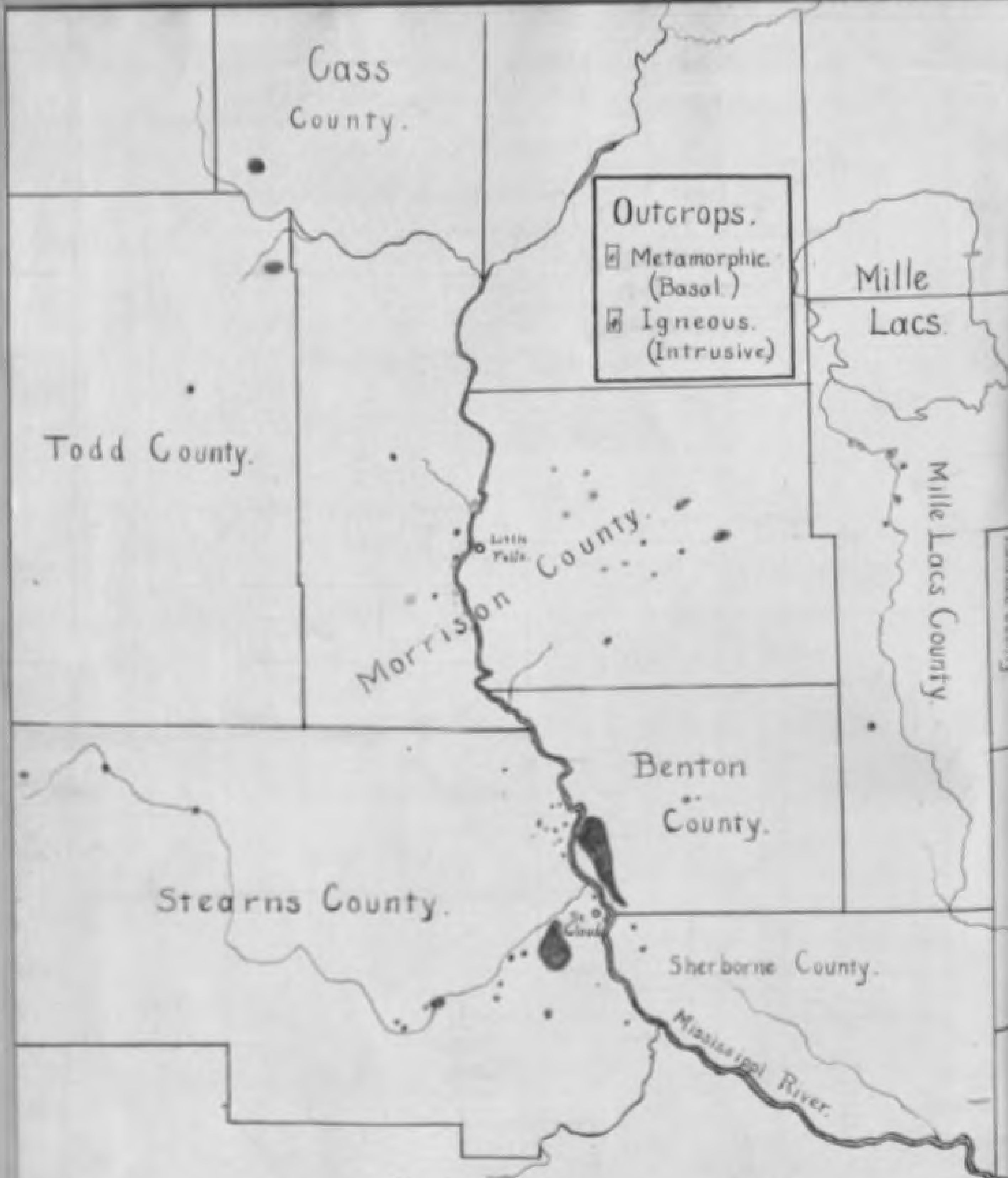


Outline Map of EAST CENTRAL MINNESOTA Showing Rock Outcrops.

Plate I

F. F Grout

THE GRANITES AND ASSOCIATED QUARTZ BASALTS

OF

STEARNS COUNTY, MINNESOTA.

A THESIS

FOR THE DEGREE OF

MASTER OF SCIENCE.

1908.

Frank F. Grout.

CONTENTS.

INTRODUCTION.

Just south and east of the group of glacial lakes which serve as a gathering ground of the Mississippi River, where the volume of the water becomes considerable, lies a district where lakes are less prominent, though most of the area is made up of swampy tracts with scattered rounded hills rising occasionally a little above the general level. This swampy level seems to be the filled up basins left by the retreat of glacier ice, and the hills are the remnants of bed rock passed over and polished and extensively striated by the ice both from northeast and northwest; but not so deeply covered that erosion failed to expose them again to the air. Where this bed rock outcrops, it consists of a variety of igneous and metamorphic rocks which have been assigned to the Kewatin age by recent writers, notably by Prof. C.W. Hall. (See reference list, page 3.)

The igneous rocks, apparently intrusive in older schists, gneisses and alstes, form the subject of this thesis. The outcrops are divided centrally by the Mississippi, and on the east side extend from T.34 N. to T. 44 N.; R.25 W. to R.32 W.; while on the west in approximate symmetry, they extend from T.123 N. to T.134 N.; and R.27 W. to R.35 W. Eight or nine counties are included, and the district cannot be divided into definite parts, in which certain types of rock are characteristically present or absent. Overlapping types and some gradation between the types seem to be characteristic. On this account the detailed statements have been limited to one county, Stearns County. Nearly all types are found.

Location.

Stearns County lies west of the Mississippi River, which is its eastern boundary, about 60 miles northwest from Minneapolis. It extends from T.121 N. to T.127 N. and from R.27 W. to R.35 W. From the northwest corner of the county comes the Sauk River, flowing toward the south center, then back to the east center of the county, passing in its course the important towns of the county - in order, Sauk Center,Melrose,Richmond,Cold Spring,Rockville - finally reaching the Mississippi just north of St.Cloud. Outcrops of bed rock appear at scattered points near all these towns and also along the Watab River,(a little north),the Mississippi,and a small stream south of St.Cloud.

Economic Summary.

Quarrying was begun in the district in 1868,and it has rapidly increased. Many quarries are now open in the district and the product is valued at about $500,000.00 yearly,this being about one-third the total value of stone produced in the state. Building and monumental stone,and paving block are the chief types,each of which is showing good increase. The varieties in favor are briefly discussed as each type is described.

Historical Resume.

In 1871,Mr.Kloos,who had been land agent of the St. Paul and Pacific Railway and sampled many Minnesota localities,including Stearns County,published a brief paper describing syenitic granites in Zeit. d. Deut. Geol. Ges. This was translated by the Minnesota Survey some years later. In 1877,Kloos co-operated with Streng in Germany to describe quite a few specimens from this region. The report was published in N.J.für Mineralogie,1877 and translated in the 13th Ann. Rep.,Geol.and Nat. Hist Surv. Minn.,1883. The field work done by Kloos was apparently rather incomplete, but the work of Streng was of surprisingly good quality, and has not been surpassed up to the time of the present work. Only a few analyses have been made since that time which are as complete and accurate as his. The conclusions he reached by microscopic work stand today as the best. The nomenclature of the subject has changed somewhat,as he foresaw,and his provisional names are not now much used, but the accuracy of his descriptions has never been questioned. The field work,unfortunately does not give a correct idea of the relative importance of the types found; and worse,does not give very accurate location for the samples, so that any doubtful observations can hardly be repeated.

This is so serious that some of his "quartz-diorytes" as analyzed may represent a nodule of less than a foot in diameter, in a slate, while another given equal emphasis, may be the wide-spread gray granite of the district.

The Minnesota Survey has done rather more extensive and accurate field work and the total of their observations is given in the detailed report of the counties of this area, and largely repeated in Vol.V on the rocks of the state. The material of the Survey is correlated with the present work as each type is considered below.

Since 1883, Prof.C.W.Hall has studied the district in detail. Most of his work is not published, but references to the district are found in his paper on the Kewatin of East Central Minnesota. The most extensive laboratory work he reports is in a paper on Soils of Minnesota, where several incomplete analyses are found. The large number of sections made and examined in connection with this work by both Prof. Hall and Dr.Van Hise, have not been described in any publication. I am indebted to all these workers for some suggestive material.

Literature.

1871. J.H.Kloos. Geological Notes on Minnesota. Zeit. der Deut.Geol.Ges. 1871, page 428. (Translated in 10th Ann.Rep., Geol. and Nat.Hist. Survey, Minnesota. (1882) page 175.)

1877. A.Streng and J.H.Kloos. The Crystalline Rocks of Minnesota. Neues Jahrbuch für Mineralogie. 1877. (Translated in the 11th Ann.Rep., Geol.and Nat.Hist. Survey, Minnesota. (1883) page 30.)

1891. C.W.Hall. Sources of the Constituents of Minnesota Soils. Bul.Minn.Ac.Nat.Sci. Vol.III, page 388.

1900. N.H.Winchell. Geol.and Nat.Hist.Survey, Minnesota. Final Reports, Vol.II and V.

1901. C.W.Hall. The Kewatin Area of Eastern and Central Minnesota. Bul.G.S.A., Vol.XII, page 343.

Object and Scope.

It is evident from this historical discussion that the methods of petrography as recently developed,have not been and cannot well be applied,on account of the incompleteness and probable inaccuracy of many of the analyses. The rest of the previous work has probably been as good as could be expected,in view of the incomplete knowledge of the surrounding geology and the impossibility of thorough exploration,due to the wooded and unsettled state of the country. It was thought that a little more detailed study would give certain evidence of rare types of rocks,that has been heretofore entirely uncertain,on account of this incompleteness and inaccuracy. Conclusions might also be reached as to related origin of the various types,and as to similarity with rocks of other petrographic districts.

Material.

Two field trips were made to the district under the guidance of Prof.Hall,who covered all the county in 1883 and has visited many parts of it since then. In 1904,the area of abundant outcrops just west and a little south of St.Cloud was rapidly surveyed; and in 1905 the neighborhood of Rockville and the northern part of the area west of St.Cloud were visited. Samples were taken and compared with those taken in times past,with perfect agreement as far as the district was visited. A great number of thin sections were made in connection with the previous work and these have been added to by the work done since 1904. Several complete analyses have been made.

RESULTS.

Structure.

Field work on the Kewatin in the region northeast of Stearns County revealed dikes of the igneous rocks intrusive in the schists and other metamorphic Kewatin rocks. Approaching Stearns County, larger masses might sometimes be seen in overlapping contact with gneisses, as near as Granite City. But in Stearns County the masses must have been of the nature of great laccoliths and have covered most of the area, for little was seen of metamorphic rocks unless we consider some minor inclusions of schistose nature in the igneous rocks.

Jointing was observed throughout, the main set of joints having a prevailing direction N. and S. to N. 20 degrees W. In many other directions a few local joints were clear. For the district of most numerous outcrops the directions are plotted. See Plate 3. The inclination of the joints is generally vertical but varies 20 degrees. Basaltic jointing is common in some dikes which break vertically through the granitic masses, often very irregularly. Granite veins and pegmatite veins will be mentioned as the localities are described.

Structure planes or "bedding planes" were noted in the large masses quite often dipping north. Weathering develops lines of weakness parallel to the surface exposed, at varying depths.

Types.

