BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 343-376, PLS 29-32 AUGUST 31, 1901

KEEWATIN AREA OF EASTERN AND CENTRAL MINNESOTA

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(*Presented before the Society December 30, 1899, and December 28, 1900*)

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Introduction

Within Minnesota from the city limits of Duluth southwestward beyond the geographical center of the state, which is lake Mille Lacs, lies a series of schistose rocks. To the southeast they disappear beneath the Cambrian sandstones, and the northwest boundary is entirely concealed by the Glacial drift. Their existence in a few localities has been known since the earliest geological explorations of the region. They were first recognized as Archean; then as Animikie—that is, Upper Huronian; and lastly, in 1894, the northernmost exposures were pronounced by Spurr to be Keewatin—that is, Lower Huronian.

The pre-Cambrian age of the series, which has rarely been doubted, is proved by the presence at two or more places of nearly horizontal sandstones in such relation to the rocks in question as to establish their subsequent age. Again, at Short Line park, near Duluth, the series under discussion is found to lie in undetermined thickness beneath the diabase flows and associated rocks of the Keweenawan.* Finally, since dikes of granite are found breaking up the intruded schists within areas regarded as belonging to the series discussed, the post-Archean age of the granites is with confidence asserted.

Geographic Subdivisions

Along the Saint Louis river where it constitutes the interstate boundary a belt of slates and schists emerges from beneath the Keweenawan to extend in almost continuous exposure up the river to Cloquet. The exposures lie in force around Thomson and Carlton, where the rocks range through every textural phase from a graywacke conglomerate to a roofing slate of excellent quality.

In the Blackhoof River valley the schists appear above the thin covering of drift and stretch southwestward to the Kettle River valley, where

* Geological and Natural History Survey of Minnesota, final report, vol. iv, 1899, p. 567, 568.

they can be followed for 15 miles with but little change in textural or mineral characters.

West of Sturgeon lake the schists have become more hornblendic. The attitude is notably changed from a gently southward dipping series to one nearly vertical or northwardly inclined. Beds of limestone are associated with the hornblende schists.

Along the Kettle and Rum rivers still other conditions are seen. The schists are markedly biotitic and of a much coarser texture than in the Blackhoof and Kettle River valleys. Dikes of diabase occur and granitic dikes and bosses constitute the larger proportion of the visible exposures.

Reaching the Mississippi river from Haven northward for not less than 30 miles, only granites of the hornblende-biotite type, occasionally broken by diabase dikes and bosses of biotitic gabbro, are seen in so many exposures that the conviction is forced that they constitute the principal rock of the region.

Finally, in another district with Little Falls as a center lies a series of schists of somewhat diverse lithologic type, always regarded as the westward extension of the Thomson slates. These have many characters—mineral, chemical, textural, and structural—in common with those. Around Thomson the clastic character of the series is clearly seen. Here alteration has proceeded so far that no traces of a granular character have been noted—a condition explained by the proximity of eruptive granites, gabbros, and diabases within the Little Falls district (see map, plate 29).

Rock Relations along the Border

It has already been stated that at Short Line park, within the city limits of Duluth, a well-boring discloses the Saint Louis River slates beneath the Keweenawan eruptives, thereby establishing the northeastward continuance of the series. In this locality there is no doubt that the schists extend beneath the Keweenawan eruptives and clastics. In the southerly part of Kimberly township, central Aitkin county, an exposure of quartzite is reported, which, having the lithologic characters of the more northerly Animikie, is on that ground relegated to that later series.* At Brainerd, in 1900, a well was bored by the Northern Pacific railway. At 163 feet schists were struck of the general habit of those northwest of Little Falls, and are presumably the same.

Around the western end of the district there is no opportunity whatever afforded for determining stratigraphic relationships beyond the drift

* Warren Upham : Preliminary report of field-work, Twenty-second Ann. Rept. Geological and Natural History Survey of Minnesota, 1894, p. 28. ("Taconic series" is the term used.)

contacts and a few artesian wells. The last afford evidence of the superposition of the Cretaceous shales over the granitic rocks. At Glenwood, on the northwestern border, granitic rocks occur at a depth scarcely greater than 50 feet below the water of lake Minnewaska. At Paynesville, southwest Stearns county, not more than 12 miles from outcrops of granitic rocks, Cretaceous shales were discovered at 70 feet below the surface. How deep the crystalline rocks lie was not determined. At Glencoe, directly south of Saint Cloud, red quartzite rocks were reached at 936 feet and bored into 700 feet farther. Just where the southern subglacial boundary lies has not yet been determined. At Anoka, 40 miles from the most southerly granites, wells determine the presence of the Paleozoics, which extend thence down the Mississippi valley. At Minneapolis granitics were reached in the Lakewood Cemetery well at 2,150 feet from a point 975 feet above the sea. Along the east side of the district along which the crystallines disappear beneath Cambrian sandstones these disappear abruptly against the Great fault, determining the western limit of the Keweenawan lava flows.

