue hematite which probably resulted from recrystallization. Any of these hard ores may be later brecciated, and again more or less cemented. Much of the ore now found has had this complex history of brecciation. On the other hand, close beside some hard ores of this sort there are in places soft hematites that seem to be a result of leaching at a more recent geological period. A certain amount of so-called soft ore is hard ore breccia with a soft clay like cement, instead of the usual hematite or quartz cement of hard ore.

MAGNETITE BODIES IN THE SOUDAN FORMATION

The published descriptions of the Soudan formation list the black banded variety as one of six modifications, giving it no special prominence, but noting that in this variety the iron oxide is commonly in large part magnetite.[21] In discussions of the ores, the jaspers are said to alternate with layers of hematite, but to contain magnetite in places.[22] It is therefore of some importance to note that there is a high proportion of gray magnetite-bearing rock in the Soudan formation as a whole. These black banded rocks are, for the most part, too lean to be shipping ore. The deposits furthermore, are practically all steeply tilted in contrast with the gently dipping widely exposed beds of the Mesabi Range. While some of the maps of the Vermilion Range may show belts of Soudan formation of fair width and great length, these have been generalized from detailed maps; as a matter of fact the Soudan formation outcrops in patches and stringers along the belts and does not constitute the whole of any extensive belt yet mapped.

The quality of the black banded Soudan formation is shown by the following tests made at the Minnesota School of Mines Experiment Station. The generally low grade of the concentrate is noteworthy. See column 3.

[21] Van Hise and Leith, *op. cit.*, p. 125.
[22] *Ibid.*, p. 140.

TABLE XI

Concentration Tests on Samples of Soudan Iron-Bearing Formation

Sample No.	Crude Ore Per Cent Sol. Iron	Tube Conc. Per Cent Sol. Iron	Tube Tails Per Cent Sol. Iron	Tube Conc. Per Cent Recovery	Crude Ore Per Cent Mag. Iron
2345	18.30	52.54	3.28	30.49	16.02
2346	29.13	58.79	5.19	44.66	26.26
2348	16.47	44.07	2.75	33.20	14.63
2800	35.84	59.63	3.13	57.89	34.52
2801	16.01	36.30	3.51	38.12	13.84
2803	17.92	35.53	2.75	46.28	16.44
2805	18.00	57.19	2.90	27.81	15.90
2806	23.87	52.54	2.82	42.33	22.24
2807	27.53	60.85	5.41	39.90	24.28
2808	23.49	56.58	5.49	35.23	19.93
2809	7.63	24.55	4.76	14.50	3.56
2810	15.63	41.02	6.79	25.82	10.59
2811	28.67	55.51	25.52	10.50	5.83
2848	17.61	54.90	3.66	27.22	14.94
2849	15.56	45.14	5.72	24.96	11.27
2850	28.21	67.02	8.92	33.20	22.25

The per cent of magnetic iron may be high enough in certain masses of Soudan formation to make them almost equal to the magnetite ores on the eastern Mesabi Range. The low grade of concentrate, however, and the relatively small bodies of ore near the surface make it unlikely that they will soon be developed. It is possible that the fine grinding needed on the eastern Mesabi ores for full recovery, would not be needed on the Vermilion magnetites. Some of the ore bands are almost free from gangue minerals.

MAGNETIC SURVEYS

The important Vermilion ore deposits were discovered through more or less conspicuous surface exposures, but the detailed mapping of the range has been greatly facilitated by the fact that most of the Soudan formation affects the dip needle and dial compass. Having by means of the magnetic effects located the formation, the explorer finds little value in the dip needle or dial in deciding where the ore is good. Dip needle and dial work were plotted by the United States Geological Survey in connection with *Monograph* 45, over a large part of the range, and some magnetic lines west of St. Louis County, related to similar Vermilion formations are shown in the map of the Lake Superior region accompanying *Monograph* 52. Little information has been available between the east end of Vermilion Lake and the west side of the county. Several surveys have been made by private companies but the results are so largely negative that none seem to have been considered worthy of publication. A few are shown in the township reports, following, but the published records of work in the *Atlas of the United States Survey Monograph* 45 are not reprinted. Some of the details of the present survey are shown in the sketches accompanying the reports on T. 63 N., R. 15 W.; 61 N., R. 18 W.; T. 61 N., R. 19 W.; and T. 62 N., R. 18 W.

The outcrops near the magnetic areas west of Vermilion Lake are not such as to lead one to expect iron-bearing formation. There are mica schist, greenstone, and intrusions of granite, gabbro, and so forth. No iron formation has been seen, though it may possibly be present under the drift. It was found that magnetic attraction was in some cases due to other rocks besides iron formation. The dip needle is deflected at or near some surface exposures of greenstone. The contacts of intrusives also develop magnetic belts. Such an effect is suspected in the long belt from Sec. 21 to Sec. 31 in T. 61 N., R. 18 W., where the granite lies south and the mica schist north of the belt. No iron ore bearing rocks are to be expected, but since no rocks outcrop in the belt itself the occurrence of Soudan formation is not impossible. A rather remarkable area of magnetic attraction is almost coincident with a series of outcrops of syenite in T. 62 and 63 N., R. 21 W. It is clear that the syenite or its contact belt produces the attraction, though the adjoining formation is Ely greenstone, in which belts of Soudan formation are entirely possible.

OTHER IRON DEPOSITS

In a region so close to the Mesabi Range it is natural that any appearance of iron minerals should arouse interest. The attention of the Survey parties has been called to a considerable number of less promising deposits.

Limonite (bog ore) deposits along streams and near springs are numerous in the county. None have been found to be extensive. Since most of the waters near these deposits are sulphate waters, it is thought that they result from decomposition of sulphides of iron rather than from oxides which might prove to be ore. The presence of yellow iron oxides then seems to be without economic significance in the district.

The east end of the Mesabi Range, where the ore is magnetic extends into the corner of the area here mapped, but in that corner the magnetite beds are thin, irregular, and steeply tilted. They have been discussed in a report on the area to the south.[23]

[23] Grout, Frank F., and Broderick, T. M., The magnetite deposits of the eastern Mesabi Range, Minnesota: Minn. Geol. Survey Bull. 17, 1919.

The Duluth gabbro which intrudes the older rocks at the southeast also contains some magnetite, the titaniferous variety for the most part. No segregations of importance occur in this part of the gabbro.

The Agawa iron-bearing formation has not been found to contain beds of commercial grade and quantity anywhere in Minnesota. The most conspicuous exposures in northern St. Louis County are those east of Rice Bay of Vermilion Lake, Sec. 36, T. 63 N., R. 15 W. The carbonate rock which outcrops in Sec. 3, T. 62 N., R. 18 W., east of Cook may also be Agawa formation, but it contains little iron.

GREENSTONE PRODUCTION

In connection with the paper industries of Minnesota, considerable quantities of tar paper are made, and the tar and paper workers also make roofing papers and artificial shingles that have a mineral surface and an appearance like slate. For some time they shipped green slate refuse to Minnesota from quarries in the Appalachian region. In 1921, on the advice of the Minnesota Geological Survey, a quarry was opened near Ely in the slate phases of greenstone, thus reducing the freight charges, the haul being several hundred miles shorter. The stone is crushed between 10- and 20-mesh and screened in a mill at the quarry and shipped to roofing manufacturers at several places. It proves entirely satisfactory.

The disposal of the screenings that pass 20-mesh screens, constituting about 35 per cent of the rock quarried, make a considerable item of expense. The slate quarries in the east have a similar waste, and have developed a market for some of the fines, as filler in paint, hard rubber, oilcloth, window shades, linoleum backing, etc. Experimental work along such lines might be profitable here. Possibly some machinery for very fine grinding might turn the waste into a valuable product.[24]

The rock of the property where the quarry is located is largely a porphyritic variety of greenstone, probably intrusive. In the work of development in 1922, a shear zone was encountered which did not mill satisfactorily. It gave too large a proportion of fine dust and was of undesirable color. It has been possible to get through this zone, however, and probably few such difficulties need be expected. The supply is unlimited.

In the season of 1921 the quarry and mill were opened and tried out. The mill had a capacity of 80 to 90 tons a day. (See Plate XII, C.) In 1922 about 4,000 tons were shipped. In 1923 two shifts were working at the mill. In 1924 the mill was enlarged and its capacity nearly doubled. The industry seems likely to be permanent and profitable.

[24] Bowles, Oliver, The technology of slate: U. S. Bur. of Mines Bull. 218, pp. 81-94, 1922.

MISCELLANEOUS MINERAL RESOURCES

ASBESTOS

Asbestos veins are known in a few places in the Ely greenstone. Much of the greenstone originally contained olivine and other magnesian minerals. The alteration which changed them to asbestos is probably related to some later intrusive igneous rocks, which are found near the asbestos deposits. Since the mineral is soft and the greenstone as a whole is resistant to weathering, the asbestos can scarcely be expected in outcrops. It is known chiefly from some drilling west of Cook, in Sec. 11, T. 62 N., R. 20 W., as reported by Mr. Ike Goodwill at Vermilion Lake. The drill cores show seams of asbestos up to half an inch in width, in rock at depths which he stated to be 450 to 680 feet.

MICA

Muscovite mica has been reported from northern St. Louis County and Koochiching County since 1887.[25] Each reference suggests that the pegmatite dikes, which commonly have muscovite sheets up to 3 inches in diameter, may somewhere have larger sheets of good quality. They recommend prospecting. Nevertheless through all these years, no one has discovered any coarser good mica, though most of the county has been cleared by logging operations and visited by many geologists and prospectors. The desirability of further work is reduced by the fact that the quality of the muscovite is imperfect. One of the largest slabs seen by the parties of the survey was submitted to the mica expert of the United States Bureau of Mines, Dr. Oliver Bowles, who reported:

> The larger piece is found to contain many minute folds or plications running in different directions. This would be termed an "A" mica, and could be used for nothing but scrap for grinding.

It seems likely that regional movements have occurred since the crystallization of the pegmatite mica and since some of the sheets are folded, there would be difficulty in locating any sheets free from this defect.

GOLD

Gold veins have been prospected at a large number of points in St. Louis and adjoining counties. The only production of gold came from the Little American mine a few miles west of the county line. This was in a quartz vein, bearing pyrite, tourmaline and ankerite, in green schists of Huronian age. The geologic setting of several other prospects seems

[25] Lawson, A. C. Geology of the Rainy Lake region: Geol. and Nat. Hist. Survey of Canada. Annual Report vol. 3 for 1887. Part F, p. 181, 1888.

Grant, U. S. and Winchell, H. V. The Rainy Lake gold region: Minn. Geol. and Nat. Hist. Survey, Ann. Rept. vol. 23, p. 93. 1895.

to be favorable—near the wall, and in roof pendants of a granite batholith—but so far none of the prospects in St. Louis County has proved profitable. Several have about the same minerals as the formerly productive Little American mine, but assays of the material show little gold and less silver.

In addition to the prospects in quartz veins, reports of gold have come from some mineralized green schist and even from the acid porphyry intrusive into greenstone. Assays made for the Survey on average samples from the test pits, by the Minnesota School of Mines Experiment Station show no gold, silver, or copper.

POTASH ROCK

Most of the igneous rock of the county has some three or four per cent of potash, but the mass in Linden township has in places over six per cent. See analysis, p. 48. This is more than is found in the average glauconite deposit and as much as appears in some rocks which have been tested for the commercial production of potash. The town plats herewith show outcrops in Secs. 7 and 18, T. 62 N., R. 20 W.; Sec. 3, T. 62 N., R. 21 W.; and Secs. 30 and 34, T. 63 N., R. 21 W. These are almost certainly parts of a continuous mass. On the south side of Section 7, is a high hill in which the syenite is available in easily accessible places for quarrying on a large scale. The outcrops in Section 34 are also high and easily quarried.

In comparison with the Leucite Hills of Wyoming, the Linden syenite has only seven tenths as much potash per ton; but the tonnage is probably greater (by similar methods of estimation)[26]; the mass is continuous rather than scattered; the location is closer to markets; and the conditions for mining must be fully as good as in Wyoming. The commercial extraction of potash from such a silicate rock is, however, a problem yet to be solved.

WATER POWER

The State Drainage Commission report undeveloped water powers at several points on the Vermilion River and along the boundaries of Canada. There are also considerable falls in Ash River, and Little Fork River, though the volume of water is much less. About 10,000 horse power is available at low water, estimating 80 per cent efficiency.

[26] Schultz, A. R., and Cross, Whitman, in U. S. Geol. Survey Bull. 512, estimate the available potash in the Leucite Hills, assuming that a neck or plug could be mined to a depth of 3,000 feet. The Linden syenite probably extends down 3,000 feet, and the total potash to that depth would be ten times as much as in the Leucite Hills.

Undeveloped Horse Power in Northern St. Louis County, Minn.[a]

Site	Head in Feet	Minimum Runoff Lowest Month in Cubic Feet per Second	Horse Power (80 Per Cent Efficiency) Lowest Month
Between Basswood and Crooked Lakes (boundary water)	53	650	3,130
Between Crooked and Iron Lakes (boundary water)	29	720	1,900
Between Iron and Lac La Croix Lakes (boundary water)	34	733	2,270
At inlet of White Iron Lake	20	no estimates	no estimates
Vermilion Lake	37	95	320
Chain Lakes on Vermilion River	90	93	761
Rice beds on Vermilion River	45	265[b]	1,084[b]
Crane Lake inlet	55	101	505
Ash River Falls	..	no estimates	no estimates

[a] Notes from report of water resources investigation of Minnesota 1911-12, by the State Drainage Commission (1912), pp. 458, 466, and 475.

[b] These figures refer to regulated rather than minimum flow.

GEOLOGY BY TOWNSHIPS

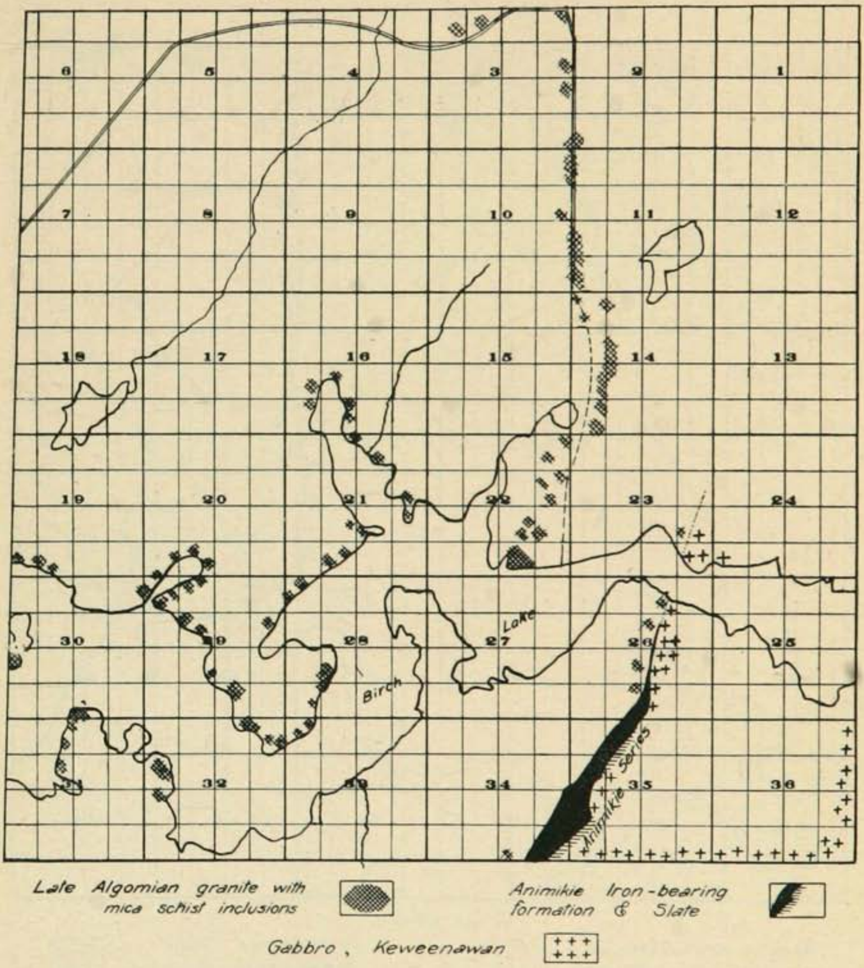
The remainder of this report is a description of the geology of the townships mapped. As a rule the maps show only the outcrops visited by the parties of surveys. Some magnetic surveys have been made and special maps are added in cases of considerable deflection of the dip needle from the normal.

In making the town plats, minor correction lines on the west and north sides of the towns have been disregarded, but the larger modifications are shown.

The townships described are the same as those shown in the geologic map, Plate I.

TOWNSHIP 61 NORTH, RANGE 12 WEST

Geology by F. F. Grout and G. M. Schwartz

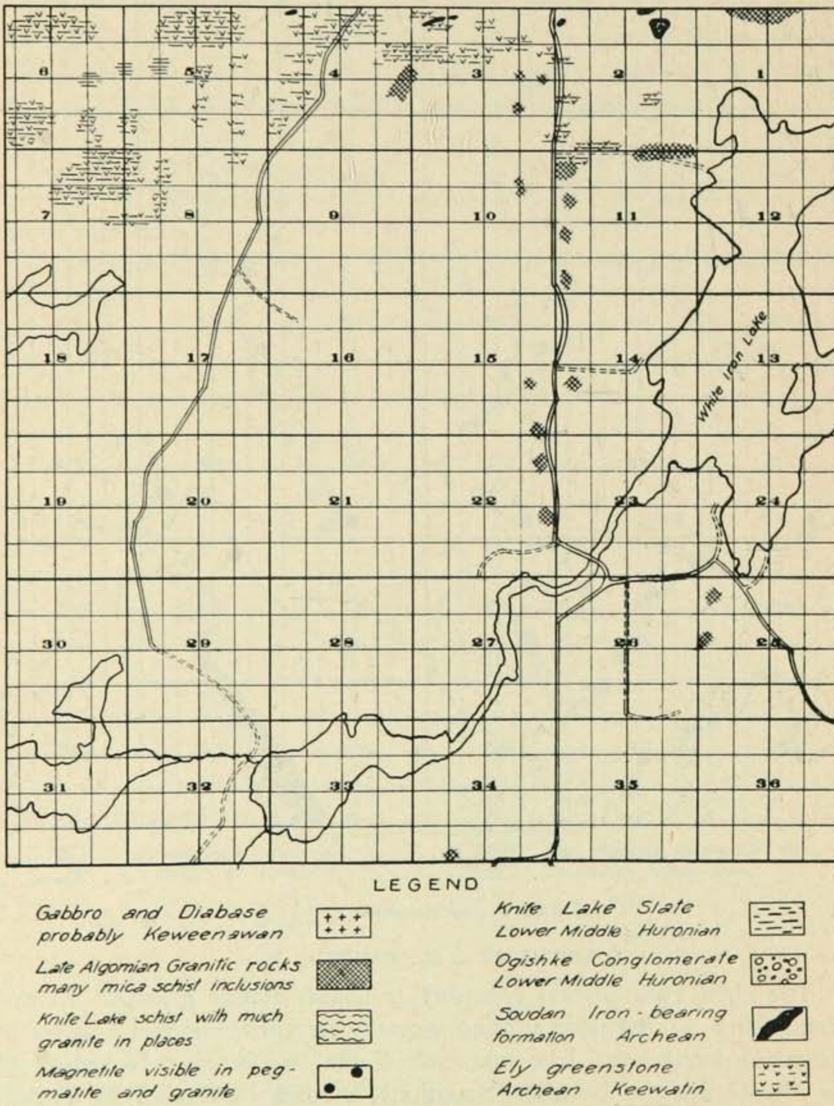


TOWNSHIP 61 N., RANGE 12 W.

The chief rock of this township is Giants Range granite. In and near Section 30, the main granite shows some variations and a series of successive intrusions. The east end of the iron-bearing formation of the Mesabi Range, (Biwabik formation), is south of Birch Lake in Section 26. The belt at this place is very narrow and not promising as a source of ore. With its associated formations, quartzite below, slate above, and some intrusive diabase, it has been strongly metamorphosed by the Duluth gabbro which occupies the eastern row of sections of the town. In the southwest quarter of Section 24, the gabbro has an inclusion of Biwabik formation that has been prospected, but it is too small to merit further attention.

TOWNSHIP 62 NORTH, RANGE 12 WEST

Geology from United States Geological Survey Monograph 45, Atlas; and by F. F. Grout and G. M. Schwartz



TOWNSHIP 62 N., RANGE 12 W.

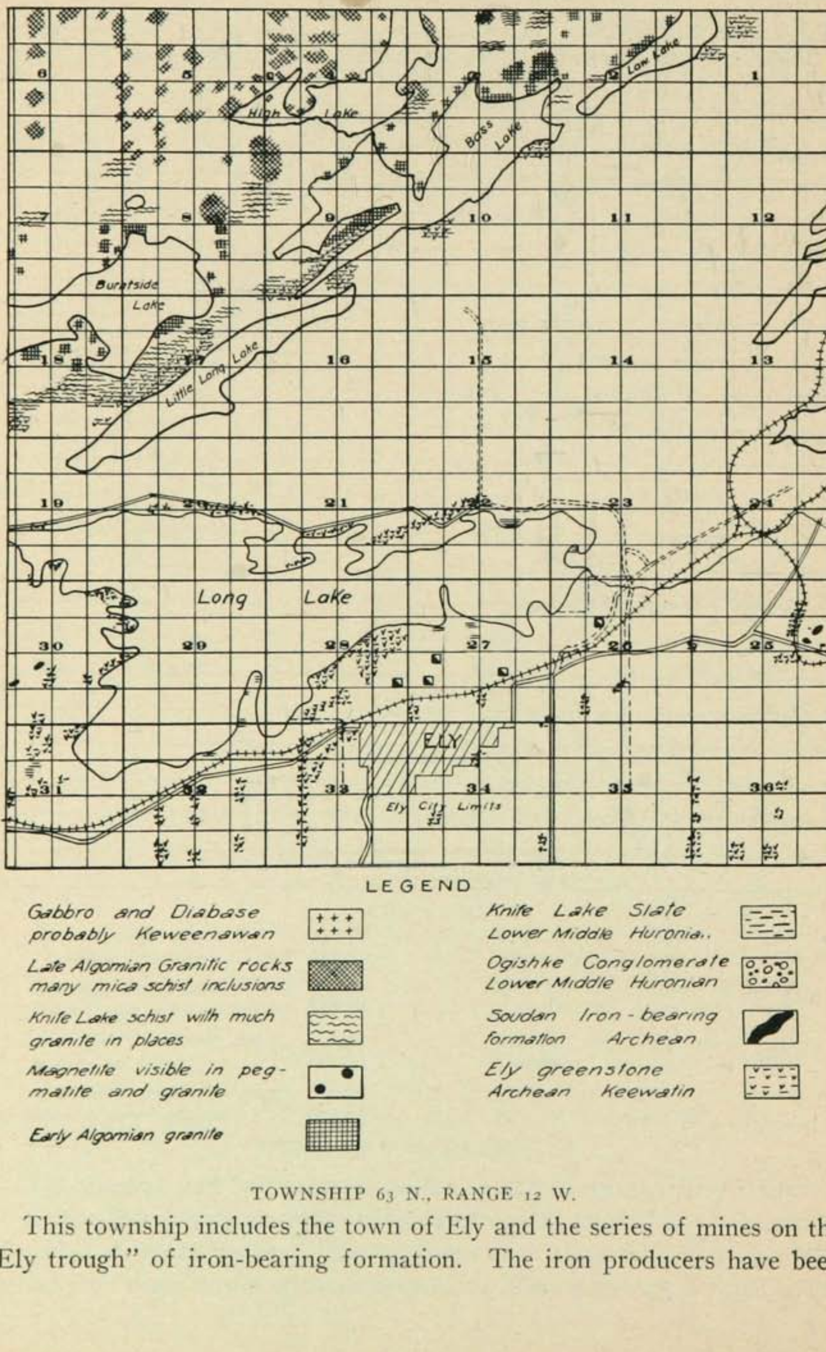
The central and southeastern parts of this township show outcrops of Giants Range granite, with only minor modifications due to assimilation of various inclusions. The northern row of sections is included in the outcrop maps in the atlas accompanying *Monograph* 45, United States

Geological Survey. The Ely greenstone here contains a few masses of Soudan iron-bearing formation, which have been test pitted by several prospectors. The formation is mostly gray and magnetic rather than red like the productive ore.

There is a small area of Knife Lake slate in sections 5 and 6.

TOWNSHIP 63 NORTH, RANGE 12 WEST

Geology from United States Geological Survey Monograph 45, Atlas; and by F. F. Grout and G. A. Thiel



TOWNSHIP 63 N., RANGE 12 W.

This township includes the town of Ely and the series of mines on the "Ely trough" of iron-bearing formation. The iron producers have been engaged for some years past in a detailed study of the formations in and near the mines, and have more information relating to that area than is available to the Survey. This report, therefore, covers only the general features of the township. The mines in the Ely trough are working and discovering occasionally new features in the structure. The Savoy mine on the east of the trough is pretty well worked out and ceased shipping in 1916. East of the Ely trough, and outside the area of St. Louis County the Section 30 and Chippewa mines have been opened and some ore shipped. The Sibley property is in Section 26 and Section 27; the Zenith and Pioneer mines are in Section 27; and the Chandler mine is in Section 28. See the section on Economic Geology, pages 76 to 81.

From northwest to southeast this township reaches from the Vermilion batholith to the Giants Range, across the whole Vermilion Range "syncline," including synclines of Knife Lake slate. Several features of such a section are noteworthy. The map of Burntside Lake area (Fig. 2, page 30) shows the relations of the older granite gneiss to younger granite and some of the schists. The contact is fairly clear though only the pegmatitic and basic border phases of the younger granite intrude the older.

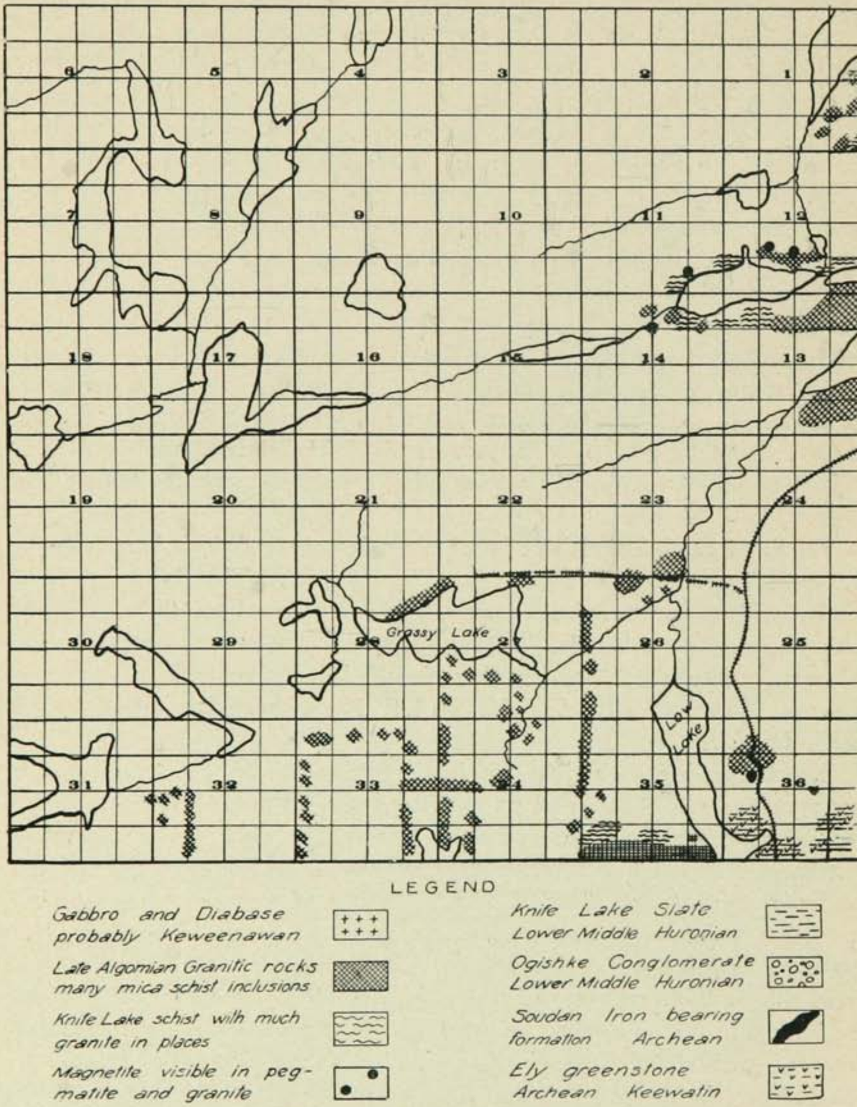
North of High Lake there is an extensive area of dark igneous rock that passes gradually into the Vermilion granite. The darker rock is banded with a variety of different modifications, most of them syenites, with abundant hornblende. Alternating with these are some extreme modifications of the normal rocks; shonkinites, hornblendites and even iron ore. These are all included in the late Algomian granite rocks, on the township plat.

The band of iron ore just mentioned was prospected by Mr. Mallman many years ago.[a] (See page 73.) Very little can now be seen except at the test pits, but the nature of the occurrence is clear. The magnetite is a band, segregated in a banded igneous rock. Its minerals are for the most part the same as those of adjacent bands of syenite and shonkinite. Its origin and nature are described on pages 72 to 76. The deposit is too small to be attractive for mining. Similar bands may occur near by, or in similar border phases of, the great batholith elsewhere. No others are known in this township. If search is to be made it should follow the areas of early banded syenite connected with the Vermilion batholith. (See Plate I.)

[a] Winchell, N. H., and H. V., Minnesota Geol. and Nat. Hist. Survey Bull. 6, The iron ores of Minnesota, pp. 6-24, 1891.

TOWNSHIP 64 NORTH, RANGE 12 WEST

Geology by F. F. Grout, G. A. Thiel, and T. S. Lovering



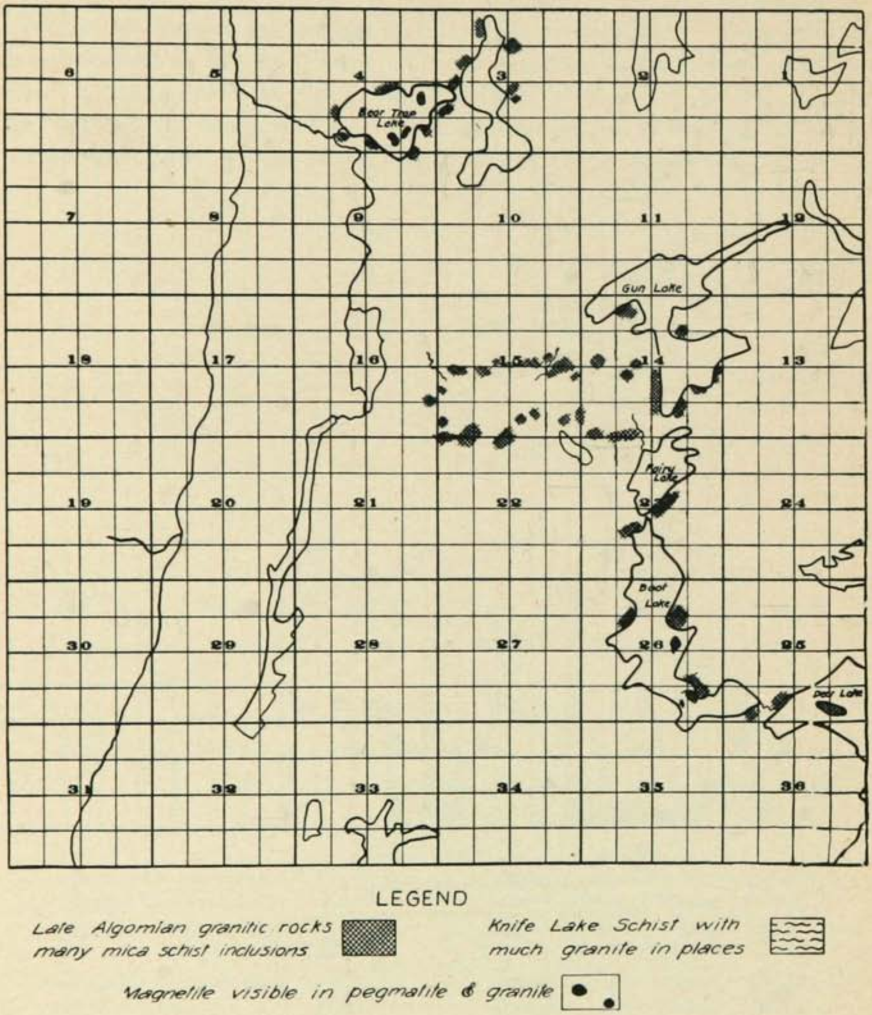
TOWNSHIP 64 N., RANGE 12 W.

The major part of this township is apparently occupied by Vermilion granite with its syenitic border phases near the south side. The southeast corner and the east side show inclusions and roof pendants, and possibly bed rock much altered, of Ely greenstone and Archean intrusives.

The later injection of granite has confused the outcrops so that many are hard to classify. There are no known exposures of Soudan iron-bearing formation in the Ely greenstone, which is here greatly altered to hornblende schist. Magnetite is visible in the pegmatites related to the Vermilion granite. It has been noted by the Survey parties in the southeast corner Section 11; a little south of the center of Section 12; a little north of the center of Section 14; and near the center of Section 36. None of the exposures in these places leads one to expect profitable deposits.

TOWNSHIP 65 NORTH, RANGE 12 WEST

Geology by G. A. Thiel

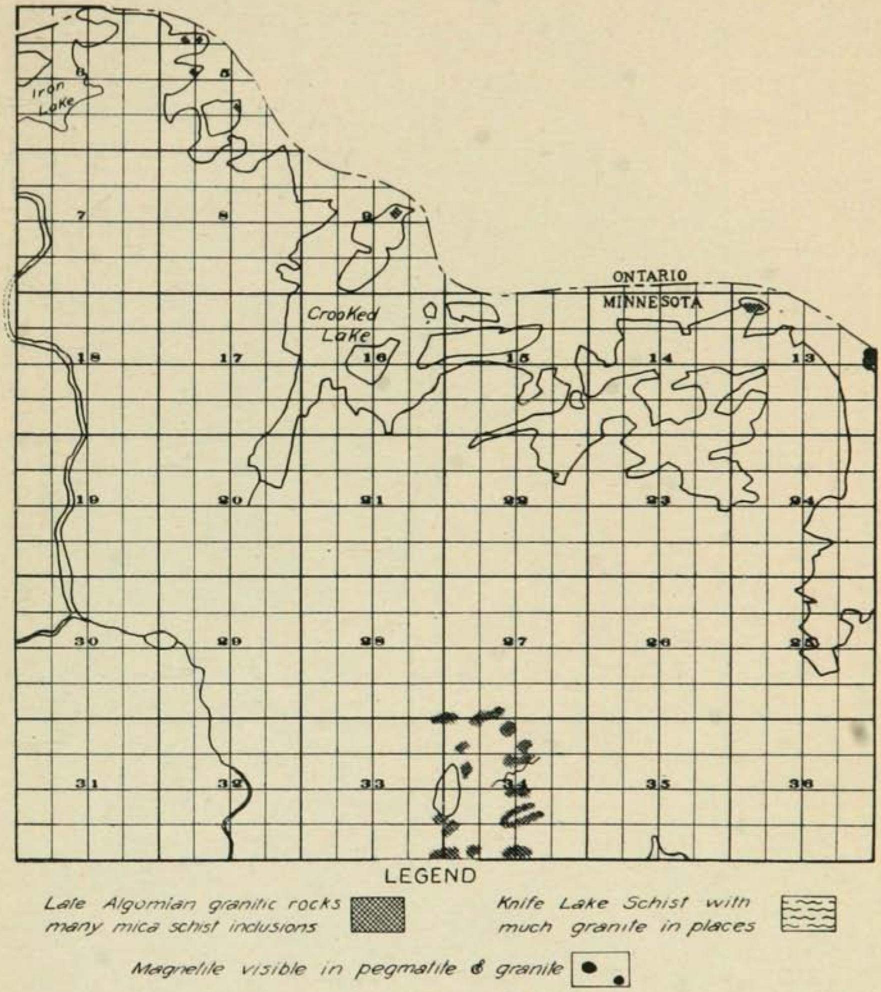


TOWNSHIP 65 N., RANGE 12 W.

The many outcrops visited in this township are all Vermilion granite, with few inclusions and little variation. Biotite schist occurs in moderate amounts on Gun Lake, but does not make the main part of any considerable outcrop.

TOWNSHIP 66 NORTH, RANGE 12 WEST

Geology by G. A. Thiel

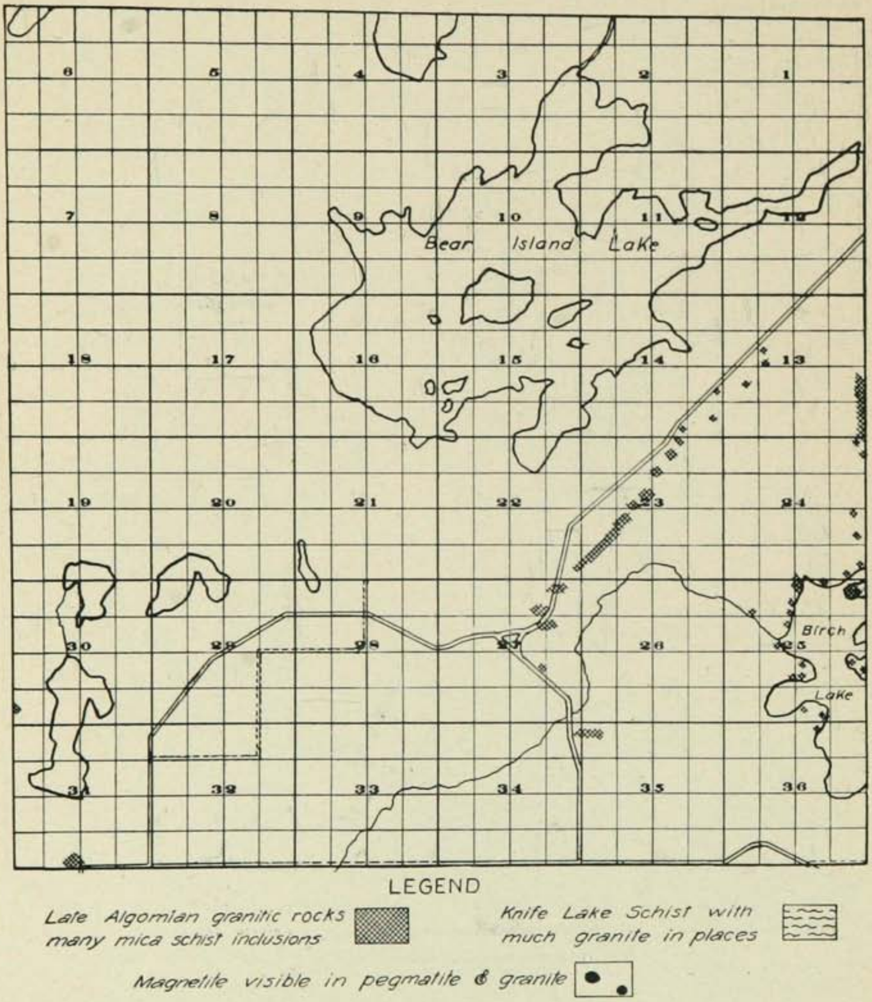


TOWNSHIP 66 N., RANGE 12 W.

The shores of Crooked Lake and the center of the south side of this township are nearly all Vermilion granite and no other rocks are to be expected. The mica schists lie near the north boundary on the Canadian side. The magnetite found in many places in the Vermilion pegmatites occurs in small amounts in this northeastern corner of the county. Some was seen on the island in the bay where the county line reaches the international boundary. The granite and traces of magnetite are known even farther east, nearly to Basswood Lake on the boundary.

TOWNSHIP 61 NORTH, RANGE 13 WEST

Geology by F. F. Grout



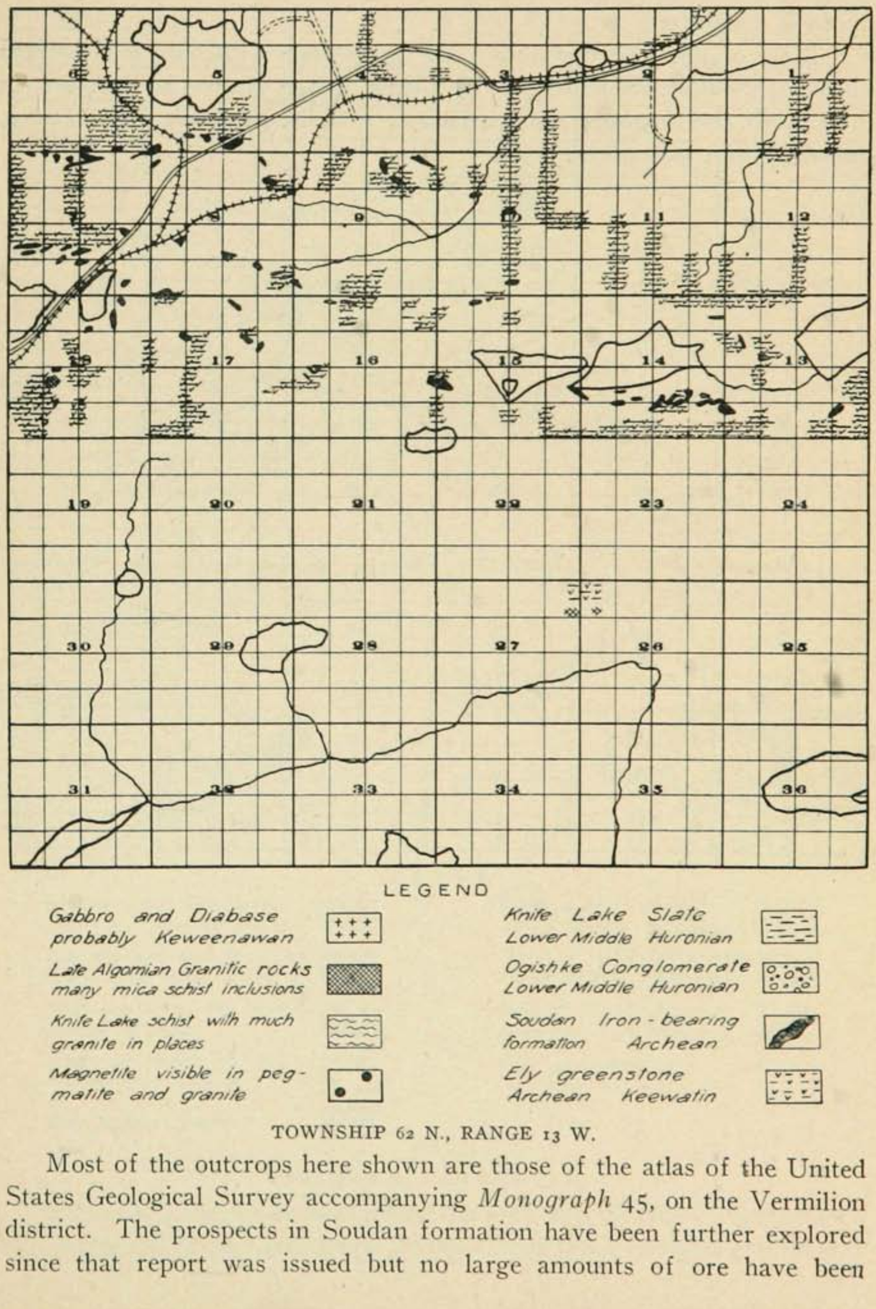
TOWNSHIP 61 N., RANGE 13 W.