Phanerites predominate, the aphanites being mostly later intrusive dikes, some acid, some basic. Most of the phanerites are persalanes and dosolanes, and vary in free quartz from amounts equal to that of feldspars to practically none. A range of gabbro outcrops crosses the county indicating some rocks of the salfemanes, evidently gallare in order. (Here would also be found the basic dikes.) Five types have been selected as representing the district, 1. Gray Granite, 2. Red Granite, 3. Rockville (or porphyritic) Granite, 4. Green Syenite, 5. Gabbro. A description of these with their inclusions, contacts, etc., will cover the district, with the possible exception of some very local occurrences that seem mineralogically and physically unrelated to any of them. One striking feature noted in several types and districts, but not described in detail below, is the poikilitic development of feldspar and quartz, such that a rock apparently uniformly grained contains feldspars of 10 to 15 times the apparent size and these enclose the other minerals. Alteration is abundant and varied. Some of the feldspars exhibit kaolin, some epidote and some are so extremely altered as to be classed with "sericite" and "viridite."

Gray Granite.

This is found quite wide-spread in the county, especially in the great area west of St. Cloud a few miles. Its occurrence, structure, etc., are detailed below. The rock consists of a fine (below 1 m.m.) to medium (1 to 5 m.m.) grained granitic aggregate of gray feldspar and hornblende, with occasional pyrite, and in case of alteration, considerable biotite. Quartz is present and can be distinguished in hand specimens in minute grains, only in rare cases reaching a size comparable to that of feldspars. In the typical case gray feldspar appears to constitute about 3/4 of the rock, the grains varying in size and perfection of outline considerably. In some, the gray color seems to be due to minute inclusions of some black mineral. In others, the majority, this is not evident. Striations may be seen on good cleavage surfaces of a few large grains. The certainty of more than one feldspar is clear in some cases, as a few scattered grains may be of pink or green color and influence the color impression given by the rock as a whole, but the proportion of the feldspars present is uncertain. The low quartz and fine color and polish make this rock the favorite. The paving block used in Minneapolis and elsewhere have been largely gray granite and it proves very serviceable in that capacity as well as being ornamental when polished. Microscopically the rock is seen to consist almost invariably of some feldspars, quartz, hornblende and biotite. Generally augite, pyrite, ilmenite, magnetite, apatite, kaolin (hematite ?) and sphene can be seen in some part of a thin section. The chief feldspars are microcline and plagioclase,orthoclase being somewhat less prominent. The quartz is quite abundant,when one considers that the megascopic study found it only by close examination in many specimens. The texture is peculiar in that there are occasional large feldspars in an irregularly fine rock of apparently secondary origin.

The microcline shows ite usual twinned structure quite well,in grains varying from 0.5 to 2 m.m.,many of which are nearly automorphic. It shows quite an abundance of dusty inclusions indicating that the beginning of kaolinization and yet not enough to obscure the gridiron structure in the least. Some small microcline grains,included or bordering on oligoclase,appear to be secondary. The larger grains may have been original. The plagioclase is much more abundant and probably constitutes nearly 50 per cent of the rock. The grains vary from 1 to 3 m.m.,in length and are usually about twice as long as wide. Twinning bands, usually narrow,may become wide and are not always persistent,across the whole length of grain. Rarely a set of cross twinning bands interrupt the main set. Carlsbad twinning is seen in a few cases in addition to the albite bands. Zonal growth is clear in some cases,and often,a well-formed crystal shows secondary enlargement. Alteration results differently in different cases. Epidote seems to be one of the main products,in some cases forming inclusions of brightly polarizing specks and even larger masses. Kaolinization has proceeded to varying extent and appears to affect some of the twinned lamellae more than others in the same crystals. The low,though wavy extinction indicates oligoclase.

Orthoclase can be recognized in a few large dusty grains often with Carlsbad twinning and imperfect form. Microperthite is more rarely seen. Probably the orthoclase contains considerable soda.

Quartz is one of the most characteristic of the minerals in the section in its numerous small grains,few of which are 0.5 m.m.in diameter. If a segregated mass of quartz is longer than this,it seems to be traversed by crevices. In all cases,the quartz seems to occupy the space left by the other constituents and a single crystal will apparently be distorted into a sinuous winding mass enclosing or nearly surrounding some crystals of an earlier generation. The result in this section is a group of isolated minute grains all showing the same interference color and all extinguishing at the same time. This approaches closely to a poikilitic structure with quartz as matrix for the other minerals. The plagioclase and other enclosures are not lath shaped and the quartz grains do not include as many grains as are common in diabase in a single augite grain. Wavy extinction is the rule. A few cases are seen in which quartz is in large aggregates which can be seen clearly in a hand specimen. A few fragments of microcline were noticed lying beside the large plagioclase crystals in parallel position as if altered from the larger grain,with quartz of this peculiar type on all sides of the fragments. The evidence of size and arrangement of quartz grains and the fact that it conforms to other grains in form indicate that much of it is secondary though a few grains may be original;e.g., those of larger size than usual. Inclusions are characteristically lacking ,but in some cases there are zones of liquid and gas inclusions and sometimes apatite crystals.

The ferromagnesian constituents of the rock vary in the interesting manner of many cases in Minnesota where augite appears to have been the chief original dark mineral constituting at different times from 10 to 25 per cent of the rock. Traces of it can usually be seen in the sections of this type,but hornblende is generally more abundant,still showing a central core of augite. Weathered specimens,and often those which appear to be fresh,show biotite,sometimes to the complete exclusion of the others,but more often associated with both of them. Hornblende is most prominent and occurs in grains up to 1.5 m.m. in diameter, showing the usual green color and pleochrism. Some masses seem to be made up of small particles variously oriented, possibly viridite,but usually a good sized grain may be seen with fairly distinct cleavage and properties of hornblende including low extinction angle. The centers of these green grains,however,change in color very often by the presence of a mass of nearly colorless,rather highly refracting augite that shows high interference color and high extinction angle. This grades outward into the hornblende by becoming granular and the hornblende seems to have penetrated the interior substance first along the cleavage and later across that direction,detaching a few fragments of the original mass. Every evidence points to the conclusion that the original mineral is changing to hornblende. Streng,in 1877,decided that the original was augite (diallage) in most of the Minnesota rocks he examined and this has been the conclusion of more recent writers. The hornblende generally develops a cleavage that seems independent of the position of the original. Apatite is a common inclusion and associate of the hornblende. Epidote may develop near contacts of feldspar with the ferromagnesian minerals.

Biotite may have been an original constituent of the rock in some places,but a study of various depths in some of the quarries indicates an alteration toward the surface with increase of biotite. Sometimes no other ferromagnesian mineral is left. Cases may be noted where a large grain of augite has a border of hornblende and in close proximity a number of small hornblende grains,beyond which is biotite in similar scattered grains,on all sides. In places biotite is developed in contact with hornblende with coincident cleavage and as the grains are rotated,similar colors result in some positions making the whole appear as a single grain.

Magnetite and pyrite in small grains are sometimes included in the feldspars or ferromagnesian minerals. Magnetite is more often found near the boundary of a grain of hornblende or between hornblende and biotite. Apatite is seen in inclusions in the hornblende,etc.,but is not abundant and is in small crystals. Sphene occurs in about one third of the specimens examined,in small brown grains,usually close to biotite,but redder in color and showing slight pleochrism instead of the absorption of biotite. Relief is rather high,but grains are so small that cleavage is not well developed. Zircon is rarely seen.

Weathering rarely produces a red color. Aside from the development of biotite the whole rock becomes brownish and then softens and crumbles.

The study of relationships between the minerals becomes complex. The prevalent wavy extinction indicates something of dynamic action. The changes in ferromagnesian minerals confirm the idea of alteration. Finally,the presence of large plagioclase crystals occasionally showing secondary enlargement,in a mass of finer grained minerals all of which seem fresher and none of which show good crystal outline,makes it seem probable that nearly the whole rock has been recrystallized or granulated since its solidification. Seldom is there any indication that the quartz now seen was an original constituent. Possibly when the composition as a whole shows large masses to have normative quartz,it is unreasonable to think it was not present;but it is recrystallized. Feldspars show extreme alteration,and augite is nearly gone. The original condition can only be estimated,not closely determined. Analyses of this gray rock are found in Table I,and,more complete ones in Table III. These show that there is some variation in the type with little change in appearance. From the more complete analyses,the average rock must contain about 50% of oligoclase; 30% of microcline and orthoclase; with quartz varying from 10 to 15% or more. There is no very great range in composition seen even from widely separated parts of the area.

The problem of correct naming involves the variation in usage of terms and the difficulty of naming an altered rock,either from its present or original condition. In Minnesota it is known as "fine gray syenite" in the reports of the state survey,and as "gray granite" commercially. It is apparently the rock described by Streng as an "augite-quartz-diorite." The name granite is retained for general field use,because it is well known,although Streng's name may apply with greater accuracy. "Syenite" as used by Werner,meant a rock predominantly feldspar and without noticeable amounts of quartz. In the field,quartz can be seen in the majority of specimens but the proportion of feldspars is uncertain; and for closer laboratory work the chemico-mineralogical classification is more accurate than others. This places the granite in the dosodic or sodipotassic sub-rang of the docalcic or alkali-calcic rang of the quardofelic orders of the persalanes and dosalanes. The types with exceptionally abundant quartz are higher in alkalies compared with lime and (Winchell's) must be placed as tehamose with the red granite. The incomplete analyses published by Winchell, and the variation in the more complete ones, indicate some very unusual types, as they fall in sub-rangs in which no analyses were known a few years ago, for instance, a dosodic, docalcic brittanare, or a presodic, docalcic hispanare, but the exact location of the samples taken is not given and the results are so incomplete as to render conclusions uncertain. The average gray granite is harzose and yellowstonose; in general a granoharzose.

The rare cases of high quartzose rocks furnish a peculiar variation. It happens that in these few outcrops the grain is coarser, the feldspar lighter colored and dark minerals not abundant. Further, the quartz has a notable brown tint, no microcline is seen and the augite is entirely lacking, so that the rock is thought to be of different type from the usual; but the microscope shows fairly close relationship, and the main features correspond. Two samples were selected which appeared to show high and low extremes of quartz. The thin sections did not reveal as great a difference as was expected, and analyses showed very slight variation. See table III below. The exceedingly acid rock (75% of SiO_2) of an analysis published by Winchell "Quartzose gray syenite", must be a quite distinct occurrence and not at all like the type here described. The specimen in the survey collection is apparently an uncommon one and may be a contact phase.

Red Granite.

This rock is found in greatest abundance in the same area near St.Cloud as the gray. Eastward and northward, however, from Stearns County, the red rock is confined to a few scattered outcrops, after which only the gray and its modifications are seen. The rock is medium to coarse grained and varies in amount of quartz, up to apparently 3/5 or more of the feldspar content, and is always visible in the hand specimens. The feldspar is apparently largely orthoclase, colored pink to red and mottled with the coloring so that it appears to be colored by hematite, possibly an alteration product. In the average case, a few grains of a greenish feldspar can also be seen. Ferromagnesian constituents are much less prominent, but occur in good sized grains, apparently hornblende, of slight greenish color in the freshest rock and changing to biotite near the rock surface. This rock is harder to work than the gray and many quarries are abandoned for less siliceous stone; but the product is a beautiful one and still considerably used as building stone and monuments. In thin section the rock is seen to consist largely of the same three feldspars as the gray syenite in rather different proportion, with quartz, biotite and hornblende as other essential minerals; and hematite, magnetite, kaolin, and a few other rarer minerals as accessories: e.g. apatite, sphene, zircon, epidote and chlorite were observed. Augite is seen as in the gray syenite, but much less commonly.