The geographic limits of the rock series under consideration may thus be summarized: On the south, while disappearing beneath the Paleozoic, they continue beneath these beyond Minneapolis, Winona, and La Crosse, where well-borings have established the presence of granitic rocks; to the east as far north as township 46, range 16 west, while beneath Cambrian sandstones westward the schists are abruptly broken by the great Keweenawan fault; northeastward they slope beneath the Keweenawan; northward they must be overlain by the westerly stretching Mesaba; but to the west the glacial drift and Cretaceous so completely obscure the relations of the older rocks that it is now impossible to correlate with positiveness the central Minnesota granites and the Minnesota Valley gneisses and gabbro-schists.

Keewatin of the Saint Louis River District

Rocks of the series and their relations

In the bed of Mission creek, sections 30 and 31, township 49, range 15 west, near the boundary between Saint Louis and Carlton counties, lies the easternmost exposure of the Thomson slates. In the gorge of the Saint Louis river, where Mission creek joins it, the slates form the river bed. From this point they are practically continuous to Knife falls, a distance by river of 15 miles. The strike is east and west, the dip generally south, at a varying angle. Above Knife falls occasional exposures are seen as far as section 27, township 51, range 19 west.

The Saint Louis river between Cloquet and Duluth has accomplished an enormous amount of erosion. Several high and precipitous knobs are isolated from the surrounding rock masses through river erosion. Those in the northeast quarter of section 15, township 48, range 16 west, and extending over the adjoining sections are relatively the highest. They disclose interesting phases in the history of the stream.

The gorge is chiefly pre-Glacial. Lacustrine deposits, quite extensive both in area and thickness, lie along the slopes of the ancient Saint Louis valley. They are evidently the shoreline accumulations of lake Duluth* laid down in a valley already cut by pre-Glacial streams. Erosion was suspended during the life period of lake Duluth, but was resumed when lake Superior began to settle to its present level.

The descent of the land surface causes the rapids; the tremendous eroding power given the water by its descent has carved out the gorge called the Dalles of the Saint Louis river. Several diabase dikes cutting the slates produce the falls several times met within the length of the "dalles."

The Keewatin slates and associated schists and quartzites lie below all other known rock formations in this region. This group is of undetermined thickness, but is estimated at 25,000 feet. Above it are seen in the Saint Louis valley the following series, in ascending order:

1. The Keweenawan series, consisting of (*a*) the gabbro in typical development, regarded as the basal number of the Keweenawan;† (*b*) a conglomerate bed, 100 feet or more in thickness, and (*c*) the extensive series of lava flows which is found in many portions of the Lake Superior basin.

2. The horizontal Cambrian sandstones from red to white in color, known as the Western sandstone.

3. Pleistocene deposits, largely lacustrine sands and clays, and unmodified material.

EXTERNAL CHARACTERS

The external characters of the Keewatin of the Saint Louis river may be briefly summarized: In color the rocks are dark. The fine slaty phases are black, and as the quartzite bands appear this color gives place to a gray which varies between black and light or greenish gray. As the rock weathers, a lighter color appears, due to the removal of carbonaceous material which locally produces the black color. Toward the north the clastic character of the rocks is clearly expressed. There are

*B. F. Taylor: A Short History of the Great Lakes, 1897, p. 10.

†The copper-bearing series of lake Superior, Monograph v, U. S. Geol. Survey, 1883, p. 156. N. H. Winchell: Geol. and Nat. Hist. Survey of Minnesota, vol. iv, 1899, p. 13.

alternations of impure quartzite, so indurated that the coarser pebbles are fused with the finer material into a semi-crystalline mass and a typical argillaceous slate with prominent cleavage.

Irving* thus enumerates the rock species:

"Among the slates, fine grained graywacke slates, clay slates, sericitic quartz slates, true quartzites, mica slates (often hornblendic), staurolitic mica slates (often garnetiferous), and hornblende schists, and among the eruptives, diabases, gabbros, and diorites, the latter presumably altered forms of diabase or gabbro."

The rocks have been traced southwestward for many miles and found to merge into a series of well defined hornblende-mica schists. A total obliteration of clastic characters and an interbedding of carbonate bands is shown. Still farther southwest a distinct limestone formation enters the series and becomes genetically an important factor.

STRUCTURAL FEATURES

The strike averages south 70 degrees west, and the dip south at an angle varying between 10 and 60 degrees. The slaty cleavage, which usually can be distinguished from lamination, is nearly vertical, with a direction nearly east and west.

At Thomson in both the slaty bands and the schists are locally numerous carbonate concretions.

The slaty cleavage seems to characterize the layers of finer and more argillaceous material, alternating with the quartzitic and conglomeratic phases. It always ceases at the contact of the argillaceous and silicious layers. The angle which it makes with the plane of contact, assumed everywhere as the bedding plane, varies, since the bedding of the rocks several times across the formation changes its attitude with the horizon. The quartzite shows the effects of enormous pressure, yet the physical condition of the rock material, so much less plastic, was so resistant that the effect of slaty cleavage was not induced.

This alternation of quartzitic and slaty layers is a notable petrographic character along the Saint Louis river. It is distinctly seen through color differences, lithologic characters, and rapidity of weathering. The coarser material carries zones or planes of nodular concretions which are of a decidedly carbonated composition. Weathering brings out the position of these concretions rapidly and in a most conspicuous manner. They indicate bands of the sedimentary rocks which contained a much greater per cent of carbon dioxide in combination. Through the subsequent

* R. D. Irving: Fifth Ann. Rept. U. S. Geol. Survey, 1885, p. 197.

alteration phenomena the segregation into nests of carbonates of iron, calcium, and magnesium was effected.