This township is occupied by Giants Range granite, although along the south side a belt about a mile wide exhibits great masses of gneiss and schist in the granite. These probably represent a portion of the roof of the Giants Range which hung down as a pendant into the granite. It is possible that some of the rock is an early phase of the Giants Range batholith but it is clearly older than most of the granite. The relations have been discussed by Allison.[a]

[a] Allison, I. S. The Giants Range batholith of Minnesota: Journal of Geology, vol. 33, pp. 488-508.

TOWNSHIP 62 NORTH, RANGE 13 WEST

Geology from United States Geological Survey Monograph 45, Atlas; and by F. F. Grout and T. S. Lovering



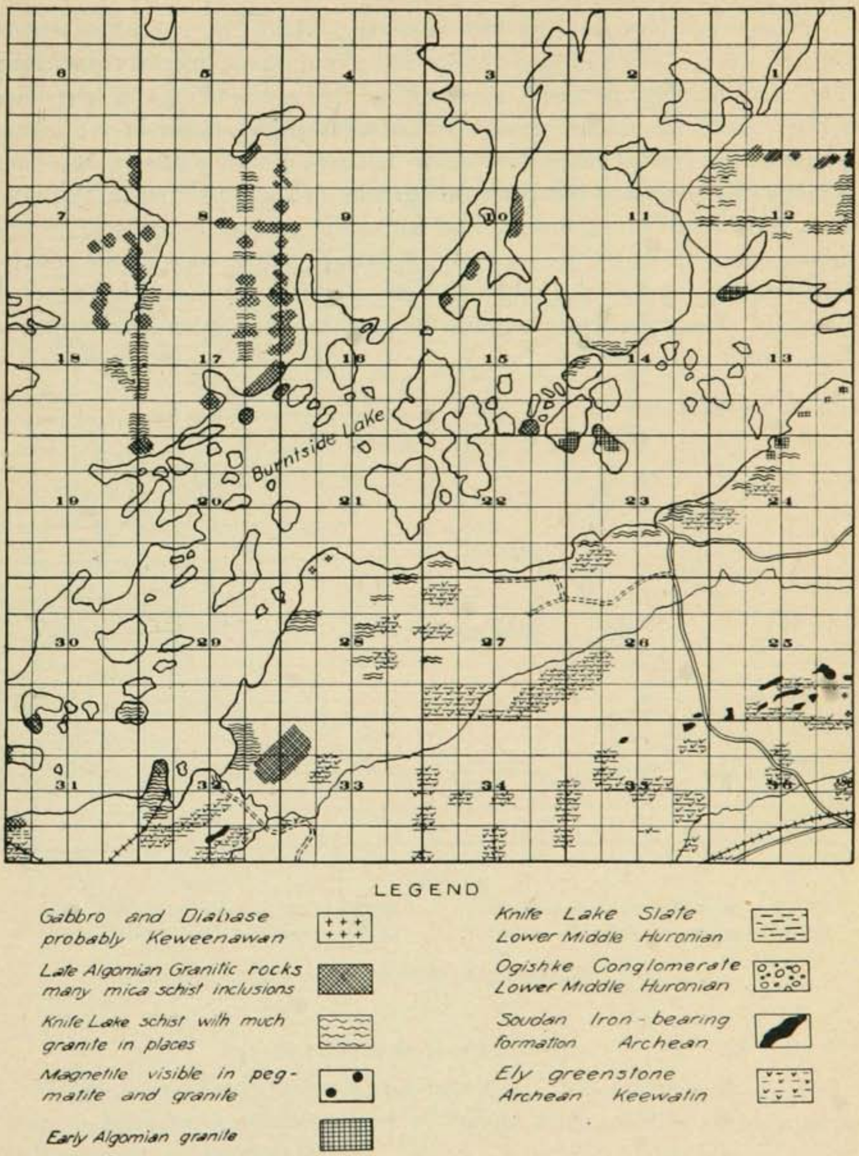
TOWNSHIP 62 N., RANGE 13 W.

Most of the outcrops here shown are those of the atlas of the United States Geological Survey accompanying *Monograph* 45, on the Vermilion district. The prospects in Soudan formation have been further explored since that report was issued but no large amounts of ore have been mined. The long belt of Soudan formation extending east and west (Section 13 to Section 18) has been traversed in detail on account of its magnetite content, but no body of ore seems likely to be developed under present conditions.

Most of the township shows Ely greenstone with only a few small belts of Soudan formation. The Giants Range granite is intrusive on the south and southeast; and a narrow syncline of Knife Lake slate is exposed near the north.

TOWNSHIP 63 NORTH, RANGE 13 WEST

Geology from United States Geological Survey Monograph 45, Atlas; and by F. F. Grout, G. A. Thiel, and J. W. Gruner



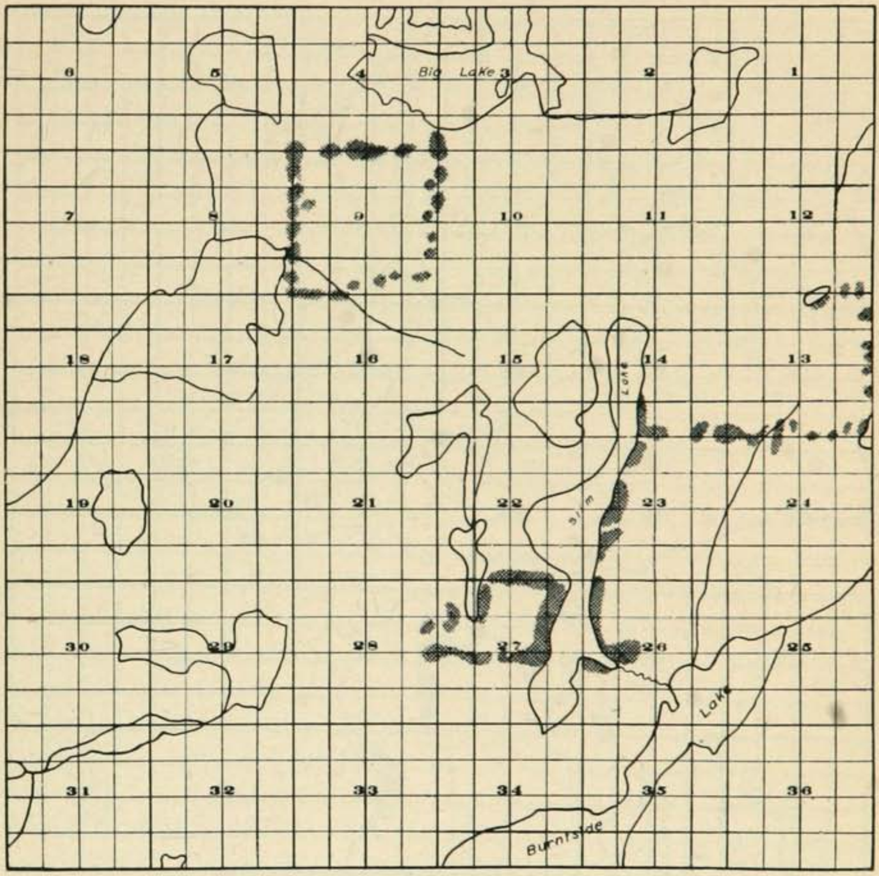
TOWNSHIP 63 N., RANGE 13 W.

Burntside Lake, extending across the township divides it roughly into two geological areas. Northwest of the lake is the Vermilion granite and southeast of it is the Ely greenstone with a few small synclines of Soudan formation and Lower-Middle Huronian slate. The borders of the Vermilion granite are locally syenitic.

Along the shores of the lake, however, where the two areas are in contact, there is much metamorphism and a complex of several formations. This was mapped in detail to ascertain the age relations of the mica schist. Two formations should be added to those shown in the monograph of the United States Geological Survey; a mica schist phase of the Knife Lake slate, and the Burntside granite probably Algomian but older than the Vermilion granite. The Burntside granite extends from the SW¼, Sec. 14, T. 63 N., R. 13 W., eastward to the edge of the county. The relations of the mica schist and green schists are shown in Figure 2, page 30. The mica schist overlies the greenstone in an anticline which is best shown in Section 28.

TOWNSHIP 64 NORTH, RANGE 13 WEST

Geology by G. A. Thiel



LEGEND

Late Algomian granitic rocks many mica schist inclusions

Knife Lake Schist with much granite in places

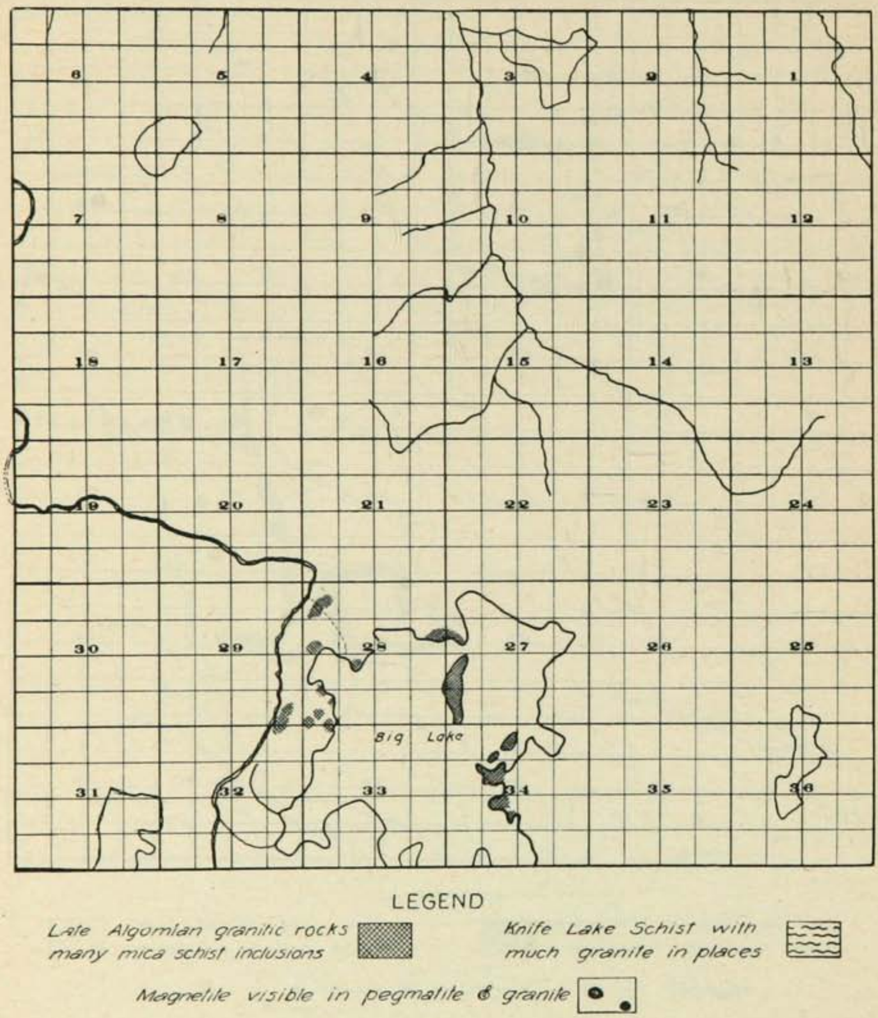
Magnetite visible in pegmatite & granite

TOWNSHIP 64 N., RANGE 13 W.

While Vermilion granite forms nearly all the outcrops of this township, it contains a small amount of biotite schist widely distributed as half assimilated fragments.

TOWNSHIP 65 NORTH, RANGE 13 WEST

Geology by G. A. Thiel

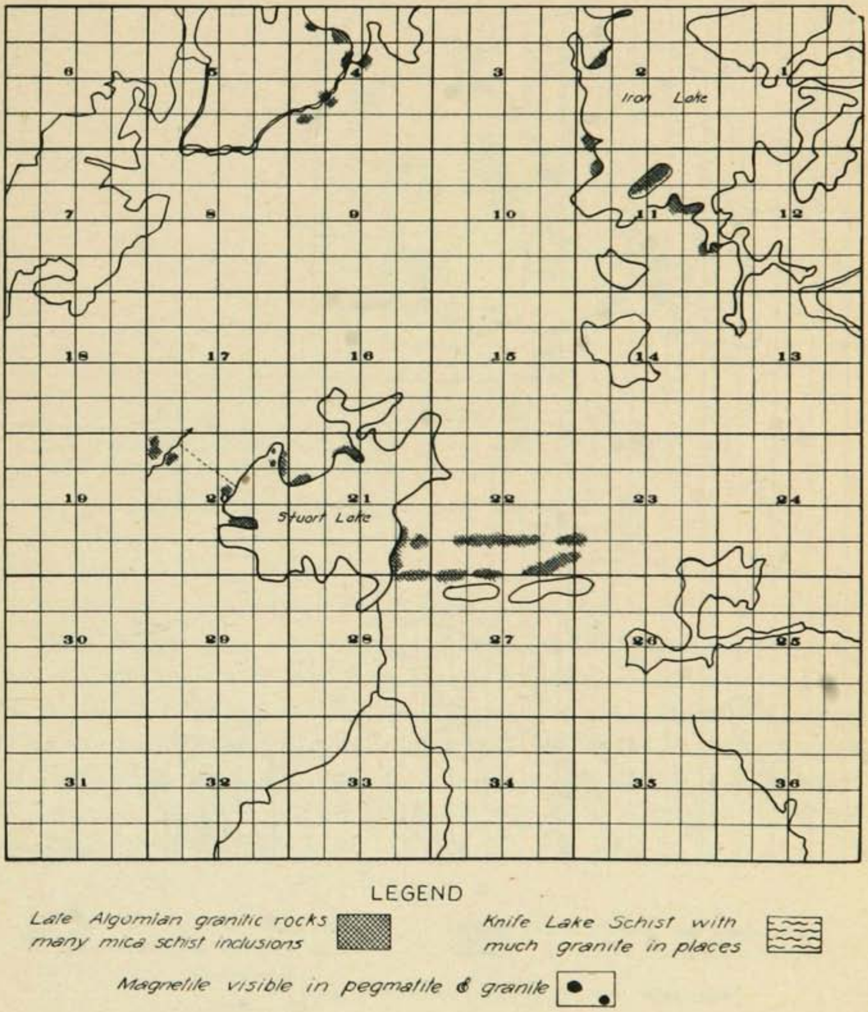


TOWNSHIP 65 N., RANGE 13 W.

This township includes many outcrops of Vermilion granite with few modifications: neither inclusions nor pegmatites are numerous.

TOWNSHIP 66 NORTH, RANGE 13 WEST

Geology by G. A. Thiel

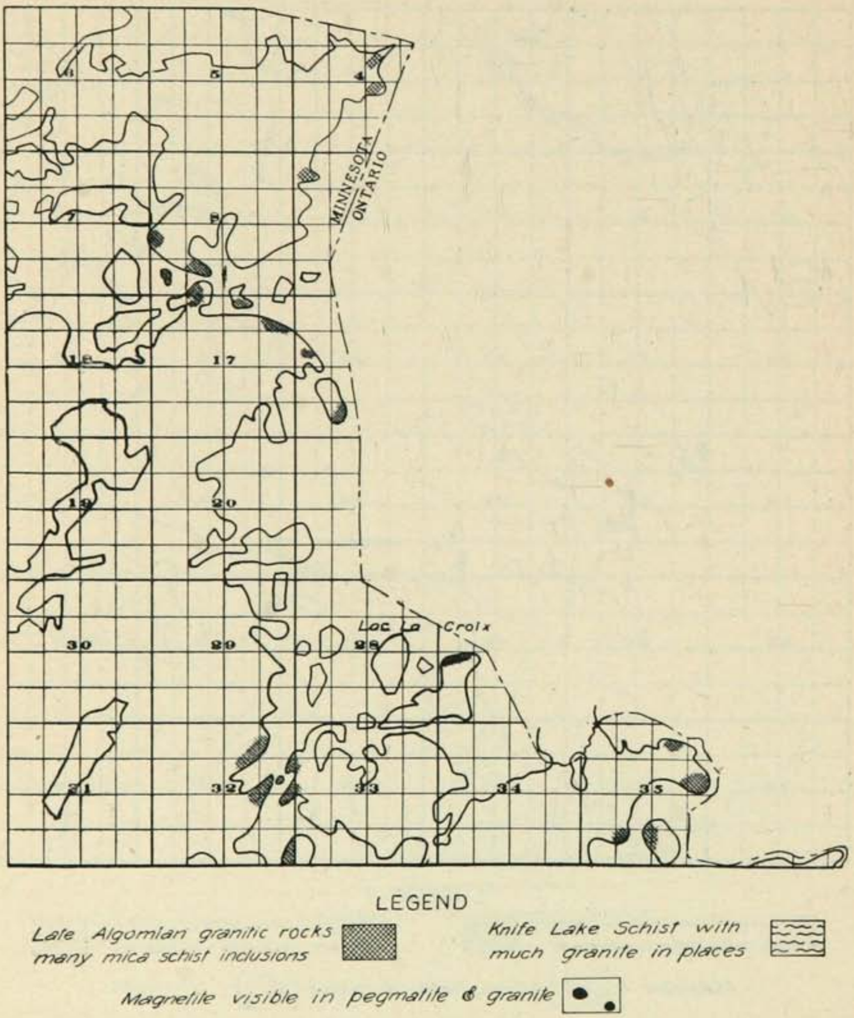


TOWNSHIP 66 N., RANGE 13 W.

This township, like those north and south of it, show numerous granite hills, and very little else.

TOWNSHIP 67 NORTH, RANGE 13 WEST

Geology by F. F. Grout and G. A. Thiel



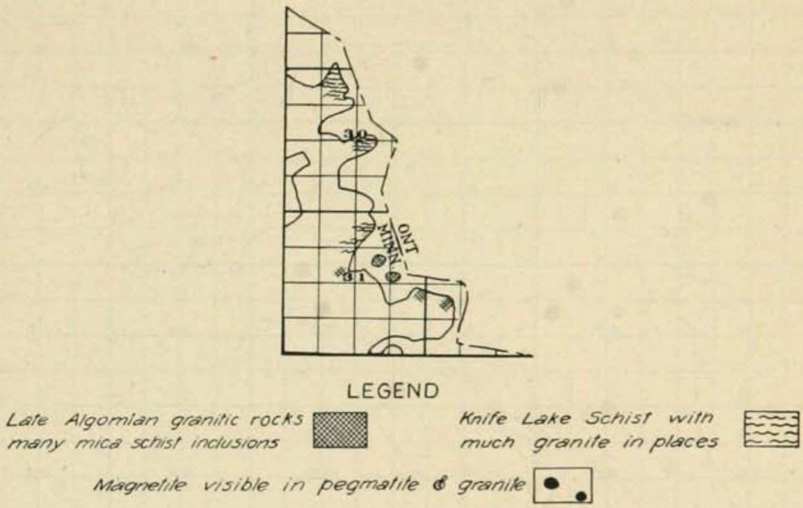
TOWNSHIP 67 N., RANGE 13 W.

This township shows many outcrops of Vermilion granite with few modifications; neither inclusions nor pegmatites are numerous.

North of Section 4 and Section 5, on the Canadian shore, there is biotite schist in a great area, but very little suggestion of the approach to a contact can be noted in the outcrops on the Minnesota shore.

TOWNSHIP 68 NORTH, RANGE 13 WEST

Geology by F. F. Grout

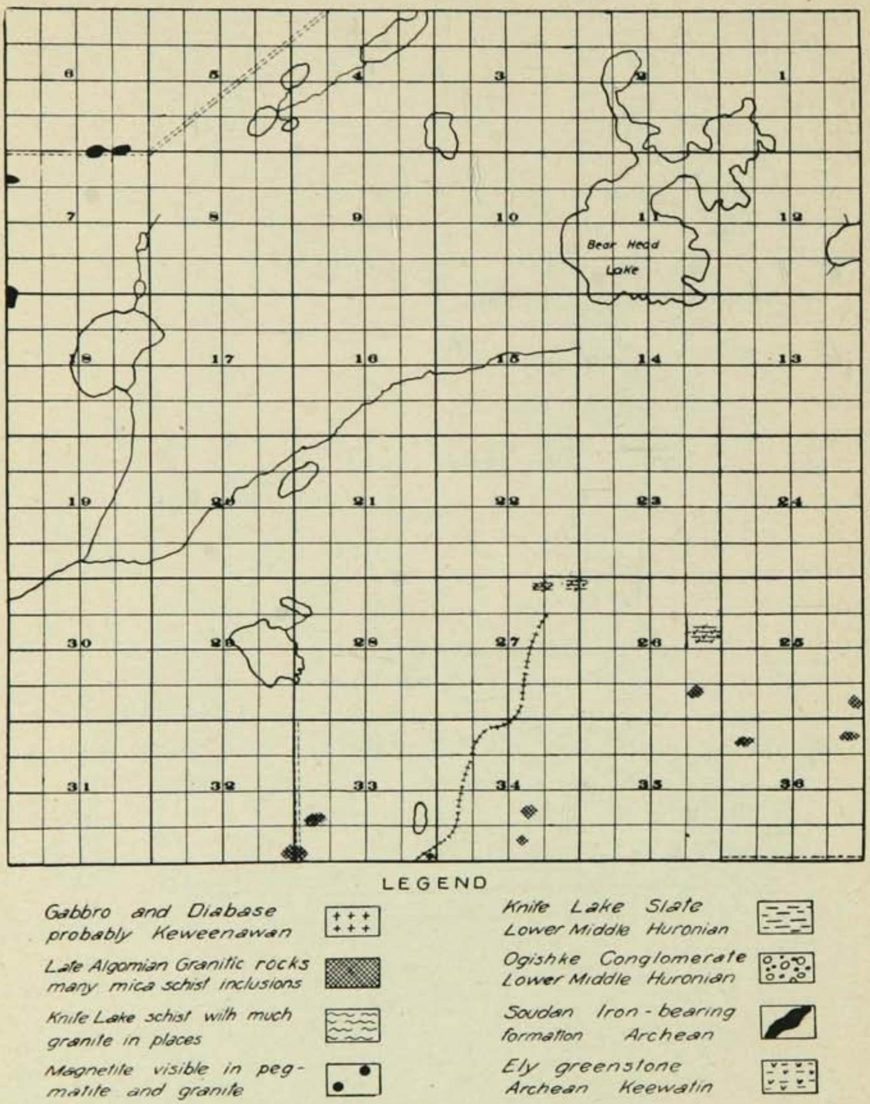


TOWNSHIP 68 N., RANGE 13 W.

This fragment of a township southwest of the Canadian boundary, has in it the contact of Vermilion granite intruding biotite schists. Close to the contact the granite has in places a gneissic, hornblendic phase. This is a very local modification, for it does not extend to the south side of Section 31. The granite boundary apparently trends a little south of east, for the schist appears on islands and on the Canadian shore east of the granite in Section 31 and Section 32.

TOWNSHIP 61 NORTH, RANGE 14 WEST

Geology by F. F. Grout, T. S. Lovering, and G. M. Schwartz



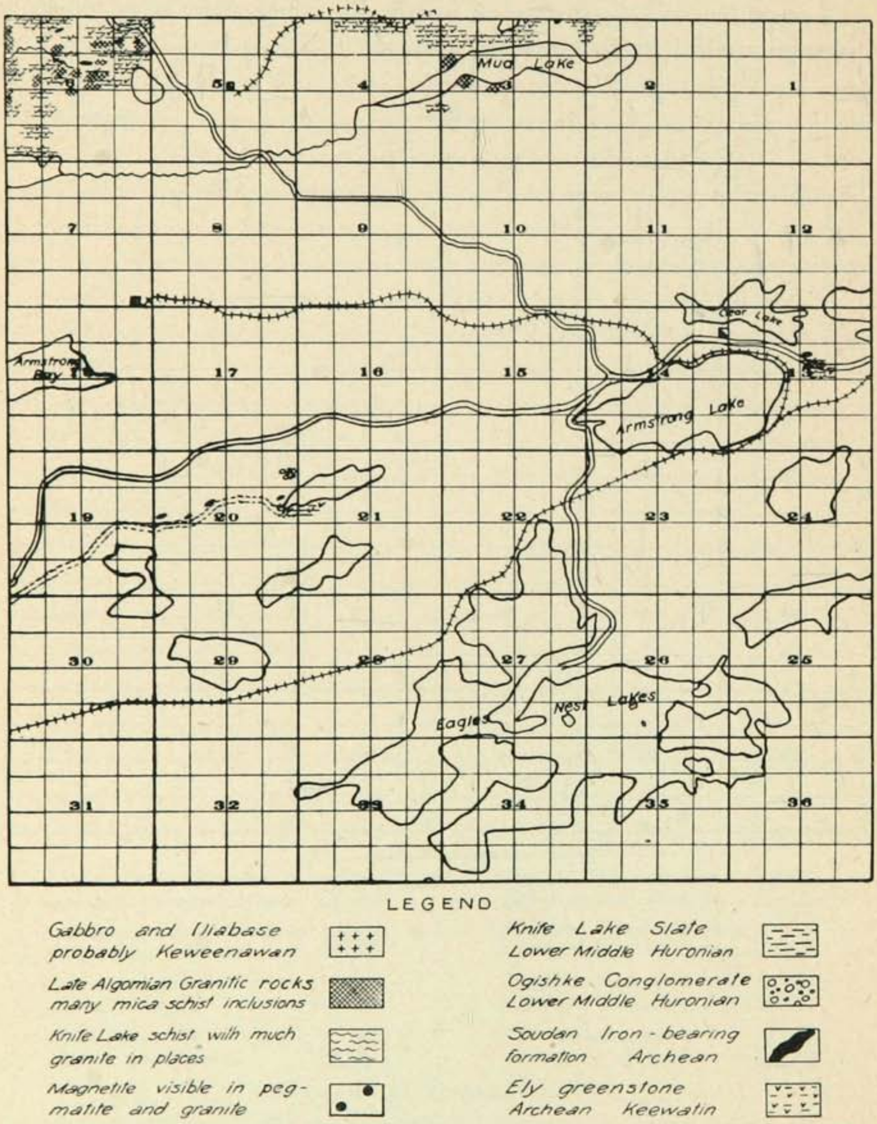
TOWNSHIP 61 N., RANGE 14 W.

The north portion of this township is shown by Plate VI of *Monograph* 52 to be occupied by Ely greenstone with a few small areas of Soudan formation. In the southeast there are outcrops of Giants Range granite; but locally in Section 34 and Section 36, there are many outcrops of older looking gneiss and schist probably included in the granite. The schists extend far north toward the greenstone and they are probably derived from that formation.

An area of Knife Lake slate, west of this township, may extend across the range line into Section 30 or Section 31, where there is an extensive swamp in which no outcrops were found.

TOWNSHIP 62 NORTH, RANGE 14 WEST

Geology from United States Geological Survey Monograph 45, Atlas; and by F. F. Grout and G. A. Thiel



TOWNSHIP 62 N., RANGE 14 W.

Most of the outcrops in this township are Ely greenstone. It is intricately folded and shows a number of belts of Soudan formation, as well as a double syncline of Ogishke conglomerate and Knife Lake schist.

The exposures are few in the south row of sections, and there may be rocks other than greenstone, undiscovered.

The explorations for iron ore have continued since early maps were issued and small amounts of ore have been shipped by two companies: the Consolidated Vermilion and Extension mine in Section 5, and the McComber mine in Section 13 and Section 14. The McComber shaft is considerably over 400 feet deep. The geologic features of both mines are complex, as are those of the Ely trough. Total shipments to date from these mines are a little over 30,000 tons.

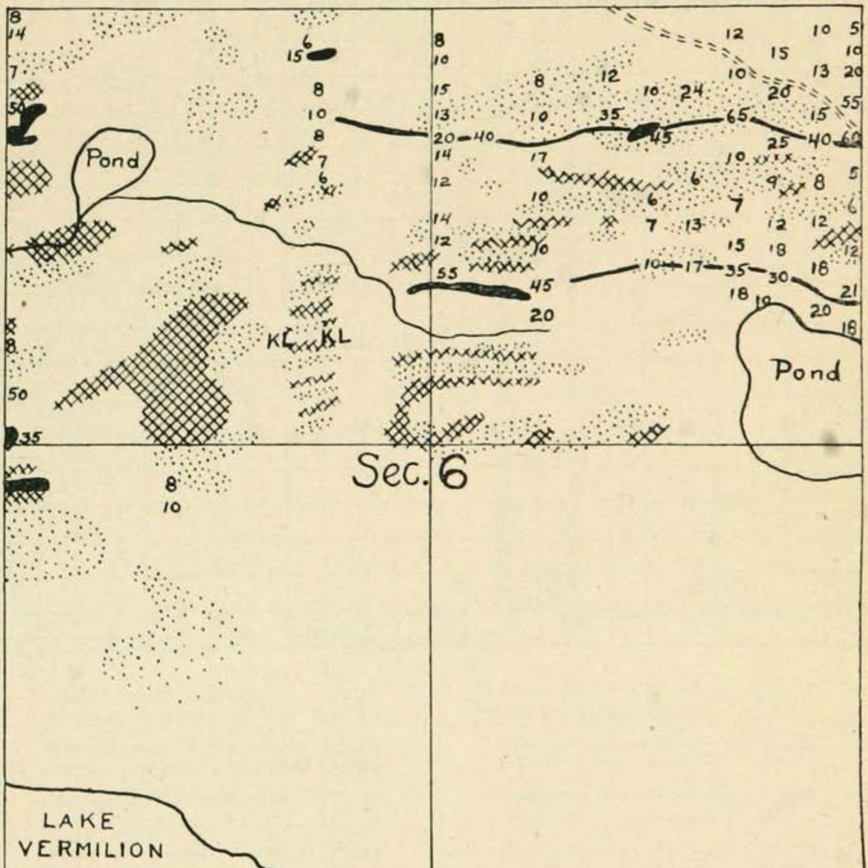


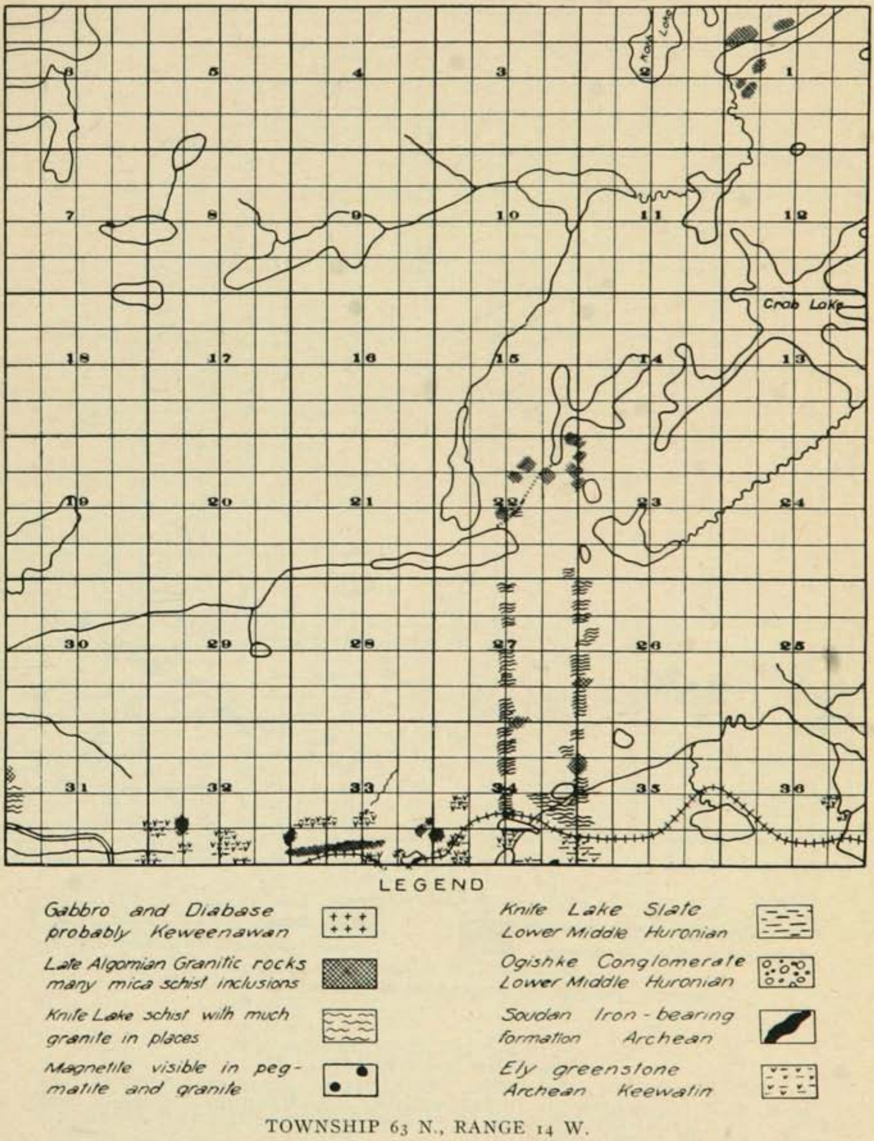
Fig. 8. Map of Sec. 6, T. 62 N., R. 14 W. showing outcrops and dip needle readings in the north part. Stippled areas, greenstone. Black areas, iron formation. Cross-lined areas, Algomian intrusives. KLKL, a small syncline of Knife Lake slate. Heavy lines along magnetic belts. Numbers show dip needle readings over 5° from normal.

Section 6 has been an area of interest to many prospectors and a detailed map of outcrops and magnetic readings in part of the area is shown in Figure 8.

In Sections 7 and 8, the Armstrong Bay mine has in recent years been carefully explored, and has developed some ore. Operations were suspended in 1924 on account of the low price of ore, but 4,748 tons of ore were shipped in 1923 and the work may be resumed whenever prices are more favorable.

TOWNSHIP 63 NORTH, RANGE 14 WEST

Geology from United States Geological Survey Monograph 45, Atlas; and by F. F. Grout and G. A. Thiel

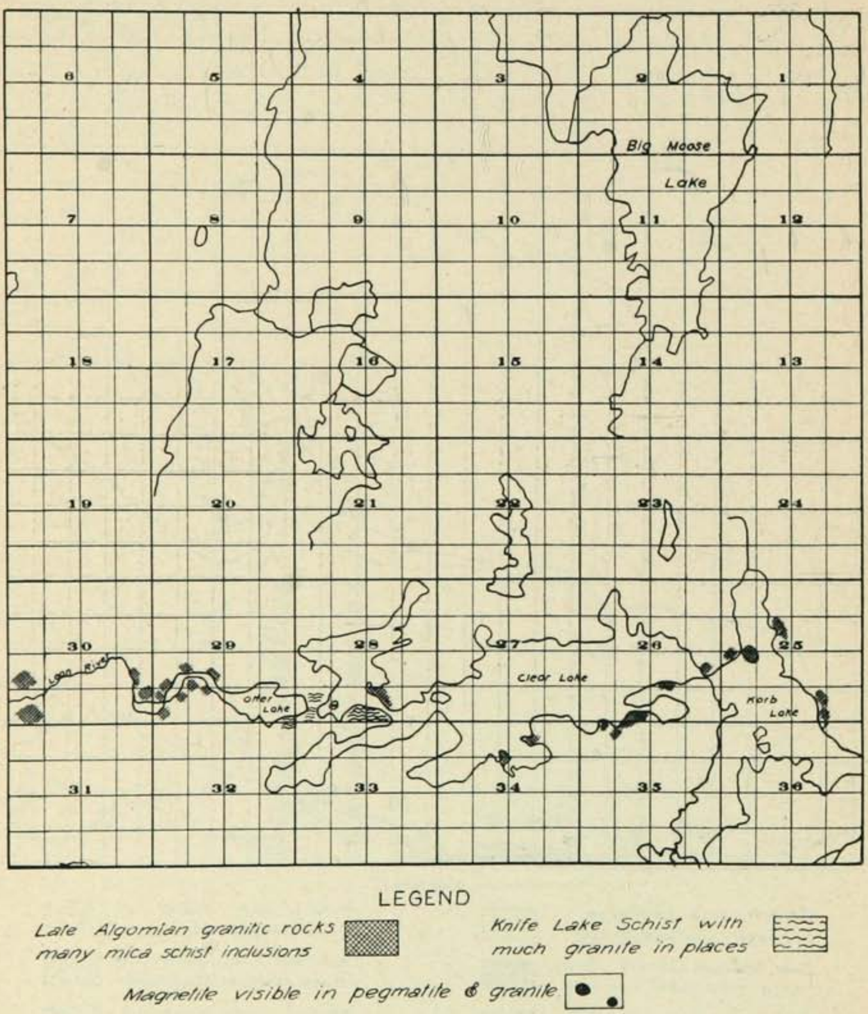


TOWNSHIP 63 N., RANGE 14 W.

The Ely greenstone so abundant in the township south of this, extends across the south line of this township. North of that is a biotite schist, supposedly Knife Lake, intruded by Vermilion granite in a complex of satellites and dikes. North of the center of the township the schist is less abundant.

TOWNSHIP 64 NORTH, RANGE 14 WEST

Geology by G. A. Thiel

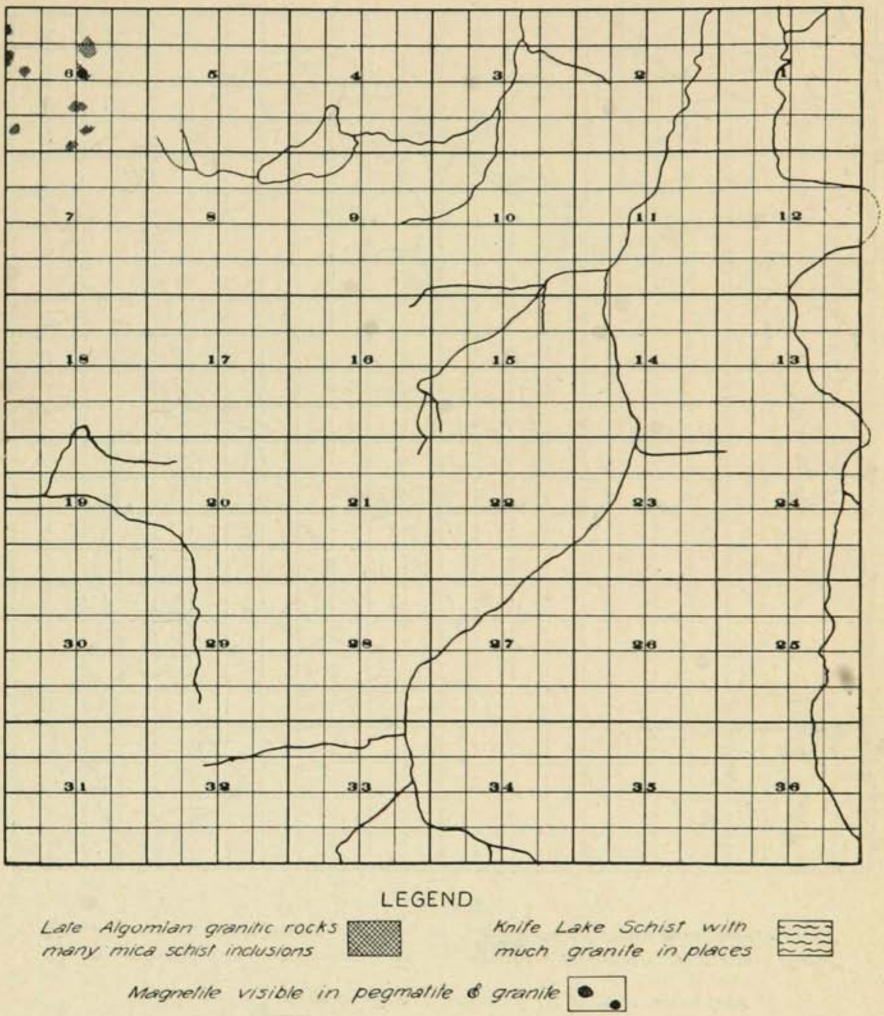


TOWNSHIP 64 N., RANGE 14 W.

The only exposures in this township are Vermilion granite with a few biotite schist inclusions.

TOWNSHIP 65 NORTH, RANGE 14 WEST

Geology by G. A. Thiel

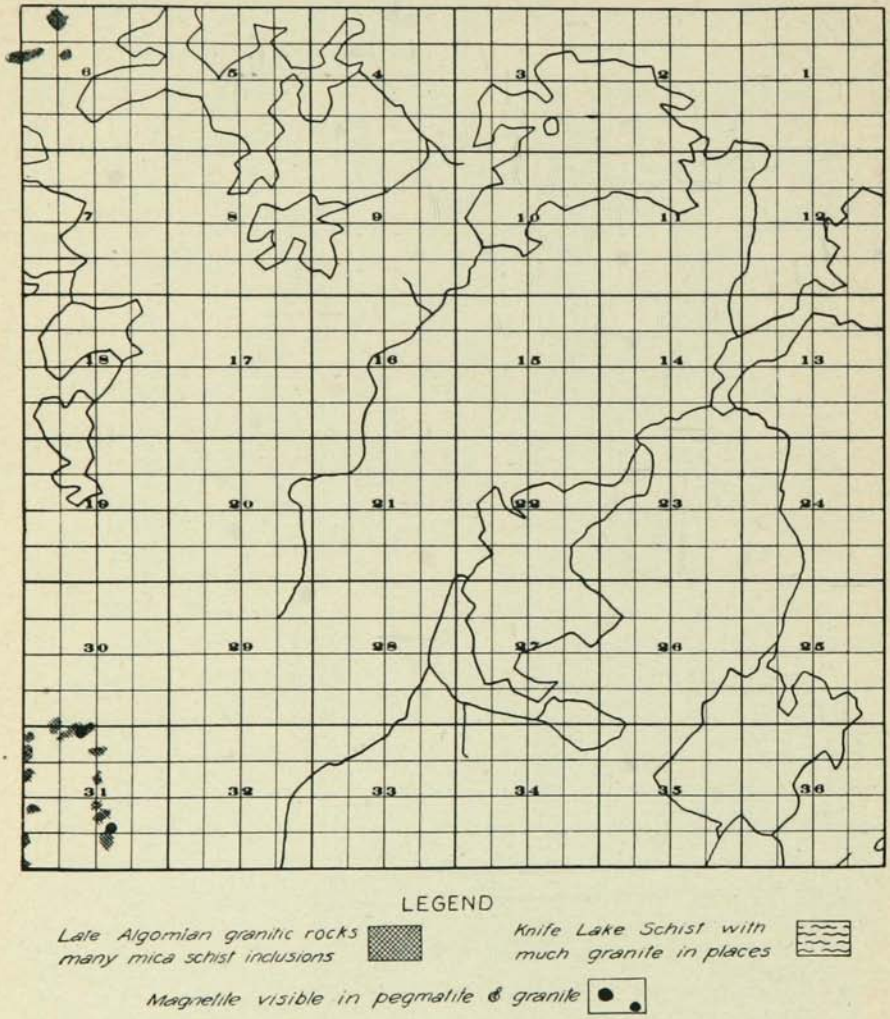


TOWNSHIP 65 N., RANGE 14 W.

This township is in the midst of the area of Vermilion granite. Near the northwest corner the granite is crossed by some lean magnetite-bearing pegmatites.