Microcline and orthoclase are equally prominent and much more abundant in the average than oligoclase. Some small grains of each feldspar occur in such relation that they appear to be secondary. But the larger, very dusty grains can hardly have moved far from the original surroundings, and often have partial crystal outline. Both of the feldspars may be rather high in soda, judging from the analyses. Hematite stains the grains freely, mostly along the borders and into the cleavage cracks, but the megascopic appearance is often uniformly colored. Kaolin and epidote result from the alteration of feldspars as in the gray rock. Microperthitic intergrowth of albite is to be noticed in about one third of the sections. From the rock analysis, it is thought that soda may constitute a part of the orthoclase.

Oligoclase is recognized in less abundance but characters similar to that in the gray rock.

Quartz is seen of an entirely different type from the secondary minute grains of the gray. Such secondary quartz as is found in gray is to be seen in the red granite, but most of the quartz is of the usual granitic type, with grains up to 3 m.m. in diameter. The largest aggregates, however, have several grains in slightly different position, and all the quartz seem to have filled up the spaces left by the other crystals, being the last to crystallize. Inclusions of liquid with gas bubbles are common and arranged in planes and bands,with all the usual characteristics of of granitic quartz.

The ferromagnesian minerals can be traced through the same succession from augite to hornblende,thence to biotite and the accessories,magnetite,sphene,etc. Less augite in proportion is to be found in the red granite than in the gray rock,and none of the ferromagnesian minerals reach a high proportion in the rock as a whole. Hornblende is seen in two characteristic occurrences; one with a single cleavage,partial crystal outline or none,and pleochrism blue green to yellow green; the other with crossed cleavages, good outline and pleochrism from brownish green to greenish black. This latter type is strongly absorptive in one direction,and never shows the association with augite,and was probably an original constituent. Apatite is the chief inclusion noted. Biotite is seen in the granular secondary portions of the rock as fine needles,and in association with the hornblende as grains up to 1 m.m, or more,across.

Occasionally a grain of epidote nearly a m.m. in diameter may be seen associated with the secondary quartz and feldspar aggregates.

Sphene,in the usual wedge shaped grains,is associated with biotite and hornblende. Rarely zircon is seen in similar position. Chlorite and calcite result in extremely altered conditions from biotite,etc.

Alteration affects the ferromagnesian constituents as in the case of the gray rock. The feldspar becomes more highly colored but loses its lustre and seems to be badly iron stained.

It seems clear that the original was a not unusual rock,an augite granite with some hornblende and common accessories and inclusions. There is no evidence of extreme alteration.

Several analyses of red granite are given in the survey reports as "quartzose red syenite",and one more complete analysis is added in Table III. These all prove to be domalkalic and sodipotassic,very distinct from gray granite. Normative quartz varies so far as to place it in either columbare or brittanare of the persalanes. It is, then,without great variation,a grano-tehamose or a granotoscanose. The tehamose rang,therefore,includes an extreme variation of the gray granite and a rather common type of the red. This common ground is not as close to the gray as to the red,and the gradation bridges a large gap to reach the gray.

Rockville Granite.

Rockville is the locality of greatest outcrops of a beautiful porphyritic granite,in which the phenocrysts are up to two inches in diameter and consist of a pink to red feldspar,bedded in a red granite of type similar to that described above. The greenish faldspar grains that occur sometimes in the red granite are rather more common in ground mass of this rock. It occurs in only three townships south and east of St.Cloud in its typical development,and from these to the main area west of St.Cloud there is indication of a gradual transition to the typical red type. The quality of the feldspar does not appear to be essentially different from that of the red granite,mostly orthoclase and microcline. No striation is visible,but analysis proves soda to be rather high for orthoclase. The size of the phenocrysts varies,probably averaging 3/4 of an inch over most of the three twonships,increasing locally,and decreasing as it grades into the normal red. The average color is a little lighter red than the granite.

The beautiful appearance of this stone and the high polish it is capable of receiving,combine with its permanence in making it very desirable for monumental work and ornamental columns,etc. Some very large blocks have been quarried and shipped and the reports have it superior to the renowned Scotch granite.

The thin sections of the stone show so few grains in a single section that little additional is to be added. Microcline is apparently the most abundant of the feldspars and the rock resembles the red granite thoroughly. Biotite is rather abundant and hornblende comparatively less,in the sections studied. Quartz is apparently partly original in grains a little smaller than the feldspars in the ground mass and partly a secondary aggregate of fine grains. The microcline is not a pure potash feldspar as indicated by an old analysis made by Pease and Keller as students in the University, as follows:

Silica,	63.37
Alumina,	21.08
Iron oxides,	0.36
Lime,	1.72
Magnesia,	Trace
Potash,	4.04
Soda,	9.32
Moisture,	0.57
Total	100.46

Accessory minerals are no doubt the same as seen in the red granite type.

The minerals of the rock weather as those of the red granite just described.

The abundance of large feldspars without much change in the composition of the ground mass indicates a slight decrease in the per cent of silica. Analyses bear this out. One old analysis of rock from Watab seems to be of a similar rock. One made more recently is found to be as reported in Table III. This indicates the probability of about 20% oligoclase, to 35% microcline and albite combined; and 30% of quartz.

This puts the rock in the quantitative classification as a toscanose of the brittanares, similar to the red granite: a grano-phyro-toscanose.

Green Syenite.

This is less a type than an extreme towards which others may vary, and which in the extreme development here described occurs only in the few outcrops of the townships of the northwestern corner of Stearns County. Other types occur there, but interest centers for the district in this green rock. At some distance it may be hard to distinguish a weathered surface of other rock from this, because greenish lichens cover a good many exposures and the weathering of the green rock occurs by early removal of the green minerals; but freshly fractured surfaces reveal clearly the peculiar nature of the rock. A mass of medium-sized grains of striated feldspars, varying in color from cream to a light pink, lie in a matrix of green epidotic granular mineral, (or perhaps it is better to say that the epidote fills the crevices between the feldspar grains as they lie irregularly packed together.) The rock is not of much economic importance as the color is not in fashion and makes it appear decomposed and soft,whether really sound or not.

In thin section are seen albite as the main constituent,and epidote second in importance; orthoclase in a few smaller grains; rarely a small grain of quartz. Other accessories are almost entirely lacking.

Epidote,which constitutes nearly one third of the rock,occurs in crystals up to 1 m.m.in length and from that down to the minutest of grains included in the feldspar. Apparently it is derived from the alteration of the feldspar and that alteration is now quite complete in some grains and just beginning in others.

The feldspar of greatest abundance is albite from its angles of extinction (slightly wavy) about 15 degrees. Alteration to epidote has proceeded from the borders inward in most cases to the destruction of the original boundary of the grain. The position and boundary of the epidote shows no evident relation to the position and boundary of the feldspar,etc.,from which it came. The feldspars are not much dusted with kaolin. Of the smaller grains,some mingled with the masses of epidote,may be secondary in origin,but are apparently similar in composition: some few may be orthoclase.

Quartz is rare and apparently secondary. Apatite is sometimes seen. The surface rock weathers white and porous for an inch or more.

The scarcity of exposures in the northwest part of the county and the variety seen in those few,make it difficult to trace the relation between this and other types of more common occurrence. Two characteristic masses were sampled and **analysed**,giving the results of Tables II and III. **These** show the dominance of sodium and calcium and place the rock in the beerbachoses of the andases of the brittanares of the dosalanes. In composition it is not far from the rather acid quartz diabase dikes to be discussed below, but it is far from them in texture and mineral composition. Very few analyses are reported with so great a surplus of sodium over potassium. Only a few beerbachoses are known and another of those is from Minnesota. This particular beerbachose is quite exceptional in the high per cent of silica, and in the quality of basic minerals contained. Both ferrous iron and magnesia are lower than in any other beerbachose, so that if classification was carried to grad and sub grad the rock would form a class by itself.

The calcium and sodium both being so high, lead to some doubt as to the feldspar containing little calcium. The Minnesota Survey report is as albite from the extinction angle and a micro-chemical test. A separation of the feldspar by specific gravity gave a powder quite free from greenish color. The heavy liquid approached 2.66 in specific gravity when separation was made, and if it increased the grains containing epidote would contaminate the powder. The feldspar had a specific gravity of 2.645 by the picnometer and contains 66.6% of silica, 22% alumina (and iron trace) and [and .77% MgO, 8.82% Na_2O, .37% K_2O] 1.4% lime. There must be over 5 times as many parts of the soda feldspar as of any other.

Gabbros and Dark Diorites.

These form a series with various extremes, not the subject of special study at this time. The main areas are confined in range from Little Falls, in Morrison County, southwest to the town of Richmond in Stearns County, and they do not intermingle as thoroughly with the other types as those thus far described do with each other. Scattered exposures may be seen, however, widely distributed.

The variation of the group here mentioned is great and a summary description can hardly be given so as to be of general application. Some prominent characters can be mentioned, and detail given as outcrops are mentioned in series later.

Hornblende may increase to nearly 90% of the rock and most of the gabbros are very dark from the presence of much of it. In some, biotite may be more prominent. The Little Falls type shows areas of interrupted biotite, of such nature as to appear to be a single grain, by its reflection of light, but quite disconnected in the field of view, by other minerals. In some, the dark silicates are no doubt partly augite. Plagioclase seems to be the feldspar present and may increase in amount till it produces a rock that approaches gray granite in appearance.

The thin sections confirm the variations suspected, but show that the original was probably almost always a rock essentially plagioclase and augite. The texture in some cases is diabasic, but more often granitic. The augite has altered into hornblende and biotite, by-products of the change being magnetite, etc. Accessories that become prominent in some cases are apatite and olivine. Less prominent are secondary quartz and chlorite and calcite, pyrite, etc.

Plagioclase, except in a few cases, makes up about 50% of the rock. Sections perpendicular to the albite twins show too high an extinction for oligoclase which is so common in the main types of the county. The analyses of several of the rocks show lime enough to produce andesine or labradorite and these are probably present, though some of the lime may be assigned to ferromagnesian minerals. The grains are of varying size, depending on the development of the ophitic structure in some. In the diabases, the plagioclase is in smaller grains and in the other gabbros in larger grains than the rest of the common minerals. Again we find cross twinning and wavy extinction is the rule.

The pyroxene of these gabbros is much fresher than that seen in the more acid rocks. Still, in cases where it is absent, the occurrence of hornblende and biotite indicate alteration from original augite quite as clearly as before. The augite is usually pink from titanium, but not very pleochroic, in small grains with high relief, (possibly diallage.) In some rocks the cleavage of many augite grains has a notably uniform direction in the rock, amounting almost to schistosity. In alteration, a few cases may be seen in which hornblende seems to be derived as a border of the augite grain, but usually biotite is more prominent, sometimes forming a distinct border, grading to augite with no perceptible hornblende. The biotite has less absorption in some grains than in the typical biotite. There is no certainty that all is secondary, however, as various forms occur. It is only in very altered specimens that hornblende makes up the large proportion mentioned as possible (90%) Inclusions in the dark silicates may persist while the rock alters. Apatite is one of the most striking; many sections with hexagonal outline,and some of large size making the rock decidedly exceptional in extreme cases. These are most often associated with hornblende.

Quartz is seen rarely in small grains with the characters of that secondary quartz in all the neighborhood.

Olivine in some cases is found in scattered grains in the fresher gabbros,where augite is not all decomposed. This too is suffering alteration. Magnetite is abundant on the borders and serpentine and even calcite are noted in the neighborhood of the decomposed grains.

Weathering and alteration depend to a great extent on the mineral content. A brown surface color is the predominant one.

Analyses of these types of gabbro are not numerous n and range as widely as the appearance of the rocks. They are dosodic and presodic in sub rang and docalcic or alkalicalcic in rang. Quartz is low,but feldspars vary so that both dosalanes and salfemanes are found. Hessoses and camptonoses are the chief names to apply. See Tables I and II. This indicates a relation to the green syenite of the west and,as will be seen later,to some of the basic eruptives in the granites.