STRUCTURE AND DISTRIBUTION OF THE CONCRETIONS

Ordinarily these concretions are arranged in bands. As the rocks are eroded or cut away by human agency, the concretions stand in rows one above the other along the line of bedding. They are so compressed that they stand in the direction of the slaty cleavage, so far as individual position goes (see plate 31, figures 1 and 2); hence they give evidence both of original position and effect of pressure. They are undoubtedly of secondary origin; they consist chiefly of iron carbonate in chemical composition; they are quite well defined as against the mass of rock enclosing them, and weather with unusual facility and rapidity.

QUARTZ VEINS

There is a large number of quartz veins. The largest one noted is a segregation which stands up in the river bed where the carriage bridge from Carlton to Thomson crosses the Saint Louis river. It carries much of the slate and exhibits a heterogeneous quantity of quartz, and smaller quantities of pyrite, chalcopyrite, and traces of associated sulphides.

The smaller quartz veins scattered throughout the rocks diminish to paper thinness. They are milky white, harder than the slate and quartzite through which they course, and are remarkably free from accessory minerals. The closest scrutiny of explorers has failed to find more than traces of gold and silver.

DIABASE DIKES

The somewhat frequent dikes are objects of interest. The greatest width noted is 50 feet in one crossing the slates and quartzites one mile southeast of Carlton on the Northern Pacific railroad. The rock is diabase, extremely finely textured along the contact zones, and mediumly crystalline in its central part. At 50 paces east of railway bridge between Thomson and Cloquet is a 3-foot dike showing on a smaller scale the characters noted in the preceding; and many other similar structures are to be seen, but nowhere, so far as observed, do they exert any perceptible alteration effects upon the slates and quartzites into which they have been injected.

JOINTS AND FRACTURES

Jointing is everywhere one of the most conspicuous characters. The sharp ridges which, through the slate belt, are a conspicuous physio-

graphic feature, are due in a large measure to jointing. The jointing which has developed along the bedding, constituting the major structure on the southward slopes and a system of fractures in which there are frequent evidences of shearing, give character to the northward slopes.

Aside from the major structures, there are minor ones which vary with the condition of the rock.

Several efforts have been made at Thomson and near Cloquet to quarry roofing slate. The color is black, weathering to a light gray. The layers of slate, intercalated between corresponding layers of quartzite schist, are from 1 to 5 feet in thickness. Each layer is cut by many joints into plates. These joints, always striking with the rock or within 10 to 20 degrees of the same direction, make an angle of 30 to 40 degrees with the bedding planes, which at the slate quarries in Thomson dip south at from 65 to 75 degrees, and at Cloquet are nearly vertical. For several hundred feet the slate has been worked out, but a persistent warping renders the product of inferior quality (see plate 31, figure 1).

The Blackhoof Valley

Around Atkinson are several outcrops of quartzite schists. The strike is north 70 degrees east, magnetic, and the dip south at an angle of 65 degrees. Farther southeast the dip, continuing southerly, drops to about 25 degrees. The rocks locally assume a decidedly contorted condition. The exposures are not numerous, but the rocks lie only a short distance below the surface, and upon these an abundant and excellent water supply is always found.

The rocks separate freely along the schist planes, and are cut into somewhat rhombic blocks by a double system of joints, one of them being nearly coincident with the dip. A light and cheerful slate-gray color characterizes the more typical exposures. The freshly cleaved surfaces are quite lustrous. As these schists merge into a softer talc-like condition, as is the case where the concretionary lenses of quartz or quartz and siderite occur, the color becomes still lighter, or dark even to blackness. At one exposure, graphite was noted along the cleavage banks. To this source the black color sometimes seen is referred.

Some years ago explorations for gold were prosecuted along belt of quartz veins which resulted in finding only small traces of the metal.

In section 31, township 48, range 17 west, and section 36, township 48, range 18 west, there occurs a belt of quartz veins. They vary in direction and lack in continuity; they occur as a succession of strings and bands, corresponding quite closely in position with the foliation of

the rock. Rarely in the vicinity of the veins the quartzite schists seem to be greatly shattered and recemented, thus having the appearance of a breccia.

In such localities the quartz is generally associated with siderite, when fresh, and with a spongy, rusty condition when weathered. This rusted, porous condition extends in places into the schist for many feet. It gives evidence of the earlier presence of some accessory mineral, probably iron-carbonate. It occurs in zones of well defined distribution.

Moose River Valley

MAHTOWA EXPOSURES

Around Mahtowa are several exposures of the quartzite-schists stretching westward from the Blackhoof valley. In section 5, township 47, range 18, is a ledge of rather massive rock, with schistose structure locally developed. The slaty cleavage characteristic at Thomson and Cloquet is lacking. The rock breaks coarsely, and carries evidence of much pyrite or iron carbonate below its zone of weathering in the cubical and rhombohedral cavities so frequently seen.

Pressure has resulted in a folding, quite clearly shown in some hand specimens. Wells give evidence of wide distribution of these rocks slightly below the surface.