TOWNSHIP 66 NORTH, RANGE 14 WEST

Geology by G. A. Thiel

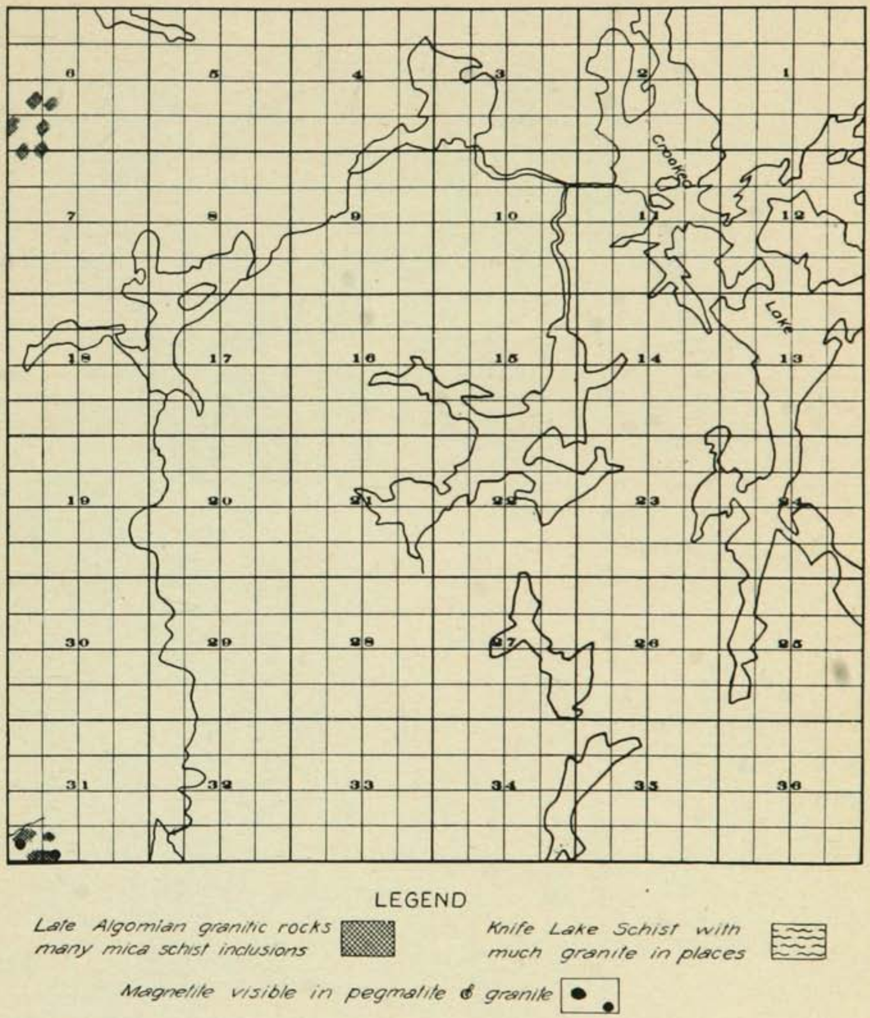


TOWNSHIP 66 N., RANGE 14 W.

This township is in the midst of the area of Vermilion granite and has few outcrops except granite, with some schist inclusions at a few places. Near the southwest corner of the township are some lean magnetite-pegmatite stringers.

TOWNSHIP 67 NORTH, RANGE 14 WEST

Geology by G. A. Thiel

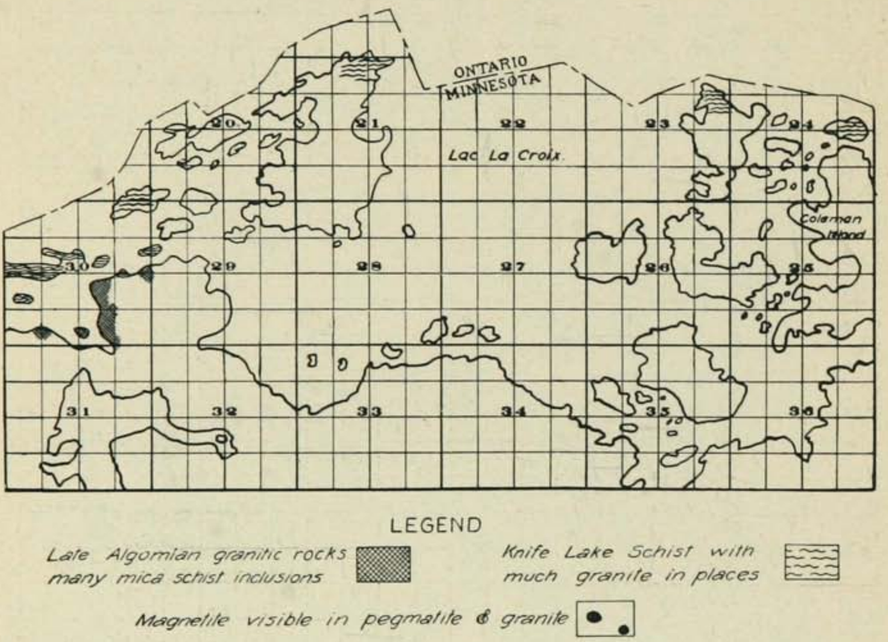


TOWNSHIP 67 N., RANGE 14 W.

This township lies near the north side of the Vermilion batholith and has exposures of granite with a few biotite schist inclusions. In the southwest quarter of Section 31, there are some lean magnetite-bearing pegmatites.

TOWNSHIP 68 NORTH, RANGE 14 WEST

Geology by F. F. Grout

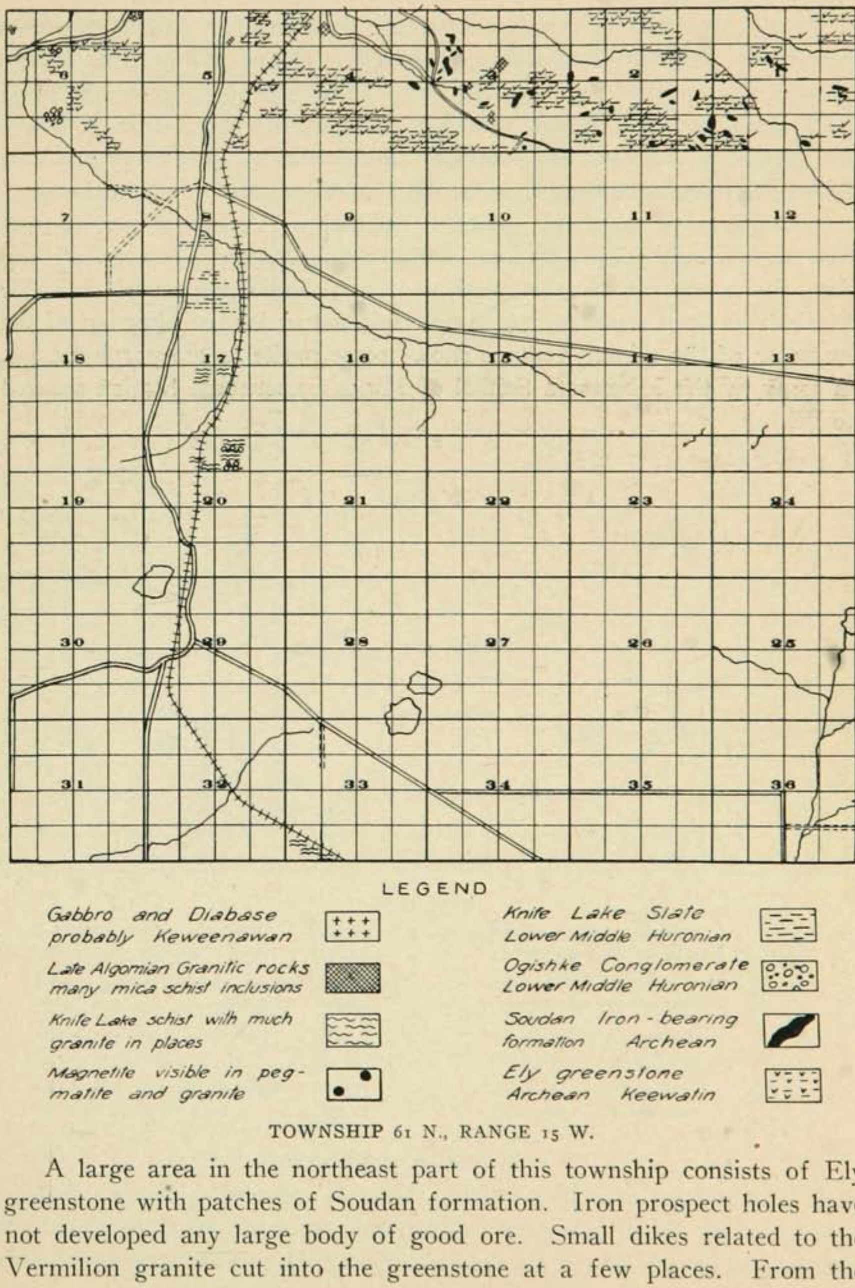


TOWNSHIP 68 N., RANGE 14 W.

This is a fraction of a township along the international boundary, but it shows the contact of the main mass of Vermilion granite extending south, with biotite schists on the north. Satellites of the granite batholith extend north into Canada beyond the schists.

TOWNSHIP 61 NORTH, RANGE 15 WEST

Geology from United States Geological Survey Monograph 45, Atlas; and by F. F. Grout and Stanwood Johnston



TOWNSHIP 61 N., RANGE 15 W.

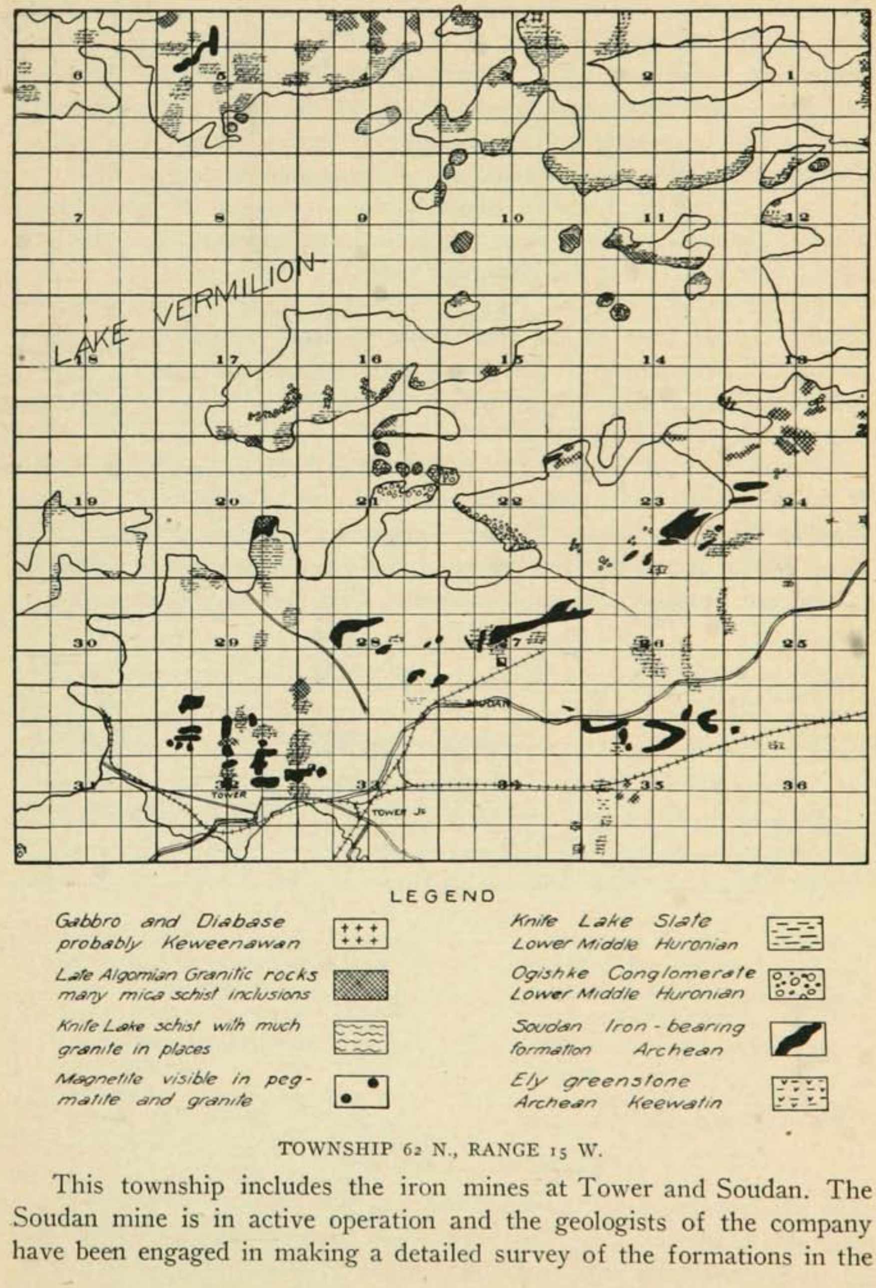
A large area in the northeast part of this township consists of Ely greenstone with patches of Soudan formation. Iron prospect holes have not developed any large body of good ore. Small dikes related to the Vermilion granite cut into the greenstone at a few places. From the center to the south and southeast sides of the township there is an area of Knife Lake slate with a few pebble beds which may be phases of Ogishke conglomerate.

In this area and for a few miles south, the Huronian slate shows most clearly the progressive alteration due to the intrusion of Giants Range granite, as described on page 18. Exposures are most accessible along the Duluth and Iron Range Railway. The station of Embarrass where the granite is exposed lies south of this township. Outcrops are less numerous from here west than in the townships north and northeast.

The intrusive porphyry, probably related to Vermilion granite, has been slightly mineralized at places within a mile south of Tower Junction, along the north side of this township. Assays indicating several valuable metals have been reported. A sample selected under the direction of the promoter of the mining venture shows some pyrite in the porphyry, but an assay by the Minnesota School of Mines Experiment Station showed no gold.

TOWNSHIP 62 NORTH, RANGE 15 WEST

Geology from United States Geological Survey Monograph 45, Atlas; and by F. F. Grout



TOWNSHIP 62 N., RANGE 15 W.

This township includes the iron mines at Tower and Soudan. The Soudan mine is in active operation and the geologists of the company have been engaged in making a detailed survey of the formations in the mine and neighborhood. The folding and intrusion have been very complex and the five or six formations alternate several times in a section across the township. Some small areas in the southern part of the town show no outcrops and the formations are known only from drill records. The central and western parts of the town are largely covered by the waters of Vermilion Lake. There are numerous exposures, however, and these have been much studied both by the state and government surveys and by mining and exploration companies. Many small mines and prospect holes show the nature of formations underground.

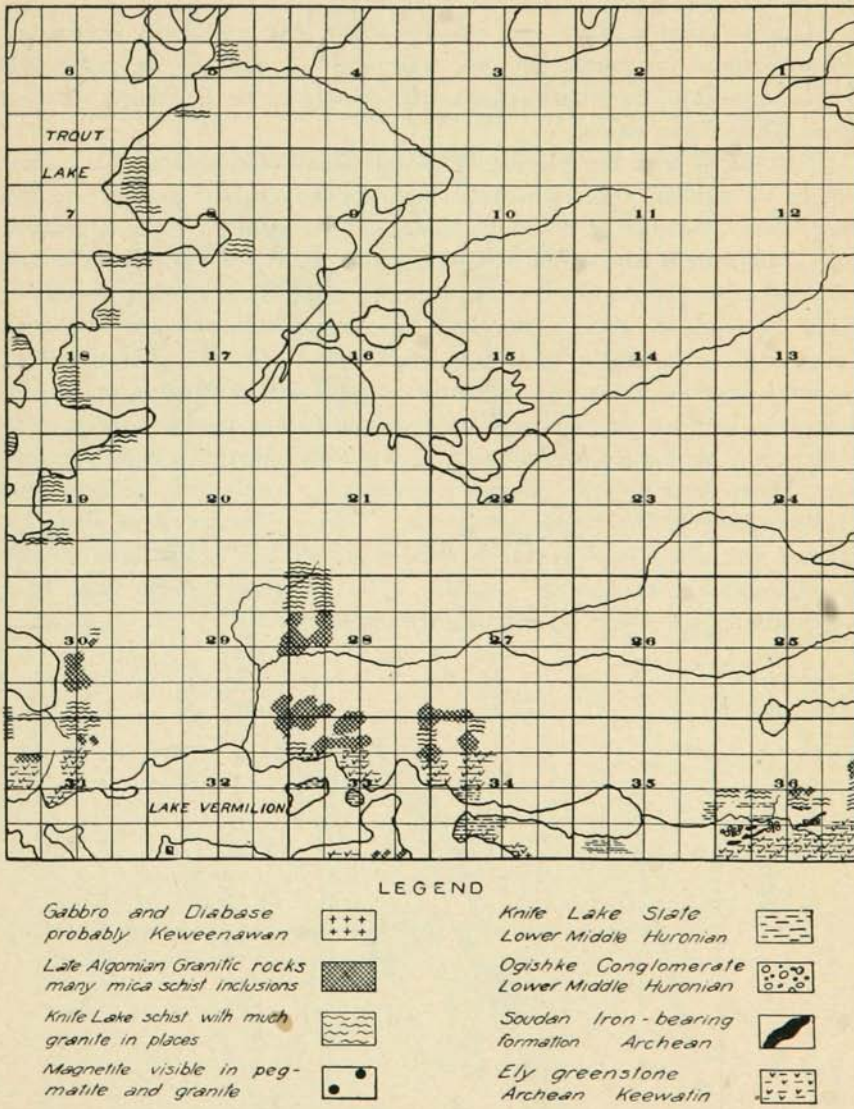
In this area the Ogishke conglomerate is exposed at many places whereas the areas east and west of this to the county lines have relatively little coarse material in the Huronian rocks.

Figure 10 is a map of Pine Island where some Soudan formation occurs. It lies west of the area shown in detail by the United States Geological Survey maps. The heavy lines in Sections 4 and 5 show a belt of maximum magnetic attraction. Little ore of shipping grade has been mined. (See page 134.)

The outcrop of iron-bearing rocks in the NW¼, Sec. 5, T. 62 N., R. 15 W., shows no magnetic attraction and may be a different formation than in the NE¼ of the section. There are outcrops of Knife Lake slates east of it and the iron-bearing rocks a few miles east in that association are probably Agawa formation. This also may be Agawa formation.

TOWNSHIP 63 NORTH, RANGE 15 WEST

Geology by N. H. Winchell and the parties of the early Minnesota Geological and Natural History Survey; and by F. F. Grout, G. A. Thiel, and Stanwood Johnston



TOWNSHIP 63 N., RANGE 15 W.

Ely greenstone and some associated Soudan formation and Huronian slate and conglomerate occur in the southern row of sections in this township, but the central and northern parts show little but biotite schist and

Vermilion granite and its syenitic border phases. These have been mapped as granite north of the schist, but the rocks alternate many times and so many outcrops show about equal parts of granite and schist that the location of boundaries is somewhat arbitrary.

The hornblende schist and chlorite schist that are clearly greenstone do not extend far north, but give way, within a mile of the south side of the township, to biotite schists that appear to be Huronian, derived from Knife Lake slates.

Associated with the greenstone in this small belt, however, are some bodies of Soudan formation, on which a good deal of prospecting has been done. Because of the long continued interest in the place, a detailed map was made of the south half of Section 36. (See Fig. 9.) The belt of Soudan formation has been drilled with a shot drill yielding enormous cores, to depths as great as 800 feet, but no important ore body has been found. It is noteworthy that there is not only a belt of iron-bearing rock in the greenstone, traced by magnetic readings and drill cores, but a considerable number of outcrops of iron formation not associated with greenstone, but rather with altered Ogishke conglomerate. Such outcrops are almost certainly the Agawa iron-bearing formation, between the Ogishke and Knife Lake formations. This is farther west than the Agawa formation has previously been reported. It is lean and yet has the appearance of Soudan jaspilite. The outcrops though large have very little if any effect on the magnetic needles.

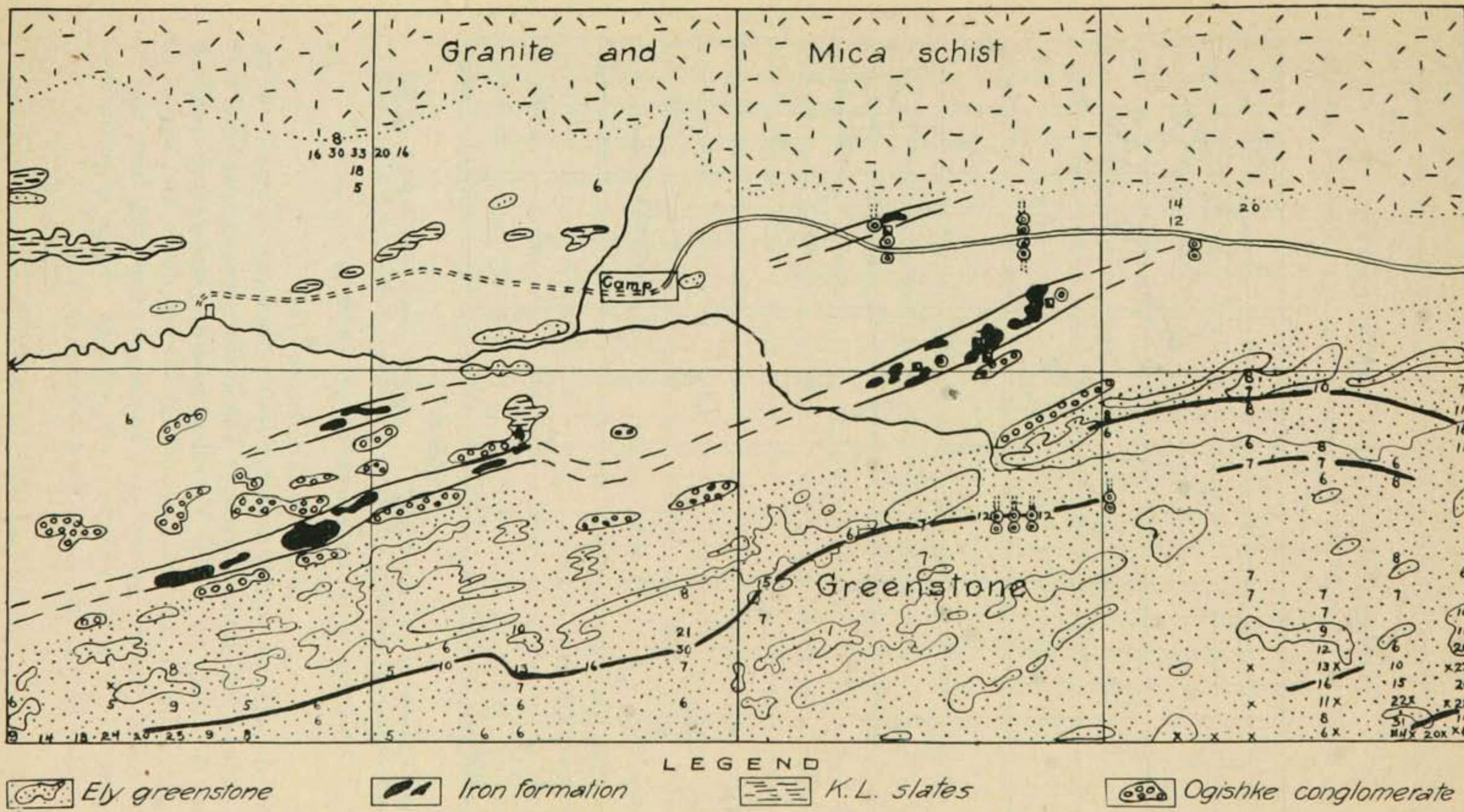
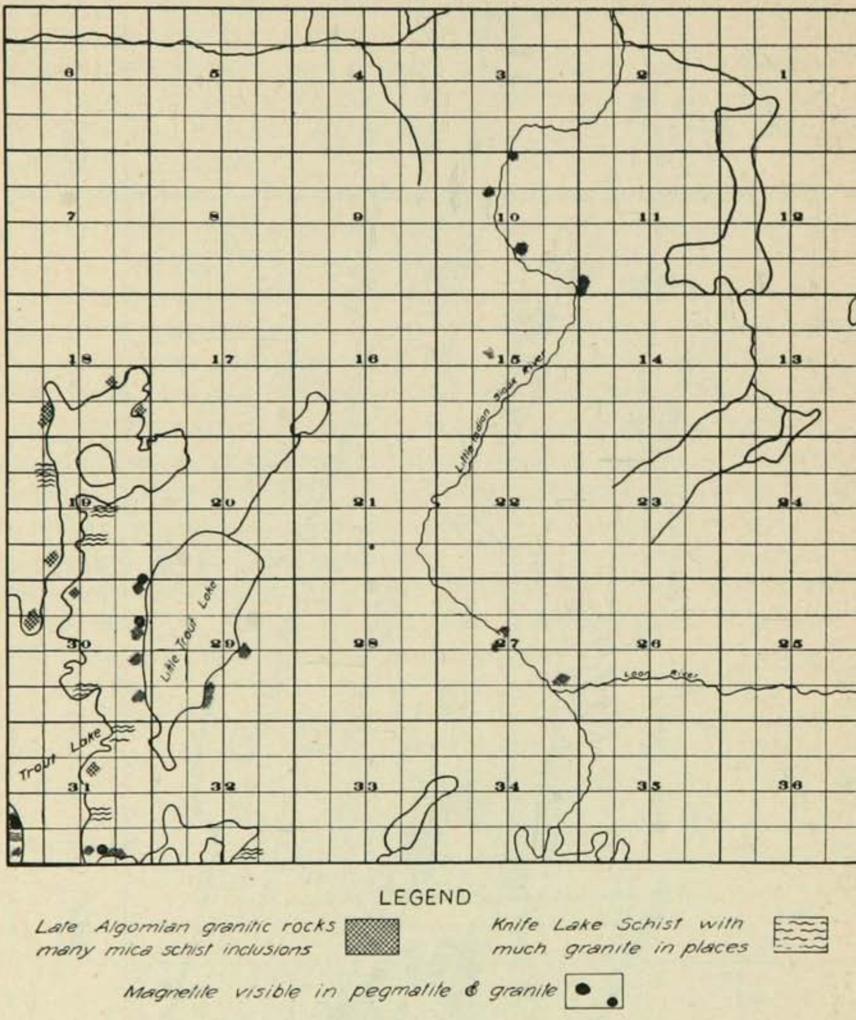


Fig. 9. Geology of the south half of Sec. 36, T. 63 N., R. 15 W. Numbers show dip needle readings more than 5° from normal. Crosses show dial compass readings more than 10° from normal. Note that the outcrops of iron formation show no magnetic attraction. Since they are associated with conglomerate they are probably Huronian Agawa formation. Soudan formation is found by drilling along the chief heavy line of magnetic attraction. A sharp fold or fault is indicated by the topography and magnetic attraction in the southeast part of the southwest quarter of Sec. 36.

TOWNSHIP 64 NORTH, RANGE 15 WEST

Geology by N. H. Winchell and the parties of the early Minnesota Geological and Natural History Survey; and by G. A. Thiel

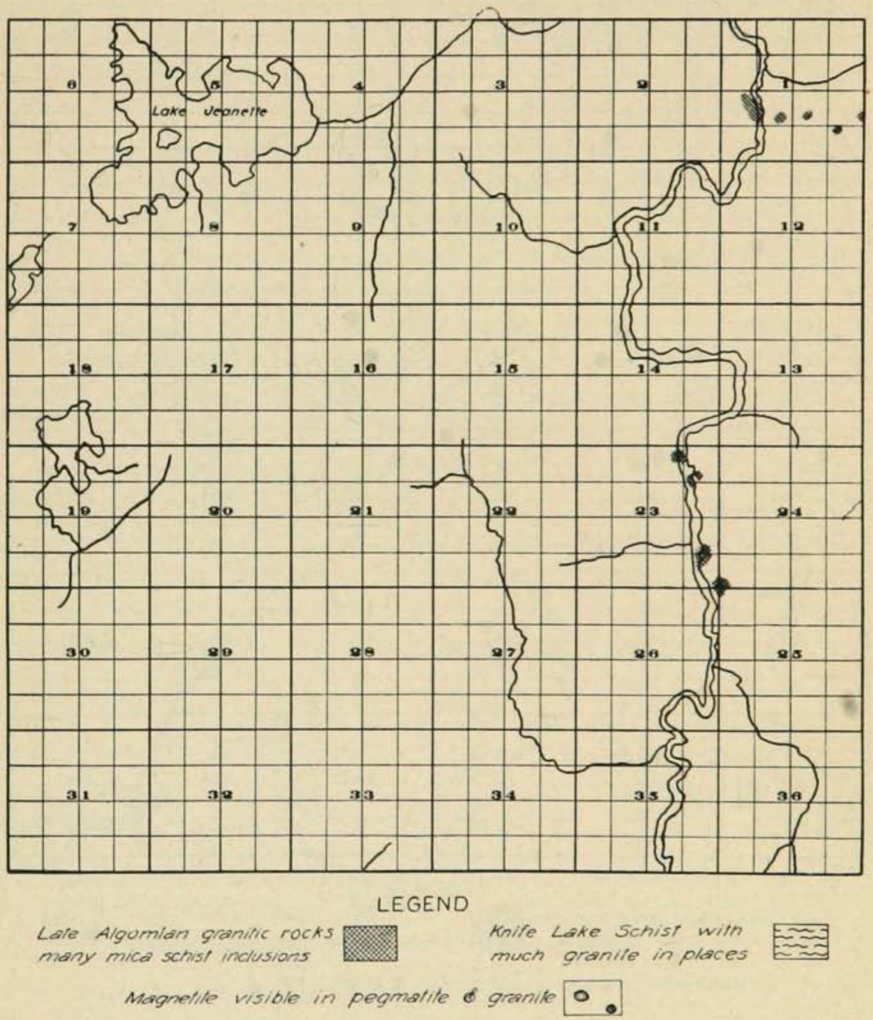


TOWNSHIP 64 N., RANGE 15 W.

All the outcrops in this township are of biotite schist, granite, or the two, more or less intimately mixed. The southwestern sections have much schist; the others are mostly Vermilion granite. Magnetite is visible in the pegmatites of this township notably on the shores and islands of Trout Lake, Sections 30 and 31. The magnetite-bearing area may be extensive, but it is not elsewhere well exposed. Some magnetite rock was seen in Section 10. All of the exposures are lean.

TOWNSHIP 65 NORTH, RANGE 15 WEST

Geology by G. A. Thiel

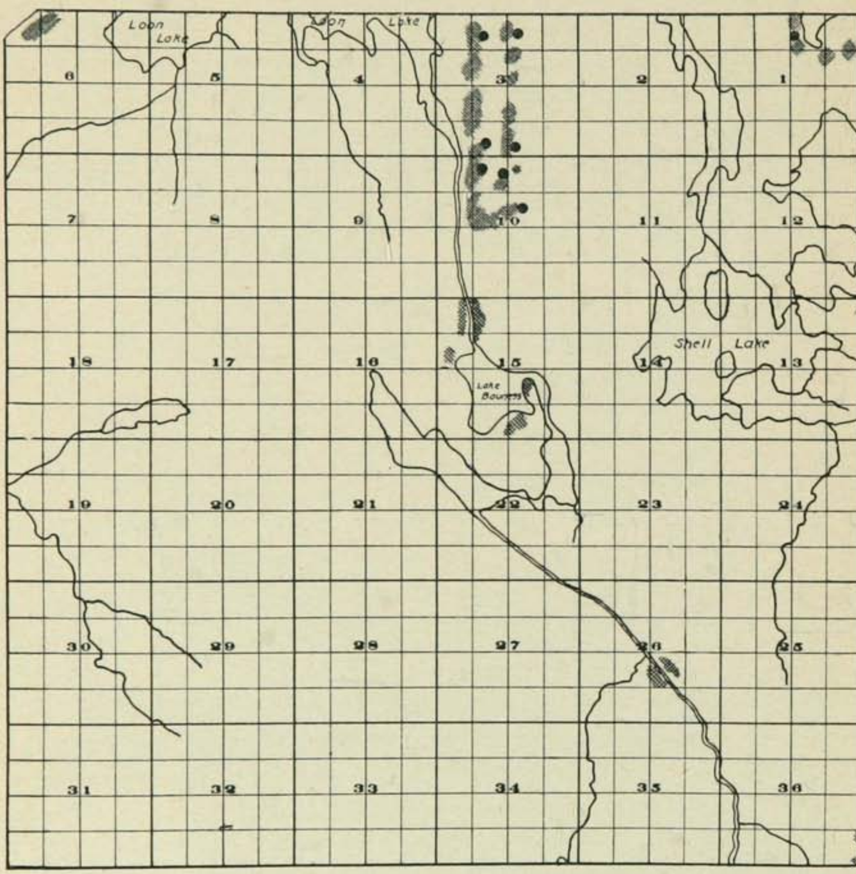


TOWNSHIP 65 N., RANGE 15 W.

Outcrops are numerous in this township and show very little but granite of the Vermilion batholith.

TOWNSHIP 66 NORTH, RANGE 15 WEST

Geology by G. A. Thiel



LEGEND

Late Algomian granitic rocks many mica schist inclusions

Knife Lake Schist with much granite in places

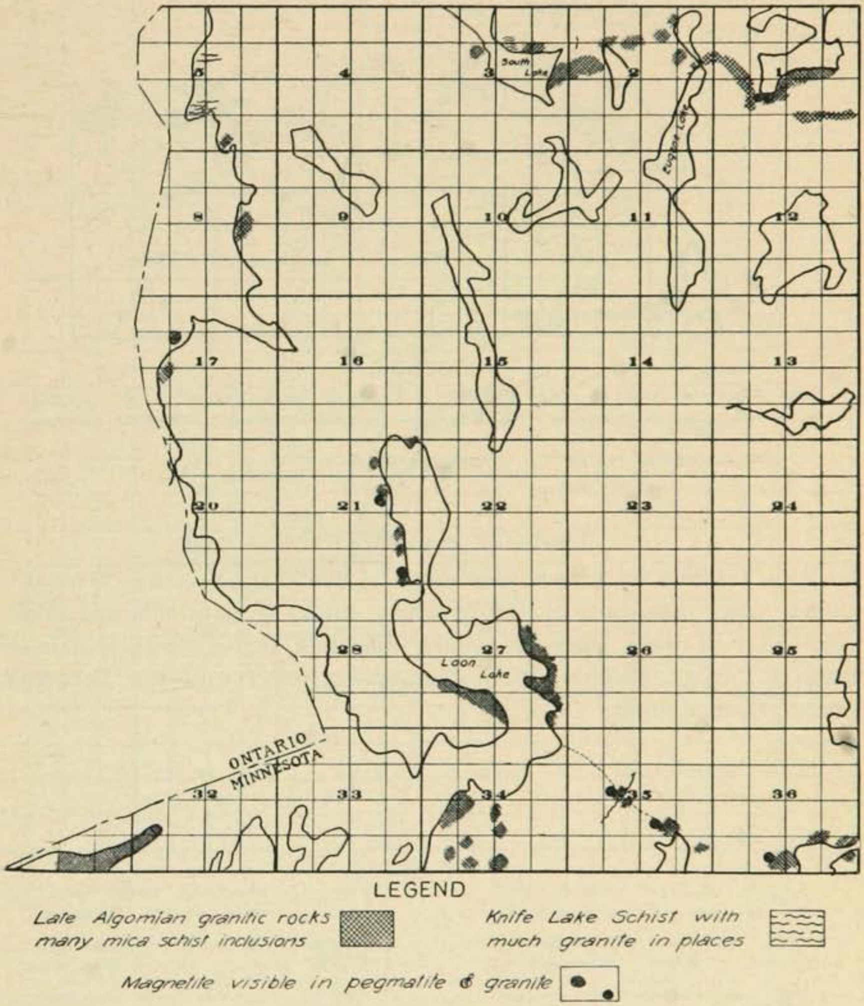
Magnetite visible in pegmatite & granite

TOWNSHIP 66 N., RANGE 15 W.

Vermilion granite is the chief formation exposed in this township and it has only a few schist inclusions. Outcrops of magnetite rock are numerous in the northern part of the township. They are lean and in Section 3, the rock is a granite rather than such a pegmatite as commonly contains magnetite in this county, and in other parts of this township.

TOWNSHIP 67 NORTH, RANGE 15 WEST

Geology by G. A. Thiel

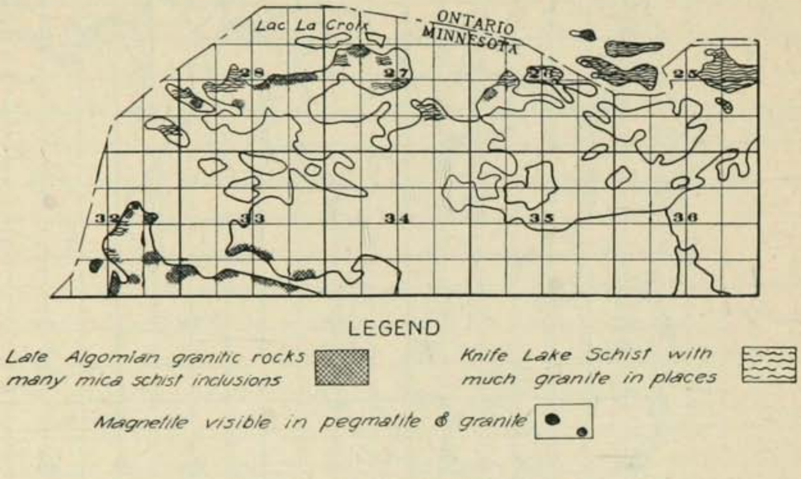


TOWNSHIP 67 N., RANGE 15 W.

This township shows very many outcrops, in practically all of which Vermilion granite largely predominates. At the extreme north side, the proximity of schist is indicated by fragments, included in the granite in greater numbers than farther south. Magnetite rock outcrops are well distributed in the area. Some of the occurrences differ from those common in this county, the magnetite being fine grained and in a normal granite rather than in coarse pegmatite. Such exposures are noted in Section 21. The magnetite granites have rarely as much as 5 per cent magnetite. More normal magnetite pegmatite is exposed in Secs. 35 and 36. None of the occurrences seen are promising prospects, since the estimated amount of magnetite in an area of 10 acres is about 2 per cent.

TOWNSHIP 68 NORTH, RANGE 15 WEST

Geology by F. F. Grout and G. A. Thiel

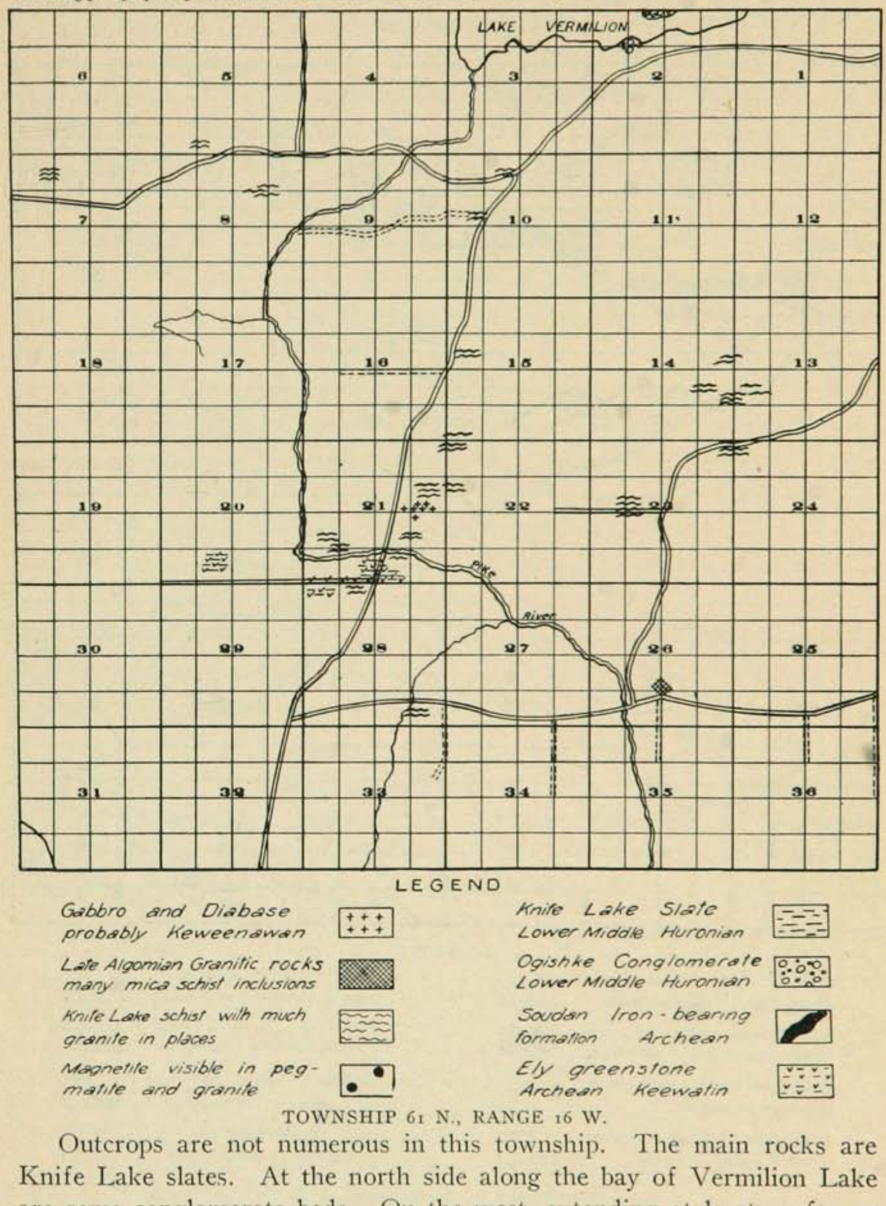


TOWNSHIP 68 N., RANGE 15 W.

This fraction of a township south of Lac La Croix has along the shores many exposures of biotite schist, cut by granite sills and dikes. Northwest of these outcrops, on the Canadian shores, there is a more massive granite, probably connected underground with the Vermilion granite farther south.

TOWNSHIP 61 NORTH, RANGE 16 WEST

Geology by party under John Uno Sebenius; and by F. F. Grout and G. A. Thiel

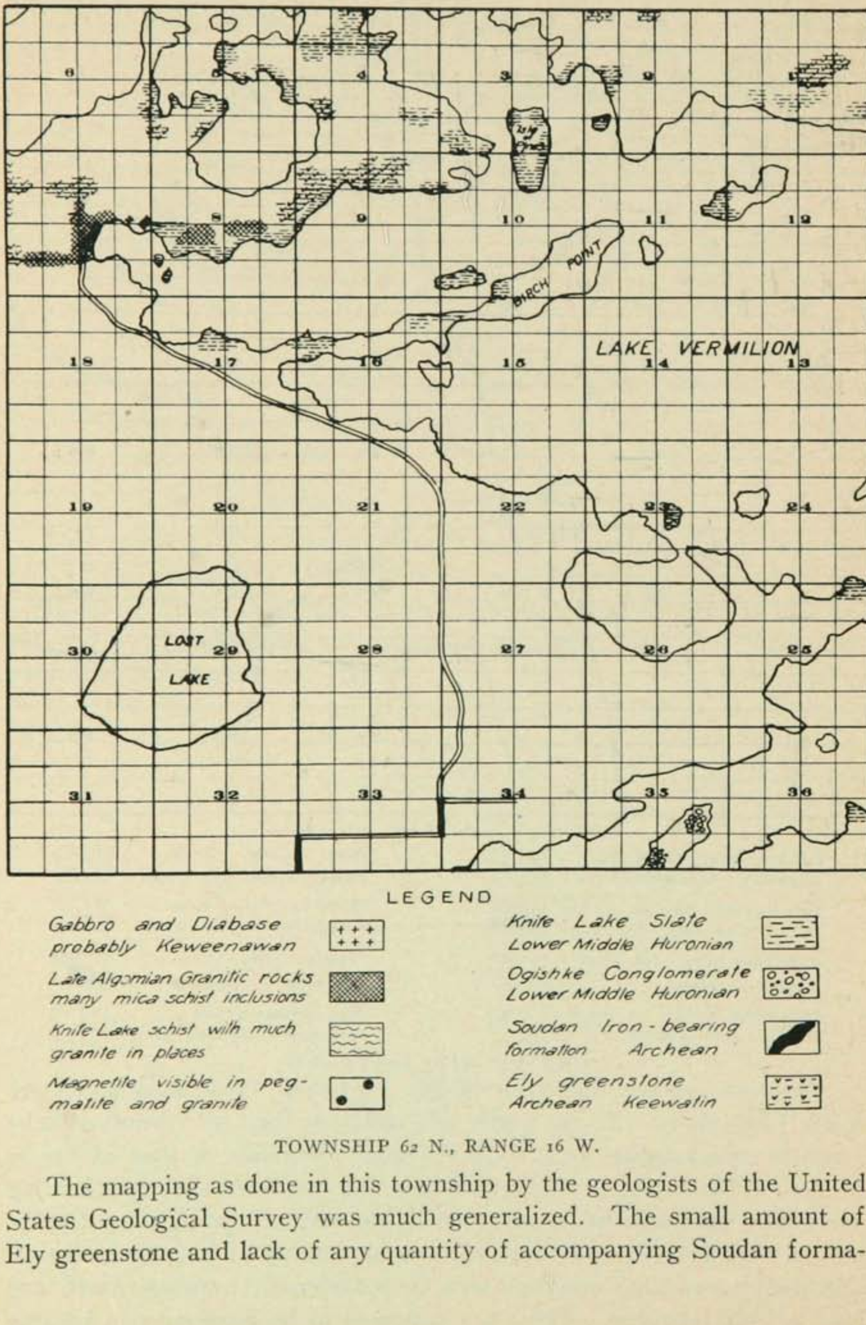


TOWNSHIP 61 N., RANGE 16 W.