In the field no contacts were seen between the gabbro and other rocks of the district so that its relation to them is a matter of laboratory study. If Streng's "augitedioryte" is a gabbro,Kloos saw a contact of such a nature as to conclude that the gabbro was intrusive in the granites.

Less Abundant Types.

The first in order of abundance should be the diabase of dikes.In thin section,the ophitic texture is very clear and,as in the granite,it is rare that a grain of augite has persisted unaltered to hornblende. But the characteristic arrangement of plagioclase in the mass of hornblende made it seem wise to retain the name diabase. The plagioclase shows such variation in extinction angles that it is best explained by assuming two kinds present in one rock. One set of angles then vary near 10 degrees and another around 30 degrees,indicating labradorite and oligoclase. Magnetite

Analyses show sufficient Na_2O for this.

and apatite are found as accessories near the ferromagnesian minerals, magnetite especially rendering the altered mineral nearly opaque. Phenocrysts of orthoclase, plagioclase and rarely, quartz, occur with the size of phenocrysts varying with the fineness of ground mass. They often appear corroded in surface exposures, but sections show only a slight rounding of the crystal angles. Analyses are found in Tables II and III.

The acid dikes are not common (seen only in red granite) but are typical red quartz porphyry at the contact, varying to coarse granite porphyry in the center. This weathers to the appearance of a conglomerate and in other surroundings would be very deceptive. Some larger masses of granite porphyry are so similar as to be undoubtedly of similar intrusive origin. An analysis is given in Table III.

The granite veins (or dikes) were only in rare cases pegmatitic; usually very fine aggregates of quartz and pink feldspar. Ferromagnesian minerals are rare and sometimes almost lacking. The fine granular texture made it resemble some pink quartzite quite closely. In thin section the rock shows uniform grains of quartz and microcline with biotite and other feldspar as occasional accessories. Finer grains of poikilitic quartz also occur in some sections. An analysis is given in Table III.

The pegmatites were usually red and very coarse. They have not been carefully sampled, but the abundant quartz is often bluish, due to enclosed needles of rutile. Some graphic intergrowth with feldspar is seen. The dark silicates are not abundant, are green in color and probably resemble those in red granite.

The schists, slates and gneisses are not here studied. But one analysis has been made, (See Table II), the granite gneiss from the abandoned town of Granite City.

GEOGRAPHICAL SUMMARY.

Reaching Stearns County from the southeast, we find a few scattered outcrops over four or five twonships, before reaching the main areas so prominent in the map, just west of St.Cloud. The first of these is in T.123 N., R.27 W., Sec. 19, and, although a small outcrop, has been quarried at times. The rock is a light greenish granite, a modification of the usual gray type, due to the abundance of greenish feldspars, although other feldspars can be seen. Biotite is not abundant, but quartz is above the average. Pyrite is visible. The rock weathers to a soft brown mass. It rises only a few feet above the marshy level and is in two parts, making a total about 200 feet long. An analysis was made as representing a geographic extreme and is number 8, of Table III.

Inclusions or segregations of dark material attract attention. These are evident as patches from an inch or two, to as much as a foot across, generally of darker color, finer grain and different proportion of minerals present. In the numerous cases in the district where samples of these inclusions were taken, the minerals were generally the same in the inclusion as outside it, but the size of grain and abundance of dark mineral varied. No detailed study was made of the patches in this outcrop, but as they seem to be similar to the variable patches in the rest of the district, they should be mentioned in some detail and more careful study of some will be found below.

Six miles west of this, in St.Augusta township, an outcrop about 250 feet in diameter is a close approach to the Rockville type. In the neighborhood a little northeast of the latter is another mass that varies from the type, not so much in texture as in the decidedly green type of feldspar in the ground mass. The whole rock is still red from the phenocrysts.

Near the northeast corner of the section is the first small outcrop of gray granite, and even this is rather coarser than the typical form. At this point is first noted the fine grained granitic veins that often penetrate the red and gray types. These are high in quartz and pink feldspar

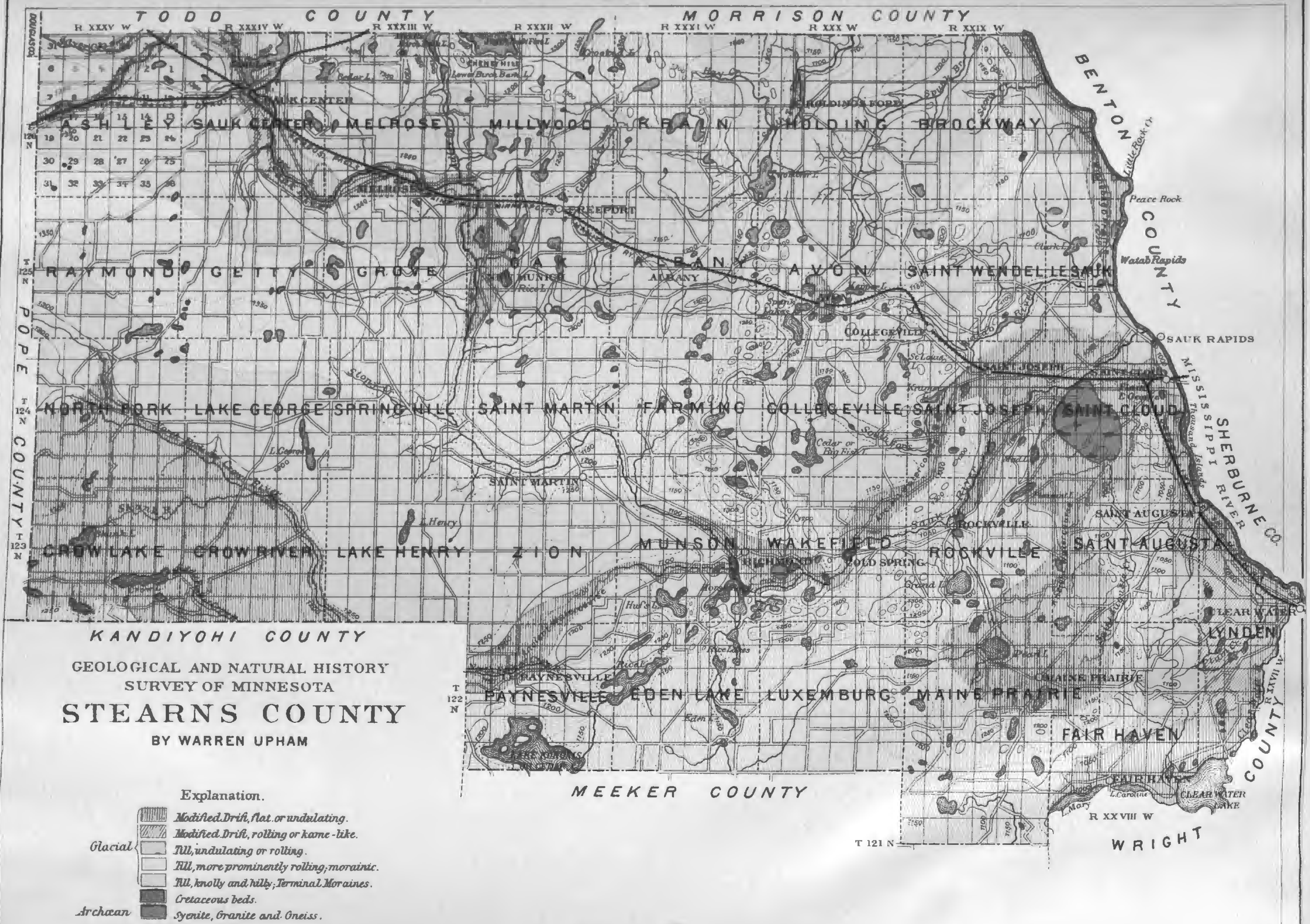

TODD COUNTY
MORRISON COUNTY
BENTON COUNTY
POPE COUNTY
SHERBURNE CO.
KANDIYOHI COUNTY
MEEKER COUNTY
WRIGHT COUNTY
R XXXV W
R XXXIV W
R XXXIII W
R XXXII W
R XXXI W
R XXX W
R XXIX W
R XXVIII W
R XXVII W
T 126 N
T 125 N
T 124 N
T 123 N
T 122 N
T 121 N
ASHLEY
SAUK CENTER
MELROSE
MILLWOOD
KRAIN
HOLDING
BROCKWAY
RAYMOND
GETTY
GROVE
OAK
ALBANY
AVON
SAINT WENDEL
LE SAUK
NORTH FORK
LAKE GEORGE
SPRING HILL
SAINT MARTIN
FARMING
COLLEGEVILLE
SAINT JOSEPH
SAINT CLOUD
CROW LAKE
CROW RIVER
LAKE HENRY
ZION
MUNSON
WAKEFIELD
ROCKVILLE
SAINT AUGUSTA
PAYNESVILLE
EDEN LAKE
LUXEMBURG
MAINE PRAIRIE
FAIR HAVEN
LYNDEN
SAUK CENTER
MELROSE
FREEPORT
ALBANY
COLLEGEVILLE
SAINT MARTIN
RICHMOND
COLD SPRING
ROCKVILLE
SAINT AUGUSTA
CLEAR WATER
PAYNESVILLE
MAINE PRAIRIE
FAIR HAVEN
SAUK RAPIDS
Peace Rock
Watab Rapids
MISSISSIPPI RIVER
Thousand Islands
CLEAR WATER LAKE
L. Caroline
L. Mary
L. Henry
L. George
Rice L.
Eden L.
Rice Lakes
Cedar or Big Fish L.
GEOLOGICAL AND NATURAL HISTORY
SURVEY OF MINNESOTA
STEARNS COUNTY
BY WARREN UPHAM
Explanation.
Glacial
Modified Drift, flat or undulating.
Modified Drift, rolling or kame-like.
Till, undulating or rolling.
Till, more prominently rolling; morainic.
Till, knolly and hilly; Terminal Moraines.
Cretaceous beds.
Archæan
Syenite, Granite and Gneiss.
Contour Lines are drawn approximately for each 50 feet above the sea.

Plate II.

and when quite fine grained have almost the aspect of pink quartzite. A detailed study of one of the veins was made and will be found below. In this outcrop the veins are but a few inches wide.

South of these, in section 30, is a typical Rockville outcrop, in which occurs a rare type of rock of great interest, the quartz-bearing porphyritic diabases. Many diabase dikes of medium basic character intrude the granites of the district commonly, and these generally carry feldspar phenocrysts of varying size, but in a few cases quartz forms good clear phenocrysts that seem entirely out of place in so basic a rock. It has been analysed, (see Table I) and studied in considerable detail. Its origin is discussed later and its characters are then given.

Again, passing westward a few miles is Rockville, where in sections 16 and 9 are many outcrops of the porphyritic granites which have been named in this paper from this locality. There is but slight variation in the immediate neighborhood. Fine pink granitic veins are often seen and a few pegmatite veins of the same color as the rock are to be seen. Dikes are not unusually common. Inclusions of different rock of size up to a foot in diameter are often noticed and well exposed in some of the quarries. They are so abundant in some places as to make it uncertain whether a large block of stone will show the desired uniformity when dressed for use. This, however, is not often detrimental and can be avoided. The beauty of a finished piece makes good material worthy of a careful search. The inclusions do not carry phenocrysts, lack the red color of the feldspars of the main rock, and usually show a heavy excess of dark silicates, but sometimes vary to an exceedingly clear white rock. The differently colored inclusions may occur close to each other in the country rock. This is one point where such inclusions were made the subject of study. The phenocrysts making up so large a part of the Rockville type show the characteristic gridiron structure. Two inclusions of finer grain and very different from each other and the enclosing rock were examined in thin section.