BARNUM EXPOSURES

The schists are widely exposed over miles of almost level surface around Barnum. At the railway depot there is some contortion, a gentle dip southward, an alternation of foliated and quartzose phases, a collection of quartz lenses, and an absence of slaty cleavage. The foliated is the dominant structure, and the southerly the dominant attitude of these rocks. Half a mile west of the station the rocks are more uniform, lithologically and structurally, and some quarrying has been done on that account. The dip southerly is slight, probably not over 5 to 10 degrees and interfoliated bands of glossy schist are only an inch or two thick at a maximum.

Northwest of the station, in section 15, township 47, range 19, there is an exposure in which a pyrite-bearing vein and diabase dike afford lithologic diversity. The badly weathered schists possess the same general characters as the rocks beside the railway. The locality is in the bank of a stream, and so covered that directions are difficult to determine with exactness. The vein has been assayed for gold; a good trace was found.

The dike is badly weathered. Its texture is medium, and composition appears uniform: a basaltic structure is in the fresher portions, and a decidedly concentric weathering where greatest alteration is shown.

MOOSE LAKE EXPOSURES

Moose lake affords an exposure or two of some interest. Near the sawmills a railroad cut has been made to the depth of several feet in the clean gray schists. There is variation in texture from a mediumly coarse yet well defined schist to a slaty variety greenish gray in color and glossy in habit, yet lacking slaty cleavage. Bands of a few inches in thickness, consisting of calcium carbonate, occur in these glossy foliated rocks. The strike is north 70 degrees east, dip varying from 0 to 25 degrees toward the south 20 degrees east. Some contortion was noted. A dike of diabase porphyrite occurs in the west part of the town, cutting through the schists without modifying their rock-habit to any perceptible extent.

Kettle River Section

From section 21, township 46, range 20 west, to section 36, township 45, range 20, a distance of 10 miles, there is a most interesting series of exposures of hornblende-biotite schists. The rocks are very uniform in their structural characters and external lithologic habit. Layers of a decidedly quartzose habit alternate with the normal schist. With these are, more rarely, bands of a carbonate. At the northernmost exposure in section 21, township 46, range 20, there is exposed a wide vein of quartz regarded as the southwestward extension of the one outcropping in the Saint Louis river at Thomson and already mentioned. A mile and a half below this exposure the schists which lie in both banks of the river for a considerable distance are badly shattered and badly altered, so much so that they have been mapped by the Minnesota survey as Cambrian sandstone.* The strike of these rocks is very nearly east and west, varying perhaps to north 80 degrees to 85 degrees east, with a southerly dip, varying from 15 to 30 degrees.

Only half a mile from the locality just noted is an exposure 20 feet or more above the river, containing a notable per cent of graphite. It is situated 100 paces from the river; direction of strike, north 60 degrees east, magnetic, dipping south 30 degrees east, at an angle varying from 3 to 30 degrees. While the exposed area is not great, the indications in the black soil, widely distributed graphite chips and attitude of

*Géol. and Nat. Hist. Survey of Minnesota, final report, vol. iv, 1899, pl. 56.

rocks themselves are that there is a large area of graphitic shales. The percentage of carbon in these shales has not yet been determined.

The graphitic shales disappear, and at the first exposure southward the normal gray glossy schists come into view. There is some variation in the hardness and mineral proportion of the schists. The structure in places is somewhat massive, elsewhere decidedly schistose. The strike is north 60 degrees to 75 degrees east, with a southeasterly dip of 20 to 30 degrees, with local measurements as low as 15 degrees. Some little contortion is also seen.

In section 9, township 45, range 20, there are some interesting nodules. They are more crystalline than those around Mahtowa and at Thomson, approaching more nearly those seen at Little Falls and Moose lake.

The Kettle River section gives the most satisfactory place for securing an idea of the thickness of the formation that the entire region affords. The northernmost exposure along this stream lies in the northern part of section 16, township 46, range 20, and the southernmost, seen before the northward dipping schists are reached, lies in section 9, township 45, range 20. In this distance of nearly 6 miles, dip was measured at many places. Nowhere was it less than 15 degrees, and at several outcrops it was 30 degrees and more. In the entire distance there was seen no trace of displacement. The average attitude, therefore, can not give less than 2,500 feet per mile, which will thus make a total of 15,000 feet as the thickness of the schists of the Kettle River valley. This, it must be remembered, is without the top or the bottom of the series being seen.

The foregoing does not include the exposures from Stony brook southward to the Blackhoof valley. In this area a folding can easily be traced beneath the more prominent slaty cleavage. Owing to this, any measure of thickness is well-nigh impossible. A conservative estimate of the rocks in sight, taking into account folding, horizontal position, crushing, and other attitudes, is 5,000 feet. Added to the thickness seen in the successive exposures along the Kettle river, which, according to strike measured scores of times, are a continuation of the schists disappearing beneath the drift in the Blackhoof River valley, this gives a total of 20,000 feet as a conservative estimate of the thickness of the series under consideration. Farther westward, as has been shown, alteration, folding, and eruptive displacement preclude all possibility of reliable estimate.