Outcrops are not numerous in this township. The main rocks are Knife Lake slates. At the north side along the bay of Vermilion Lake are some conglomerate beds. On the west, extending at least as far as Section 21, is a belt of Ely greenstone, but no associated iron-bearing rocks have been seen by, or reported to, the men of our parties. On the hill north of Pike River in Section 21, is an outcrop of basic igneous rock (diabase) resembling outcrops seen in considerable numbers north and west of this township. These are supposed to be Keweenawan because of their general nature and intrusive relations to Knife Lake slate.

TOWNSHIP 62 NORTH, RANGE 16 WEST

Geology by early state and federal surveys revised by F. F. Grout, G. A. Thiel, and Stanwood Johnston



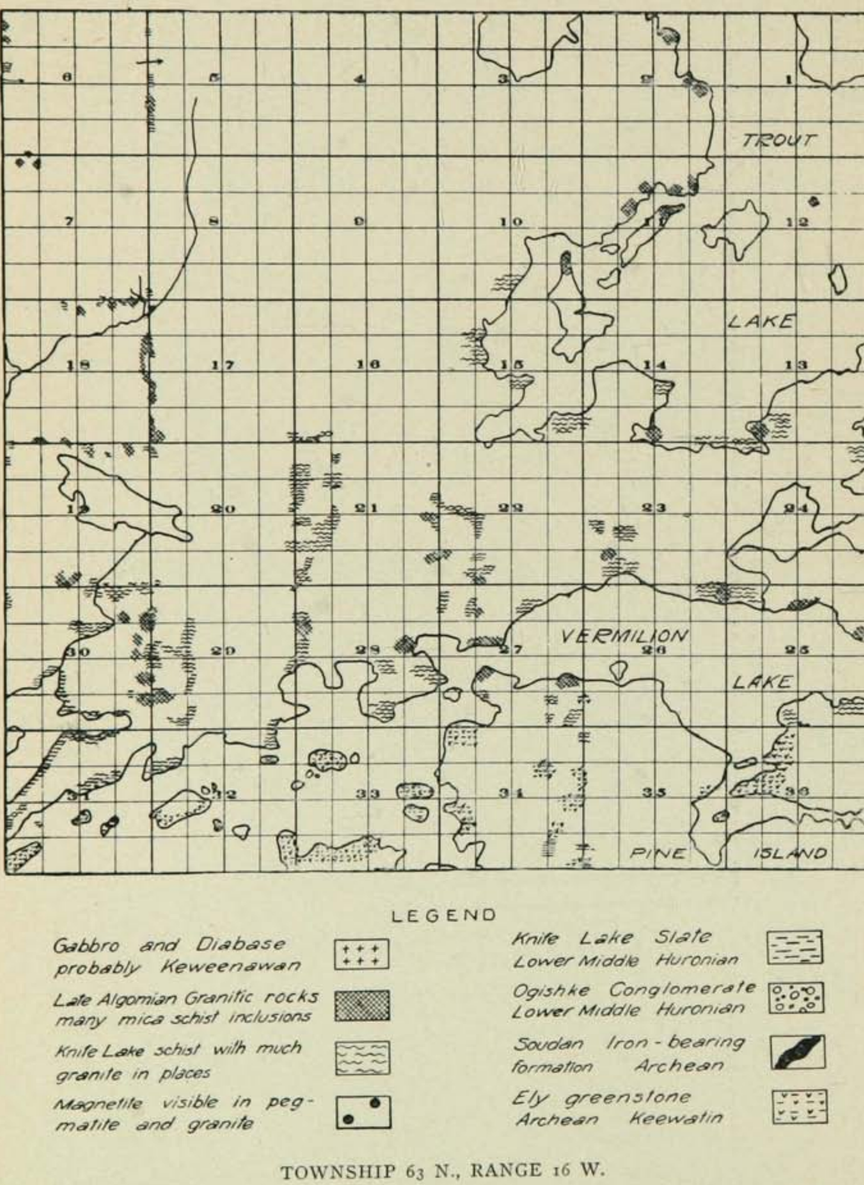
TOWNSHIP 62 N., RANGE 16 W.

The mapping as done in this township by the geologists of the United States Geological Survey was much generalized. The small amount of Ely greenstone and lack of any quantity of accompanying Soudan formation made the detail of relatively little importance. Most of the sections have outcrops of Lower-Middle Huronian sediments. The greenstone forms a few outcrops in the north, and a sodic syenite is intrusive into the greenstone and slates in Sections 7 and 8. Possibly the granite southwest of the township underlies part of the swampy area in Section 31.

In a few places the greenstone and green slate are mineralized with pyrite and crossed by pyritic quartz veins. Gold has been reported but assays by the Minnesota School of Mines Experiment Station showed no gold, silver, or copper.

TOWNSHIP 63 NORTH, RANGE 16 WEST

Geology by early state and federal surveys revised by F. F. Grout, G. A. Thiel, and Stanwood Johnston



TOWNSHIP 63 N., RANGE 16 W.

This township has many exposures of the transition phases from formations of the Vermilion Range to the granite of the Vermilion batholith. At the south on Pine Island is typical Ely greenstone and Knife

Lake slate. On the north shore of Vermilion Lake, and even at points on the north shore of Pine Island, granite dikes become abundant. Among the dikes the greenstone is hornblendic and the Knife Lake slate is greatly changed in appearance—to a biotite schist. Throughout most of the township the confusion of granite intrusive, and hornblende and biotite schist makes mapping very difficult. Granite, however, is certainly more abundant at the north than near Vermilion Lake. Syenitic border phases of the granite occur south of Trout Lake.

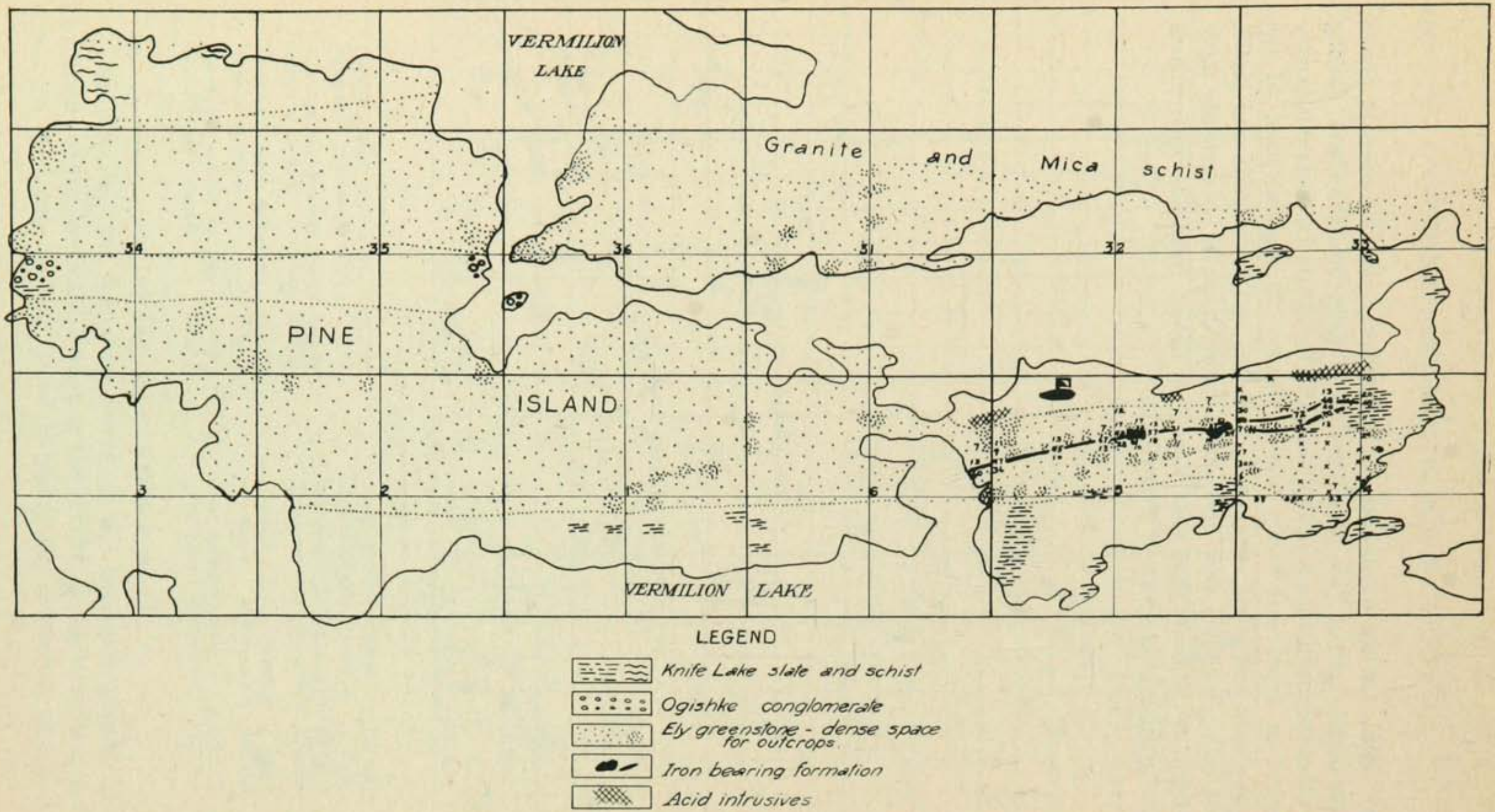
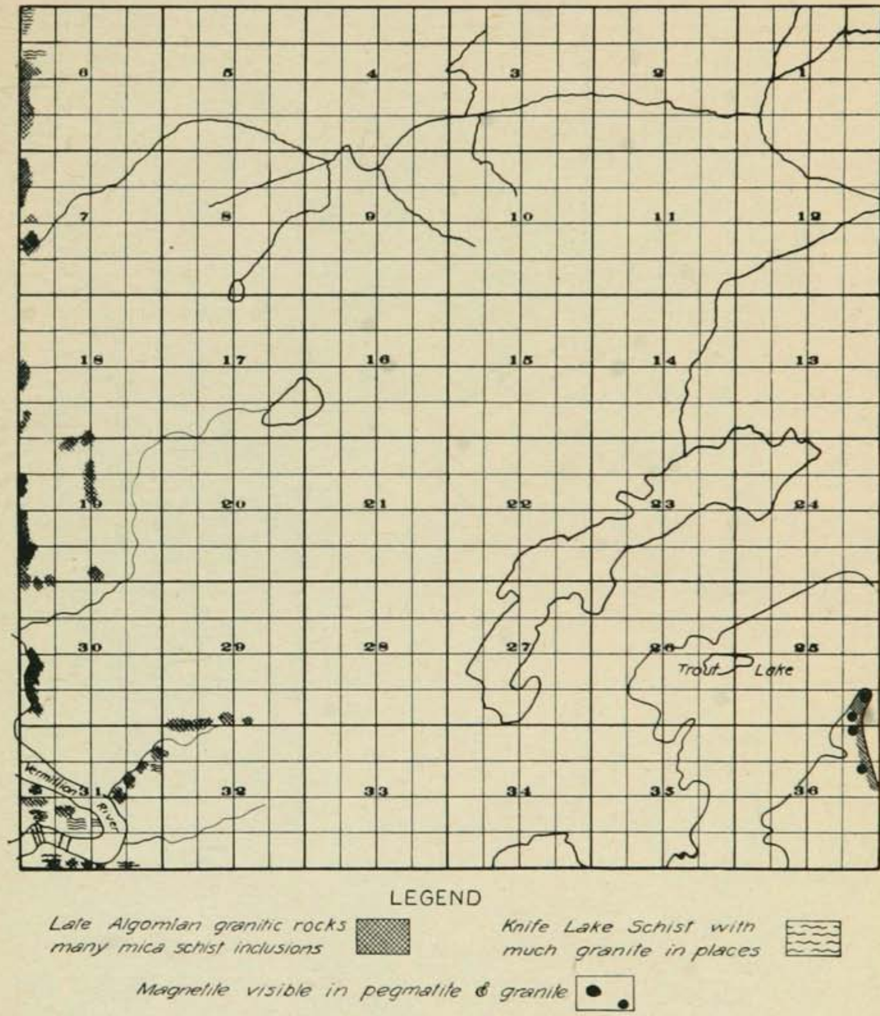


Fig. 10. Geology of Pine Island, Vermilion Lake; parts of T. 62 and 63 N., R. 15 and 16 W. Small figures show dip needle readings over 5° from normal. Crosses show dial compass readings over 10° from normal.

TOWNSHIP 64 NORTH, RANGE 16 WEST

Geology by early state and federal surveys revised by F. F. Grout, G. A. Thiel,

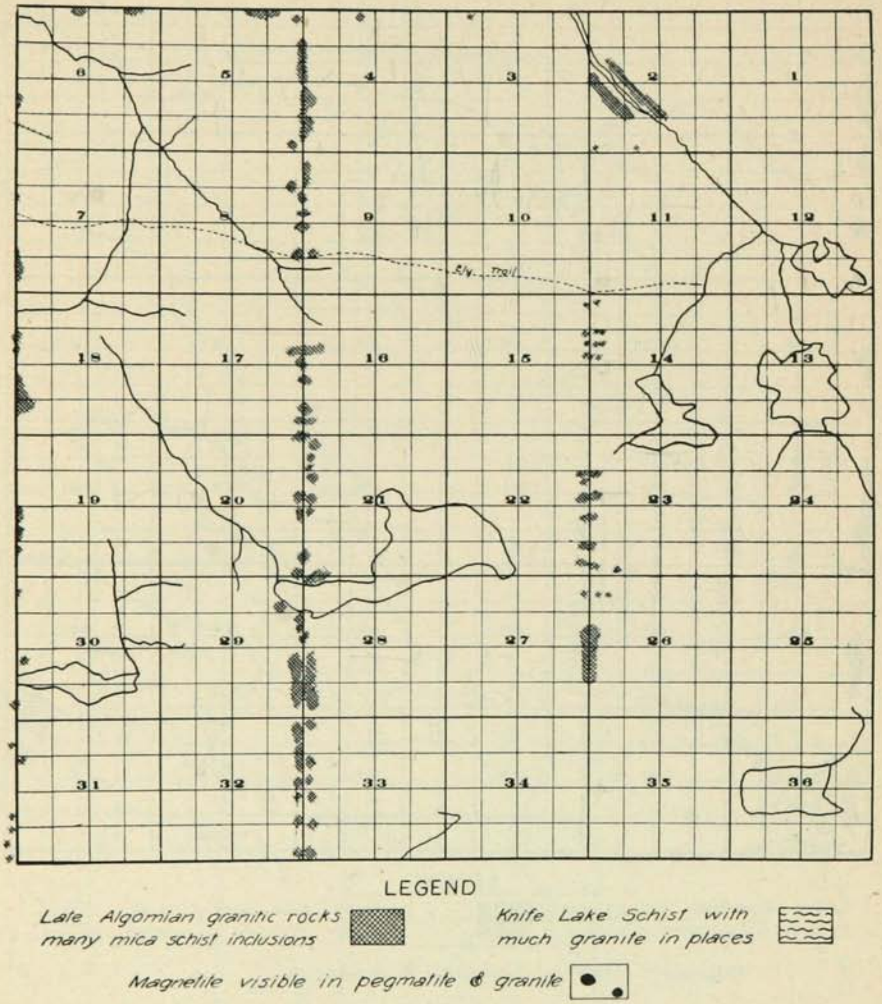


TOWNSHIP 64 N., RANGE 16 W.

At the south of this township the biotite schist forms appreciable outcrops, but the Vermilion granite increases in abundance at the north. On islands in Trout Lake in Sections 25 and 36 there are exposures of perhaps 20 acres in which magnetite may constitute 2 per cent of the rock. Dip needle readings were taken by Edward Steidtmann in this township and north to the boundary along several lines, but no abnormal attraction was found.

TOWNSHIP 65 NORTH, RANGE 16 WEST

Geology by Edward Steidtmann

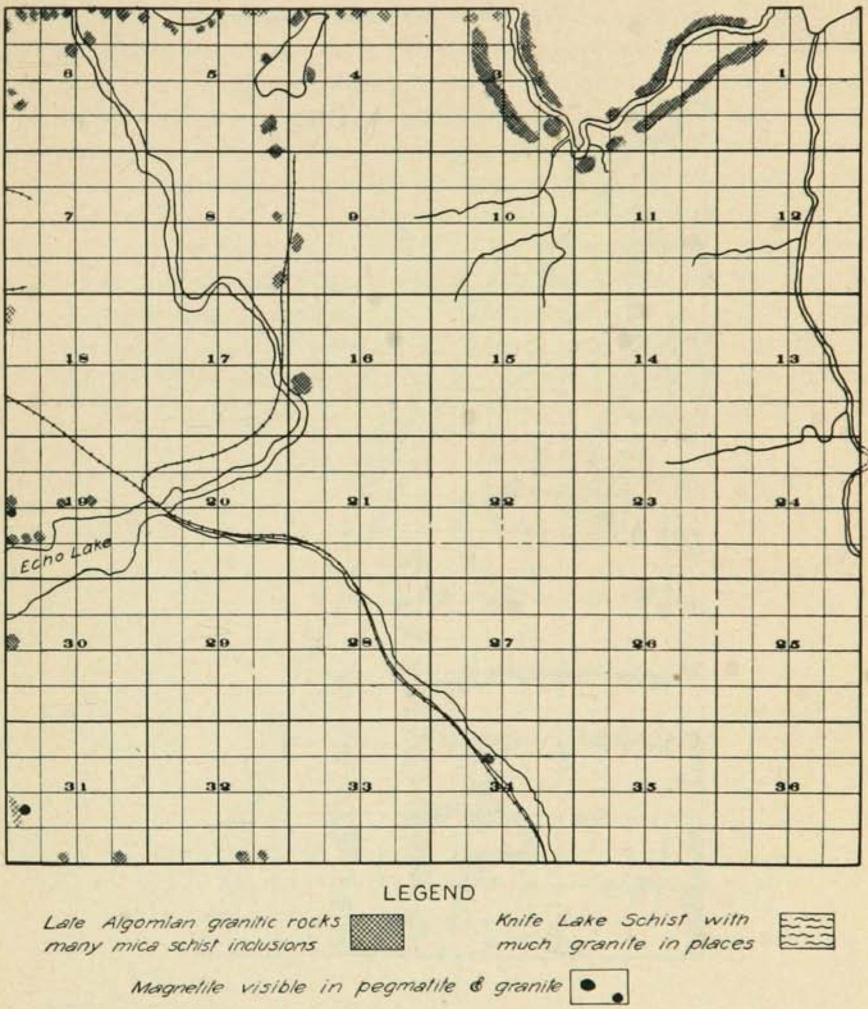


TOWNSHIP 65 N., RANGE 16 W.

This township is in the midst of the area of Vermilion granite. Only a few included biotite schist fragments interrupt the alternation of swamps and granite hills. Many dip needle readings were taken and all were normal.

TOWNSHIP 66 NORTH, RANGE 16 WEST

Geology by F. F. Grout, G. A. Thiel, and Edward Steidtmann



TOWNSHIP 66 N., RANGE 16 W.

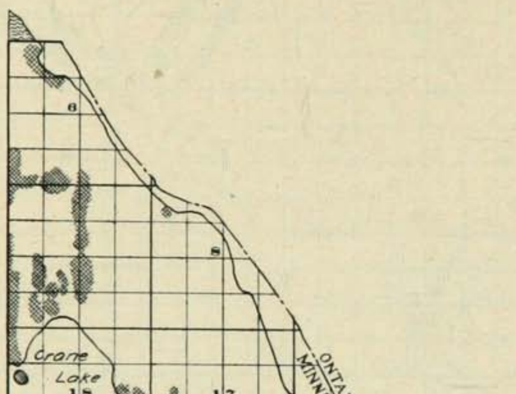
This township is in the midst of the area of the Vermilion granite. Only a few included biotite schist fragments appear. Many dip needle readings were taken and all were normal.

TOWNSHIP 67 NORTH, RANGE 16 WEST

TOWNSHIP 68 NORTH, RANGE 16 WEST

(Small fraction mapped with Township 67 North.)

Geology by F. F. Grout and Edward Steidtmann



LEGEND

Late Algomian granitic rocks many mica schist inclusions

Knife Lake Schist with much granite in places

Magnetite visible in pegmatite & granite

TOWNSHIP 67 N., RANGE 16 W.

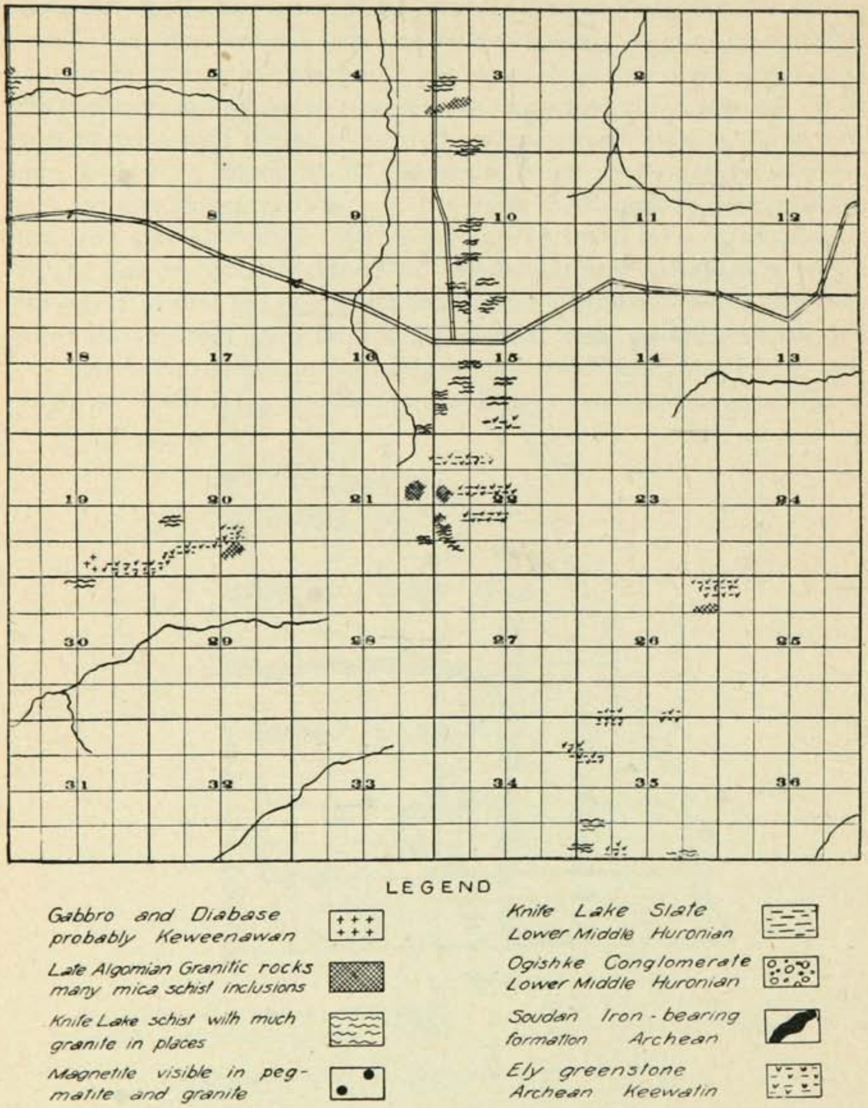
TOWNSHIP 68 N., RANGE 16 W.

These townships are along the north side of the area of Vermilion granite. Near Crane Lake the biotite schist masses are large enough to show on a map of this scale, but elsewhere they are few and small. Nearly everywhere there are small amounts of magnetite in erratic pegmatites. In the southwest, the pegmatites are not so common and magnetite where seen at all, is in the fine to medium grained granite. Exposures of magnetite in pegmatite were noted in Sections 18, 19, 20, 28, 32, and 33, some of them being as large as 20 acres with magnetite estimated at 2 per cent. An area of 20 acres in the SW¼ of the SE¼, Section 33, may be a little higher in magnetite than the others. In Sections 20, 29, 30, and 32 considerable areas of normal granite show about one per cent of magnetite. Dip needle readings were taken along several lines through this township by Edward Steidtmann but no abnormal attraction was found.

The map includes also a small fraction making up T. 68 N., R. 16 W.

TOWNSHIP 61 NORTH, RANGE 17 WEST

Geology by party under John Uno Sebenius; and by F. F. Grout, G. A. Thiel, and F. E. Williams



TOWNSHIP 61 N., RANGE 17 W.

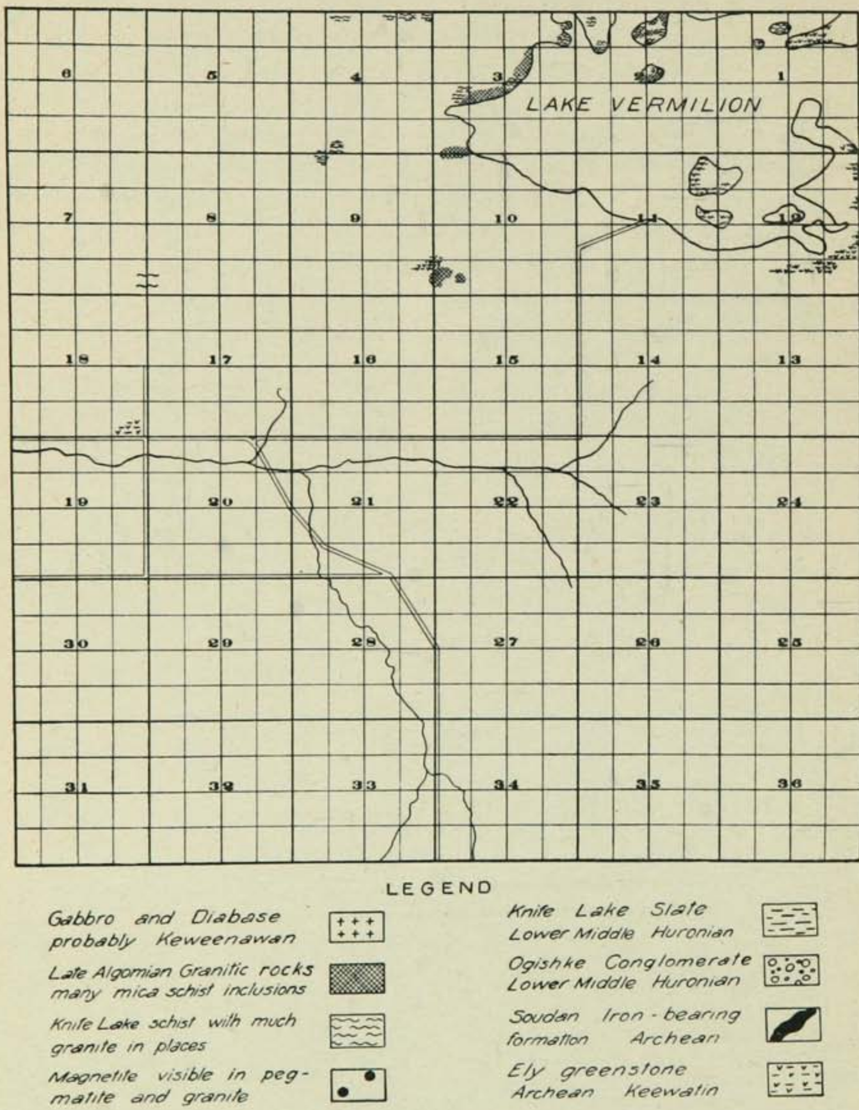
This township shows mostly gravelly drift. There are a number of masses of schist and granite, in such irregular and disconnected outcrops that the structure can not easily be ascertained. Well characterized Ely greenstone can be found in the southern half, somewhat altered to hornblende rocks by intrusions of the Giants Range granite. Slates of the Knife Lake formation are folded into rudely parallel belts alternating with the greenstone, and altered by the same granite to biotite schists. They are well exposed along the roads.

The granite of the small masses in the northern part of this town are so far from either of the main batholiths,—the Giants Range and Vermilion masses,—that their connections are uncertain.

Several years ago some exploration was done by shallow drilling east of Angora in Section 7. No information could be obtained as to the results. No abnormal dip needle readings were noted except at the east side of Section 21, where the reading was one degree from normal.

TOWNSHIP 62 NORTH, RANGE 17 WEST

Geology by F. F. Grout, G. A. Thiel, Stanwood Johnston, and F. E. Williams



TOWNSHIP 62 N., RANGE 17 W.

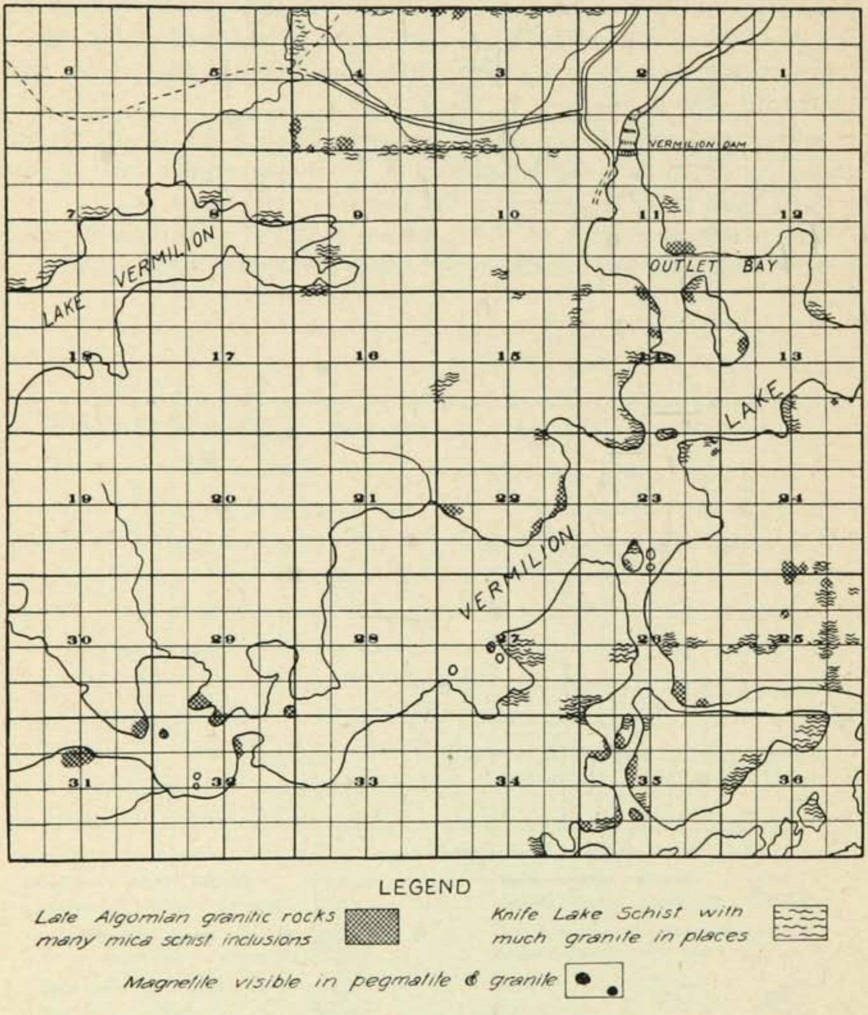
Few outcrops are known in the southern part of this township, but the bed rock is probably a mixture of granite and biotite schist of the Knife Lake formation. The northern part of the town, however, has much more numerous outcrops of Ely greenstone. This appears to be the western extension of a long belt or series of belts crossing Vermilion Lake and extending from far to the east. In this township the main belt of Ely greenstone is much restricted. There are, however, some small anticlines between Huronian sediments, and the belt may be continuous. The lake beach of the glacial Lake Agassiz has been traced as far east as this township, and the soil of the Little Fork River Valley is for that reason different on the west of this town.

Along the northern side of the township Knife Lake schists are intruded by the syenitic border phases of Vermilion granite, and a particularly good exposure occurs on the lake shore in Section 3.

The northwest portion of the town was explored by dip needle tests, by F. E. Williams, and no abnormal readings were obtained anywhere.

TOWNSHIP 63 NORTH, RANGE 17 WEST

Geology of the early work of the Minnesota Geological and Natural History Survey revised by F. F. Grout, Stanwood Johnston, and G. A. Thiel



TOWNSHIP 63 N., RANGE 17 W.

This township includes the outlet of Vermilion Lake. In the bay of the lake, south of the outlet, there is a complete gradation from schist to granite. The present interpretation of the gradation is that the granite intrudes the schist *lit-par-lit* and possibly assimilates a little of it.

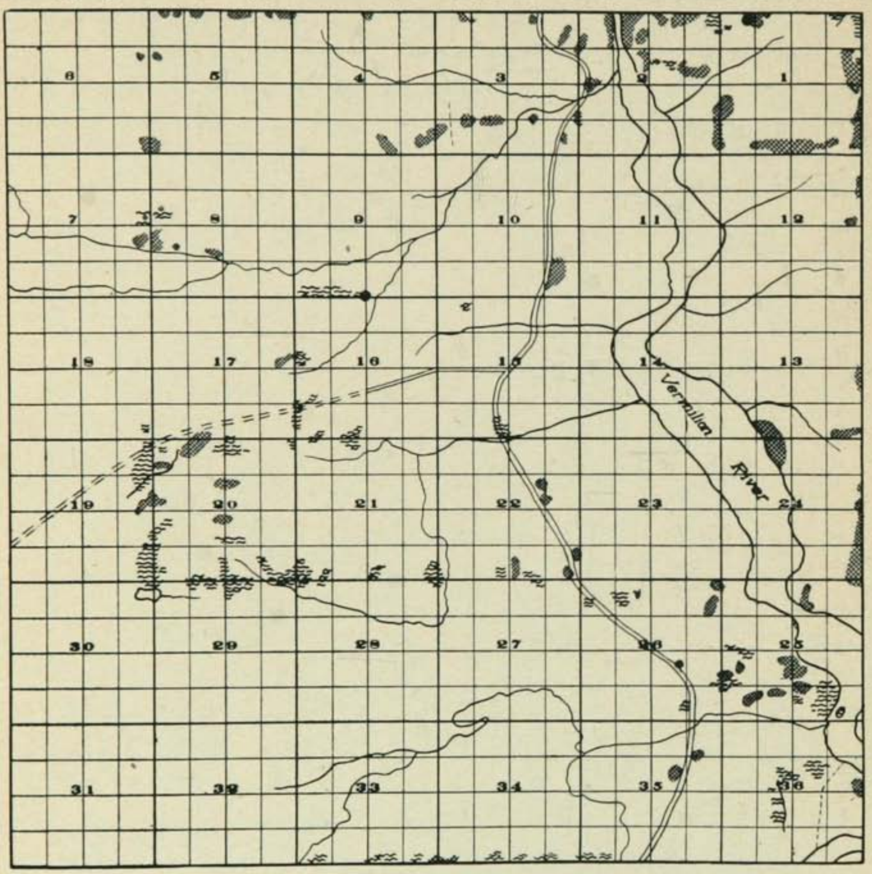
Most of the rock is schist of the Knife Lake formation. The granite intruding the central and southwest parts of the township seems to be related to the Vermilion granite farther north. At the southeast corner there are some small areas of green rock, but its age and relations are not clear. It may be a green phase of the mica schist, or the Ely greenstone which lies a few rods farther south.

The ridge in the center of Section 14 has exposures of green rock but this appears to be a chloritic fault breccia or gouge, rather than a distinct formation.

The southwest parts of the town are more drift-covered than other parts.

TOWNSHIP 64 NORTH, RANGE 17 WEST

Geology by F. F. Grout, G. A. Thiel, Stanwood Johnston, and Edward Steidtmann



LEGEND

Late Algomian granitic rocks many mica schist inclusions

Knife Lake Schist with much granite in places

Magnetite visible in pegmatite & granite

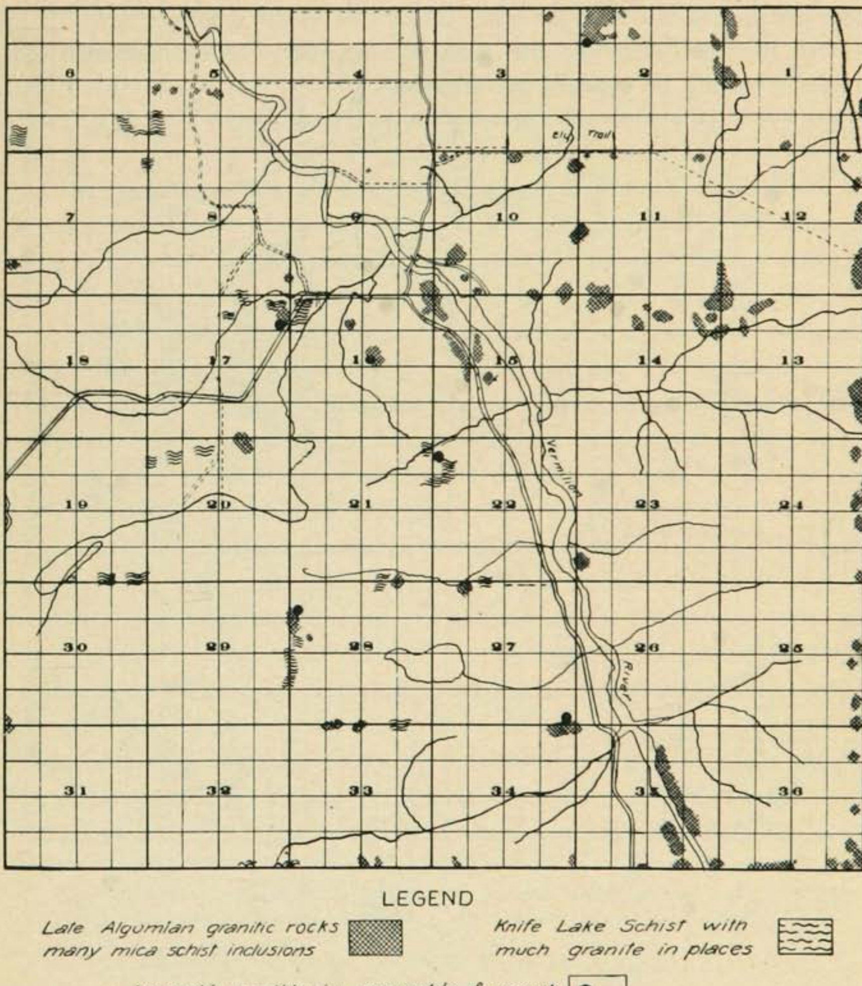
TOWNSHIP 64 N., RANGE 17 W.

This township has fairly numerous exposures and includes the transition from areas dominantly Knife Lake schist on the south, to those dominantly granitic on the north. No other rocks were seen. Gravelly drift is abundant.

Small and lean deposits of magnetite in pegmatite dikes were seen in scattered spots, chiefly in Sections 1 and 16, of this township. No area of 10 acres seems to carry as much as 2 per cent magnetite, and none of the several lines tested by Edward Steidtmann shows any abnormal magnetic attraction.

TOWNSHIP 65 NORTH, RANGE 17 WEST

Geology by F. F. Grout, Stanwood Johnston, and Edward Steidtmann



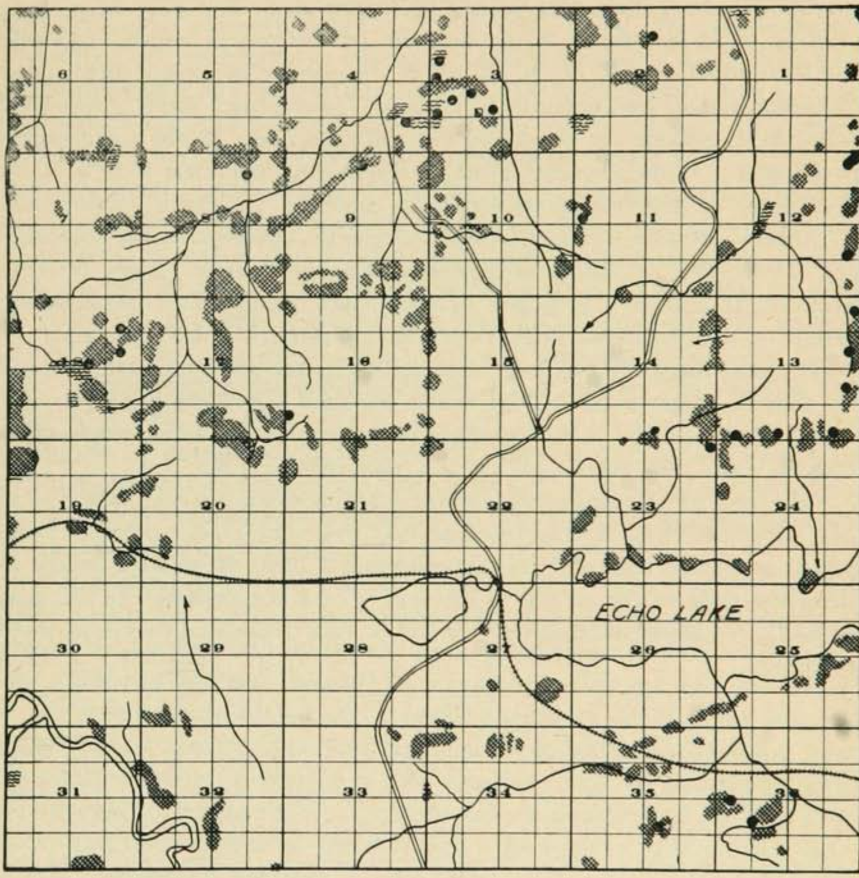
TOWNSHIP 65 N., RANGE 17 W.

This township is north of the main area of biotite schist of the Knife Lake formation, but the Vermilion granite which outcrops at many places is nowhere free from inclusions of the schist. Some schist areas are so large they may be roof pendants rather than broken fragments. Magnetite outcrops in noteworthy amounts in Sections 16, 22, 27, and 28. No large areas seem to have more than 2 per cent magnetite. The bluff near the road in Section 16, about a mile west of the "halfway house" on the Crane Lake Road, is one of the few places where typical lean magnetite pegmatite can be seen near an automobile road. Most of the deposits are reached only by canoe or on foot in the woods.

No abnormal magnetic attraction was discovered by the thorough test of the township by Edward Steidtmann.

TOWNSHIP 66 NORTH, RANGE 17 WEST

Geology by F. F. Grout and Stanwood Johnston



LEGEND

Late Algomian granitic rocks many mica schist inclusions

Knife Lake Schist with much granite in places

Magnetite visible in pegmatite & granite

TOWNSHIP 66 N., RANGE 17 W.

This township is well toward the center of the area of the Vermilion granite batholith, but has in nearly every outcrop some fragments of Knife Lake biotite schist included in the granite.