The lighter in color contains pink feldspar which (in section) is seen to be as variable as in the gray granite; some, microcline; some, oligoclase; and some probably orthoclase. They are highly kaolinized and associated with the secondary quartz in an approach to poikilitic structure. Hornblende and biotite are seen in large grains, but augite is not found.

The darker inclusion is of entirely different type. In thin section, minute crystals of biotite and hornblende are dotted very thickly over a nearly transparent ground. This appears to break up into grains of microcline as the nicols are crossed, and the feldspar grains bear no evident relation to the others. The little colored spots are scattered through and around them in apparent confusion. Some feldspar is dusty with kaolin and rarely some secondary quartz of the usual type is seen. Both are filled with an abundance of needles of apatite.

A few miles up the Sauk River from Rockville, between Cold Spring and Richmond, lie a series of outcrops (mostly north of the river) which are largely basic in character. Gabbros and diorites, with gneissic and other modifications, are seen with the usual variation in short distances. Some more acid rocks are found. The gabbro weathers deeply and dark minerals are removed, leaving the surface, often, a porous brown mass of decaying feldspar. When quarried to a depth of several feet, it is found in good quality for building purposes and is sometimes so used. North of Richmond is a mass quarried for stone to build the old school house at Richmond. An analysis has been made of this rock (see Table II), and its relations discussed below. It is granitic in texture and very dark colored when fresh. In places, bands of coarse grained, highly feldspathic rock pass through, but their nature was not determined. It was from this neighborhood that Kloos reported a contact of granite overlying a gabbro (augite dioryte) and from the position and dip, decided the latter was intrusive in the former.

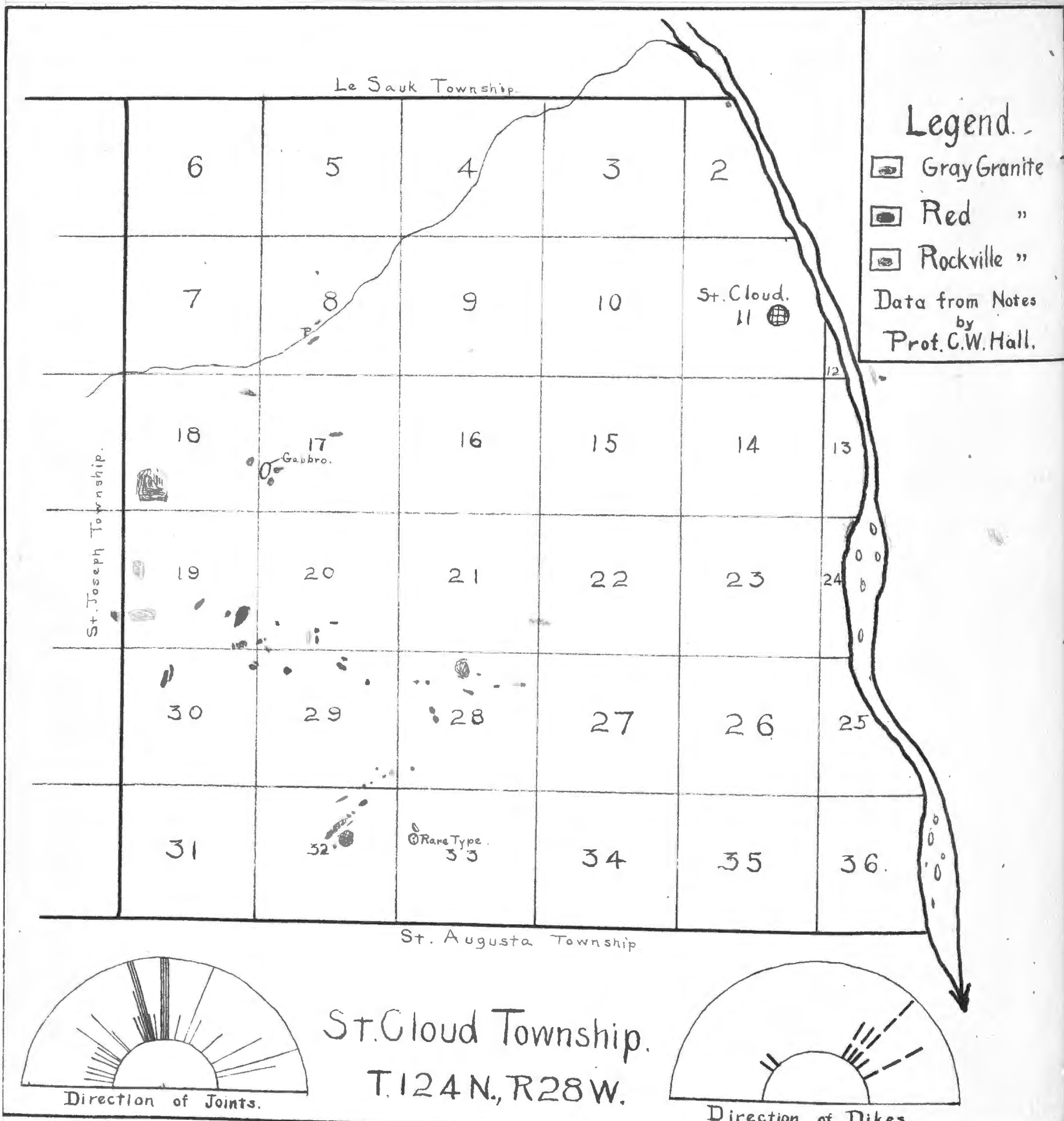
In Sec.20, T.123 N., R.30 W., of this area is a very large mass rising higher above the surroundings than most of the masses seen, reaching as much as 75 feet above the plain and being several hundred paces long. Most of the mass is quite uniform when exposed, but weathered everywhere. A dike of fine grained gabbro can be traced for some distance and is brokenly confused with a band of gneissic red granite of fine grain which also passes for some distance along the slope of the outcrop.

Near the northwest corner Sec.21, just west of Cold Spring, are a few weathered outcrops of red granite of common type as far as can be seen in the weathered specimens. Some veins and segregations may be noted. Between this and Cold Spring are several outcrops, variable red granite and Rockville types being prominent.

Along the river south of Cold Spring, at a dam, there is a contact of considerable interest, though the type of rock seems to be local and gneissic - quite exceptional in most respects - with large pink feldspars in a banded dark ground mass. This is in contact with red granite.

Northeast, toward St.Cloud, are two outcrops in T.124 N., R.29 W., before reaching the main area as shown on the map. (Plate III) One of these in Sec.27 is quite a variation from the Rockville type in that the ground mass is very fine, though the phenocrysts still range over half an inch across. The color also varies to a brownish and much lighter tint. The other outcrop in Sec.26 is more like the usual Rockville type, but not a very extensive outcrop a and a little lighter pink than usual. A diabase dike cuts into it showing the character to be described in connection with the large area east. A small quartz vein may also be noted.

Just at the east of this township and in a large part of St.Cloud township (T.124 N., R.28 W.) the outcrops are numerous and often of considerable extent. These have been mapped in Plate III on a larger scale than in the other maps. The Rockville type persists only a mile or two to the east and in Sec.20 and 19 of St.Cloud township one or two outcrops occur showing a red granite with just a few phenocrysts indicating a gradation between types. Except for these, the main exposures are the red and gray types. In Sec.33 is a variation in which dark phenocrysts lie in a fine pink ground - not a large exposure. In Sec.17, between a large area of red granite and a smaller one of gray, is an outcrop of gabbro with rather fine grain and prominent biotite scales. In some parts of the area a red porphyry is


Le Sauk Township.
St. Joseph Township.
St. Augusta Township.
6
5
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St. Cloud.
11
12
18
17
Gabbro.
16
15
14
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28
27
26
25
31
32
Rare Type.
33
34
35
36
Legend.
Gray Granite
Red "
Rockville "
Data from Notes by Prof. C.W. Hall.
Direction of Joints.
St. Cloud Township.
T.124 N., R28 W.
Direction of Dikes.

Plate III

seen in small dikes and in the north in Sec.8,reaches larger proportions as outcrops of quartz porphyry and granite porphyry with large (1/2 inch) feldspars.

The red and gray are seen to be very irregularly scattered over the area and their relation was carefully studied,but no clear evidence is seen. Contacts are seen in half a dozen outcrops. Small masses and dikes of gray may be seen enclosed in the red. In Sec.30,the gray rock overlaps a mass of red as if more recent. Variations occur in each,but at the closest approach they still appear distinct. The gray rock often weathers reddish,but does not have the same distribution of the color nor the same texture as the red. Quartz may increase in the gray till nearly as high as in the red. Only one specimen in the department collections has mixed appearance. This is No.801 of the Geol. Survey,said to have been located east of the river,a few miles southeast of St.Cloud. This has all the appearance of a light red except that it has also some of the gray striated feldspars which seem to owe their color to inclusions. Such a combination is rarely found. The Survey reports a variation in the color of this specimen and gives analyses of each. See Table I. Strange to say,the analyses show the rock not as a gradation from the acid red granite to the mediun gray,but more basic than either. This is quite surprising as the rock still carries free quartz and has quite the appearance of red granite.

The outcrops quite uniformly exhibited various inclusions,dikes and veins. Inclusions are of about the type seen in Rockville,but vary in importance and abundance. Veins (or dikes) of quartz,pegmatite,and fine granite are often seen,the latter being most common.

Dikes of diabase are common and sometimes carry phenocrysts of feldspars,etc. Dikes of quartz porphyry are more rare,but quite as striking. About as rare and more interesting,are the quartz diabase dikes such as were mentioned farther south. All of these vary rapidly in dimensions and sometimes in direction,as they follow an irregular crevice in the granite. The width of these formations varies from 15 feet to nothing. Some could be followed a hundred paces or more. The texture always varied from fine at the side to a maximum size of grain in the center.

Before leaving this thickly dotted area it is again worth calling attention to the irregular way in which the two main types are scattered throughout.

Minor variation from the types occurred in many outcrops. Chlorite developed in the gray granite in an outcrop in Sec.28. The only case in which much quartz was noticeable in the gray rock was in Sec.30. Green feldspar increased in red type to a maximum in Sec.29 near the north side. Along the Mississippi above St.Cloud are a few exposures of these same types,and east of the river another area of abundant exposures like the one shown in Plate III above. To the northwest of these,leaving the river,are quite a few scattered outcrops. Nearest to St. Cloud are granites for five or six miles from the river, after which gabbros occur closely resembling those near Richmond and probably quite a connected series from that place to Little Falls,farther north,along the river where they again outcrop.

In the granites of this region northwest of St.Cloud are some indications of gradation from red to gray granites,especially in Sec.21 and 17,T.125 N.,R.28 W. Typical red is no longer seen. Here an outcrop of considerable length varies from dark red granite (much finer grained, though,than the red type) to a light pink and then begins to develop a few gray grains. An outcrop of gray granite farther east (in the river bank) shows quite a proportion of pink grains,but there is still a wide break between the two rocks,especially in feldspars seen.

An inclusion in the red of this area was sectioned for study and found to consist of plagioclase,hornblende and biotite in an aggregate similar to the dark one described in Rockville,except that in that the feldspar was microcline. This is oligoclase. Inclusions of this type are abundant for a short distance and some are several feet in diameter.

The first outcrop north of the area mapped in detail, is in Sec.21,where a three-foot band of gray type penetrates a mass of red,about 30 feet exposed,with sharp contacts and no gradation. Next is seen a red porphyry like one of the most northernmost of the area mapped; next,a good mass of typical gray granite with an extra amount of quartz in some parts. It weathers brown and the original quartz grains seem to have a slight brownish tint.