Region west of Sturgeon Lake

At this point there is seen a decided change in the attitude and character of the rocks. The structure becomes sharply crystalline and in

places markedly fibrous with a decidedly hornblendic habit. Some narrow and unobtrusive veins appear, carrying pyritous contents. The most conspicuous veins, however, are the white quartz. The veins vary from a foot or two in thickness to paper thinness, are quite irregular in direction, locally are considerably contorted, as a rule free from pyritous or other metallic accessories, and very frequently assume a lenticular aspect, when are found quite liberal proportions of coarsely crystalline feldspathic content.

The strike of this group of rocks shows some variation. Along the road between sections 19 and 30 the strike of the foliation is north 80 degrees east, with a dip of the laminæ partly south and partly north. Passing south of the road 200 paces, and the strike is north 70 degrees east and the dip 80 degrees north; 200 paces north of the road the strike appeared to be north 65 degrees east and the dip 75 degrees north. The rock at this point is more coarsely crystalline than elsewhere. An abundance of garnets is present, strongly suggestive of contact alteration. The rather small crystals are of the ordinary variety.

Farther south, in section 30, township 45, range 20, the rock is more finely crystalline than to the north, and exhibits some variety of texture and color. Instead of the dark green, so dark as to appear black to the eye, the rock has a pea-green color in many of its bands. The direction is nearly east and west. This determines the direction of the ridges which stretch across these sections. The hornblendic rock is locally so fibrous that slender pieces 6 to 7 feet long are seen lying about. The strike over all these long parallel hillocks is nearly the same, and the dip varies from vertical to north 40 degrees.

Through section 25, extending nearly north and south, is a creek valley. At present it is little more than a long narrow marsh, yet its walls, its width, and depth suggest at an earlier date a much larger stream. It may be an old channel of glacial origin. The seeping water at present moves northward, but at the time of its cutting very likely a large stream flowed toward the south. Its nearly vertical walls, from 20 feet to 40 feet high, show interesting structure lines, joints, folia, possible bedding planes, and other phenomena. The valley exhibits all of the characters of an abandoned valley of erosion.

The most interesting lithologic feature of this locality is the presence of several exposures of limestone. This rock, approached from the north, is disclosed by the fragments which lie in the bed of the stream. The most northerly exposure of the rock in place is in the east half of section 25, township 45, range 21 west. It lies 8 to 10 feet in thickness, dipping southward at about 20 degrees. The rock is rather fine grained and thoroughly crystalline. Its color is a light pink with a faintly trans-

lucent habit. Along the east wall of the valley of erosion which unites with Birch creek, only a few paces from the first exposure just described, are several other spots where the limestone outcrops, but nowhere is such clear, evenly crystalline material. It is, instead, at the surface a crumbling mixture of quartz and carbonate, so as to be a quartzose limestone of quite variable composition. This rock is so easily decomposed, and the beds thereby become so overshadowed, as it were, by the more enduring hornblende schist with which it seems to be interstratified, that the structural relations are difficult to discover. It is quite probable that the valley along whose walls these exposures occur has been formed because of the presence of a rock thus easily eroded.

Several miles to the west of Rutledge, in section 30, township 44, range 21 west, are masses of gneissic rock protruding from the otherwise universal sheet of glacial drift. Coursing through these rocks in various directions and at various angles of inclination are dikes of granite. These dikes are narrow, yet varying in width. Structurally, they are pegmatitic; mineralogically, they consist of quartz, orthoclase, microcline, and plagioclase, with muscovite as the principal bisilicate constituent. The gneissic rocks are modified profoundly by acid intrusives, the most prominent result being a coarser texture, the presence of accessory garnets and pyrite, and the tendency to assume gneissic foliation.

Snake River Localities

Along Snake river, in township 42, range 23, through several sections, at intervals a more conspicuous occurrence of granitic dikes and inclosing schists is seen. At the log dam and sluice in section 9 occurs a most confused association of these rocks. A diabase dike several feet in width and of vertical position here breaks across the river. The schists are biotite muscovite of a mediumly coarse texture, not only strongly schistose, but even clearly foliated. The muscovite is locally well crystallized and again segregated into nests of radiating individuals, pinnately distributed along the fracture planes induced in the rock by this mineral.

The granite is usually gray, locally fine grained, but when in contact with the schists inclined to take on a pegmatitic habit having every appearance of coarse-grained granitic dikes. There are many veins and lenticular masses of quartz, some of them reaching a thickness of one foot or more. The jointing of these rocks is quite pronounced. The direction is vertical, and the joints stand from 4 to 10 feet apart. The remarkably zigzag character of the channel, as the river cuts its way through walls nearly vertical and 15 feet high, is apparently due to the

strength of this jointing and the success of the river in following these lines of least resistance as it carved its bed in the fresh crystalline rocks.

Rum River Valley

Along the Ann and upper Rum rivers, including some hitherto undescribed localities around the east side of lake Mille Lacs, are many exposures of a medium grained hornblende biotite granite with no visible areas of schists. There are two types of granitic rocks: one red and somewhat coarse grained, seen along the west branch of the Rum river and its tributaries; and the other light gray and medium grained, characteristic of the Ann river valley. There are representatives of the two granite types, the red and the light gray, found in the region intervening between the Kettle river on the east and the Mississippi on the west, comprising several thousand square miles in the very center of the state. These Rum River and Snake River outcrops would seem to be along the eastern border of the granitic area, where the exposures disclose a series of dikes breaking into and markedly modifying the older schists which stretch southwestward from the graywacke beds of the Thomson district.