This area has been the center of most active exploration for magnetite pegmatites in recent years. The parties of the Survey have therefore searched the region with care and have obtained fairly definite data regarding the limits of the prospects. From the center of active exploration in

Sec. 3, T. 66 N., R. 17 W., the exposures may be found scattered on all sides for many miles. They are much less abundant, however, in the surrounding townships than in this particular one. The comparison may perhaps be shown fairly by the number of sections in which magnetite has been noted. In T. 66 N., R. 17 W., magnetite in conspicuous grains in pegmatite has been noted in 15 sections. In the town south, it has been noted in 5 sections; in the town west, in 5 sections; in the town north, in 8 sections; in the town northeast, in 8 sections. It is clear that T. 66 N. is a center of distribution, as well as a center of activity in exploration.

Several locations of conspicuous magnetite outcrops in the township are noteworthy. A small area occurs near the quarter corner between Sections 35 and 36. It is one of the richest looking outcrops, but the extent of the magnetite body shown in exposure is small. Crystals of nearly pure magnetite as large as a hen's egg are not rare, but it would be difficult to get a carload of crude ore that would assay 35 per cent iron. In Sections 9, 18, and 20 there are areas of many acres which might contain 2 per cent magnetite, but few that contain 3 per cent.

The rest of the magnetite outcrops in this township and in the next one north are those of the International Iron and Steel Company prospects; and some lean outlying exposures that have no interest except to show the wide extent of the formation. These are described in the next section. No abnormal magnetic attraction was discovered except as there reported.

MINE OF THE INTERNATIONAL IRON AND STEEL COMPANY

The International Iron and Steel Company with offices in Minneapolis have explored a property in Sec. 3, T. 66 N., R. 17 W., for several years. The leader of the enterprise was for a time Mr. Charles Eden, who had previously explored a similar deposit near Ash River Falls. A camp was built, and a series of test pits and drill holes was put down. One shaft northeast of the camp is said to be 90 feet deep. Four holes, drilled in 1921, are located on the sketch, (Fig. 11). Dr. J. H. Bong, vice-president of the company, reported to the Survey as follows: the hole southeast of the shaft is said to have been drilled 1,200 feet and found 32 feet of "ore"; a hole a short distance north of the shaft is 89 feet deep; a hole northwest of the shaft is said to have been drilled over 500 feet, finding 57 feet of "ore"; the hole farther west was deep but found only "lean ore." Some further drilling was planned, but nothing was done in the summer of 1924.

Figure 11 shows the outcrops seen by Survey parties, and estimates as to the per cent of magnetite in the exposures. The magnetic attraction was tested over much of the area, every 50 feet, and the abnormal readings are shown on the same sketch.

The relation of readings to ore is very rough. For example, in the NE¼ of the SE¼, Sec. 4, some abnormal dial readings occur nearly a quarter of a mile north of the outcrops showing magnetite, with many rock exposures between showing no magnetite. This can not reasonably be attributed to underlying ore connected with the outcropping belt of magnetite, for similar abnormal readings occur south of the belt. The dip needle readings in Section 3 show a similar lack of correlation with the exposed magnetite rock. It may be said in summary of the magnetic work, that the variation in the readings is probably a little greater near ore than elsewhere, but only a very little.

The outcrops shown in Figure 11 are somewhat generalized but can be located by the use of the sketch. The richer areas fade into lean areas in a single outcrop and the belt shown is not to be considered solid ore. In several places one can walk across the belt where outcrops are abundant and find no visible magnetite. Nevertheless when magnetite is found it seems to be in this belt. Outcrops on both sides are free from magnetite.

The richest outcrop seen, large or small, would not assay more than 15 per cent of iron in the form of magnetite. At the 90-foot shaft in the NE¼ of SW¼, Sec. 3, the writer selected two samples from the dump: the first is of the magnetite-bearing material (from which the owners may have already taken some of the best); and second the non-magnetic rock. These assayed 8.11 per cent magnetic iron in the magnetite rock and .26 per cent magnetic iron in the waste. In the belt mapped

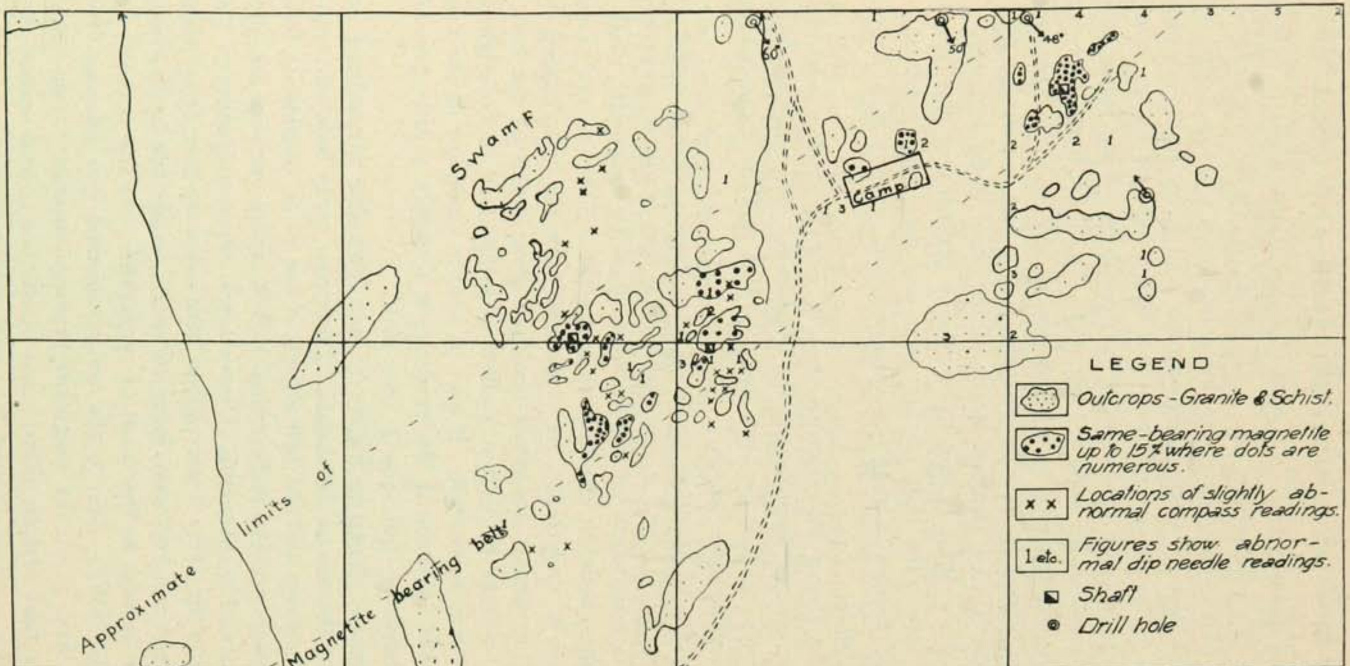


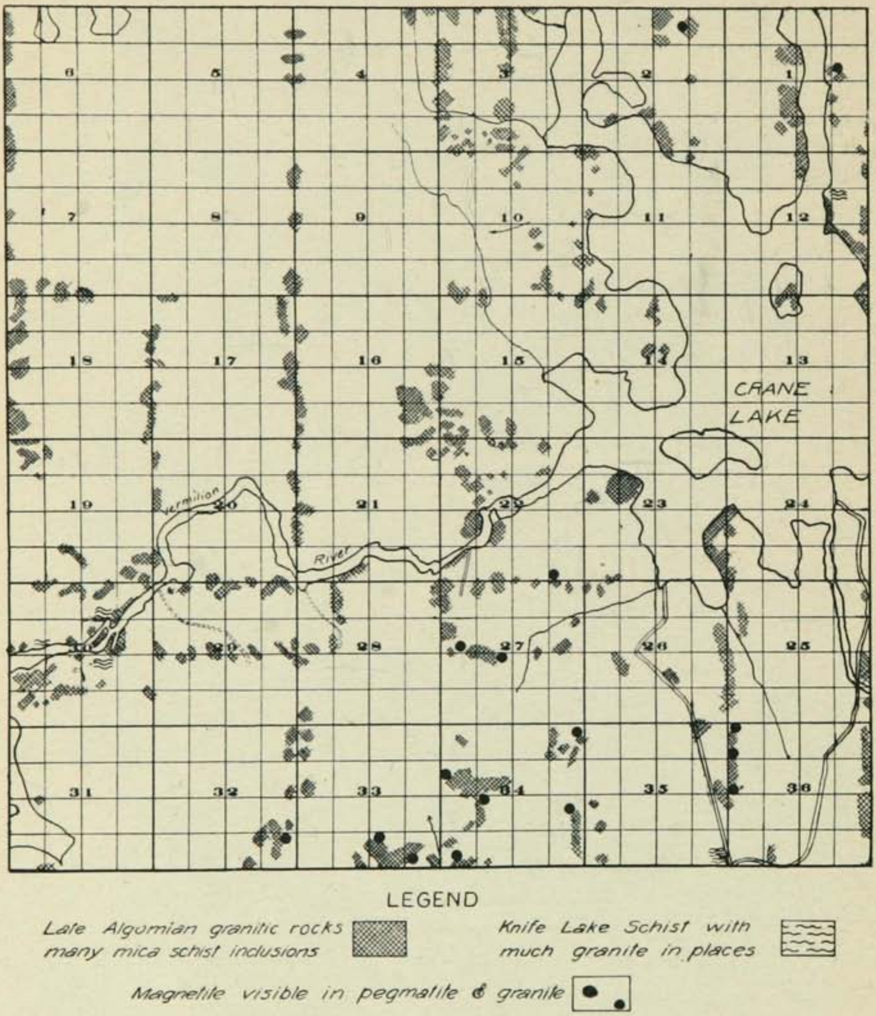
Fig. 11. Map of the southeast quarter of Section 4 and southwest quarter of Section 3, T. 66 N., R. 17 W., where the International Iron and Steel Company have been conducting active explorations.

as magnetite-bearing, it is certain that not over 10 per cent of the rock exposed is as rich as that assayed as magnetite rock. A reasonable estimate of the magnetic iron content of the whole belt is therefore not over 2 per cent. See pages 64 to 68 as to the size and quality of magnetite deposits.

The rocks at the shaft are pegmatite, granite, hornblende schist, and sedimentary biotite schist in great confusion. Most of the magnetite occurs in the pegmatite dikes, stringers, and segregations. The structure is probably that of a border zone between an intrusive granite and its brecciated roof or roof-pendant. The ore-bearing pegmatite stringers are very crooked, but generally strike north to northwest. The granite is more massive and free from inclusions in Section 10 south of the shaft, and the swampy ground north of the belt is an indication of soft schists. The average strike of the schists, N. 60° E., agrees with the trend of the belt on the map. If this view of the geologic setting is correct, the belt may be extensive in depth as well as laterally. There seems to be no reason to expect richer material, nor magnetite rock in larger more uniform bodies underground than at the surface. No prediction as to where the magnetite will be found can be made ahead of actual exploration.

TOWNSHIP 67 NORTH, RANGE 17 WEST

Geology by F. F. Grout, Stanwood Johnston, and Edward Steidtmann



TOWNSHIP 67 N., RANGE 17 W.

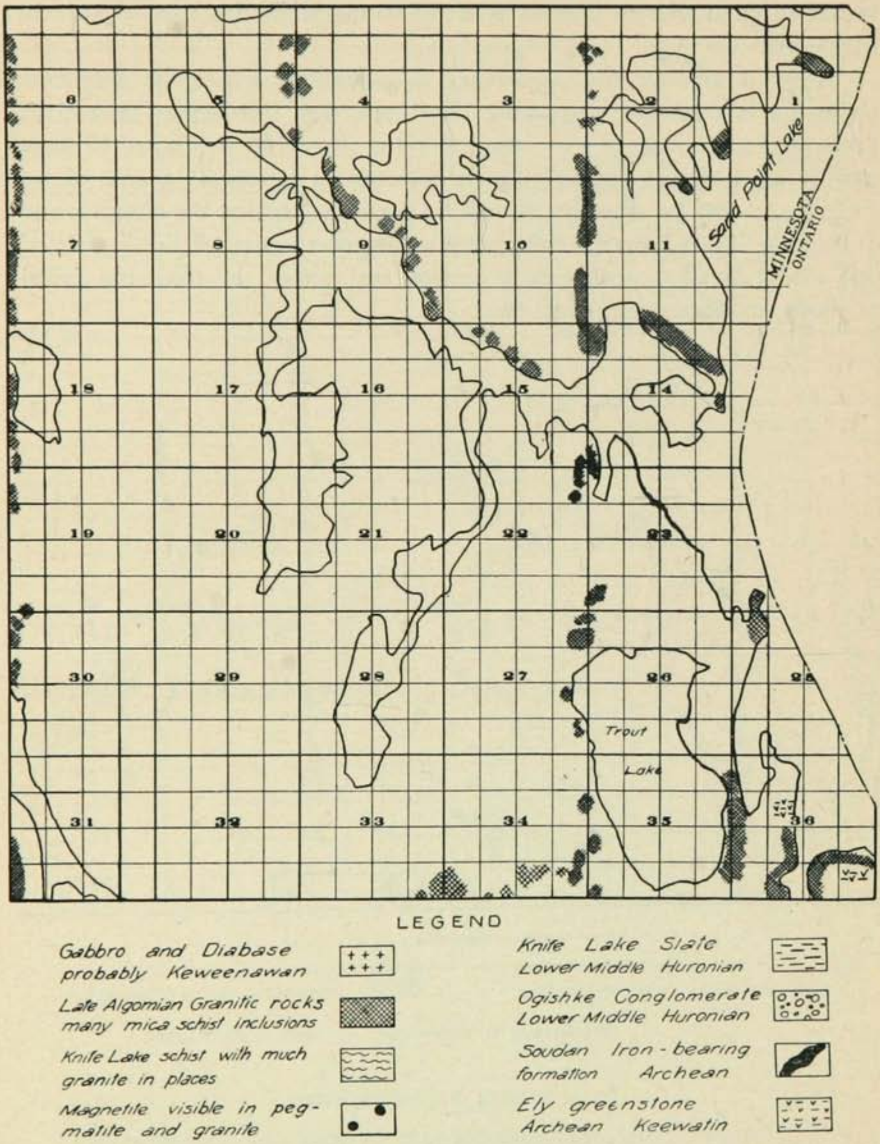
The numerous outcrops in this township are almost uniformly Vermilion granite with inclusions of biotite schist, both crossed by pegmatite dikes and stringers.

Magnetite is commonly seen, especially in the pegmatites such as are characteristic of the whole region. In Section 33, however, there is an exposure about 50 feet square which may have 20 per cent iron as magnetite; it is about 200 paces north and 1,150 west of the southeast corner of the section and is clearly a local occurrence—surrounded by leaner rock, so that an area of 20 acres would show less than 5 per cent magnetite.

There is also an odd occurrence in Section 1, where the magnetite pegmatite is found in segregated bunches a few feet across instead of dikes. All of it is very lean. Fine grained magnetite was noted in some granite of normal texture, in small outcrops in Sections 35 and 36, of the same township. Finally, there have been reports that the compass and dip needle showed strong deflections in the north part of Section 27 of this town; detailed work in this section and across the township failed to show any abnormal attractions.

TOWNSHIP 68 NORTH, RANGE 17 WEST

Geology by F. F. Grout and Edward Steidtmann

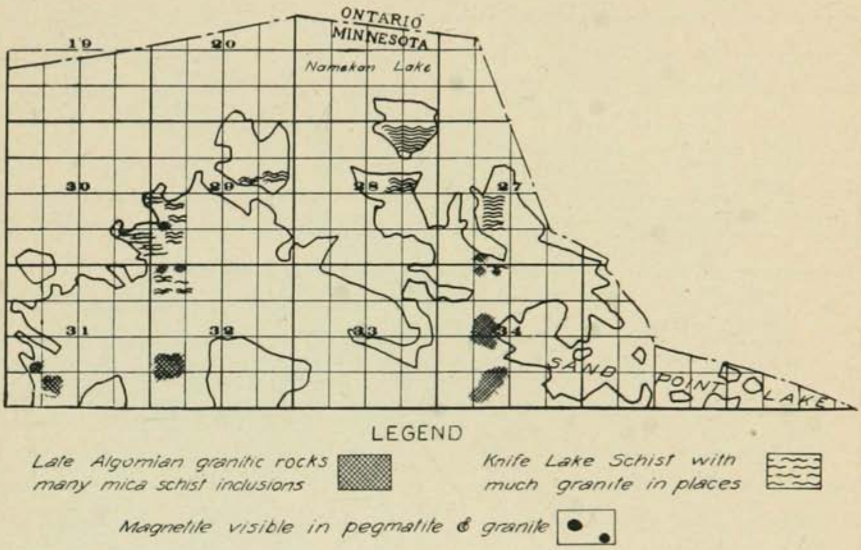


TOWNSHIP 68 N., RANGE 17 W.

The Vermilion granite is the chief formation exposed in the township and on the shores of Sand Point Lake the granite is remarkably uniform in grain, and free from pegmatite and schist inclusions. Some rocks on the south side of Sand Point Lake are hornblendic and possibly are metamorphosed from Ely greenstone; or they may be early phases of the granite. Magnetic mapping by Edward Steidtmann failed to reveal any abnormal attraction.

TOWNSHIP 69 NORTH, RANGE 17 WEST

Geology by F. F. Grout

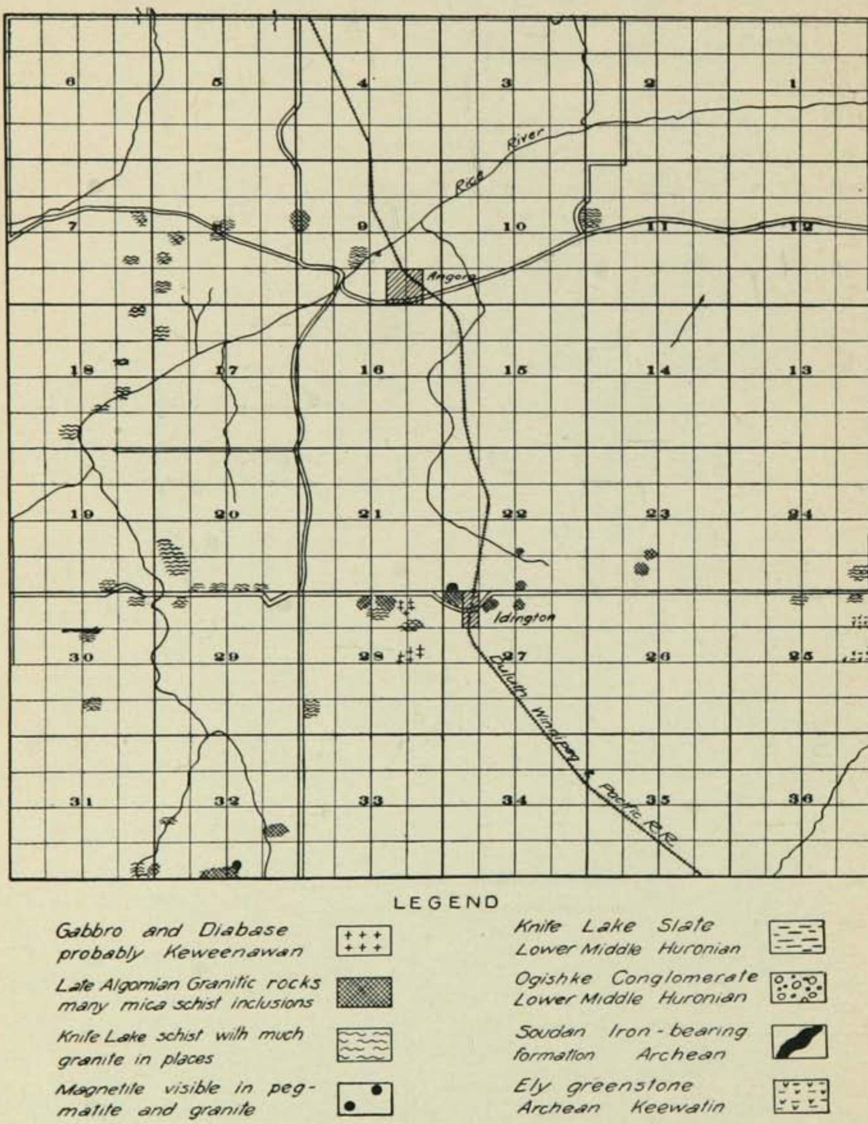


TOWNSHIP 69 N., RANGE 17 W.

In this fraction of a township there are many outcrops of Vermilion granite, but near the international boundary it is in contact with biotite schists. This contact is more definitely located, and not so much confused by minor intrusions as the contact south of the granite. No abnormal magnetic attraction has been discovered.

TOWNSHIP 61 NORTH, RANGE 18 WEST

Geology by party under John Uno Sebenius; and by G. A. Thiel, F. E. Williams, and F. F. Grout



TOWNSHIP 61 N., RANGE 18 W.

The bed rock in most of this township is biotite schist of the Knife Lake formation, but an area of older greenstone extends into Section 25 from the east; and the Giants Range granite, outcropping in the southern row of sections, has several small offshoots towards the center of the township. Small masses of a later basic intrusive occur in Section 28. The drift and swamps conceal so much of the rock that the relations are only roughly estimated. The lake beach of glacial Lake Agassiz crosses the north side of the town.

The Giants Range granite is cut by pegmatite dikes containing magnetite in the northwest corner Section 27, and a few miles south of the town line in the S.W.¼ of Sec. 9, T. 60 N., R. 18 W. This is somewhat similar to the magnetite pegmatites of the Vermilion granite, and suggests a connection in the sources of the two batholiths. The area between the two is so little altered, however, that the dikes can hardly be assumed to be related to the distant outcrops of Vermilion granite; they are evidently pegmatites of the Giants Range.

The magnetic attractions shown in this town (Fig. 12) are apparently related to a granite contact, but since the rocks are not exposed there may be some iron-bearing formation under the drift. The northern part of the township seems to show normal attraction everywhere.

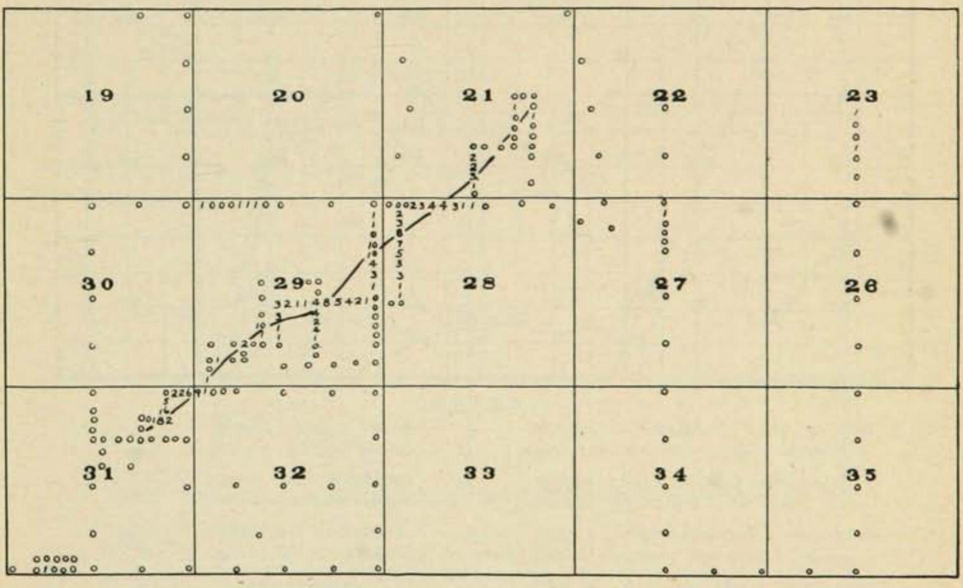
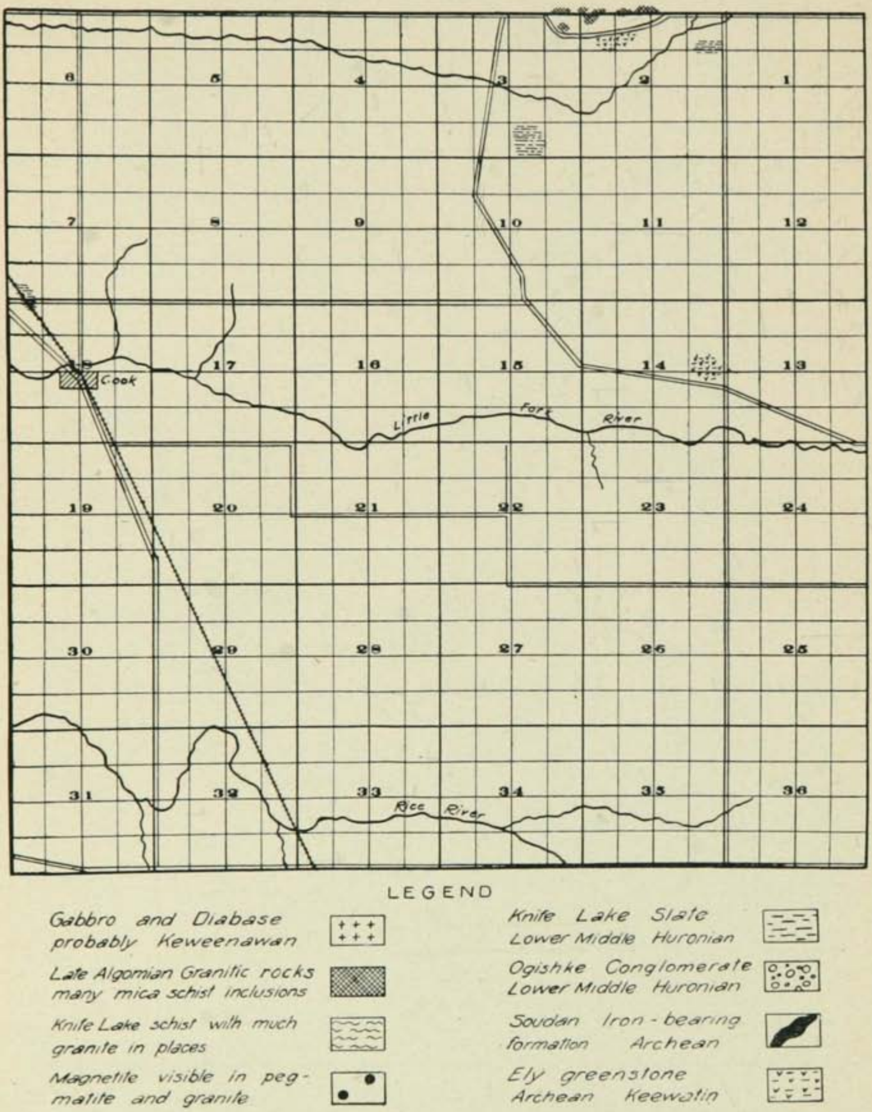


Fig. 12. A sketch showing dip needle readings by F. E. Williams in the southwest part of T. 61 N., R. 18 W.

TOWNSHIP 62 NORTH, RANGE 18 WEST

Geology by F. F. Grout



TOWNSHIP 62 N., RANGE 18 W.

This township is probably crossed by two belts of Ely greenstone and two of Knife Lake slate, alternating with them. Outcrops are few, but the main features of the bed rock geology are estimated from those seen and those in adjoining townships. The Knife Lake slate (with a basic dike) is exposed north of Cook in a railway cut. This is fresher, less micaceous and apparently shows less effect of granite intrusion than any other outcrops of slate west of Vermilion Lake. Ely greenstone forms a hill in Section 14, and another at the northeast corner of Section 3. In this last outcrop the greenstone is intruded by many small bodies of the granite which forms a considerable area a little farther north. The confused petrographic character and lack of exposures in the adjoining country may throw some doubt on its correlation with the Ely greenstone.

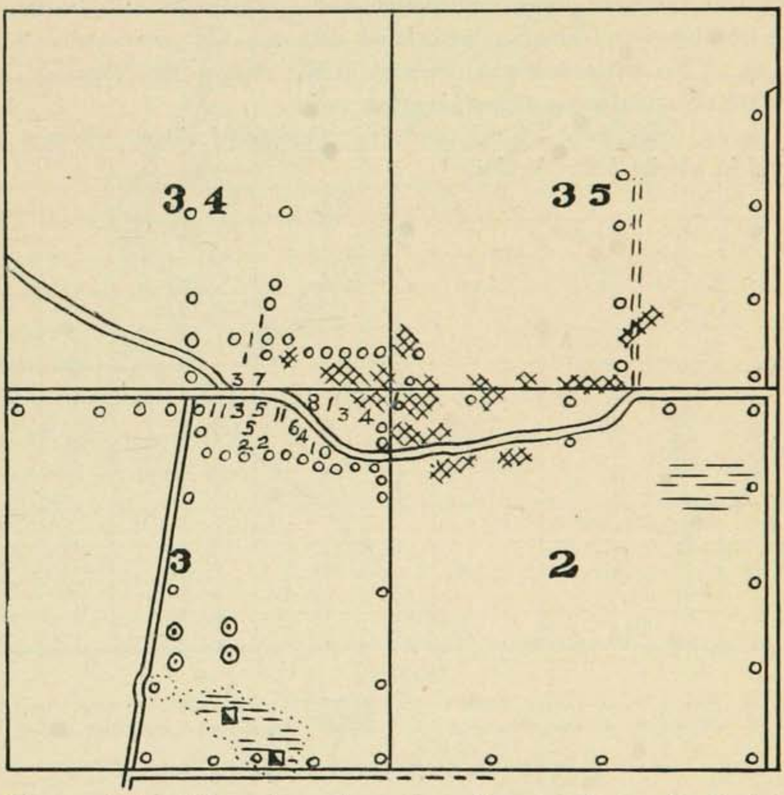


Fig. 13. Sketch of the geology and magnetic readings along the township line between Towns 62 and 63 N., R. 18 W. Small circles show normal magnetic attraction. Circles with dots show locations of drill holes. Readings and geology by F. E. Williams and Frank F. Grout. The cross lined areas are outcrops of granite and hornblendic rocks resembling hornblendite or altered Ely greenstone. In the eastern part of Section 2 and south side of Section 3, the rocks seem to be Huronian.

In the southeastern part of Section 3 there is an "island in the swamp," a low outcrop of cherty carbonate rock that is probably an unusual phase of Huronian sediment. Some iron ore samples have been reported, but no magnetic attraction could be detected and the rock now exposed has more manganese stain than iron. Prospects do not seem to be promising.

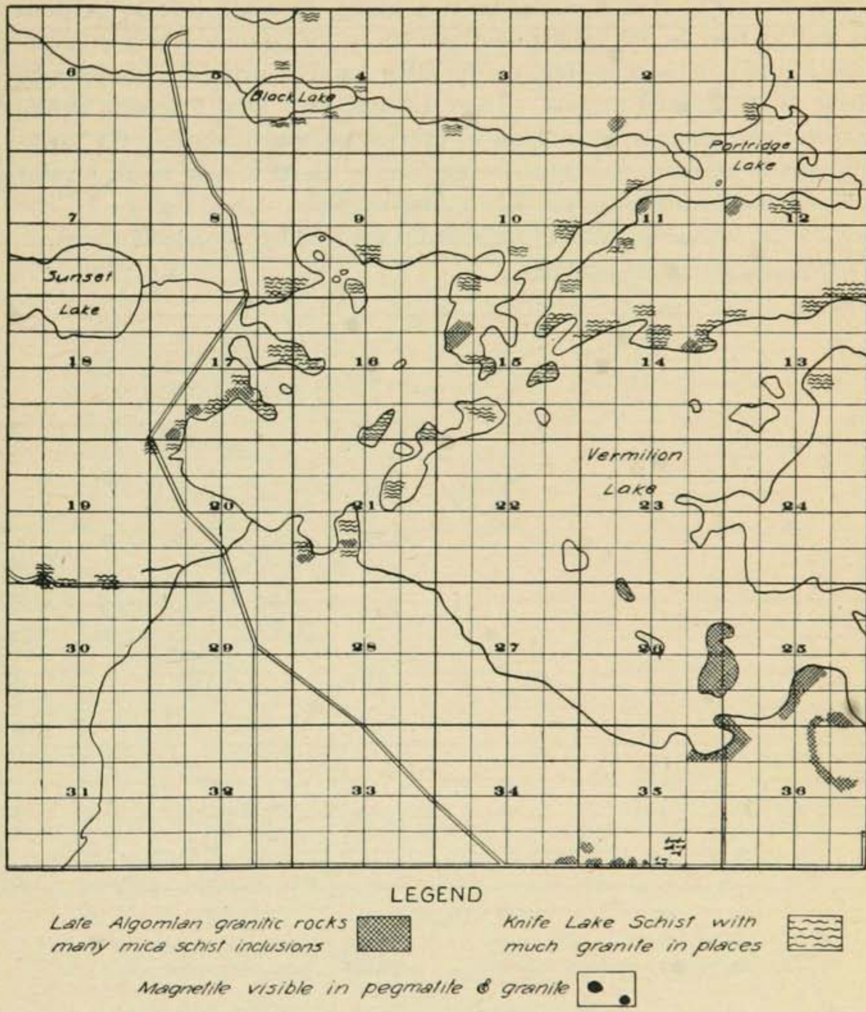
Several years ago the Beatty Brothers dug some test pits and drilled holes to a depth of about 100 feet in this rock, hoping to find iron formation. They concluded it was igneous rock with a very small amount of magnetite, no better than at the surface.

Some magnetic rock deflects the dip needle in Section 3, northeast of this outcrop, where the east-west road bends south around a hill. This is in an area that seems to be Ely greenstone, intruded by granite and felsites. The magnetic attraction suggests a contact effect, but since the rocks near the most intense attraction are concealed, it may be due to some iron-bearing formation associated with the Ely greenstone. (See Fig. 13.) No attraction was detected in the rest of the township, and there are no other signs of iron-bearing rocks.

The soil over most of the township consists of clayey material deposited in glacial Lake Agassiz.

TOWNSHIP 63 NORTH, RANGE 18 WEST

Geology by N. H. Winchell, F. F. Grout, and F. E. Williams



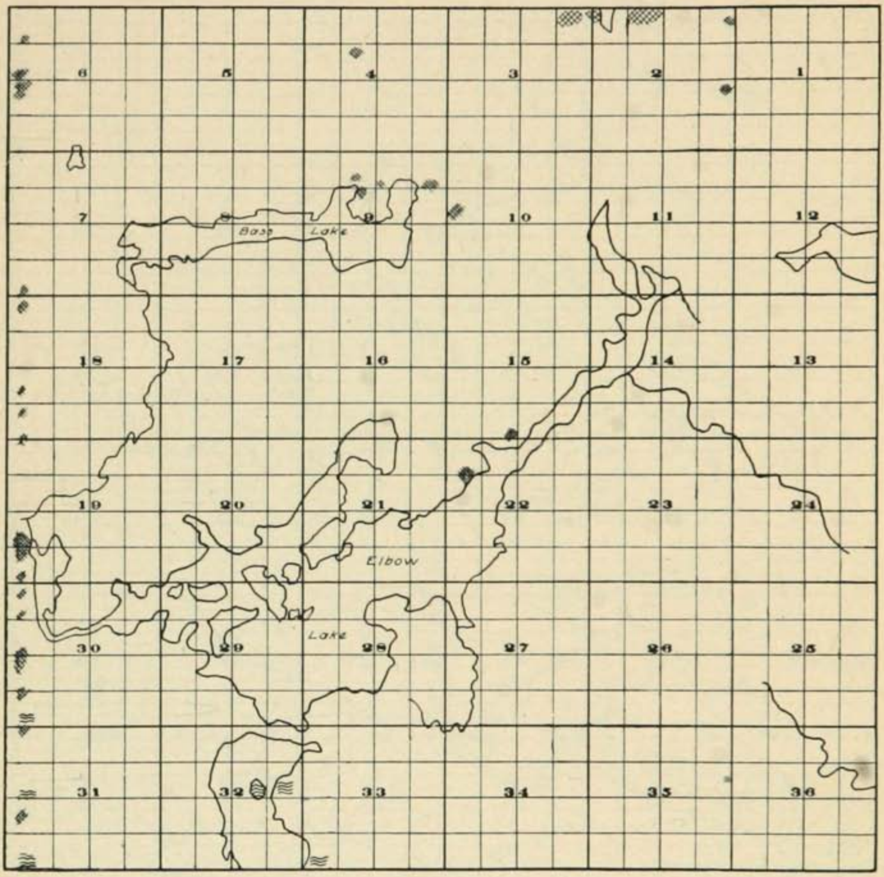
TOWNSHIP 63 N., RANGE 18 W.

This township includes the western end of Vermilion Lake with a good many outcrops along the shore. There are a few exposures also at other places in the township, but drift covers most of the southwestern parts. Nearly all the rock is a mixture of granite and schist, in patches too small to map as distinct areas. Granite is abundant in the southeast and in small areas elsewhere. It seems to be petrographically related to the Vermilion rather than to the more distant Giants Range batholith.

The schist which is abundant in the west and north, is mapped as altered Knife Lake slate, from its petrographic character and possible connection under the drift. The hornblendic rock along the south side of Sections 34 and 35 may be Ely greenstone altered by the granite which is abundant in the same section, but, on the other hand, it may be a hornblendic phase of the granite magma. There is some very local magnetic attraction in these sections, near a hill of greenstone, extending into the township south. Granite outcrops in large areas about a mile north of this hill and the attraction is possibly a contact effect. (See Fig. 13.) The rest of the township has been repeatedly covered by dip needle traverses showing no abnormal readings.

TOWNSHIP 64 NORTH, RANGE 18 WEST

Geology by N. H. Winchell and Edward Steidtmann



LEGEND

Late Algomian granitic rocks many mica schist inclusions

Knife Lake Schist with much granite in places

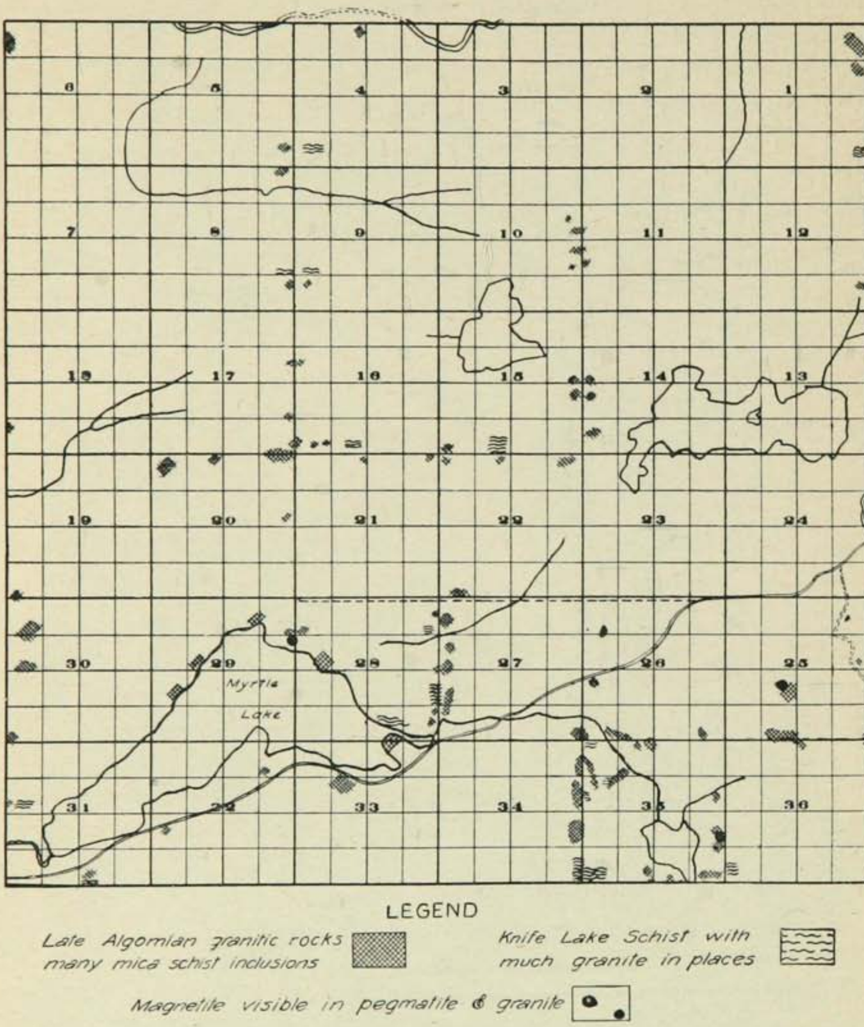
Magnetite visible in pegmatite & granite

TOWNSHIP 64 N., RANGE 18 W.

The southern side of this township exposes the northern border of the biotite schist of the Knife Lake formation. Vermilion granite largely predominates in the north, but includes fragments of schist. Dip needle readings were taken by Edward Steidtmann along four lines through the township, but no abnormal attraction was discovered.

TOWNSHIP 65 NORTH, RANGE 18 WEST

Geology by F. F. Grout, Stanwood Johnston, G. A. Thiel, and Edward Steidtmann

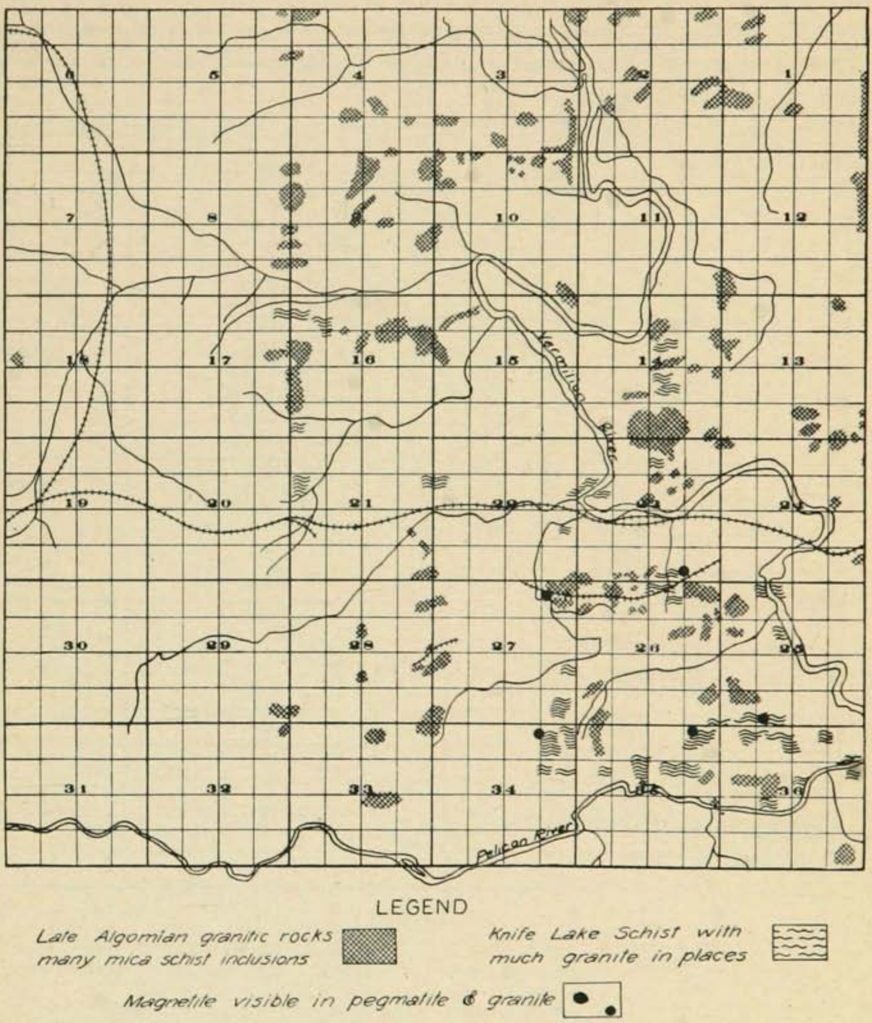


TOWNSHIP 65 N., RANGE 18 W.