In Sec.6 are a couple of outcrops one of which is almost as coarse as the red type,but the other is a fine grained red granite with little hornblende or biotite. Both exposures show bands up to a foor it width,consisting apparently of pegmatite,but sometimes appearing much like h the Rockville type.

Just west of these a few paces is the gabbro,and from this point northwest and southwest are several exposures, but only gabbro until the northwestern part of the county is reached,and even there gabbros are found in undetermined relation to the more acid rocks. In Melrose are some exposures of fine red,slightly gneissic granite,and some of darker rock. The extent is so limited that the question arose as to whether they were not fragments from a large mass at some distance away. The dark silicates of the rock have a notable green color.

At Sauk Center are other types,however,one a diorite or hornblende gabbro and the other represented by an outcrop of gneisses varying in composition and mutually enclosing each other.

Finally,in Ashley township,at the extreme northwest of the county,lies the extreme northwest of the county,lies the extreme green type and a gneissic red granite.

Outside the county are a few other types,e.g.,just east of the river (Watab) is a gray quartzose rock in which phenocrysts increase almost to the Rockville texture without a particle of red color.

To the north,in Cass County,are a series of epidotic, slightly gneissic gray granites. See analysis Table III.

The gneisses,schists and slates come in toward the northeast. In the extreme east,in Kanabec County,gray (cream) granite outcrops. Reports from east of Mille Lacs are not definite.

TABLE I. Published Analyses.

No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Other.
1.	74.72	12.30	3.19		0.25	1.51	1.91	2.25	—	—
2.	65.12	16.96	4.69		1.99	4.77	3.07	2.18	—	—
3.	64.13	21.01			1.26	6.90	3.31	1.22	—	—
4.	62.66	19.29	4.67		3.06	5.93	2.45	1.62	—	—
5.	66.88	11.69	1.68	8.94	3.55	5.45	1.25	0.20	1.03	CO_2 = —
6.	65.27	15.76	1.36	3.44	2.14	3.70	4.57	3.97	0.42	P_2O_5 = 0.26
7.	56.59	12.41	5.39	10.28	2.02	6.70	4.27	1.02	1.45	P_2O_5 = 0.44 TiO_2 = 0.22
8.	69.47	14.94	4.07		0.29	1.60	3.37	4.56	—	—
9.	78.12	11.14	2.68		trace	0.62	3.33	4.48	0.43	—
10.	74.43	12.68	3.82		0.25	1.28	1.55	2.33	—	—
11.	67.70	16.11	2.47	2.29	1.11	2.89	3.64	4.47	0.83	P_2O_5 = 0.13
12.	56.49	17.49	3.51	3.72	4.01	6.64	4.49	3.20	1.14	P_2O_5 = 0.18
13.	52.35	15.72	2.90	7.32	7.36	8.98	2.81	1.32	1.35	P_2O_5 = 0.30 CO_2 = 0.23
14.	52.00	15.75	3.55	12.84	3.42	7.39	3.37	1.24	0.35	P_2O_5 = 1.06 CO_2 = 0.11
15.	51.27	23.72	1.35	3.81	3.30	10.50	3.35	0.65	1.23	P_2O_5 = 0.37 CO_2 = 0.35
16.	48.87	18.72	3.28	5.55	9.53	11.93	2.10	0.73	0.93	P_2O_5 = 0.08 CO_2 trace
17.	46.52	13.87	3.71	8.79	10.04	11.00	2.13	1.01	1.05	P_2O_5 = 0.32 CO_2 = 0.47
18.	61.19	15.22	3.20	3.55	2.38	7.94	3.17	2.62	0.40	—
19.	58.77	13.12	5.45	6.87	4.93	5.99	1.94	2.83	0.45	—
20.	71.64	11.82	3.94		0.32	1.41	5.22	2.49	0.88	—
21.	58.72	16.53	9.56		1.36	6.37	2.13	4.41	0.81	—
22.	48.97	15.32	4.14	6.58	9.85	10.93	2.69	0.69	1.14	P_2O_5 = 1.18 Li_2O = trace
23.	70.05	14.91	1.71	1.09	0.82	1.97	4.77	5.09	0.81	P_2O_5 = 0.07
24.	73.30	14.20	5.40		0.50	3.00	2.00	1.40	0.30	—

TABLE I. Published Analyses.

No.	Reference	Names		Location
1.	* M.G.&N.H.S. Vol. I. p 198.	"Gray Quartzose Syenite." Tehamose		E. St. Cloud
2.	" " "	"Fine Gray Syenite." Yellowstonose.	Gray Granite.**	" "
3.	" " "	"Fine Gray Syenite." Yellowstonose.	Gray Granite.**	Sauk Rapids
4.	" " "	"Fine Gray Syenite" Bandose.	Gray Granite.**	Watab
5.	** Neues Jahrbuch f. Min. 1877.	"Quartz Dioryte." Dosodic docalcic Hispanare	Gray Granite.**	Little Falls
6	" " " "	"Quartz Dioryte." Dacose	Gray Granite.**	Watab
7.	" " " "	"Quartz Dioryte" Dacose	Gray Granite.**	Sauk Center
8.	*** Bul. Minn. Ac. Nat. Sci. Vol. III. p 388.	"Granite, Medium Color." Toscanose.	Red Granite.	St. Cloud
9	M.G.&N.H.S. Vol. I p 198.	"Red Quartzose Syenite." Alaskose.	Red Granite.	Watab
10.	" " "	"Red Quartzose Syenite" Riesenose.	Red Granite.	E. St. Cloud
11.	Neues Jahrbuch f. Min. 1877.	"Red Granite." Toscanose	Red Granite.	Sauk Rapids.
12.	" " " "	"Augite Dioryte" Andose.	Gabbro.	Little Falls.
13.	" " " "	"Augite Dioryte" Camptonose	Gabbro.	" "
14.	" " " "	"Augite Dioryte." Camptonose	Gabbro.	Richmond
15.	" " " "	"Augite Dioryte." Hessose.	Gabbro.	Little Falls
16	" " " "	"Augite Dioryte" Camptonose	Gabbro.	Richmond
17.	" " " "	"Augite Dioryte" Auvergnose	Gabbro.	Little Falls
18	M.G.&N.H.S. Vol. V. p. 551	"Light Gabbro" "or Altered Granite." Tonalose		St. Cloud
19	" " "	"Dark Gabbro" "or Altered Granite" Harzose		" "
20	Bul. Minn. Ac. Nat. Sci. Vol III p 388	"Granite Porphyry (Miscalled "Gray Granite") Lassenose.		" "
21.	" " " " "	"Quartz Diabase" Shoshonose.		Augusta
22	Neues Jahrbuch f. Min. 1877.	"Melaphyre" Auvergnose.		Sauk Rapids
23	" " " "	"Porphyritic Granite" Toscanose		Watab
24	Bul. Minn. Ac. Nat. Sci. Vol. III p 388.	"Red Granite". Dosodic Riesenase		St. Cloud.

* N. H. Winchell and Survey Staff ** A. Streng. *** C. W. Hall. and Students ** "Quartz Dioryte" ** is of uncertain Quality.

RELATIONSHIPS.

As for the main types of rock - red and gray - intrusion seems to have occurred at nearly the same time. Dikes of gray penetrate the red and they cooled slowly enough so that the texture is quite uniform throughout. No alteration at contacts of large masses is characteristic. One must have solidified,however,before the other came in contact with it. There is no sign of mixture and little evidence in their field relations,that they had a common source.

It is clear that later than either of these,another period of eruption brought out the diabase dikes and possibly these are contemporaneous with the Keweenawan lava flows farther east. In is noteworthy that the direction of dikes is toward Duluth,the center of Keweenawan volcanic activity. The relation of the gabbros and isolated outcrops of distinct types is hard to interpret. Kloos reports a contact (not seen) indicating that the gabbro is more recent than the granites and intrusive in them. All the igneous types appear to have been intruded through older rocks now represented by the schists and slates and gneisses which are seen north and east of this county.

The appearance of some of the gray rocks of the district has led Wadsworth to conclude that they are altered gabbros. The gray feldspars and the augite and the fact that little of the quartz appears to be original confirms this idea. But the addition of such a quantity of quartz from an unknown source,(or the removal of basic constituents to unknown position,leaving the quartz),makes it hard to accept this idea. Winchell early rejected it.

The analyses furnish another line of reasoning. When the most accurate of the available analyses are plotted, it is easily seen that in spite of the variety of rock types in the area,it is not necessary to go outside it to get quite a complete gradation from any extreme to the others. In Plate IV,17 analyses have been arranged in order of decresing silica,and the lines showing the amounts of the other main constituents are very instructive. Several unsuspected similarities developed,such as that between the gabbro masses and the diabase dikes.

TABLE II.

Unpublished Analyses by Students.

Kindness of Prof C.F. Sidener.

Sample.	1. Gabbro.	2. Green Syenite.	3. Diabase.	4. Gabbro.	5. Granite Gneiss	6. Pinkish Gray. Granite.
SiO_2	52.34	61.10	50.31	44.16	68.40	64.02
Al_2O_3	14.17	19.05	15.30	14.89	15.56	15.61
Fe_2O_3	2.40	2.11	1.79	1.19	0.38	1.58
FeO	10.78	0.68	8.14	6.83	4.06	4.61
MgO	3.51	1.35	5.84	14.40	1.21	2.29
CaO	7.25	7.00	9.04	13.01	2.37	3.46
Na_2O	3.73	8.17	5.18	1.92	4.36	4.07
K_2O	2.37	0.40	2.00	0.97	3.14	3.98
$H_2O(+)$	0.22	0.16	—	0.05	0.03	0.08
$H_2O(+)$	0.39	0.21	1.43	0.89	0.10	0.35
TiO_2	2.31	0.71	2.80	0.89	0.52	0.68
P_2O_5	0.80	1.25	—	—	0.46-	0.01
MnO	0.09	0.42-	0.51-	trace	0.16	0.13
Others.	CuO – trace CoO – "	S – 0.92±	—	—	traces.	—

Totals high

Analyst	Rang	Location.
1. E. McM. Pennock	Camptonose.	1650 N. 275 W. Sec. 30 T. 123 N., R. 30 W.
2. Olund and others	Beerbachose.	1525 N. 2000 W. Sec. 18 T. 126 N., R. 35 W.
3. B. F. Noehl.	Limburgose.	425 N. 1700 W. Sec. 18 T. 124 N., R. 28 W.
4. Lillian Nye	Portugare.	1700 N. 200 W. Sec. 13 T. 129 N., R. 30 W.
5. G. Dietrichson and others.	Lassenose.	500 N. 2000 W. Sec. 19 T. 41 N., R. 29
6. Bicknell and others.	Adamellose	1525 N. 1800 W. Sec. 33 T. 124 N., R. 28 W.

New Analyses.

TABLE III.

No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O-	H_2O+	TiO_2
1.	76.30	12.58	0.47	1.20	0.02	0.84	2.70	5.00	0.00	0.27	0.15
2.	73.80	14.67	0.63	1.19	0.32	0.99	2.46	4.87	0.04	0.39	0.19
3.	72.41	14.33	1.09	1.47	0.30	1.66	5.19	3.40	0.02	0.08	0.23
4.	70.07	16.79	0.64	2.58	0.71	2.27	2.82	3.82	0.10	0.06	0.33
5.	65.50	17.38	0.83	2.85	2.28	3.68	3.36	3.09	0.03	0.16	0.42
6.	64.40	14.93	1.63	3.13	3.05	4.18	3.31	3.95	0.07	0.15	0.57
7.	63.52	16.71	1.58	2.61	2.70	4.54	3.89	3.96	0.01	0.05	0.48
8.	62.76	17.73	1.69	3.04	2.66	3.94	3.23	3.72	0.07	0.13	0.61
9.	57.12	18.74	2.62	2.42	4.28	7.06	3.37	1.53	0.08	1.16	0.42
10.	56.36	20.76	4.48	0.21	1.08	8.76	5.89	0.45	0.00	0.60	0.57
11.	52.91	17.56	0.00	8.61	4.90	7.55	3.72	1.70	0.03	1.34	0.92
12.	48.45	12.70	2.00	13.20	4.33	8.44	3.94	1.20	0.11	1.19	3.00

TABLE III.

by Frank F. Grout.