Morrison County

Northwestward from the foregoing, between lake Mille Lacs and the Mississippi river, at the mouth of the Elk, are many exposures of granites and gneisses. At the Mississippi itself are extensive areas of hornblende-biotite schists carrying garnets and staurolite in profusion. At the large reef below the mouth of the tributary Swan river a bed of rather fine grained pink limestone was reported several years ago. The accounts would seem to make it identical with the limestone exposed southwest of Sturgeon lake. If this surmise be correct, the two localities have between them many intrusions of granitic eruptives. At Little Falls and westward are intrusions of basic rocks, both diabase and gabbro. Extensive exposures of biotitic olivine gabbro occur in section 13, township 129, range 30 west, and in a succession of outcrops southward far into Stearns county. In the northwestern corner of Morrison county altered schists occur striking westward and standing nearly vertical. In their alteration much calcium carbonate has been formed, which at the present time constitutes a considerable bulk-percentage of the schists. Beyond Morrison county northwestward the schists have not been seen. Eruptives, both acidic and basic, are exposed; the former as epidote granites at Ashley, Ward, and in southwestern Cass county; the latter, besides several diabase dikes at several localities, in an area of interesting apatite-diorite at the mouth of Fish Trap brook. Northward of the

Morrison County exposures, glacial drift covers the schists, as remarked in the mention of the Brainard deep well (*ante*, page 345).

Taken as a whole, Morrison county, in its content of rock types among the ancient crystallines, is among the most diversified areas of the state. The range of granitic rocks represents several varieties, and gneisses in the eastern part of the county are important. Gabbros, diorites, and diabases appear in unexpected force to the west of the Mississippi river. Finally extensive belts of hornblende-biotite schists are seen to cross the course of the river, locally loaded with staurolitic crystals and garnets, while in the more disturbed areas lenses of a peculiar hornblendic quartzose habit appear, of sufficient lithologic interest to receive the name quartz-diorite from Doctor Kloos.

Granite Areas

Throughout a large area in Benton, Sherburne, and Stearns counties the rocks are, so far as seen, wholly granitic. There is considerable variation in texture, color, and chemical composition. An acidic type prevails, represented by the Le Sauk granites, with 74 per cent of SiO_2. A heavy proportion of quartz is in such varieties. Again the per cent of SiO_2 sinks nearly to 69 per cent. Here the proportion of quartz is small and the color prevailingly dark. These characters correspond with a heavy proportion of hornblende as the bisilicate constituent.

A discussion of these granite areas is without the scope of this paper. Their presence along the Mississippi is mentioned chiefly to enforce the westward extension of the area believed to be Keewatin, which stretches from the city of Duluth southwestward even beyond the central portions of the state.

Lithology of the Series

THE PROBLEM PRESENTED

The effort is made in the following pages to trace a petrographic and genetic relationship between the carbonate schists, graywackes, and graywacke slates of Thomson, Carlton, and Cloquet, and the thoroughly crystalline dolomite, biotite, and hornblende-biotite schists as represented along the Mississippi, Snake, and Kettle rivers, in the several localities enumerated on the preceding pages. Such a relationship is not infrequent in this part of the continent.

OTHER LOCALITIES CITED

Fifteen years ago Van Hise* traced out and established the relation-

*C. R. Van Hise: Upon the origin of the mica-schists and black mica-slates of the Penokee Gogebic iron-bearing series, Amer. Jour. Sci., vol. xxxi, 1886, pp. 453–459.

ship between (1) well defined graywackes and graywacke-slates, (2) biotitic graywackes, (3) biotite-schists and muscovitic biotite-schist of the Penokee-Gogebic range as a graded series from the slightly altered graywackes to the crystalline mica-schists, this relationship being formulated in the following proposition:

"the result being the production from a completely fragmental rock, by metasomatic changes only, of a rock which presents every appearance of complete original crystallization, and which would be ordinarily classed as a genuine crystalline schist." *

At nearly the same time Lawson worked out the relationship between the clastics and schists of the Rainy Lake and Lake of the Woods region and stated his results,† showing that the granite of the region is of later origin than the folded schists, and that the period of folding occurred at a date earlier than that of the deposition of the typical Huronian of Logan—that is, the Animikie.‡

Two years later Lawson,§ in stating the results of his studies around Rainy lake, says with reference to one particular locality, that the detrital origin of the series of fissile soft green chloritic and hornblendic schists is established through their forming the paste of a pebble-and-boulder conglomerate (page 83 F), and touching another locality he says (page 84 F) that the matrix of a conglomerate is a more or less calcareous, decomposed schist.

Again, in the Black hills of South Dakota, a region to be associated genetically with that extending from lake Superior southwestward, within which lies the district under discussion, Van Hise observed ‖ that slates, quartzites, and conglomerates occurring in a broad central belt become more crystalline and grade into schists about the volcanics to the north and the granite of Harney peak to the south. "In the transition in both directions, graywacke-slates change into mica-slates, the mica-slates into non-foliated mica-schists, the non-mica-schists into foliated mica-schists (which are both garnetiferous and staurolitic) and even into gneisses."