Vermilion granite with biotite schist inclusions is abundantly exposed in this township. Magnetite occurs in a few scattered exposures in Sections 25, 29, and 35, but all are very lean. Dip needle readings were taken by Edward Steidtmann along four lines through the township, but no abnormal attraction was discovered.

TOWNSHIP 66 NORTH, RANGE 18 WEST

Geology by F. F. Grout and Stanwood Johnston



TOWNSHIP 66 N., RANGE 18 W.

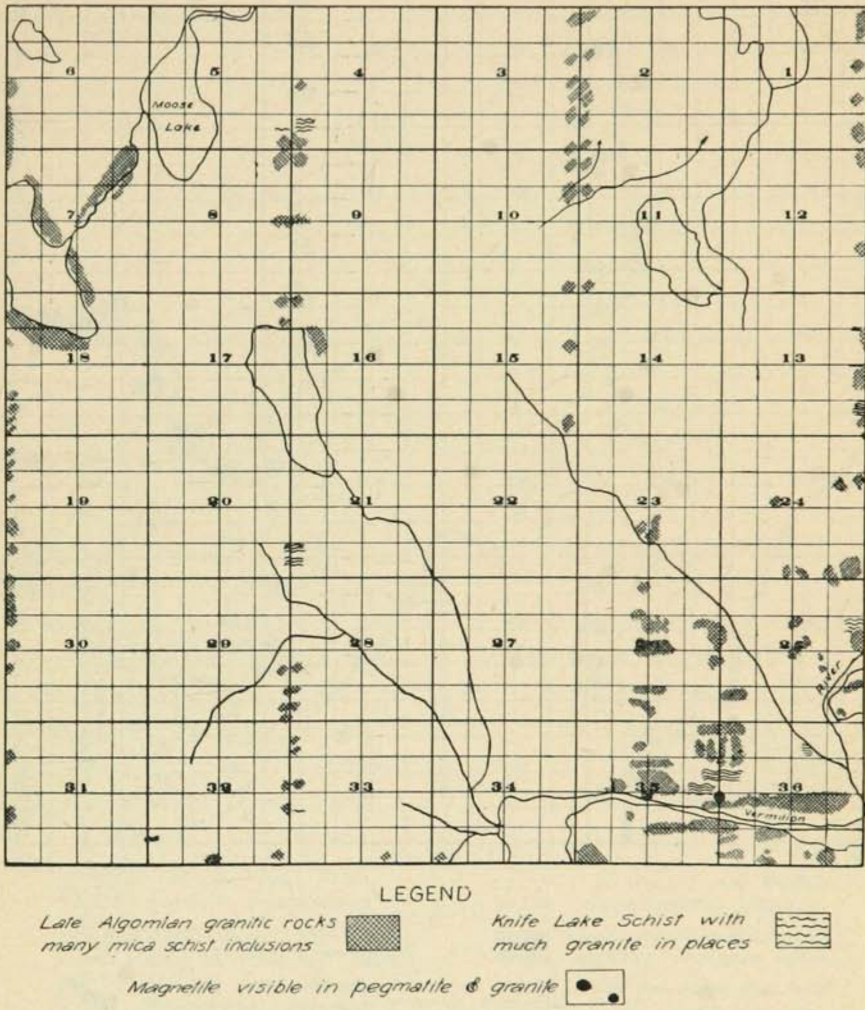
This township adjoins on the west the township actively explored for magnetite pegmatite. The geology is analogous, the exposures being chiefly Vermilion granite, with biotite schist inclusions. Possibly some large masses of schist may have the nature of roof pendants. The Vermilion River follows a structure of this sort, and the frontispiece shows the river cutting a gorge into schist between granite hills.

A cluster of outcrops of magnetite pegmatite in the southeast part of the township may be a sort of continuation of the cluster explored by the International Iron and Steel Company a few miles northeast. They are probably richest in Section 25, where an area of 20 acres may contain as much as 2 per cent magnetite. Other exposures of magnetite are in Sections 23, 27, 34, and 35.

Dip needle readings by Edward Steidtmann showed no abnormal attraction.

TOWNSHIP 67 NORTH, RANGE 18 WEST

Geology by F. F. Grout and Edward Steidtmann

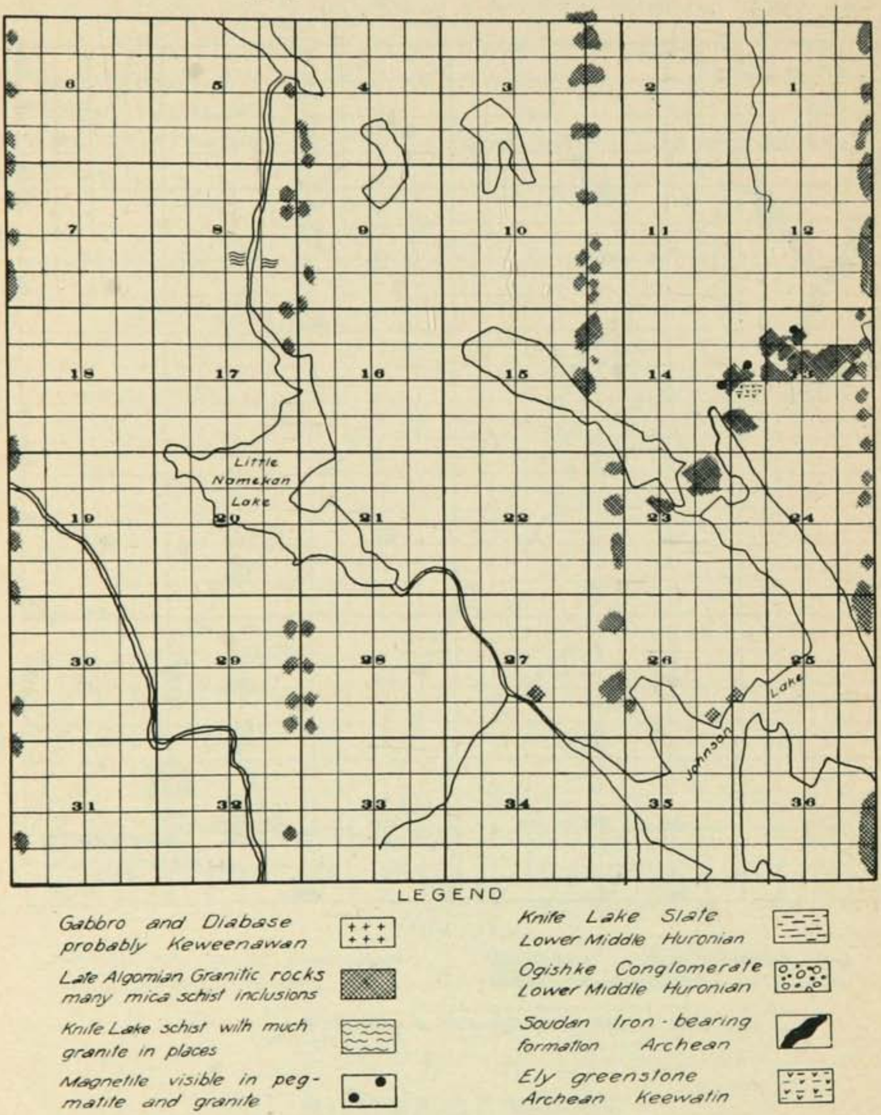


TOWNSHIP 67 N., RANGE 18 W.

The Vermilion granite with many biotite schist inclusions makes up the numerous exposures in this township. Magnetite in small amounts was seen in some pegmatites along the Vermilion River in Section 35. No abnormal magnetic attraction was discovered.

TOWNSHIP 68 NORTH, RANGE 18 WEST

Geology by F. F. Grout and Edward Steidtmann

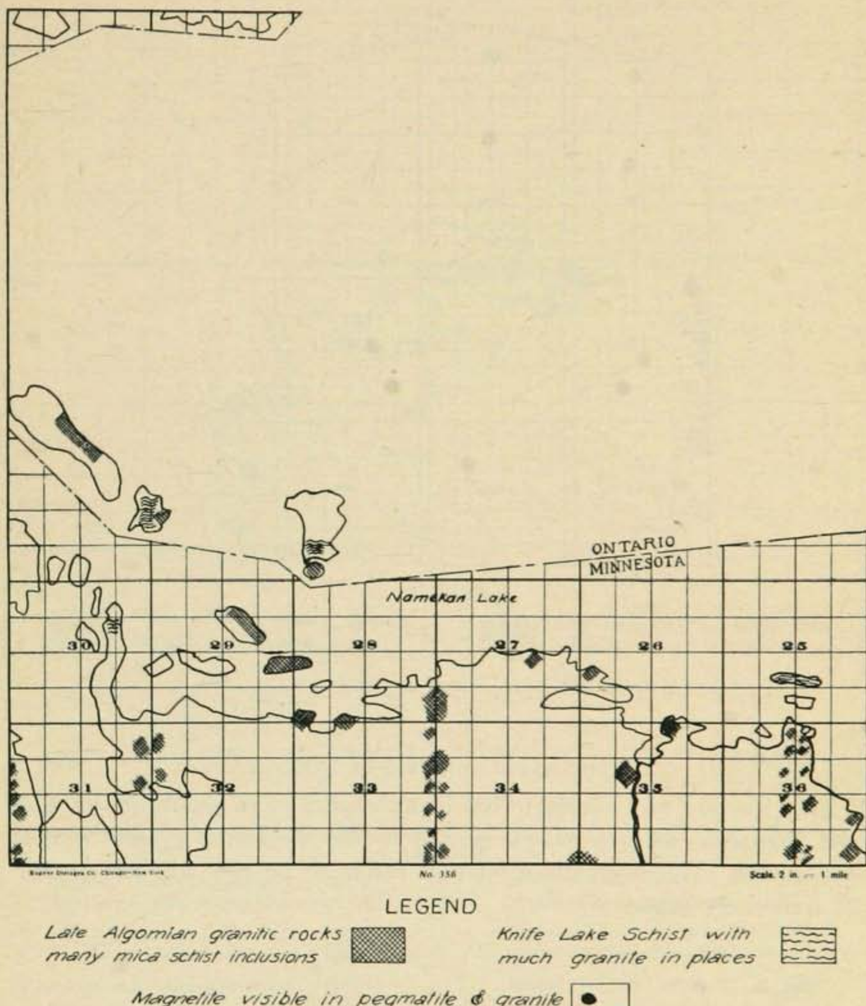


TOWNSHIP 68 N., RANGE 18 W.

The Vermilion granite is the chief formation in this township. There are numerous schist inclusions, mostly biotite schist; but in Section 13 there is a hornblende schist area. This rock may be derived from Ely greenstone or from an early hornblendic phase of the granite. Magnetite is visible in small amounts in the pegmatites in Section 13, but seems to be independent of hornblende rock. Dip needle readings by Edward Steidtmann show no abnormal attraction.

TOWNSHIP 69 NORTH, RANGE 18 WEST

Geology by F. F. Grout and Edward Steidtmann

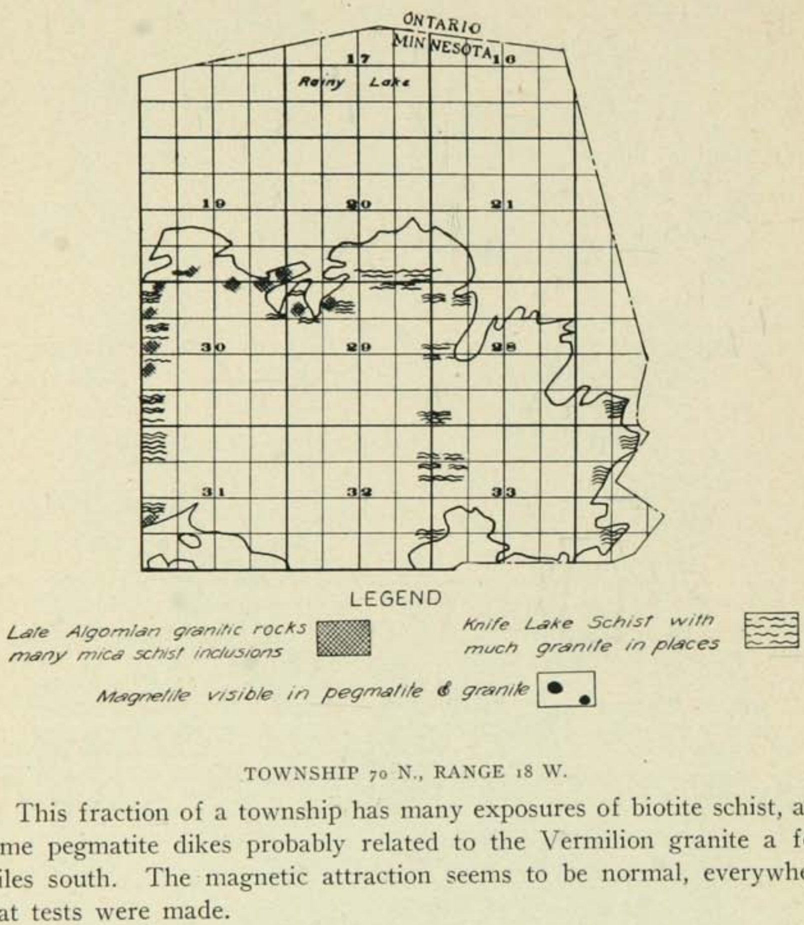


TOWNSHIP 69 N., RANGE 18 W.

This fraction of a township includes the contact of Vermilion granite and the biotite schist which extends far into Canada. A few satellites of granite occur farther north. The granite along the south shore of Namekan Lake in this township is more gneissic than elsewhere in the county, but good exposures indicate that the gneiss is only a local modification. Dip needle readings show no abnormal attraction.

TOWNSHIP 70 NORTH, RANGE 18 WEST

Geology by F. F. Grout and Edward Steidtmann

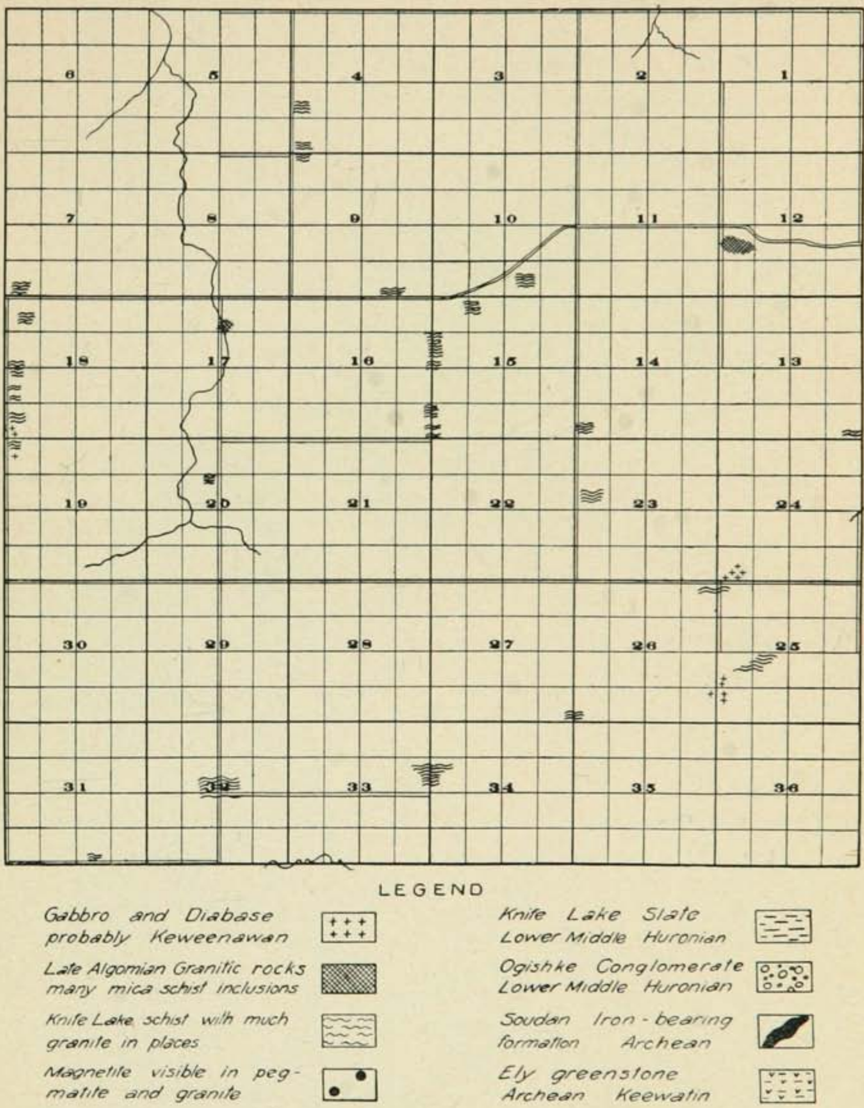


TOWNSHIP 70 N., RANGE 18 W.

This fraction of a township has many exposures of biotite schist, and some pegmatite dikes probably related to the Vermilion granite a few miles south. The magnetic attraction seems to be normal, everywhere that tests were made.

TOWNSHIP 61 NORTH, RANGE 19 WEST

Geology by party under John Uno Sebenius; and by G. A. Thiel and F. E. Williams



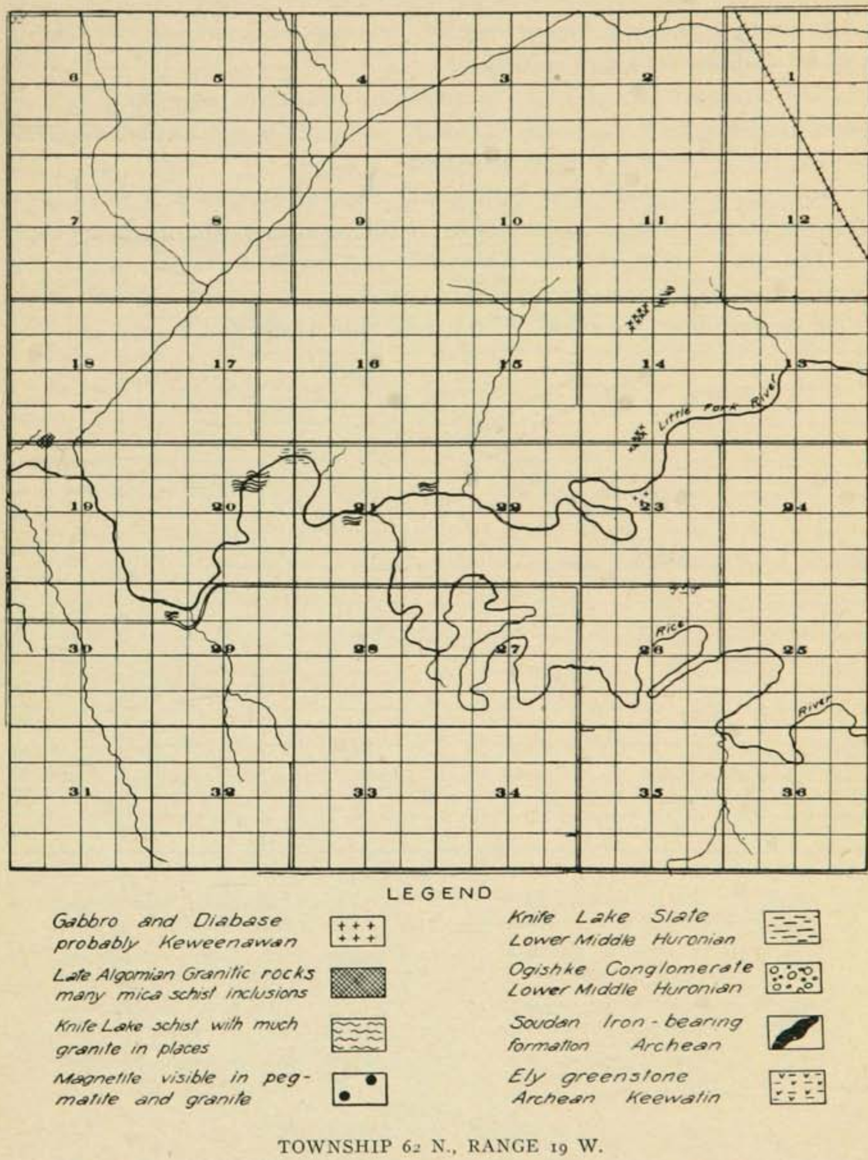
TOWNSHIP 61 N., RANGE 19 W.

This township shows many exposures of biotite schist and few of any other rock. The schist is assumed to be derived from Knife Lake slate, because of its petrographic character and its position adjoining other areas of Knife Lake formation. A few small masses of igneous rock, both acid and basic, are scattered about, but none seem to be extensive. The glacial drift conceals their relations. The beach of glacial Lake Agassiz crosses the northwest side of the town and north of that the soil is more largely clay.

A feeble magnetic attraction has been noted in certain places by F. E. Williams. It is supposed to be related to the border of an igneous intrusion not to iron-bearing formation. The rocks near the places showing abnormal magnetic attraction, however, are concealed. Readings from one to three degrees from normal were obtained in the southwest corner Section 18; one-fourth mile north of the center of Section 17; the northeast quarter of the southeast quarter of Section 28; the southeast corner of Section 10; and about one eighth of a mile south of the center of Section 12.

TOWNSHIP 62 NORTH, RANGE 19 WEST

Geology by F. F. Grout



TOWNSHIP 62 N., RANGE 19 W.

There are so few outcrops in this township that its structure is very uncertain. The clayey lake deposits of glacial Lake Agassiz cover nearly all the surface. The formations are similar petrographically to those in townships east and south. The few exposures may be listed in brief.

Ely greenstone with ellipsoidal structure may be seen near the road in the northeast quarter of Section 26. A graywacke phase of Knife Lake slate outcrops near the center of the south side of Section 11. These two rocks probably extend widely and are intruded by granite in Section 19 and by diabases or gabbros in Section 14.

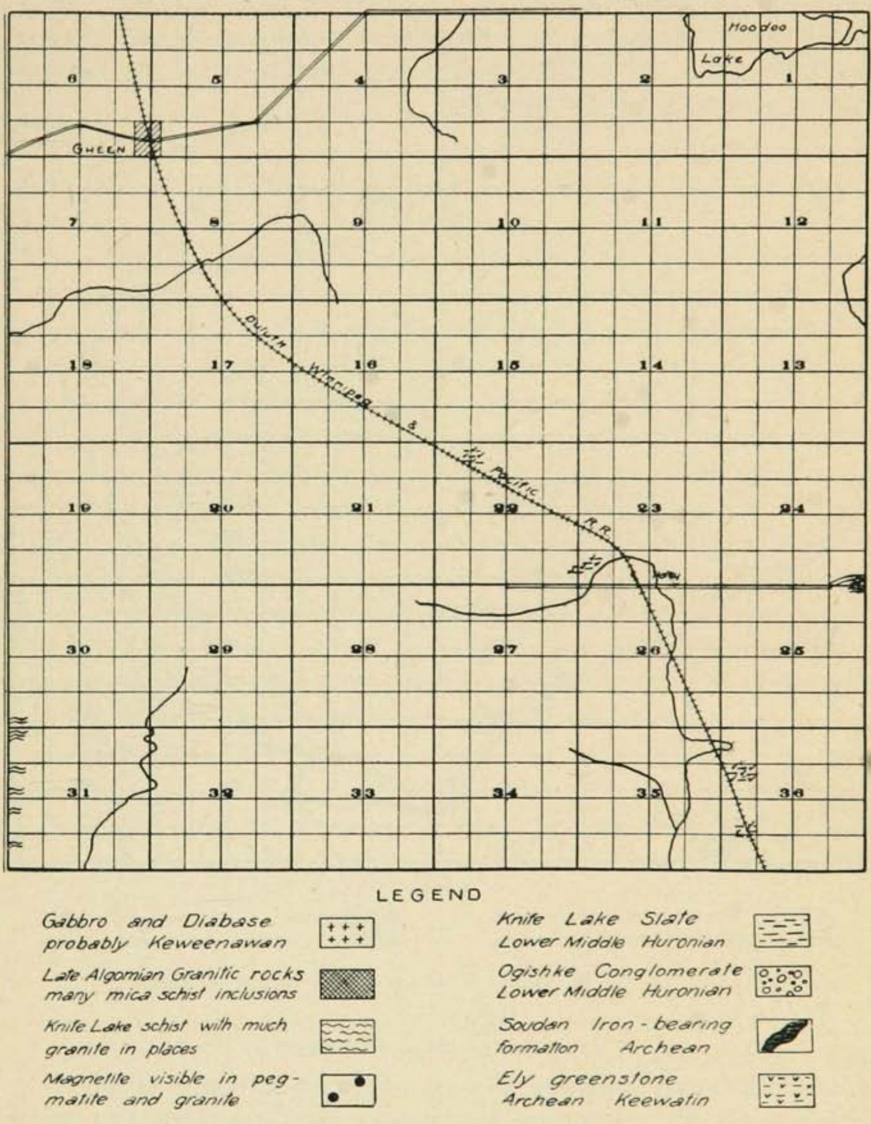
The structure of the rocks in adjoining townships suggests a belt of greenstone crossing the town, but only one outcrop has been discovered, so that the continuity is very uncertain.

It is reported that some drilling was done in Section 3 of this township but no information is available as to the results, or what was expected.

The town was fairly well covered by dip needle traverses, by Survey parties and no abnormal attraction was discovered, except a dip of about three degrees near the center of the west side of Section 7.

TOWNSHIP 63 NORTH, RANGE 19 WEST

Geology by F. F. Grout

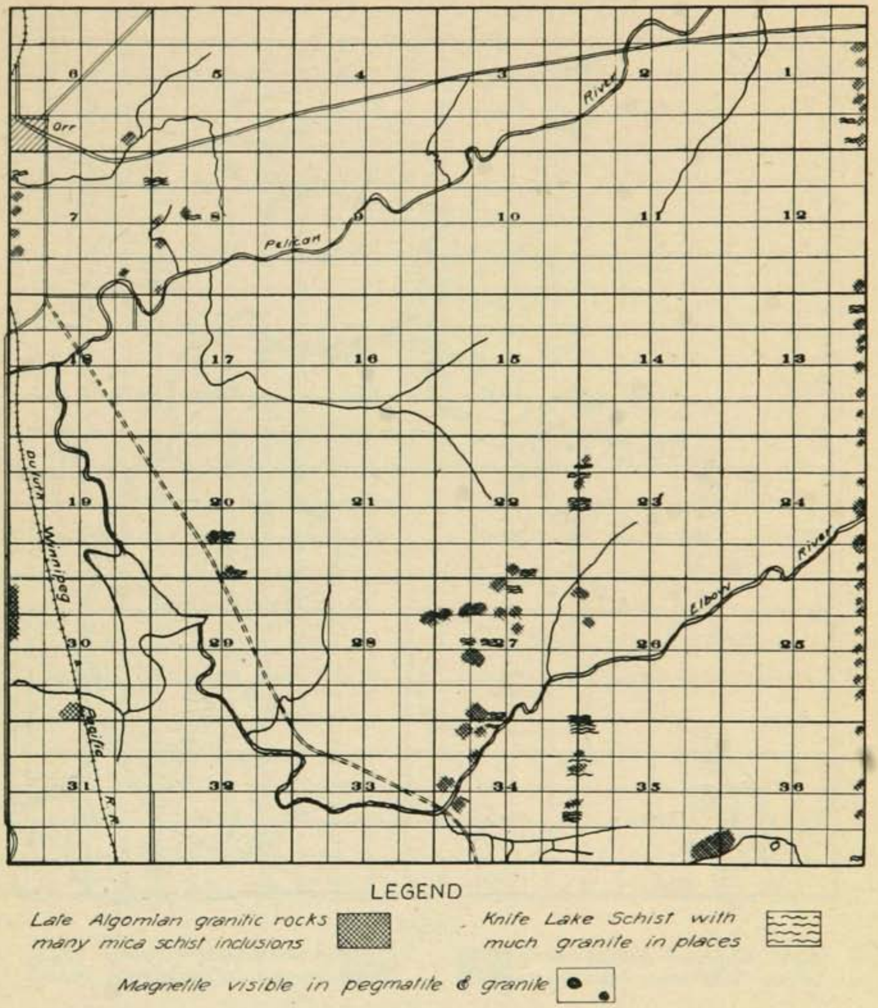


TOWNSHIP 63 N., RANGE 19 W.

The outcrops in the southeastern portion of this township are prominent and scattered knobs of greenstone. They suggest a large anticline possibly connected with the supposed Ely hornblende schist several miles east in Sec. 3, T. 62 N., R. 18 W. The southwest part of the town has some biotite schist. Granite occurs a little northwest of the town. The relations of these formations are concealed by heavy drift, which on the southwest has been reworked by the waters of Lake Agassiz. The old beach of this lake crosses the town from northwest to southeast. Several traverses with a dip needle by F. F. Grout failed to reveal any abnormal magnetic attraction in the township.

TOWNSHIP 64 NORTH, RANGE 19 WEST

Geology by F. F. Grout and Edward Steidtmann



TOWNSHIP 64 N., RANGE 19 W.

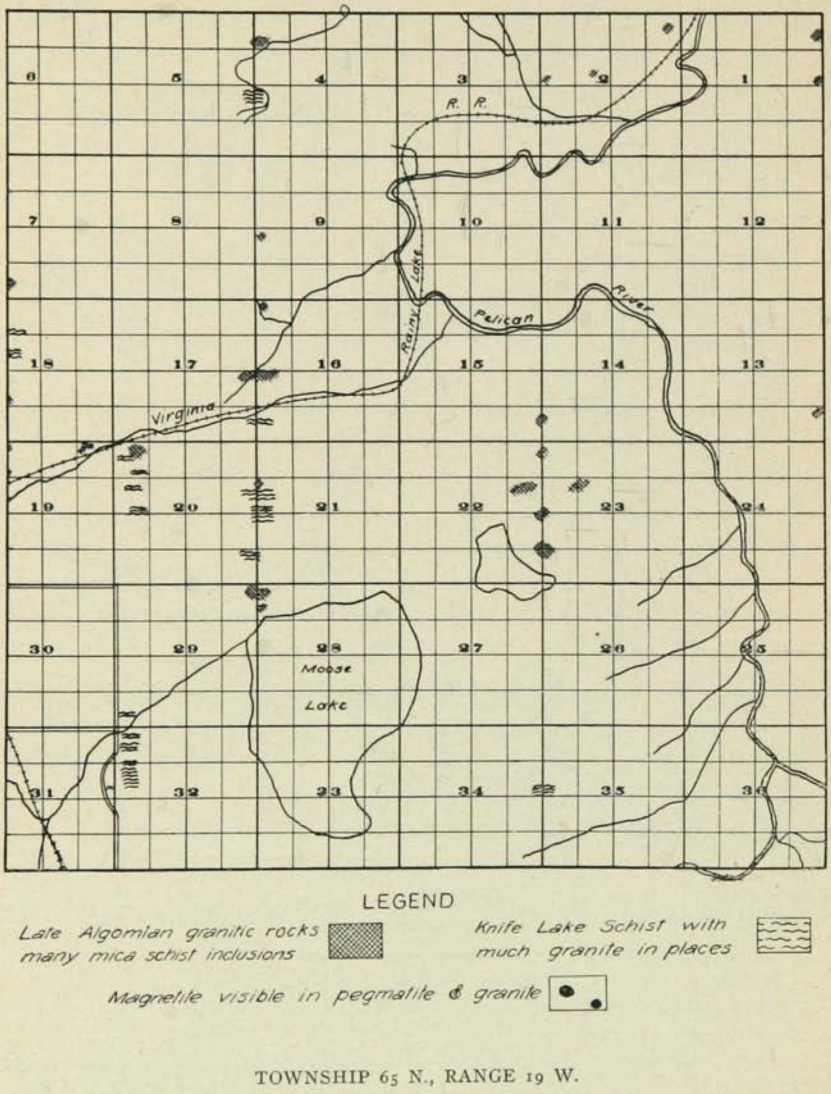
In this township the outcrops consist of Vermilion granite and biotite schist, and practically every outcrop has both rocks. In the southern part, schist occurs in larger proportion than it does farther north. Hornblendic gneiss is reported at one place[a], probably in Section 24.

It is reported that a drilling exploration for gold was once made in Section 34. Dip needle readings by Edward Steidtmann failed to show any abnormal attraction.

[a] Minn. Geol. and Nat. Hist. Survey, Final Rept., vol. 4, p. 226.

TOWNSHIP 65 NORTH, RANGE 19 WEST

Geology by Edward Steidtmann

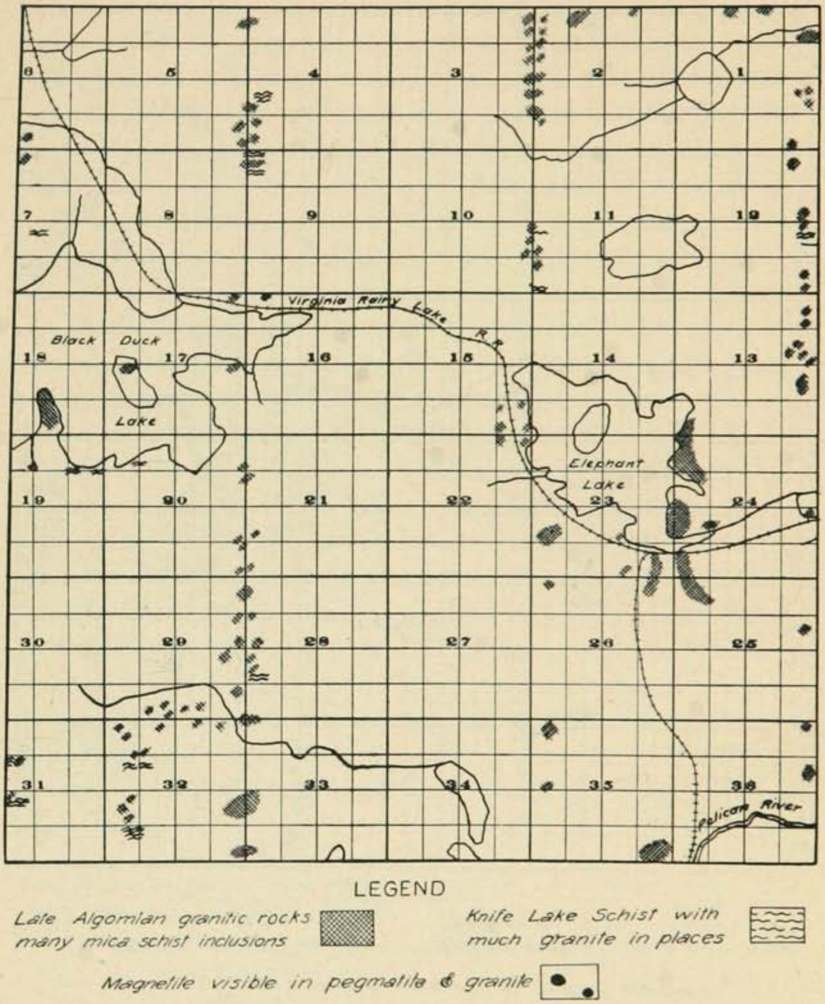


TOWNSHIP 65 N., RANGE 19 W.

Vermilion granite with a few biotite schist inclusions makes up the chief rock in this whole township. No abnormal magnetic attraction was discovered.

TOWNSHIP 66 NORTH, RANGE 19 WEST

Geology by Edward Steidtmann

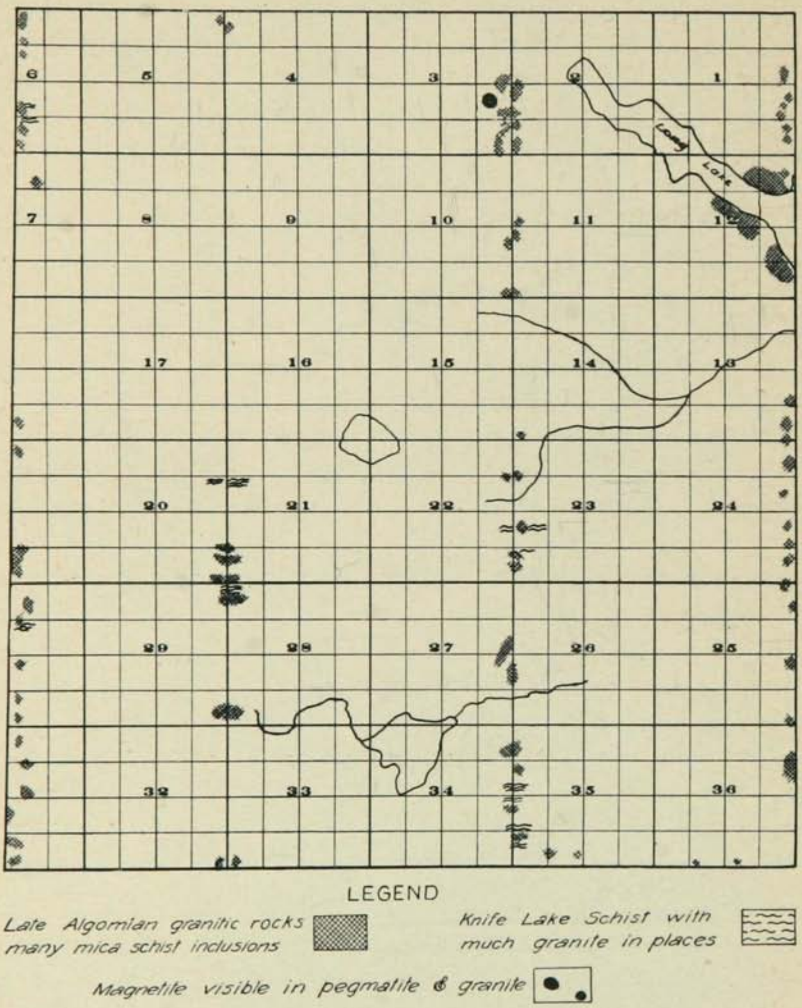


TOWNSHIP 66 N., RANGE 19 W.

Vermilion granite with a few biotite schist inclusions makes up the chief rock in this township. No abnormal magnetic attraction was discovered.

TOWNSHIP 67 NORTH, RANGE 19 WEST

Geology by Edward Steidtmann

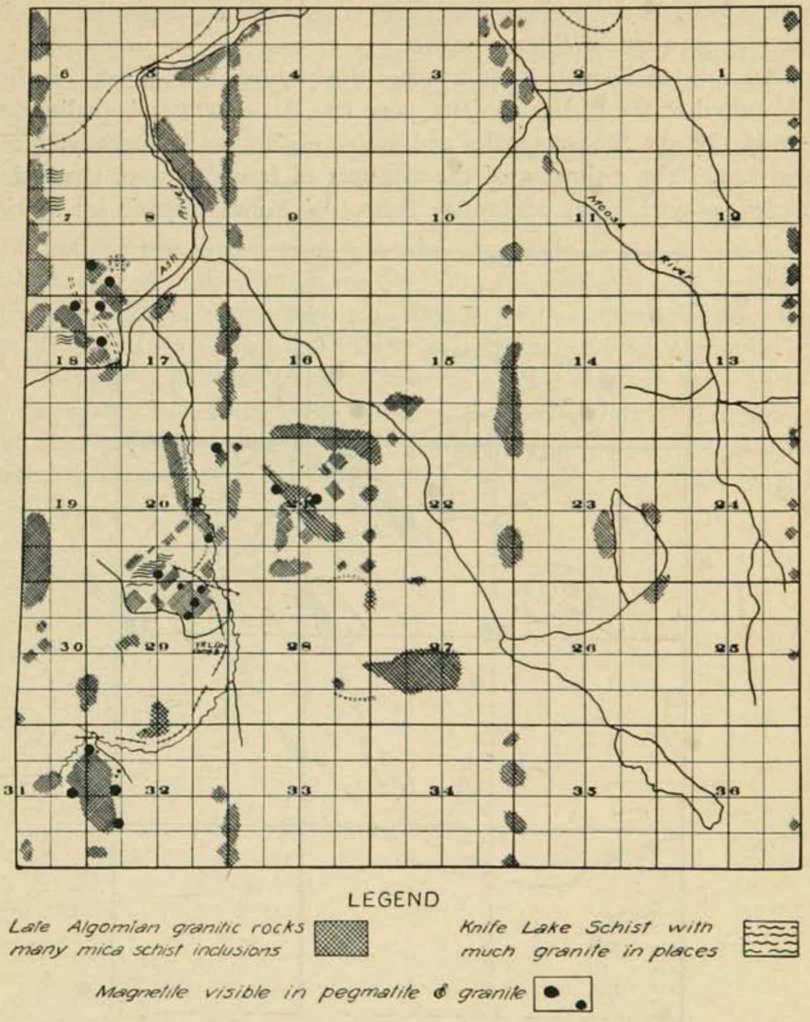


TOWNSHIP 67 N., RANGE 19 W.

This township was mapped as Vermilion granite but contains a large proportion of biotite schist as inclusions in the granite. Magnetite is visible in pegmatite masses in Sections 2 and 3, but dip needle readings by Edward Steidtmann along several lines through the township revealed no abnormal attraction.

TOWNSHIP 68 NORTH, RANGE 19 WEST

Geology by F. F. Grout and Edward Steidtmann



TOWNSHIP 68 N., RANGE 19 W.

This township shows Vermilion granite with small areas of schist much like the towns on all sides of it. It deserves special note, however, on account of the prospecting that has been done for iron ore. The schist associated with the granite is like that found elsewhere; chiefly biotite schist, but in a few places hornblende schist.

The iron deposits that have attracted attention are mostly in the western half of the township. Probably the most promising exposure is in the north half of the northeast quarter of Section 29. Other widespread exposures occur in Sections 7, 8, 17, 18, 20, 21, and 32. (See Fig. 14.) Reports have been received that similar rock occurs in Section 15, but none was seen by the Survey parties.

The rock in Section 29 is a magnetite pegmatite stockwork such as is described in the earlier sections, page 62. Its extent and quality were estimated by the Survey parties and are shown by the accompanying map (Fig. 14). The estimates of the amounts of iron ore were checked by samples assayed at the Minnesota School of Mines Experiment Station.

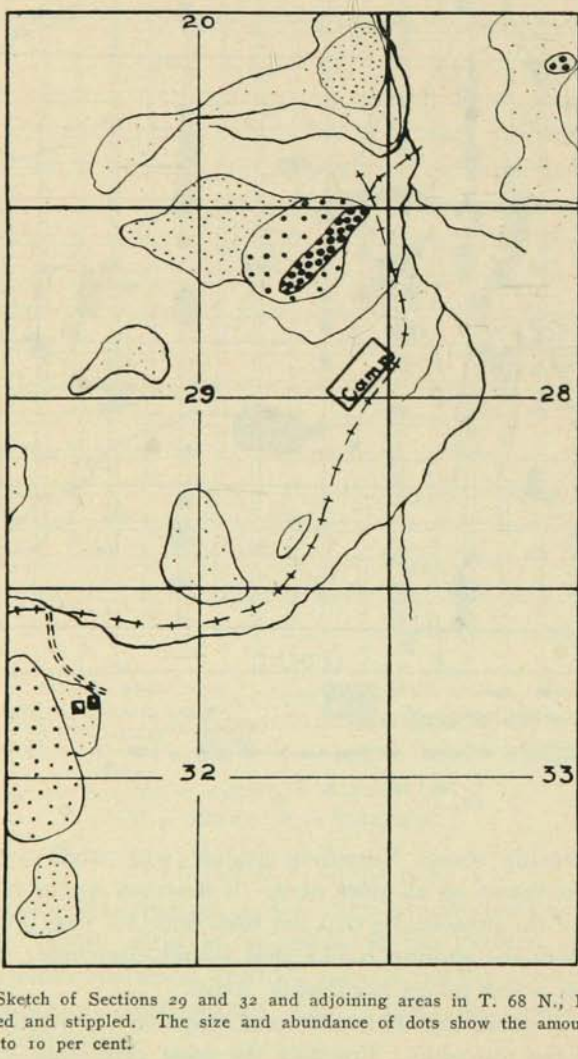


Fig. 14. Sketch of Sections 29 and 32 and adjoining areas in T. 68 N., R. 19 W. Outcrops are outlined and stippled. The size and abundance of dots show the amount of magnetite varying from 0 to 10 per cent.