No.	P_2O_5	Others	Norm		Names	Location	Remarks
1.	0.18	Cr_2O_3 = 0.08 MnO = 0.05 CO_2 = 0.32	Q 36.24 Or 21.13 Ab 30.39 An 5.56 C 3.77	Hy 3.01 Mt 1.16 Il 0.30	Granite Porphyry. Tehamose.	300 N. 1050 W. Sec. 20 St Cloud. T. 124 N., R 28 W.	Sp.G. = 2.51
2	0.04	CO_2 = 0.30 Traces.	Q 36.24 Or 28.36 Ab 20.96 An 6.12 C 3.57	Hy 2.65 Mt 0.46 Il 0.46	Fine Pink Vein Granite Tehamose.	1670 N, 385 W. Sec. 29. St Cloud. T. 124 N., R 28 W.	Sp.G. = 2.59
3	0.23	CO_2 = 0.21	Q 24.96 Or 20.02 Ab 44.01 An 6.39	Di 1.64 Hy 1.29 Mt 1.62 Il 0.46	Typical Red Granite Toscanose.	1670 N. 385 W. Sec. 29 St Cloud. T. 124 N., R. 28 W.	Sp.G. = 2.64.
4	0.34.	MnO = 0.04 CO_2 = 0.23	Q 31.86 Or 22.24 Ab 23.58 An 11.12 C 4.39	Hy 5.50 Mt 0.93 Il 0.61	Rockville Granite. Toscanose.	500± N, 1500± W. Sec. 9. Rockville. T. 123 N., R. 29 W.	Sp.G. = 2.66.
5	0.30	MnO = 0.08 * CO_2 = 0.31	Q 22.20 Or 18.35 Ab 28.30 An 15.85 C 2.75	Hy 9.55 Il 0.76 Mt 1.16 Ap 1.01	Gray Granite. Amiatose. near Yellowstonose. near Harzose & Tonalose.	1425 N. 800 W. Sec 21 St Cloud. T. 125 N., R. 28 W.	Sp.G. = 2.66. Quartz seemed more abundant than usual in hand specimens.
6	0.57	MnO = 0.09 ** CO_2 = 0.18 BaO = 0.05 S = 0.12 ZrO_2 = 0.07	Q 22.50 Or 22.80 Ab 27.25 An 5.00 C 3.67	Hy 11.20 Mt 2.32 Il 1.22 Ap 2.02	Gray Granite Harzose.	50 from N.E. Cor. Sec 28 St Cloud. T. 124 N., R. 28 W.	Sp.G. = 2.68
7	0.44	MnO = 0.07 CO_2 = 0.23	Q 11.28 Or 23.91 Ab 33.01 An 17.51	Di 4.05 Hy 7.48 Mt 2.32 Il 0.91	Gray Granite Harzose.	Sauk Rapids. Main Quarry.	Sp.G. = 2.70 A type of rock widely distributed east of the Mississippi.
8	0.63	MnO = 0.12 CO_2 = 0.22.	Q 18.42 Or 21.68 Ab 27.25 An 14.73 C 3.16	Hy 9.44 Mt 2.55 Il 1.22 Ap 2.02	Greenish Gray Granite Harzose.	680 N. 700 W. Sec 19 Clear Water. T. 123 N., R. 27 W.	Sp.G. = 2.73 Southern extreme of district.
9	0.45	CO_2 = 0.34. MnO = 0.06	Q 11.16 Or 8.90 Ab 28.30 An 31.69	Hy 12.28. Mt 3.71. Il 0.76. Ap 1.34.	Greenish Gray Granite (Gneissic) Bandose. near Tonalose.	1300 N. 1800 W. Sec. 28 Cass County T. 134 N., R. 32 W.	Sp.G. = 2.81 Northern extreme of district.
10	0.28	CO_2 = 0.36 MnO = 0.08.	Q 4.98 Or 2.78 Ab 47.68 An 24.74	Di 6.05 Wo 3.25 Hm 4.48 Il 0.46 Ti 0.78	Green Syenite Beerbachose.	1525 N. 2000 W. Sec 17 Ashley T. 126 N., R. 35 W.	Sp.G. = 2.83 Western extreme of district.
11	0.20	Cr_2O_3 = 0.20. MnO = 0.11. CO_2 = 0.18	Or 10.01 Ab 31.44 An 26.41	Di 9.02 Hy 11.17 Ol 8.00 Il 1.67	Quartz Diabase. Hessose	300 N. 1000 W. Sec 20 St Cloud. T. 124 N., R 28 W.	Sp.G. = 2.84. Near Andose
12	0.70	Cr_2O_3 = 0.08 MnO = 0.22 CO_2 = 0.27	Or 7.23 Ab 30.39 An 13.34	Di. 23.19 Ol. 10.99 Mt. 3.02 Il. 6.08 Ap. 2.02	Diabase (Dike) Auvergnose	370 N. 1000 W. Sec 20 St. Cloud. T. 124 N., R. 28 W.	Sp.G. = 2.90

* Cr_2O_3 absent in Gray Granites. ** Barium, Sulphur and Zirconia, were probably in similar amounts in all the Gray Granites. CO_2 was determined only approximately

1.	No.9,	Table I.	Most acid type."Red Granite".(N.H.W.,Analyst.)
2. "	1,	" III.	Granite Porphyry.
3. "	2,	" "	Granite Vein.
4. "	3,	" "	Red Granite.
5. "	4,	" "	Rockville Granite.
6. "	5,	" "	Gray Granite.
7. "	6,	" "	" "
8. "	7,	" "	" " East end of area.
9. "	8,	" "	" " South end of area.
10."	18,	" I,	"Light Gabbro" Granite.(Dodge and Sidener)
11."	19,	" "	"Dark Gabbro" Granite.(Dodge and Sidener)
12."	9,	" III	Greenish Gray Granite. North end of area.
13."	10,	" "	Green Syenite. West end of area.
14."	11,	" "	Quartz Diabase Dike.
15."	1,	" II	Gabbro.(Student,Analyst)
16."	12,	" III	Basalt,or Diabase dike.
17."	17,	" I	"Augite Dioryte".Gabbro. Most basic type. (Streng,Analyst)

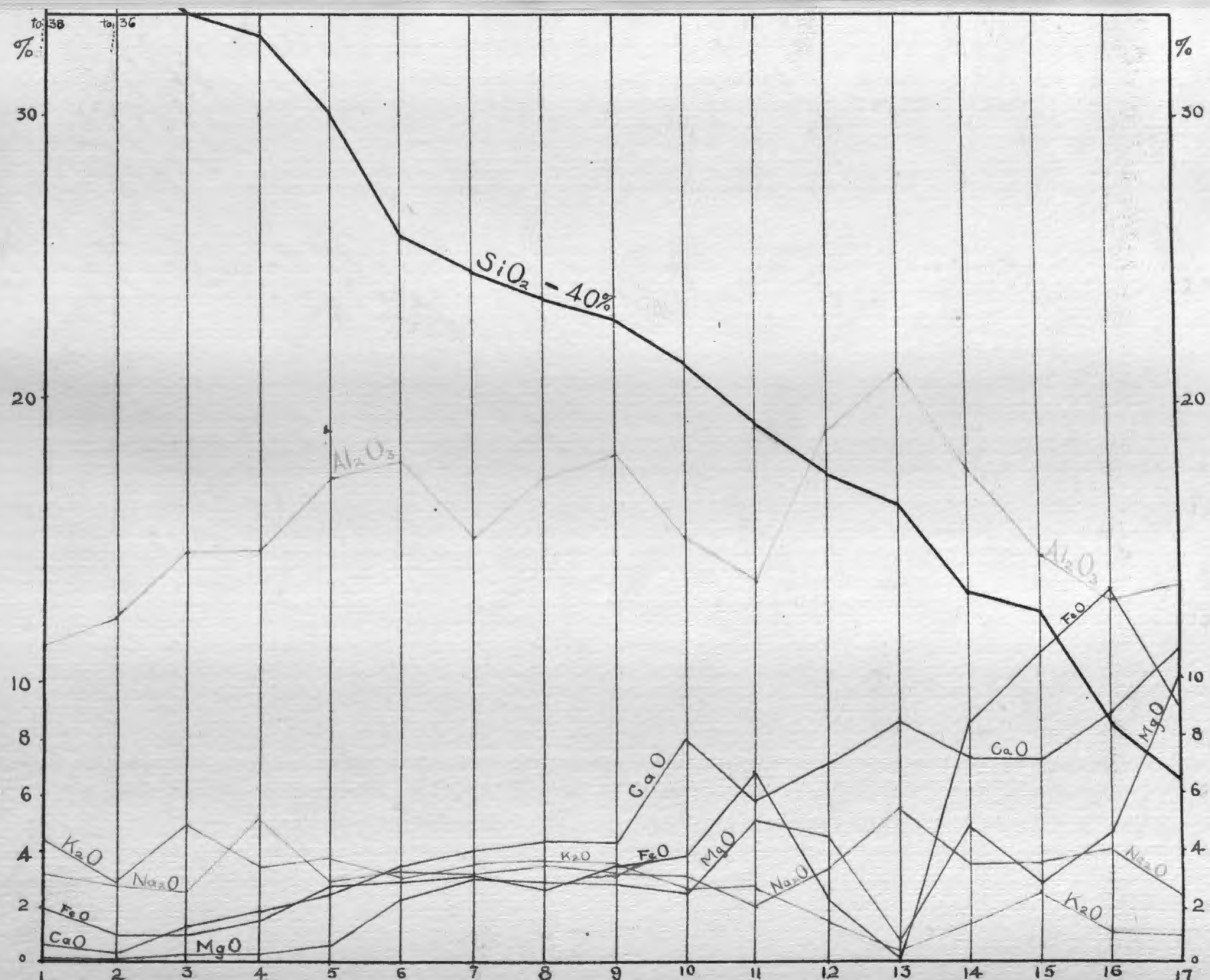

Plate IV

Diagram of Variation of 17 Rocks from Stearns County.

The closest approach to a gap, in the series as indicated by the silica line, is between the red and Rockville types of the first 5 analyses and the gray of the next few. Between the gray and the gabbro there seems to be no such break, but the intermediate types are exceptional rocks, such as quartz-diabase and the green syenite. The gabbros themselves range from 52 to 46% in silica.

When arranged in this order, the other constituents vary a little erratically, it seems, but some general statements can be made and exceptions noted.

The diagram shows quite a uniformity in direction of all curves till rock number 10 is reached. Samples 10 and 11 are the unusual types, appearing to be intermediate between red and gray granite. Following these are two epidotic types and the quartz-basalt. Across this part of the diagram the line for each constituent makes a decided zig-zag. The smoothness of lines is greatly increased by omitting these peculiar types and altered masses. For example, in the development of epidote the ferrous iron largely disappears, (12 and 13), leaving ferric iron, which is not prominent in most rocks, and is omitted from the diagram.