HISTORICAL NOTES

The group of rocks around Thomson and Carlton, as has already been stated, have long been considered clastics in origin. In a vague sort of

* Loc. cit., p. 454.

† A. C. Lawson: Report on the Geology of the Lake of the Woods, Ann. Rept. Geol. and Nat. Hist. Survey of Canada, 1886, pp. 1–151*cc*.

‡ Loc. cit., p. 13.

§ Geol. and Nat. Hist. Survey of Canada, Ann. Rept., new series, vol. iii, pt. i, report F, pp. 1–190.

‖ C. R. Van Hise: The pre-Cambrian rocks of the Black hills, Bull. Geol. Soc. Am., vol. i, 1890, pp. 203–243. Quotation is from p. 223.

way the rocks at Little Falls have been regarded as stratigraphically related to the "Thomson slates." No evidence has been adduced, either in their structural or mineralogic relations, to confirm this view. Again, the granites at Saint Cloud, Sauk Rapids, and Watab have been held to be Archean, and it was assumed further that could a contact be found beneath the drift, it would disclose the Little Falls "slates" as lying unconformably on the granites. The granites of the Saint Cloud area were held to be of the same age as the gneisses and gabbro schists of the Minnesota River valley. It was also thought that the Keweenawan eruptives at Chengwatana, Taylors Falls, and other places were poured out and spread over the slates and schists as lavas cover older rocks in every other region, and that the Cambrian sandstones stretched through the upper Mississippi River valley northward until the worn edges of all the underlying pre-Cambrian formations were covered by them over thousands of square miles, into the very heart of the Lake Superior synclinal trough.

THE GRAYWACKES

These rocks occur around Thomson, Carlton, and Cloquet in extensive exposures, typical in the village of Thomson. Their prevailing color is a dark gray, which on weathering fades almost to white. The variation in mineral composition is clearly evidenced on the weathered surfaces. The rocks are everywhere shattered and fractured through crustal movements until it is practically impossible to quarry blocks of satisfactory size. Even the slates are so fractured and warped that only three or four localities in the entire district have been found where plates of sufficient size for commercial purposes can be extracted. Plate 32, figure 1, shows this shattered condition near the railroad depot at Thomson, where glaciation has smoothed the hardened graywacke surface. Here the quartz, resisting corrosion, stands out in rounded or etched grains, while numberless pits which the surface carries represent the former resting places of the more easily decomposed carbonate and silicate constituents. The grains vary greatly in size; the largest are the size of marrowfat peas, the others diminishing until a texture of slaty fineness is attained. As a rule, the finer the texture the darker the color, the slates being very black. The rock is thoroughly indurated. It has a harsh feel when broken across the planes of foliation. The individual grains are so cemented that a conchoidal fracture and non-granular habit characterize the more massive beds. The thickness of these beds could not be measured, outcrops showing from 50 to 100 feet each; hence the total must reach thousands of feet.

In mineral content, the coarser varieties, or the graywacke proper,

contain quartz in large proportion. The grains are largely multigranular—that is, worn down from granitic quartz—and partly unigranular. Feldspar in two or three varieties is frequently seen; so, too, are particles of fine black slate and rounded pebbles of an ancient diabase. That the feldspars result from the degradation of granitic rocks rather than basic eruptives is indicated by their albitic rather than anorthitic habit. Microcline is a less frequent, yet by no means rare constituent, while orthoclase was proved in only two or three instances.

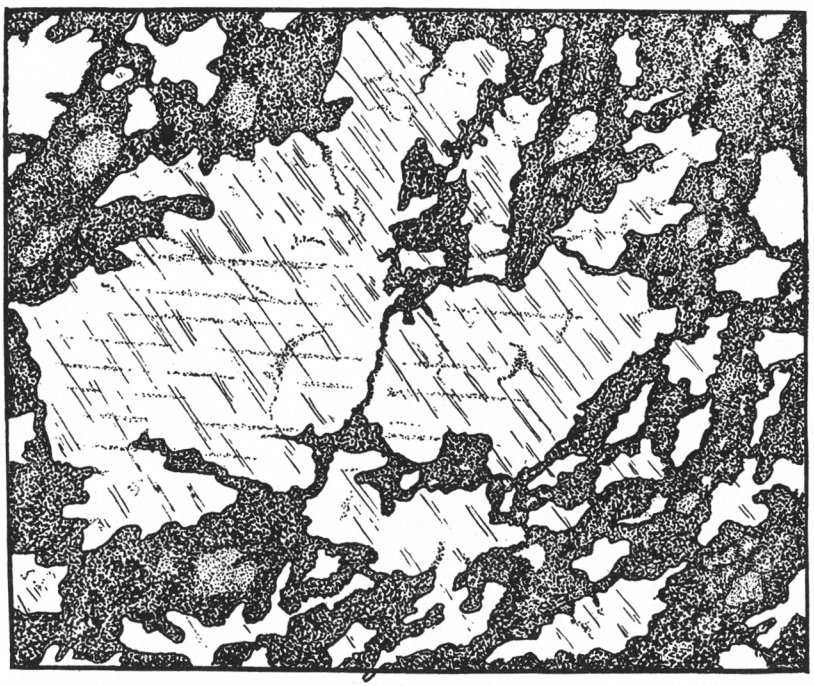


FIGURE 1.—*A Grain of Albite Feldspar.*

The albite feldspar is corroded and changing into a finely granular uniaxial material. To the right the feldspar is almost wholly altered. From slide 1053, from one of the freshest specimens of graywacke taken at Thomson.