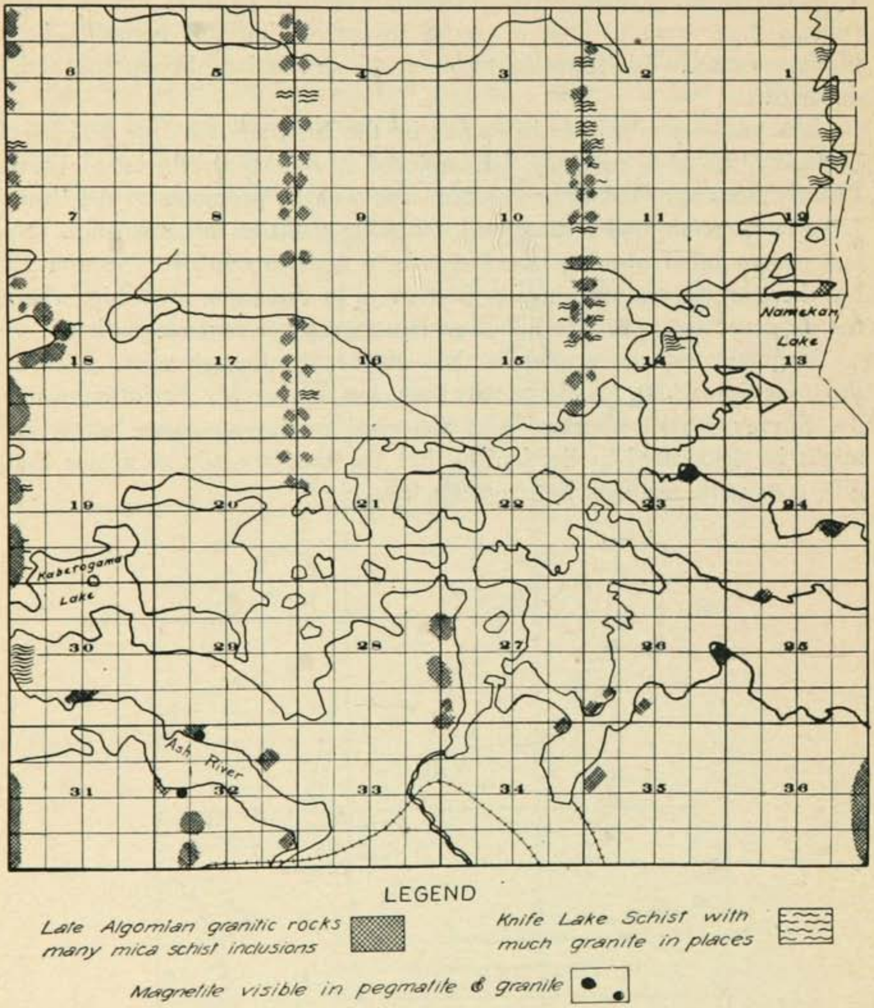
If the hill contains about the same materials as that exposed at the surface, it is certain that no large tonnage could be quarried containing as much as 15 per cent of magnetic iron. Possibly a hill of 40 acres extent might contain 5 per cent of iron in coarse magnetite, but this seems to be a liberal estimate. See pages 66 to 68 on the size and quality of magnetite deposits.

The property is said to be owned by the International Iron and Steel Company, the same company that explored a property southwest of Crane Lake. Years ago, Mr. Charles Eden, who was the promoter of the Crane Lake exploration, had a camp and exploring outfit in this township. No test pits or other openings were seen in a hurried trip over Section 29, but there are several openings in Section 32 of this same township, where the exposures on a 40-acre hill show less than 5 per cent magnetite.

Magnetic tests were made with a dip needle through some areas of this township where magnetite was seen, but neither Mr. Steidtmann nor the Survey parties obtained any abnormal readings. Some attraction might be discovered in Section 29, but the ores are not of a sort that give consistent readings by magnetic tests.

TOWNSHIP 69 NORTH, RANGE 19 WEST

Geology by F. F. Grout and Edward Steidtmann



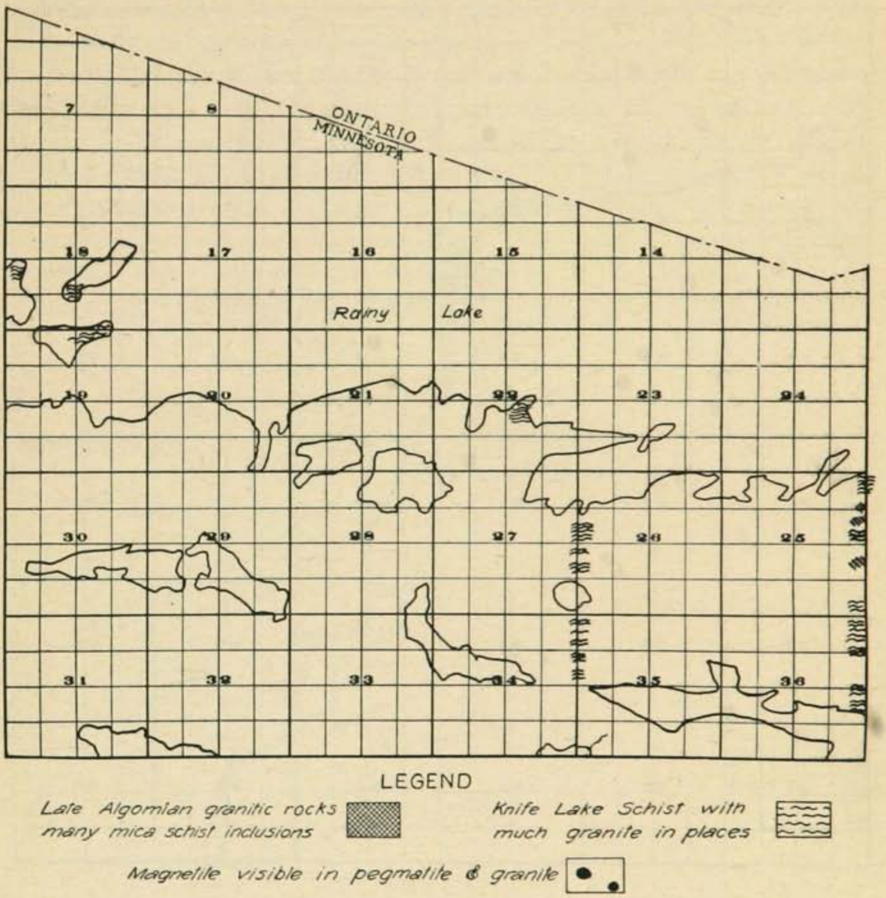
TOWNSHIP 69 N., RANGE 19 W.

This township has many exposures of Vermilion granite but it lies near the northern border of the mass and biotite schist inclusions are numerous on the north side.

In Section 32, on both sides of the wide place in Ash River, magnetite pegmatites may be seen in the rocky shores, but they are very lean in comparison with the prospects a few miles south. Dip needle readings were taken by Edward Steidtmann along many lines, including some near the magnetite exposures, but no abnormal attraction was found.

TOWNSHIP 70 NORTH, RANGE 19 WEST

Geology by F. F. Grout and Edward Steidtmann

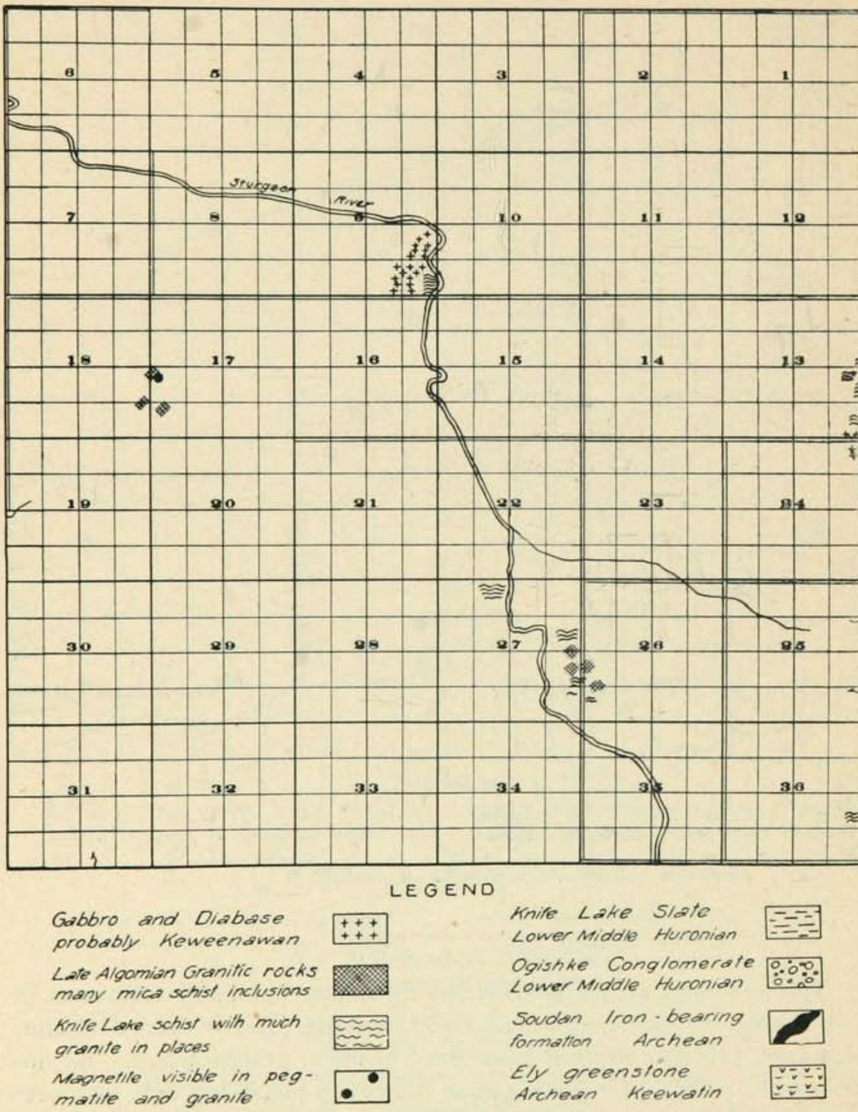


TOWNSHIP 70 N., RANGE 19 W.

This township on the international boundary has many exposures of biotite schist correlated with the Knife Lake slate. A few dikes of granite pegmatite, probably derived from the Vermilion granite magma, intrude the schists. They have some coarse muscovite plates but none has been found free from defects. Dip needle readings were taken at many points by Edward Steidtmann and found to be normal.

TOWNSHIP 61 NORTH, RANGE 20 WEST

Geology by party under John Uno Sebenius; and by F. E. Williams and G. A. Thiel



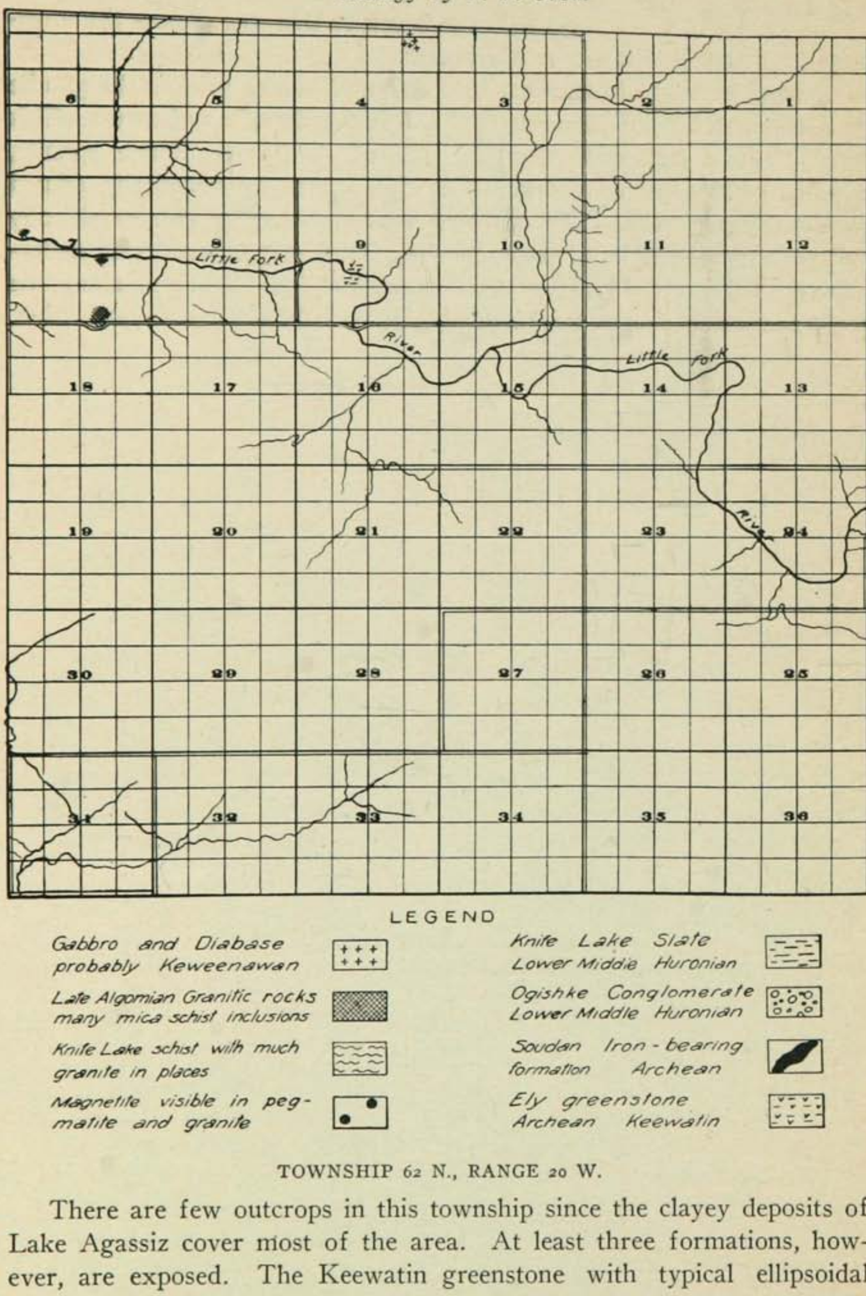
TOWNSHIP 61 N., RANGE 20 W.

The bed rock of most of this township is probably biotite schist of the Knife Lake formation. It outcrops at a few widely separated points. Intrusive into it are several small masses of granite, probably related to the Giants Range batholith which outcrops extensively in the township south of this one. In Section 9 there is also a basic intrusive. Most of the bed rock is concealed by drift which, in the north half, was reworked by the waters of Lake Agassiz. The beach of this lake crosses the township from east to west, near the center.

A small amount of magnetite can be seen in minute veins in the granite of Section 17, but it is too scattered and lean to be of any interest. This seems to be a magnetite pegmatite related to Giants Range granite, whereas most of those mentioned in this report are genetically related to Vermilion granite. The two are somewhat similar petrographically and are supposed to be of the same age. They may be connected underground. Dip needle readings were taken by F. E. Williams along the roads in the east side of this township and all indicated normal attraction.

TOWNSHIP 62 NORTH, RANGE 20 WEST

Geology by F. F. Grout



TOWNSHIP 62 N., RANGE 20 W.

There are few outcrops in this township since the clayey deposits of Lake Agassiz cover most of the area. At least three formations, however, are exposed. The Keewatin greenstone with typical ellipsoidal structure, forms the bed rock of rapids in the Little Fork River in Section 9. No exposures of Knife Lake slate or schist have been found. but the exposure two miles south indicates that the formation probably crosses the southeastern part of the township. Several exposures are also known near the northeast corner of the township. Intrusive into these formations are a diabase in Section 4 and a syenite in Sections 7 and 18. (See Fig. 16.)

The syenite, which has been found to contain nearly 7 per cent potash, (see Table VIII, analysis 17), is well exposed in a hill on the road south of Section 7. Its feldspars are elongated and roughly parallel, striking N. 35° E., and dipping steeply northwest. This is possibly one of the most accessible large masses of rock available in the country with an average potash content of 6 or 7 per cent. The potash is present almost wholly in feldspar, however, and its commercial extraction is probably impossible under present prices and by methods now known.

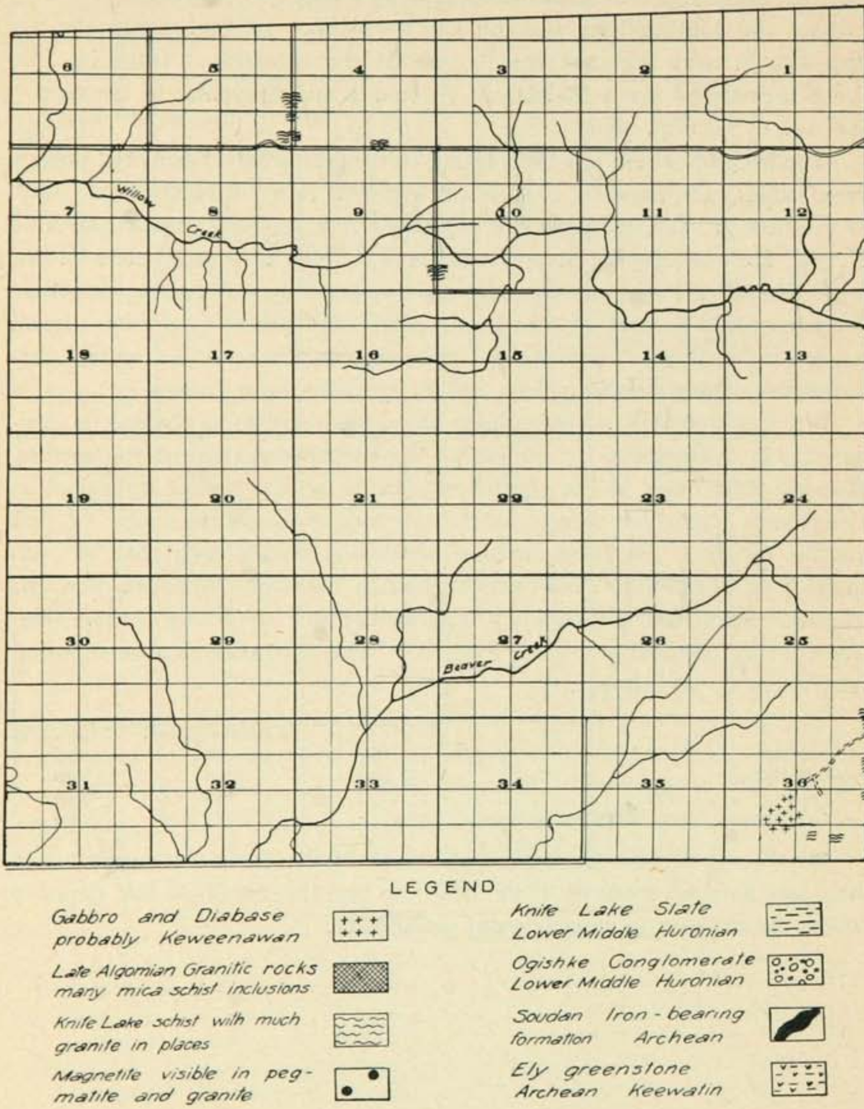
Mr. Ike Goodwill, of Vermilion Lake, has done some drilling in Section 11, in exploration for minerals. He sketched a map of the section, showing four holes in the southwest quarter of the section arranged in a northeast line about three-fourths mile long through the center of that quarter section. The hole farthest southwest struck rock that he considers iron formation. No such formation outcrops, however, and the magnetic attraction in Section 7 is evidently due to syenite rather than iron-bearing formations. (See Fig. 16.) The northeast hole he reported from memory as follows:

	Thickness, feet	Depth, feet
Surface	50	50
Greenstone	370	420
Diorite	30	450
Greenstone (with seams of asbestos)	230	680

Mr. Goodwill believes the asbestos rock in the ground is much better than any sample obtained from drilling; but the depth of the deposits makes the expense of development prohibitive.

TOWNSHIP 63 NORTH, RANGE 20 WEST

Geology by F. F. Grout



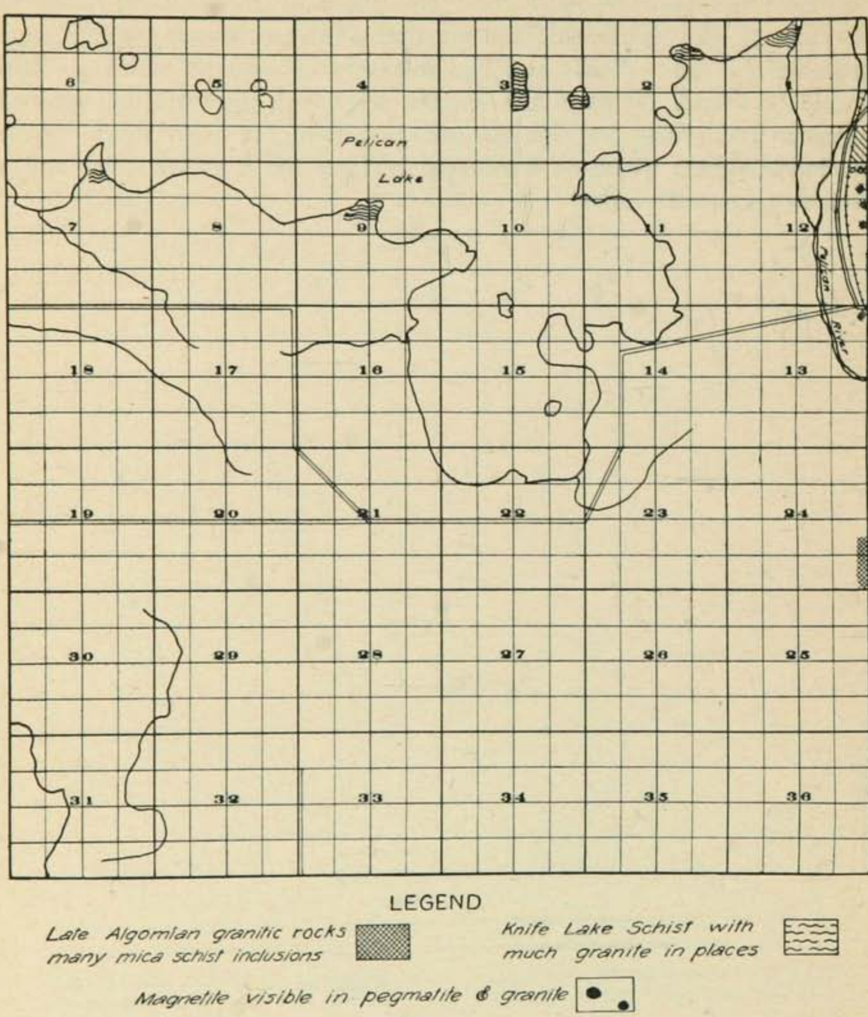
TOWNSHIP 63 N., RANGE 20 W.

The bed rock in this township is almost wholly biotite schist of the Knife Lake formation, if one may judge from widely scattered outcrops. In Section 36 there is a great hill on which the outcrops are mostly gabbro, with aplitic stringers. The drift cover is heavy in most places and Lake Agassiz clays are prominent.

Gold has been reported from one phase of the basic intrusive in Section 36, just mentioned. During 1922 and 1923 several samples were received by state officials and local assayers in most of which no gold could be found. Most of the samples were dark gray medium grained igneous rock, with no sign of mineralization, but with much coarse poikilitic biotite, which on weathered surfaces has a yellow color and a somewhat metallic luster.

TOWNSHIP 64 NORTH, RANGE 20 WEST

Geology by F. F. Grout

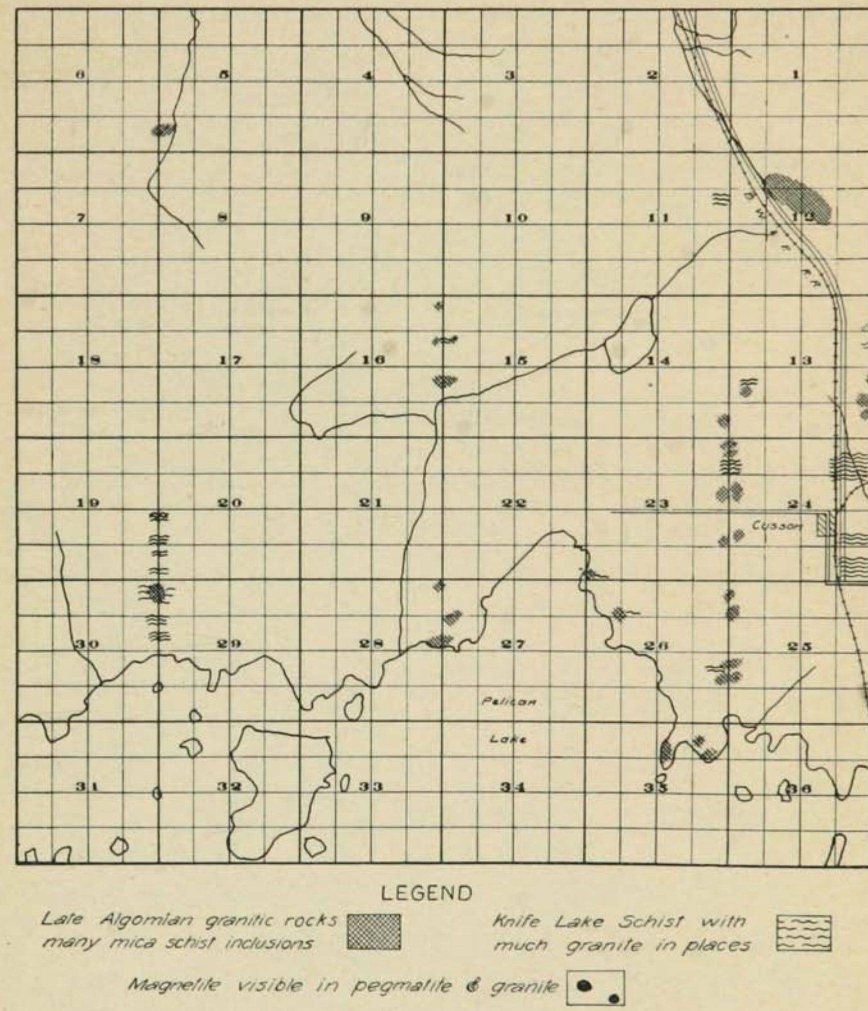


TOWNSHIP 64 N., RANGE 20 W.

This township lies in the transition zone between a large area of biotite schist on the south and a large area of Vermilion granite on the north. The granite is visible in considerable areas south of Orr, in Section 12, and on the north shores of Pelican Lake; but the schist also seems to be abundant. No abnormal magnetic attraction has been detected in this area.

TOWNSHIP 65 NORTH, RANGE 20 WEST

Geology by F. F. Grout and Edward Steidtmann

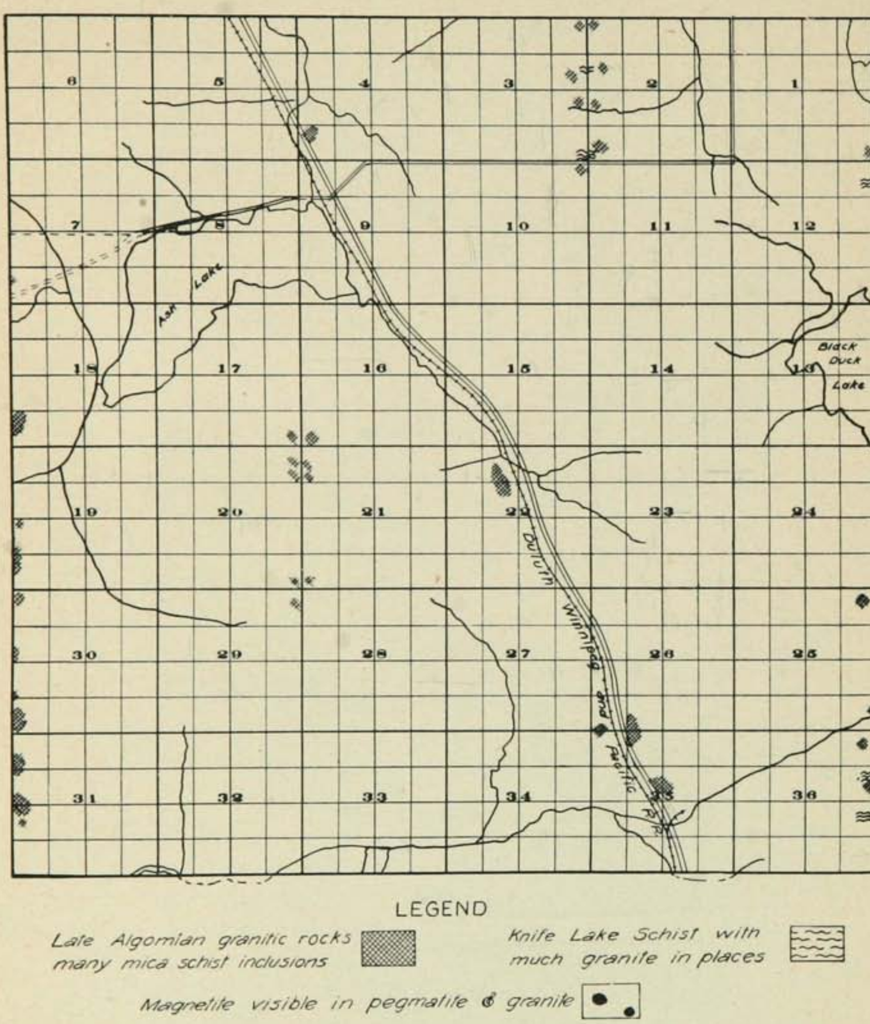


TOWNSHIP 65 N., RANGE 20 W.

This township shows many outcrops of Vermilion granite, most of which have abundant biotite schist inclusions. The area was covered by Edward Steidtmann and party taking dip needle readings at frequent intervals but no abnormal attraction was found.

TOWNSHIP 66 NORTH, RANGE 20 WEST

Geology by F. F. Grout and Edward Steidtmann

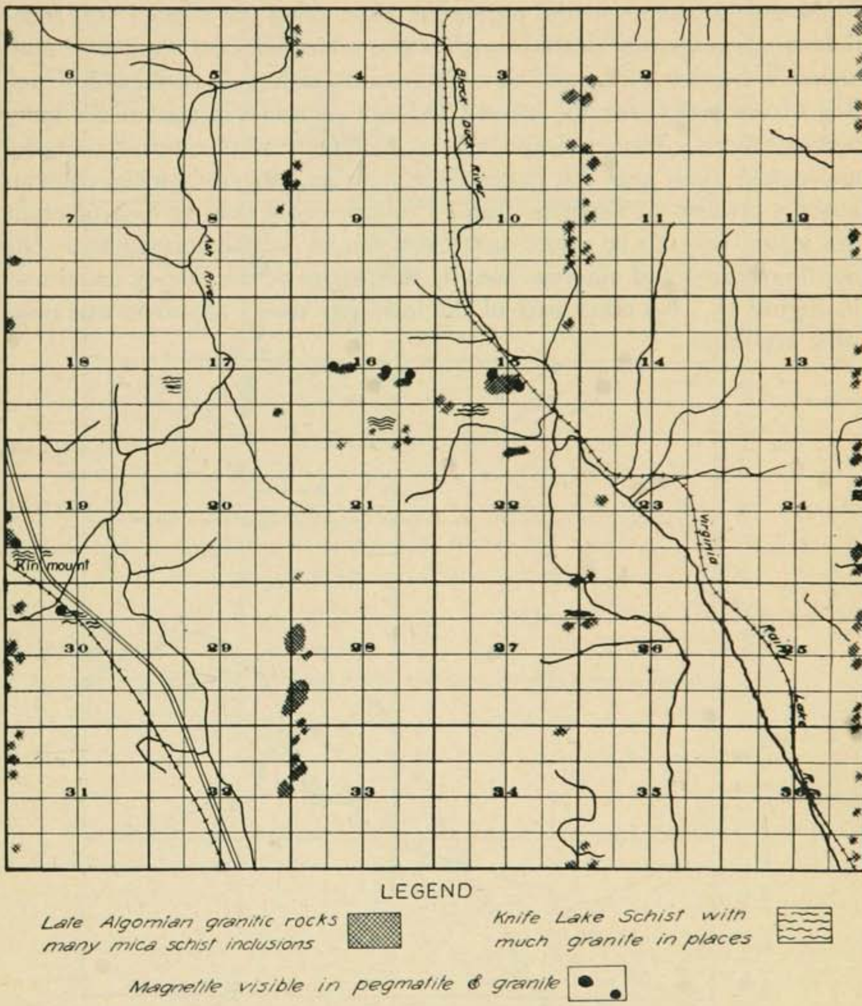


TOWNSHIP 66 N., RANGE 20 W.

This township shows many outcrops of Vermilion granite, most of which have abundant biotite schist inclusions. Dip needle readings by Edward Steidtmann revealed no abnormal magnetic attraction.

TOWNSHIP 67 NORTH, RANGE 20 WEST

Geology by F. F. Grout and Edward Steidtmann



TOWNSHIP 67 N., RANGE 20 W.

This township in the midst of the area of Vermilion granite shows many outcrops, and the granite is nearly everywhere filled with biotite schist inclusions. A few belts of schist are so large and continuous that they should be considered as roof pendants rather than inclusions. Such a belt of schist, with granite north of it, was traversed by the Survey parties through Sections 15 and 16, almost to Ash River. A projection of this area westward suggests that it may be connected with the schist in the railway cut just south of Kinmount near the southwest corner of Section 19, but the rocks between are not exposed.

Magnetite occurs in the pegmatite dikes along the contact just mentioned, where granite lies north of biotite schist. Its occurrence at Kinmount in Section 19, as well as in Sections 15 and 16, is further confirmation of the belief that the contact and belt of schist is continuous for 3 miles or more. The exposures nearest Kinmount were carefully sampled and assays show that the richest belt, perhaps 100 yards wide, contains about 5 per cent of magnetic iron. Probably more than 10 tons of crude ore would have to be mined to yield a ton of salable concentrate. Dip needle readings and outcrops seen by the parties of the Survey are shown in Figure 15. No other part of the township shows any abnormal magnetic attraction.

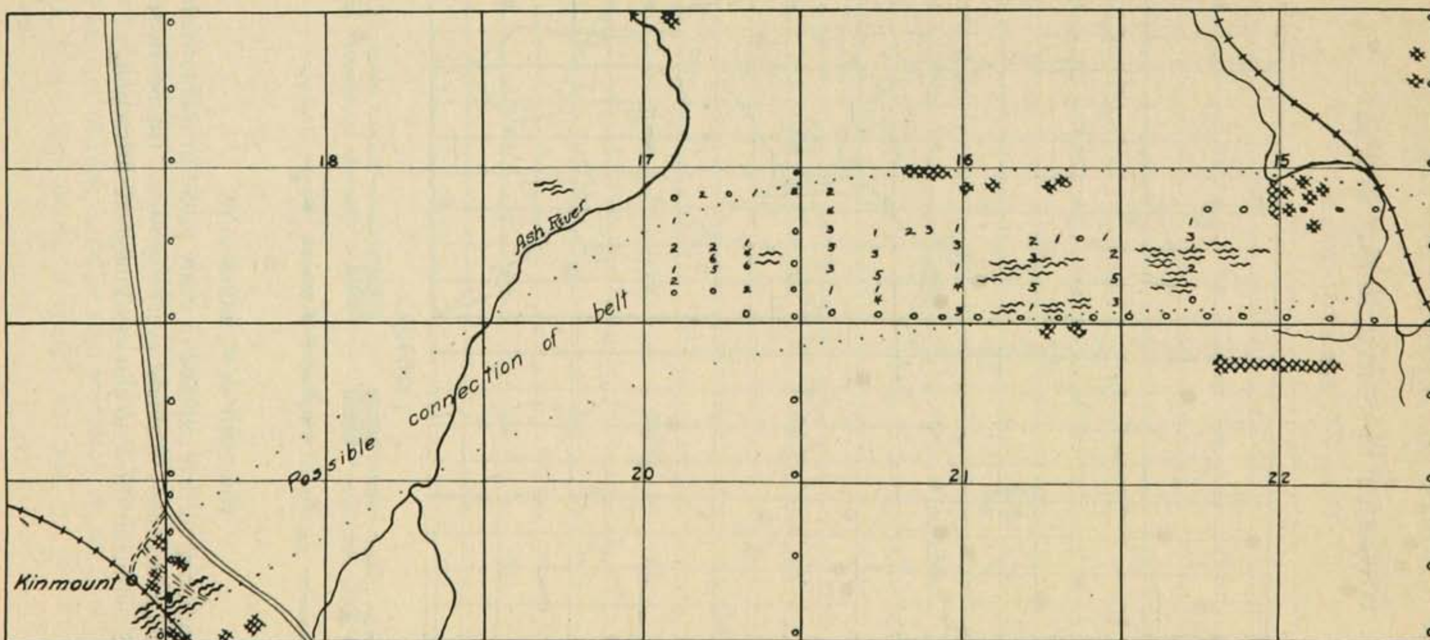
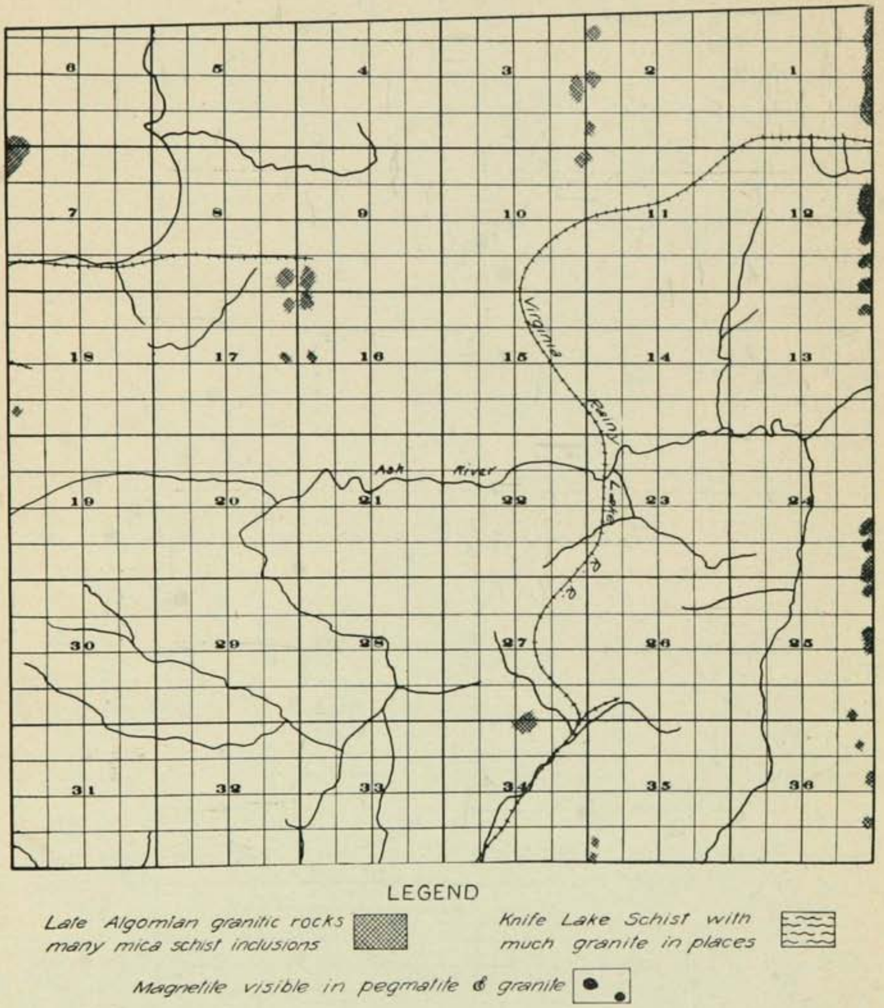


Fig. 15. Map of some outcrops in a belt in T. 67 N., R. 20 W., east of Kinmount. Figures show dip needle readings by Edward Steidtmann. The magnetite appears most abundantly in a belt 100 paces wide north of the schist.

TOWNSHIP 68 NORTH, RANGE 20 WEST

Geology by Edward Steidtmann

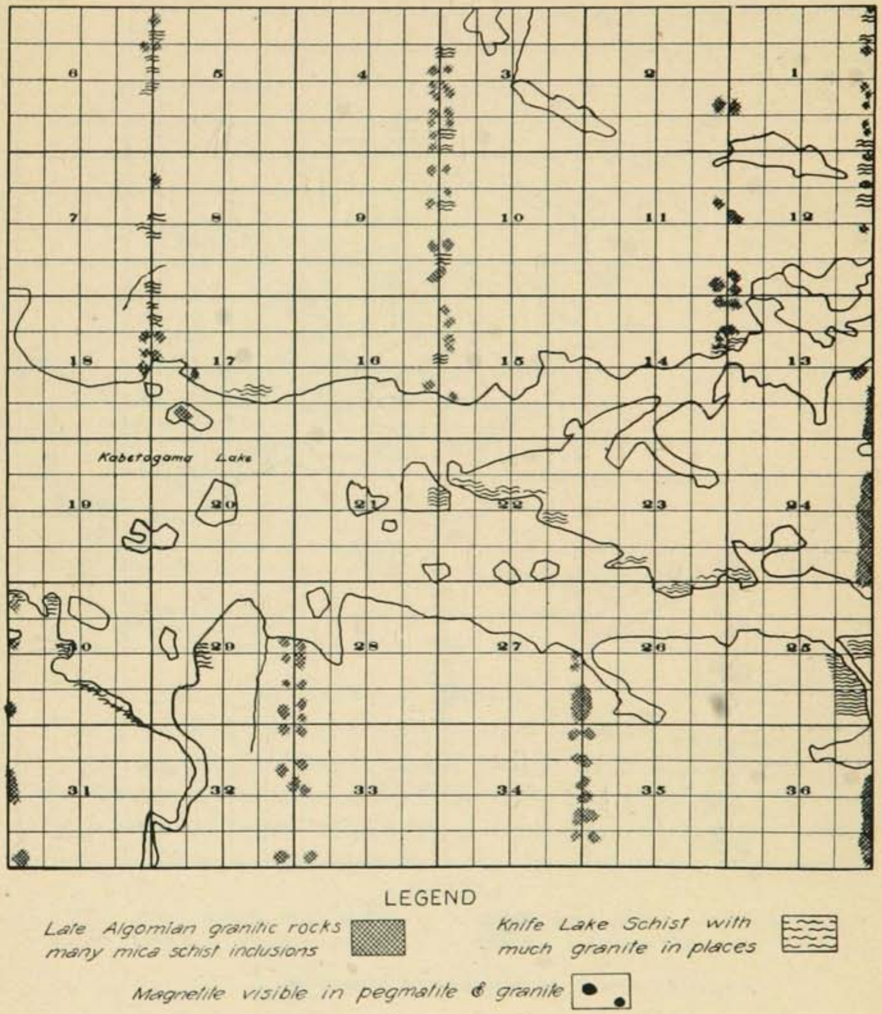


TOWNSHIP 68 N., RANGE 20 W.

The Vermilion granite is exposed in many places in this township and has biotite schist inclusions in almost every exposure. Dip needle readings by Edward Steidtmann show no abnormal magnetic attraction.