The greater variation of basic, rather than acid, rocks in a district seems to be the rule rather than the exception, however, and is shown by diagrams such as those from Magnet Cove, Arkansas, and other places. To explain the variation of rocks in a certain petrographic district, it is now popular to appeal to a process of differentiation, and although this is not the place for a complete discussion, a few words may be said regarding the evidence of the district.

The amount of alteration which is evident in most specimens leaves the nature of the original intrusion in such doubt that it is conceivable that there may have been quite a similarity in the ratios of several constituents. The most striking point is the dominance of lime over magnesia, which is seen not only in the diagram, but in every analysis, whether the analyst was experienced or not. The regularity of the increase in titanium and specific gravity as the rocks become basic is well seen in Table III. The ratio of alkalies is not as simple. In the more acid rocks, soda and potash show about equal importance (in per cent),but toward the basic end of the series,soda predominates,and is extreme in the altered green syenite of Ashley.

The ratio of soda to alumina is one of rather constant values. With an average molecular ratio of 0.3,the extremes are reached in case of the quartz-diabase at 0.21 and the green syenite at 0.60. Both these are unusual and extreme rocks,so that for the district the ratio may be given as very close to 0.3,and the constancy is an indication of a common origin; the same indication as was given by the regularity in the variation of other constituents.

Differentiation.

The theory deduced from such data,from many localities, is that an original uniform magma,may differentiate,and,as eruption or solidification takes place,form many types of rock,all of which retain certain characteristic and fundamental properties of the original; or form a series,with these properties varying in a systematic way,so that the average represents the original. In the petrographic district of central Minnesota Plate IV indicates more of such connected origin than is to be expected of such altered rocks. But the field occurrence shows that there were successive eruptions of different material; and hence the differentiation occurred before eruption. There is no sign of geographic variation from one extreme to another,as has been found in some districts. The variety of feldspars furnishes some indication of a varying origin. It is of interest,however,to calculate the average of the analyses made,which results in a combination very much like the abundant gray granite of the district. Since this type and average are classed as harzose,near tonalose,it is noteworthy that good calculations of the average rock of America and of the world result in tonalose. The composition of the district as a whole,is not,therefore,unusual; but differentiation assisted by subsequent metamorphism to an unknown extent,resulted in some very rare types.

	I.		II.		III.
Silica,---------------	62.5	----	59.71	----	58.24
Alumina,--------------	15.2	----	15.38	---	15.80
Ferric oxide,---------	2.2	----	2.63	---	3.33
Ferrous oxide,--------	4.1	----	3.52	---	3.87
Magnesia,-------------	2.7	----	4.36	---	3.84
Lime,-----------------	5.2	----	4.90	---	5.22
Soda,-----------------	3.2	----	3.55	---	3.91
Potash,---------------	2.5	----	2.80	---	3.16

I. Average of Central Minnesota Rocks.
II. " " American Rocks. (Clarke)
III. " " Rocks in General.(Washington.)

Probably the most prominent differences are the lower magnesia and higher silica in the Minnesota rocks.

Other parts of Minnesota furnish rocks of rather similar type to most of those tested. Lake Superior basic rocks and Pigeon Point granites have close chemical relatives in central Minnesota,but the field relations are remote.

Comparison with other districts should not omit the central Wisconsin rocks,where lime dominates over magnesia as is the case here,and where soda dominates over potash even more prominently than here. There are many points of similarity in the districts. The chemical study (and very little else) in Wisconsin,gave evidence that the three main types,(rhyolites,granite-syenites,and gabbro-diorites) were remotely connected and the separation of these types from the original occurred before eruption. In Wisconsin, too,a single one of these types will show quite a noteworthy gradation,even in a single outcrop. Such differentiation must be due to,and accompany the crystallization of the rock. No such masses were found in Minnesota. As evidence in this regard,the dikes have been studied,in search of variation in the space of a few feet. Practically no change was noted in composition of either the acid or the basic dikes from side to center. This same test was made on a fine pink granitic dike or vein,in a red granite of the usual type. The results were again negative. All dikes were about 13 feet wide and showed some change of texture, but the greatest chemical variation noted was in the content of silica which in one case varied 1.50% from side to center, with an opposite and naturally smaller variation in the other constituents. The samples showed some slight weathering both in the field and in the combined water of analysis, so that no very firm conclusions were reached. To give each analysis would be practically to duplicate four of the analyses of Table III. Numbers 1,2,11 and 12 were so analyzed. In this connection see analyses 18 + 19. Table I

TABLE IV.

Outline of Classification

Class	Order	Rang	Sub-rang	Types of Rock.
I. Persalane *				
	1. and 2. absent.			
	3 Columbare	Alaskase	Alaskose	Red Granite
		Alsbachase	Tehamose	Pink Vein Granite Quartz Porphyry. Quartose Gray Granite
		Riesenase	Riesenose	Red Granite.
			Dosodic	Red Granite
	4 Brittanare	Toscanase.	Toscanose	Red Granite. Rockville Granite.
			Lassenose	Red Granite Porphyry. (Granite Gneiss.)
		Coloradase	Amiatose.	Gray Granite.
			Yellowstonose	Gray Granite.
	5. to 9. absent.			
II. Dosalane.				
	1 and 2 absent.			
	3 Hispanare.	Docalcic	Dosodic.	"Quartz-Dioryte".
	4 Austrare.	Dacase	Dacose. Adamellose.	"Quartz-Dioryte" Gray Granite (Pink Tint)
		Tonalase	Harzose	Gray Granite.
			Tonalose	"Gabbro" "Granite".
		Bandase	Bandose.	Gray Granite.
	5 Germanare	Andase	Shoshonose	Quartz Diabase.
			Andose	Quartz-Diabase. Gabbro.
			Beerbachose.	Green Syenite.
		Hessase	Hessose	Quartz-Diabase. Gabbro.
	6 to 9. absent.			
III. Salfemane				
	1 to 4 absent.			
	5 Gallare	Camptonase	Camptonose	Gabbro.
		Auvergnase	Auvergnose	Gabbro Diabase
	6 Portugare	Limburgase Docalcic	Limburgose Dosodic	Diabase. Gabbro
	7. to 9 absent.			

* Analyses are so rare in these groups that no name is given.

* The rocks and classes found in new analyses of Table III, are in large type.

A study of the tabular arrangement of the rocks in classes shows three points of interest: 1)the analyses of some of the rocks of the district may fall in classes where analyses are rare,or unknown; as for example,dosodic,docalcic brittanares and hispanares. 2) the resemblance of the gray granite to the average rock of the world - a tonalose. 3) the andases,including two rare types,the green syenite, and the quartz-basalts. These are discussed in detail elsewhere and the rocks of other classes seem to possess no unusual interest,as analyses are common and such rocks are wide spread.

THE QUARTZ OF BASALTS.

The interest in the diabase dikes mentioned above is especially great in this case on account of the simplicity of their field relations. The problem that presents itself is primarily,how free quartz can occur in such a basic igneous rock. See Table III. It is noted in several American basalts as isolated grains,corroded by the magma and very similar to grains mechanically picked up by the magma; but Diller,in Bul.79,and Iddings,in Bul.66 of the U.S.Geol. Survey,each conclude they have a case where quartz is an original constituent formed under peculiar conditions.

In general,the minerals of a dike may be of three different types and be formed at different times.

1) Magmatic origin: before intrusion.
2) During intrusion:e.g.,from the walls.
3) In the present position: (a) secondary.
   (b) crystals from fusion.

The first is the condition assumed by the students of quartz basalts in other American localities where sheets and flows contain quartz. They seem to consider it necessary to assume a change of condition such as occurs at time of eruption,to account for the change of minerals formed.

The following facts may be stated as evidence in the case of the Minnesota dikes. The country rock is red granite as described above. The dike ranges from a very fine grained porphyrite to a medium coarse diabase in a distance of two feet from the walls. Through the whole dike are crystals of quartz,orthoclase and plagioclase much larger than the grains in the ground mass. The size of the phenocrysts varies from side to center in proportion to the grains of the ground mass,the diameter being 10 to 15 times that of the other grains. The crystals of feldspar average larger and more abundant than those of quartz,but no change in kind or relative abundance of minerals is to be found in crossing the dike. The feldspars are often 1/2 inch in diameter: the quartz seldom 1/4 inch. All seem somewhat corroded.

In thin section,no such corrosion is to be seen as was expected from the hand specimen. The crystals show a fairly good outline. In analogy with other quartz basalts, it was thought the quartz might show an augite rim, indicating some action of the magma on crystallized quartz, but if such has occurred, the rim is extremely narrow. Plagioclase occurs in two generations, most of it being labradorite, but possibly some of the ground mass may be oligoclase. Augite is almost entirely altered to hornblende. The phenocrysts of orthoclase often showed a rim or border, highly kaolinized, with center comparatively clear. The quartz, as distinctive mineral, was most carefully studied and compared with other occurrences. Numerous inclusions of gaseous and liquid nature are seen in planes in various directions. No difference can be found between this quartz and that in a very acid dike of quartz porphyry, near one of the dikes. The quartz of the red granite walls seems to be identical also, except in crystal outline and association.

At several points along the dike walls, fragments of the granite are included; and aside from the absence of crystal outline and clustering of grains of various minerals, there was evidence of the source in the fact that the grains of this type were of quite uniform size; which was larger than the phenocrysts near the wall and much smaller than those near the center of the dike. Such inclusions were noted only for an inch or two from the wall.

An analysis of the rock is found above. Its classification on that analysis places it near the andases. On account of minerals and texture the name might be extended to a "hornblende-ophiti-phyro-andase", and a modification must be added to indicate phenocrysts of quartz and feldspars.

As to the origin of quartz, the regular variation in size of phenocrysts seems to be an objection to either of the first two given above as possible. Corrosion, if it occurred, would tend to decrease the size of crystals in the center (being a function of time of action). The opposite is the case. The fact that the quartz occurs in phenocrysts is conclusively against any suggestion of secondary origin.

All the evidence points to the crystallization from a molten mass in its present position. And this is not so difficult to accept, as one might judge from the prevalence of the other explanation. Crosby's theory of origin of phenocrysts was so stated in the American Geologist for 1900, that it might cover this case, if we can imagine any conditions which would produce quartz crystals from such a basic magma. For as the quartz was removed, the residue would change in composition and this alone would change the minerals resulting from the solidification, without recourse to any such change of conditions as occurs at a time of volcanic eruption.

It is necessary to assume some peculiar conditions to account for the separation of quartz, because we find it did separate from a solution so basic that under laboratory conditions we cannot produce quartz from it. These are conditions of pressure, and the presence of water vapor, and mineralizers. Experimental work is difficult and expensive and has not been attempted.

Other quartz basalts were compared and found chemically somewhat similar to this one. It is noteworthy that 10 of the 16 quartz-bearing basalts, diabases and gabbros analyzed are andases. The Minnesota rock is even more basic than most of them. By grouping all these together, and finding the extreme variation in ratios of oxides, the limits of the group are not as wide as those of the andases. In other words, this natural group of rocks shows less variation than a single group of the arbitrary classification proposed by Cross, Iddings, Pirrson, and Washington. It may be that the peculiar combination of elements in this group is more conducive to the separation of free quartz than any other equally basic set of elements. As Washington has recently calculated the range of composition of rocks in which leucite may occur, so it may be possible to find what composition may produce quartz. But it seems likely that more variables occur and the calculation is postponed till more data are available.

SUMMARY.

The rocks of central Minnesota, while composed of an average amount of the usual elements, have differentiated into several main types and a few very interesting extremes. Subsequent alteration may have increased the peculiarities in some cases. Interest centers in two rocks, the quartz diabases and the green syenite. The unsolved problems are the origin of free quartz in a basic rock, and the development of an extreme type, containing almost nothing but albite and epidote.