TOWNSHIP 69 NORTH, RANGE 20 WEST

Geology by F. F. Grout and Edward Steidtmann

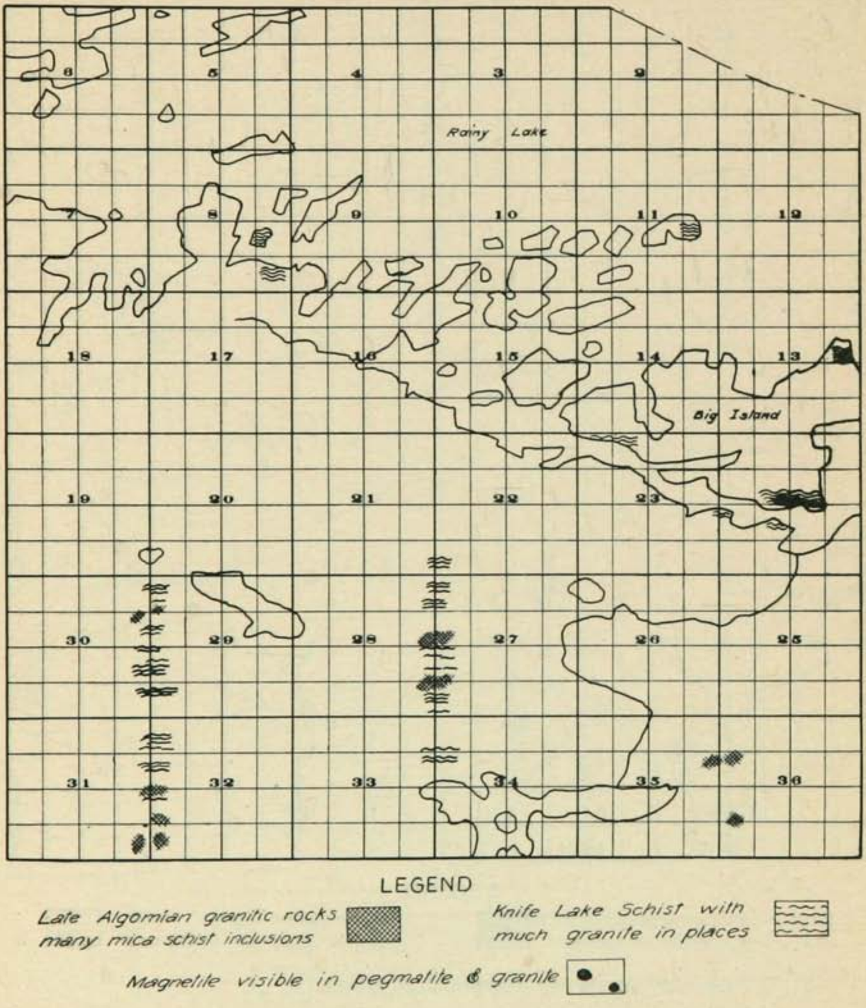


TOWNSHIP 69 N., RANGE 20 W.

The Vermilion granite with numerous biotite schist inclusions is widely exposed in this township. Traces of magnetite can be seen in granite and pegmatite intruding the schist in Sections 22 and 23. Only a small amount of rock could be seen to contain as much as 2 per cent of magnetic iron. Dip needle readings indicate no abnormal magnetic attraction.

TOWNSHIP 70 NORTH, RANGE 20 WEST

Geology by F. F. Grout and Edward Steidtmann

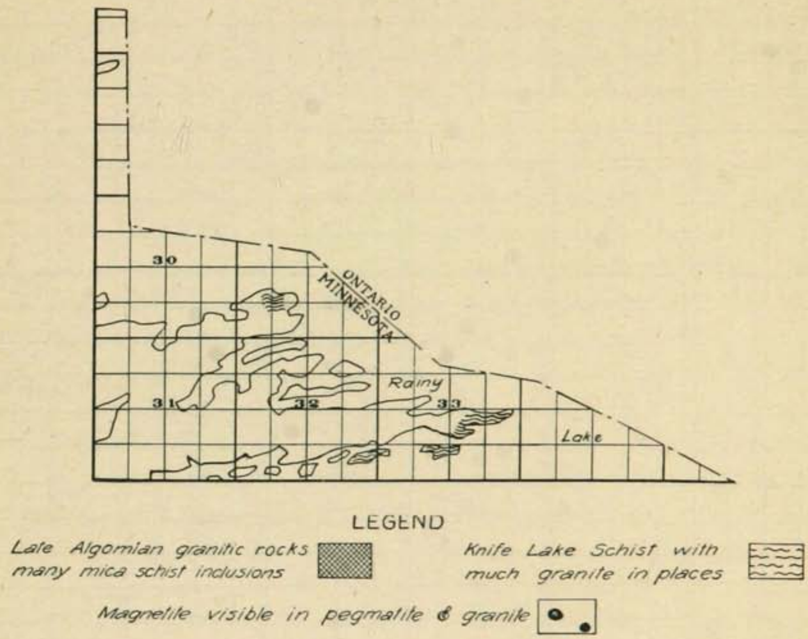


TOWNSHIP 70 N., RANGE 20 W.

In this township the outcrops are biotite schist and granite as in the township south of it. In this township, however, the schist predominates. There are ill-defined areas of granite, and large dikes of pegmatite. Dip needle readings by Edward Steidtmann show no abnormal magnetic attraction.

TOWNSHIP 71 NORTH, RANGE 20 WEST

Geology by F. F. Grout

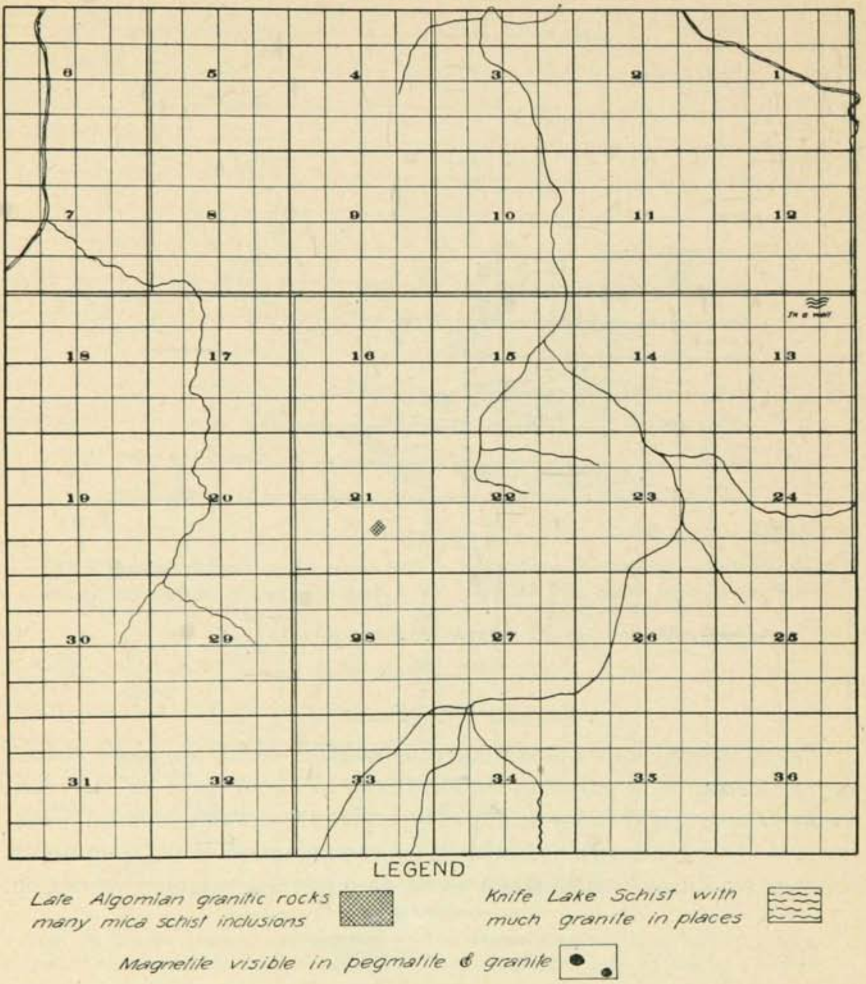


TOWNSHIP 71 N., RANGE 20 W.

This township shows many outcrops most of which are biotite schist, but pegmatite dikes of considerable thickness occur even in the most northern outcrops in Rainy Lake. These dikes have tourmaline and muscovite in them but neither seem to be of commercial quality. Dip needle readings by Edward Steidtmann show no abnormal magnetic attraction.

TOWNSHIP 61 NORTH, RANGE 21 WEST

Geology by party under John Uno Sebenius; and by G. A. Thiel



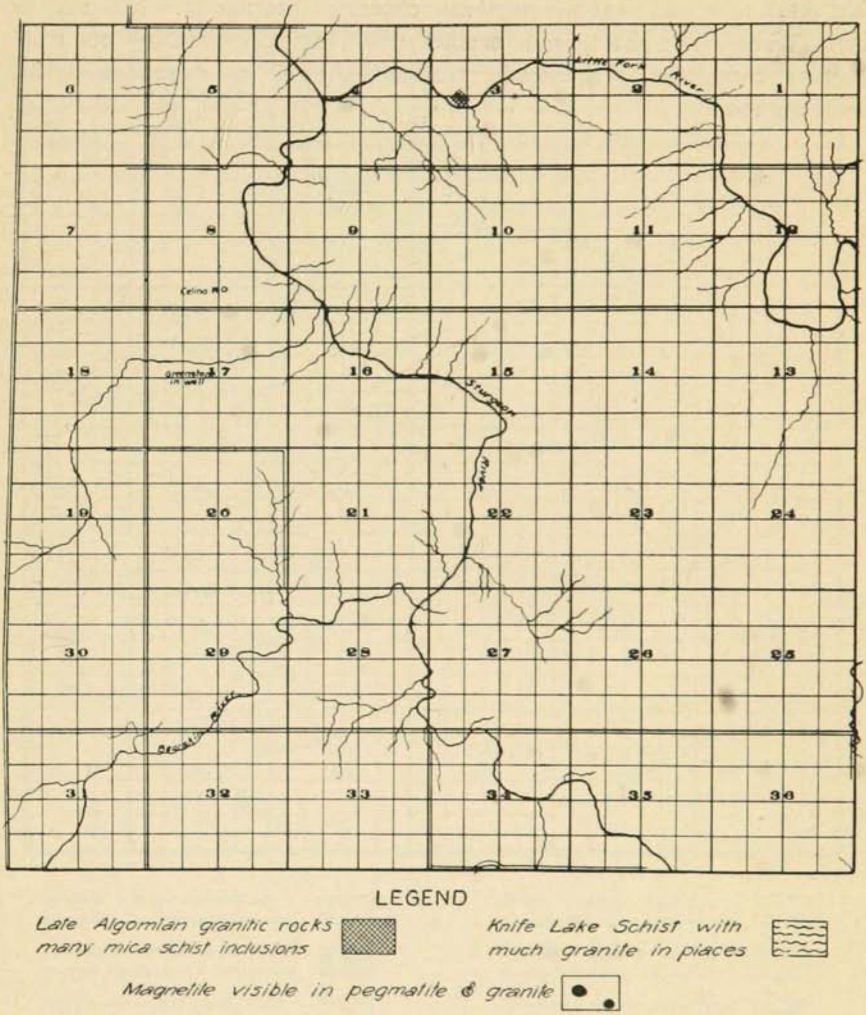
TOWNSHIP 61 N., RANGE 21 W.

The rocks of this township are mostly concealed under deep drift, but the probable formations may be estimated. The mica schist outcropping in the town just east probably extends far into this area; it seems to be the rock encountered in a well in the northeast quarter of Section 13. Granite is exposed in Section 21, but is probably a small offshoot from the Giants Range batholith, which is well exposed in the adjoining township south. These exposures are mapped for the first time. West and north of this township there is so much Ely greenstone that considerable of the northwest part of this township may be tentatively mapped as having greenstone bed rock.

The beaches of glacial Lake Agassiz cross the north side of the town.

TOWNSHIP 62 NORTH, RANGE 21 WEST

Geology by F. F. Grout



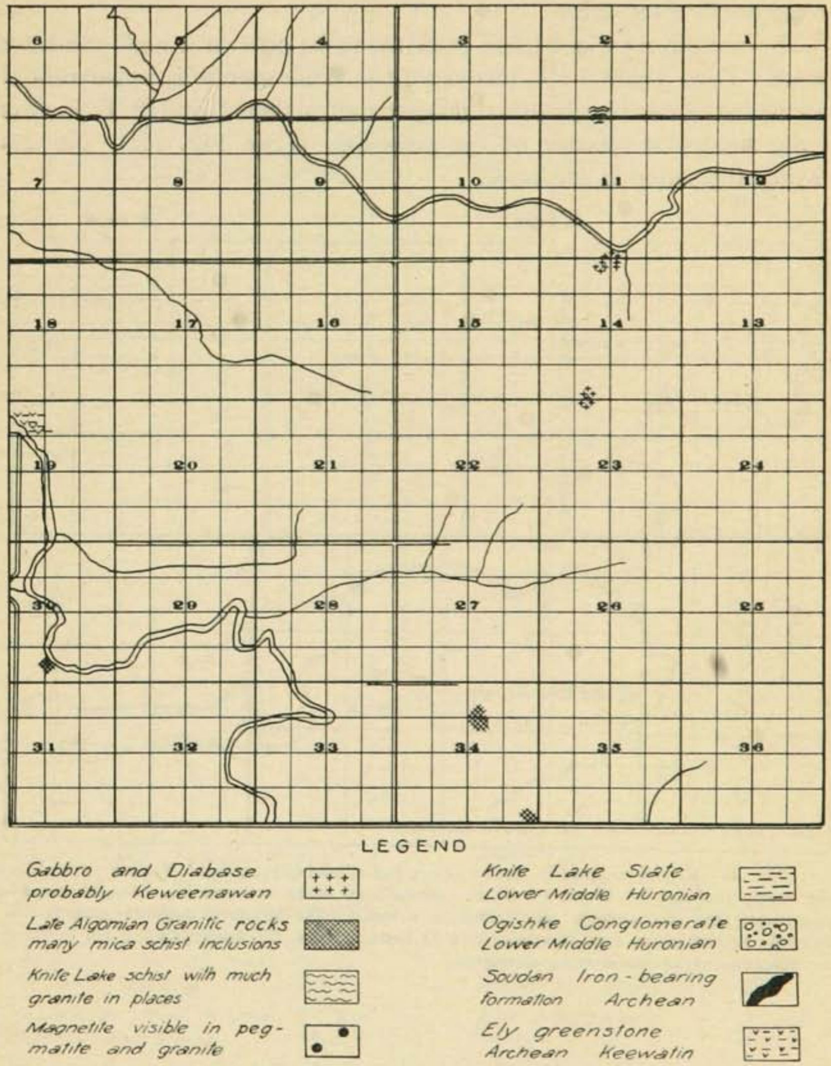
TOWNSHIP 62 N., RANGE 21 W.

Few outcrops have been noted in this township. Most of the surface is clayey soil deposited by the waters of Lake Agassiz.

Along the river in Section 3, is an exposure of syenite like that farther east and north. Half a mile south of Celina, a well encountered bed rock that seems to be Ely greenstone and since that formation occurs on all sides it may be assumed to occupy most of this town. Basic intrusives occur on the southwest and it is likely that syenite is widespread along the north side. (See Fig. 16.) "Black jasper" is reported by J. H. Nelimark in a well near the northeast corner of Section 31. This may be black diabase like that a mile farther west, but it is probably not iron-bearing formation. Dip needle readings showed no attraction in the neighborhood.

TOWNSHIP 63 NORTH, RANGE 21 WEST

Geology by F. F. Grout



TOWNSHIP 63 N., RANGE 21 W.

The biotite schist of the northeast and Ely greenstone of the southwest are probably the chief formations of this township. They are intruded by syenite in the southwest and by diabase gabbro in the east central parts of the township. No contacts between these several rocks were noted, but the age is estimated from the relations of the same petrographic types farther east. Glacial drift which conceals most of the bed rock, has been modified by the waters of Lake Agassiz so that clayey soil covers nearly everything.

The syenite mentioned has been found to contain a high content of potash. (See Table VIII, analysis 17.) This syenite is apparently the rock which causes the abnormal magnetic attractions found by F. F. Grout in the southwest quarter of the township. (See Fig. 16.) No iron-bearing formation is indicated.

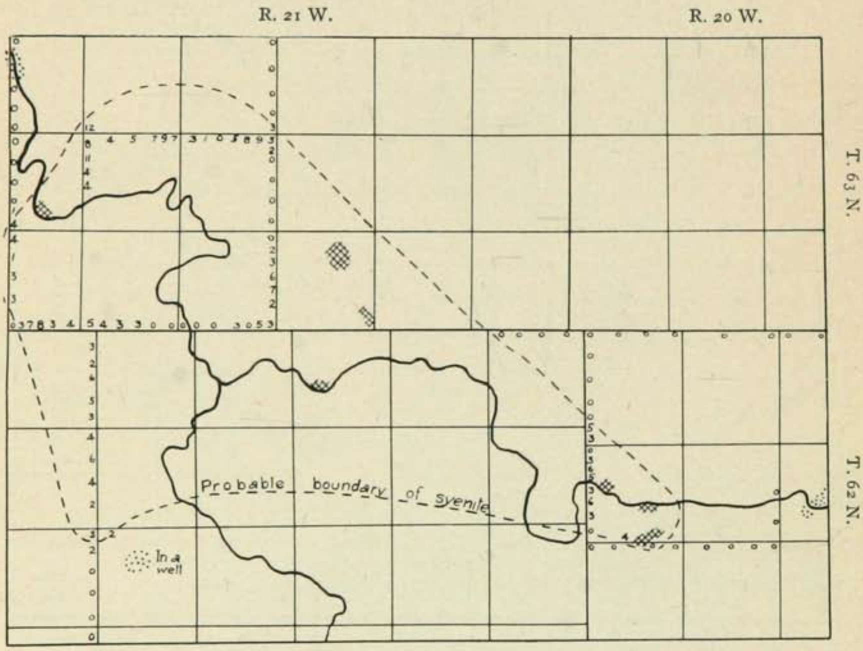
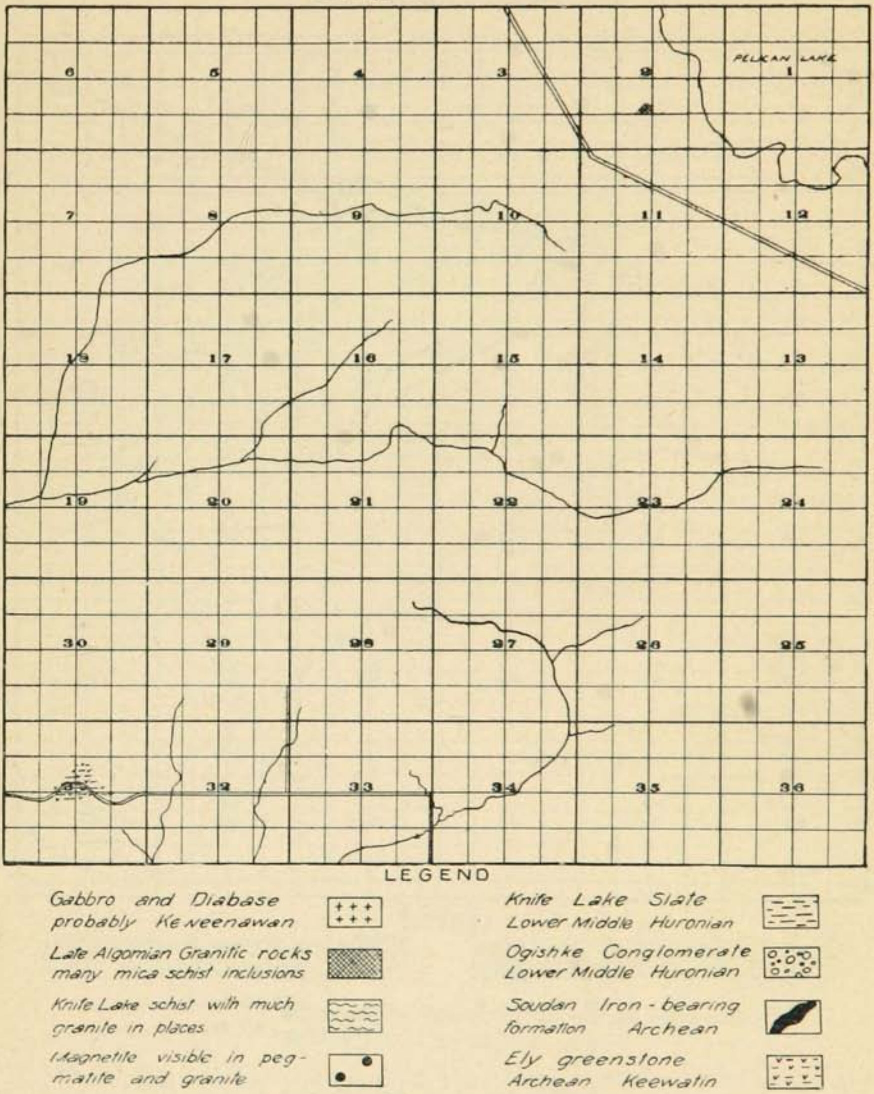


Fig. 16. Map of outcrops in Linden Grove and adjoining townships. Figures show abnormal dip needle readings by Frank F. Grout. Cross lined areas are syenite. Stippled areas, Ely greenstone, (the southwestern area known in a well). The abnormal magnetic attraction is so definitely related to the area of syenite and its boundary that the magnetism can not be taken as an indication of an iron-bearing formation.

TOWNSHIP 64 NORTH, RANGE 21 WEST

Geology by F. F. Grout

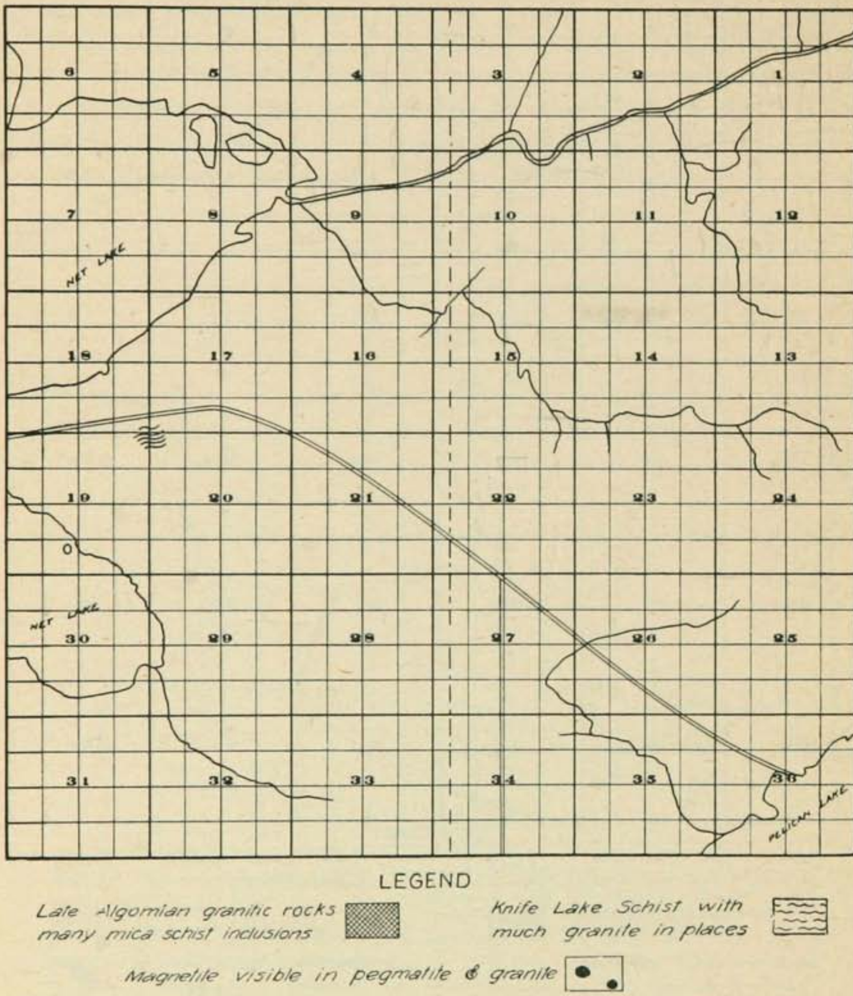


TOWNSHIP 64 N., RANGE 21 W.

The chief rock exposures in this township are the Ely greenstone in the southwest and Vermilion granite in the northeast. It is believed, however, that the biotite schists which are exposed southeast of the town extend into it for several miles. The granite has inclusions of schist and larger bodies no doubt exist within a short distance. Glacial drift, modified on the southwest by the waters of Lake Agassiz, covers most of the bed rock. Dip needle readings were taken by Edward Steidtmann and the Survey parties along the roads of the township, and all were found to be normal.

TOWNSHIP 65 NORTH, RANGE 21 WEST

Geology by F. F. Grout

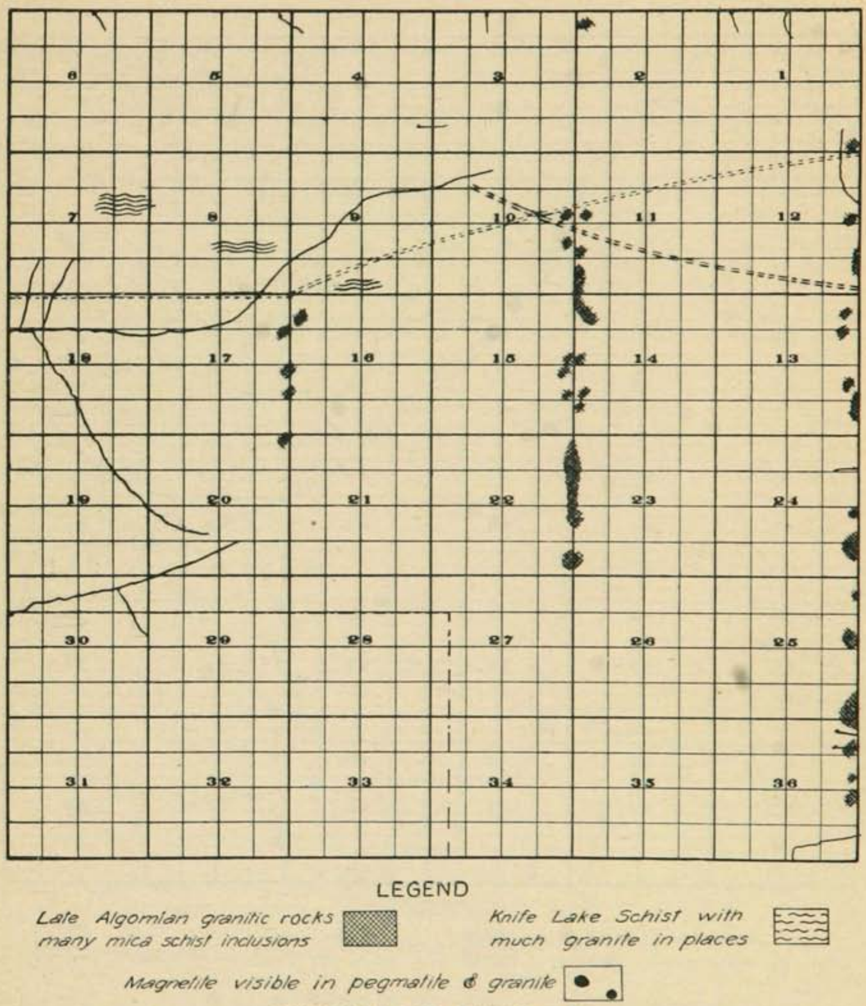


TOWNSHIP 65 N., RANGE 21 W

This township is in the area of Vermilion granite, but is near the southwest side where biotite schist is abundant. On the shore of Net Lake, just west of Section 19 of this township at the Indian village a dike of diabase intrudes the schists. Dip needle readings were taken along the roads in the southern part of this township by Edward Steidtmann and all were found to be normal.

TOWNSHIP 66 NORTH, RANGE 21 WEST

Geology by Edward Steidtmann



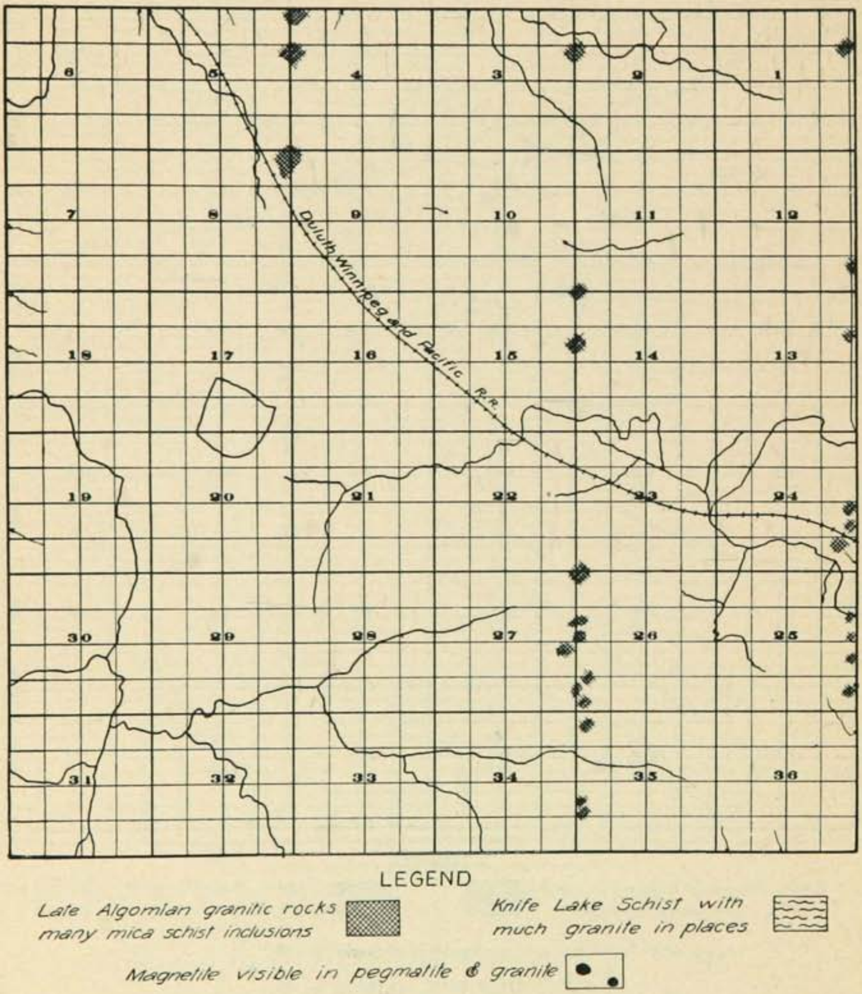
TOWNSHIP 66 N., RANGE 21 W.

This township has outcrops of Vermilion granite with biotite schist inclusions. Some areas of schist as much as a mile wide may occur[a] but have not been visited. A special trip was made west of Ash Lake to see outcrops and get dip needle readings in an area of supposed iron deposits, but no magnetite was found. The outcrops and dip needle readings were mapped by Edward Steidtmann and party. No abnormal attraction was found.

[a] See map of northern St. Louis County in Vol. IV of the Final Report of the Geological and Nat. Hist. Survey.

TOWNSHIP 67 NORTH, RANGE 21 WEST

Geology by F. F. Grout and Edward Steidtmann

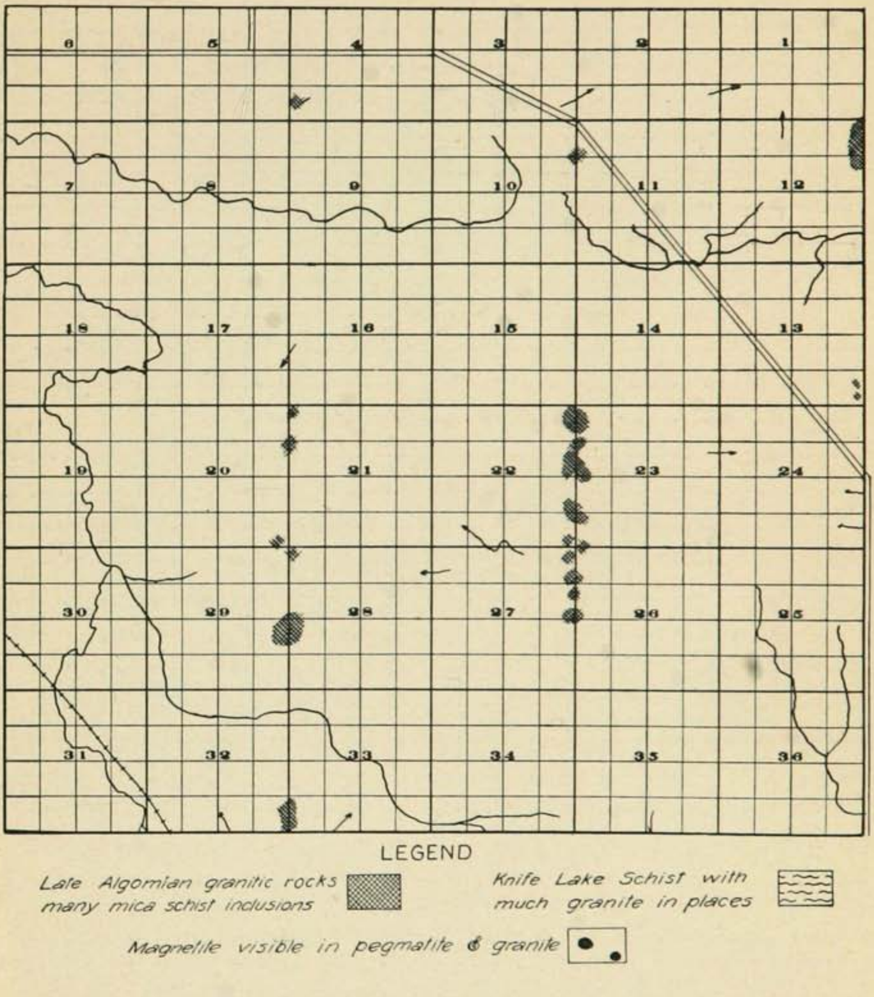


TOWNSHIP 67 N., RANGE 21 W.

This township has many outcrops of Vermilion granite with biotite schist inclusions. Dip needle readings have been mapped by Edward Steidtmann and party. No abnormal attraction was found.

TOWNSHIP 68 NORTH, RANGE 21 WEST

Geology by Edward Steidtmann



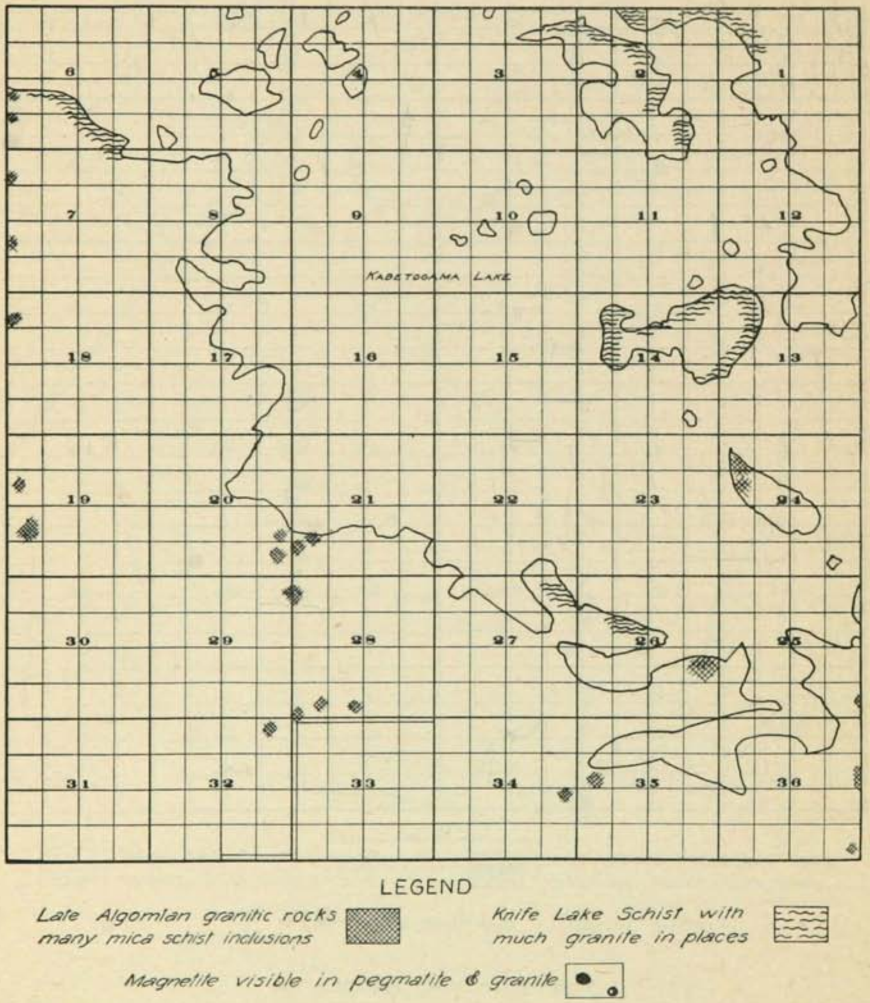
TOWNSHIP 68 N., RANGE 21 W.

The Vermilion granite is the chief rock in the many exposures in this township, but biotite schist inclusions are numerous. Pegmatites cross these formations very much as in the townships where magnetite is found, but no magnetite or magnetic attractions were discovered in this area.

West of the county line, in the SW¼ Sec. 2, T. 68 N., R. 23 W., near the town of Ray, magnetite pegmatites outcrop with about the same character as those in St. Louis County, but they are very lean. Some drilling is said to have been done in this section, in connection with mineral prospects.

TOWNSHIP 69 NORTH, RANGE 21 WEST

Geology by F. F. Grout and Edward Steidtmann

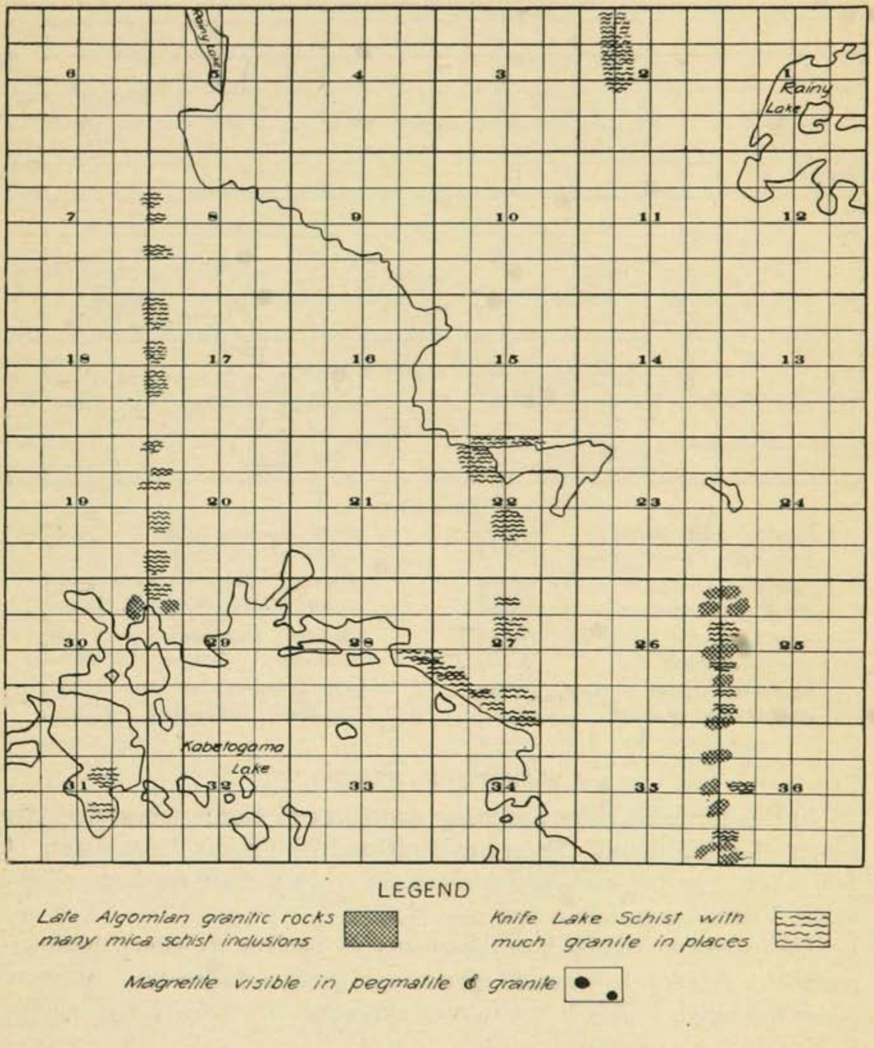


TOWNSHIP 69 N., RANGE 21 W.

The Vermilion granite in the southern part of this township has many large inclusions of biotite schist, and the schist farther north has many granite intrusives. The line between the two formations is therefore somewhat arbitrary. Dip needle readings by Edward Steidtmann showed no abnormal attraction.

TOWNSHIP 70 NORTH, RANGE 21 WEST

Geology by F. F. Grout and Edward Steidtmann

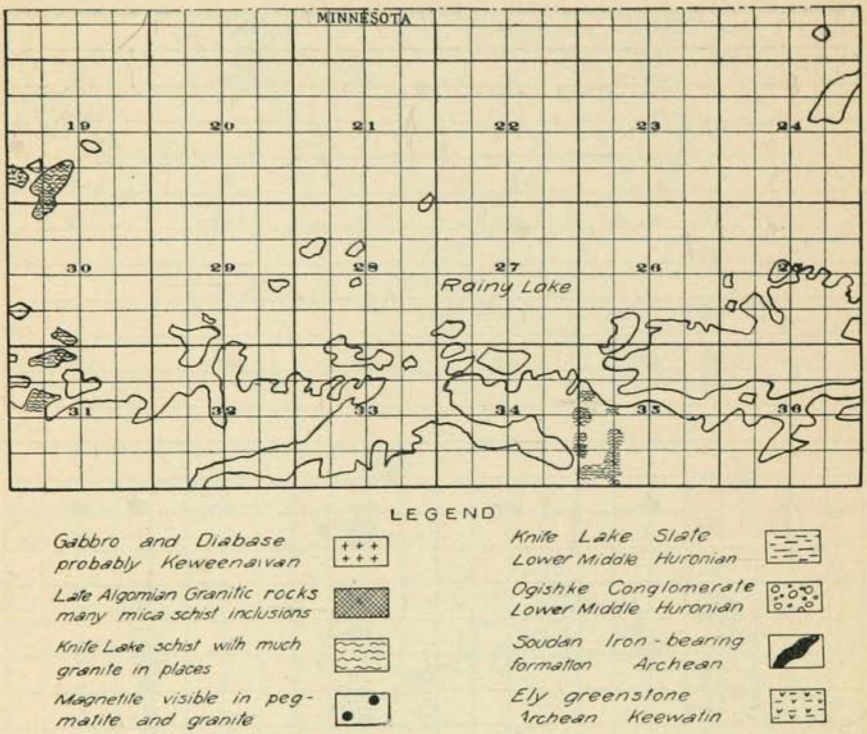


TOWNSHIP 70 N., RANGE 21 W.

In this township there are many exposures of biotite schist along the shores of Kabetogama Lake. These are correlated with the Knife Lake slates. They are cut by granite and pegmatite dikes which are probably related to the Vermilion granite, outcropping a few miles to the south. None of the rocks seem to have any commercial interest.

TOWNSHIP 71 NORTH, RANGE 21 WEST

Geology by F. F. Grout



TOWNSHIP 71 N., RANGE 21 W.

In this township there are many exposures of biotite schist along the shores of Rainy Lake. These are correlated with Knife Lake slates. A few dikes of granite and pegmatite cut the schist and are no doubt related to the Vermilion granite a few miles south.

The island extending into the county in Section 19, along the international boundary, has a small exposure of green schist of the Ely greenstone formation. This is the eastern exposure of a fold that is mapped in Koochiching County.

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