Microscopically quartz appears in even greater proportion than macroscopically. A considerable proportion of the matrix binding the coarser grains is finely crystalline quartz, bearing every evidence of secondary origin. Again, it is the result of alteration *in situ*. The rule of distribution is, the more altered the rock the more finely crystalline, proportionally, is quartz seen to be. The original grains of this mineral can usually be distinguished from the secondary by the frequent occurrence

in the former of rutile needles, bands of liquid or empty inclusions, a wavy extinction, and other quite general characters. Hornblende is present as a secondary constituent, distributed in fibrous individuals within the matrix enveloping and gradually absorbing the clastic grains, both fine and coarse.

The feldspars are next to command interest. Rarely are the individual grains of their original size and contour. The outline is not sharp and smooth as one would expect in a rounded grain, but the contact line shows a finely crystalline interlocking of several mineral species. A slight kaolinization characterizes the freshest feldspars, and this increases with the degree of alteration undergone. Complete replacement has undoubtedly taken place in some of the feldspars. Figure 1 shows their usually partially altered condition. The grain is still present in spots and lines which lie with considerable regularity of direction. The finely crystalline alteration product in this case is a uniaxial mineral and is thought to be siderite.

The matrix now binding these grains of quartz, feldspars, and less frequent rock and mineral fragments together is very finely crystalline. It consists largely of quartz, yet partly of hornblende, biotite, and kaolinic and chloritic minerals. In origin it is largely interstitial deposited as independent particles. Its source is doubtless within the rock mass itself and for the most part in the corroded grains of quartz, feldspar, and other more easily soluble silicates. Not all the matrix material is secondary, since naturally many fine grains of the constituent minerals were sifted in among the larger ones as the rock was laid down.

The quartz and feldspar fragments even in the least altered sections show no clear traces of secondary growths. In this respect they differ from these same mineral grains in the Penokee-Gogebic range as described by Van Hise.*

THE GRAYWACKE SLATES

The most conspicuous difference between these rocks and those just described is that of texture. The gradation from the coarsest graywackes to the fine and often glossy graywacke slates is difficult to follow because so imperceptible. There is nowhere any sharp line of separation. Even where the division can be located within a band 2 or 3 inches wide the line is still indistinct. The actual separation is to be sought for in the texture of the sediments out of which these rocks have been developed. The deposits were alternatingly coarse and fine. Where coarse, the graywackes have come down, and where fine, the graywacke slates occur in increasing fineness until the clay slates, which have been quarried in

*Loc. cit., p. 456.

several places around Thomson and Cloquet, represent the existing alteration stage.

THE CLAY SLATES

These are extremely finely crystalline rocks occurring in bands from 2 or 3 to many feet in thickness between the layers of graywacke and graywacke slate. The difference between the clay slates and those apparently lies in the effect which pressure and shearing have left upon them. The slates have a well defined cleavage, so complete that considerable quarrying has been done, while the graywackes have a typical schistosity, the more perfect as the rocks are more thoroughly altered. The two are seen side by side in many situations, as plate 31, figures 1 and 2, clearly shows.

The texture of the clay slates is so extremely fine that the mineral composition cannot satisfactorily be determined. In comparison with the commercial product of the Slatington quarries of Pennsylvania, no marked difference was seen. Series of slides made from the ordinary roofing slates of Thomson and Cloquet and from the graywacke series gathered at different points within this district gave texture the chief distinction to be made. The fundamental difference is no doubt one of chemical composition, brought about by the variation in the size of grain and consequent transportation at the time sediments were depositing. The transverse cleavage characterizing the slates is due to movements produced by lateral compression. This force has been sufficient to produce the cleavage phenomenon in the fine sediments through their capacity for microscopic faulting, and to place in vertical direction the carbonate concretions which occur both in slates and associated graywackes (see plate 31, figure 2).

THE HORNBLENDE GRAYWACKES

These rocks differ from the foregoing graywackes in the extent to which alteration has progressed. Quartz which appeared in those as well preserved rounded grains here has to a large degree passed into a microcrystalline stage. Feldspars appear in rare and isolated fragments and in areas of finely crystalline alteration products, namely, quartz, calcite, siderite, muscovite, and hornblende. The figure selected for illustrating this phase of the alteration is one in which hornblende is developing a large area in crystallographic continuity out of what are regarded as grains of feldspar and quartz. Numerous globular dark grains, identified as magnetite, are scattered through the secondary portions of the field. More rarely than in the preceding are seen fragments of the earlier rocks out of whose degradation these hornblende gray-

wackes were formed. It is to be noted that the secondary minerals are in much smaller individuals than those from which they were derived (see figure 2), where hornblende is developing as a secondary product in the metamorphism of these rocks.

THE HORNBLENDE SCHISTS

These rocks are regarded as the accomplishment of the processes of rock and mineral alteration acting on the graywackes. A perfectly crystalline hornblende-schist is the abundant rock in the region west of Moose lake and Sturgeon lake. While hornblende occurs in the freshest

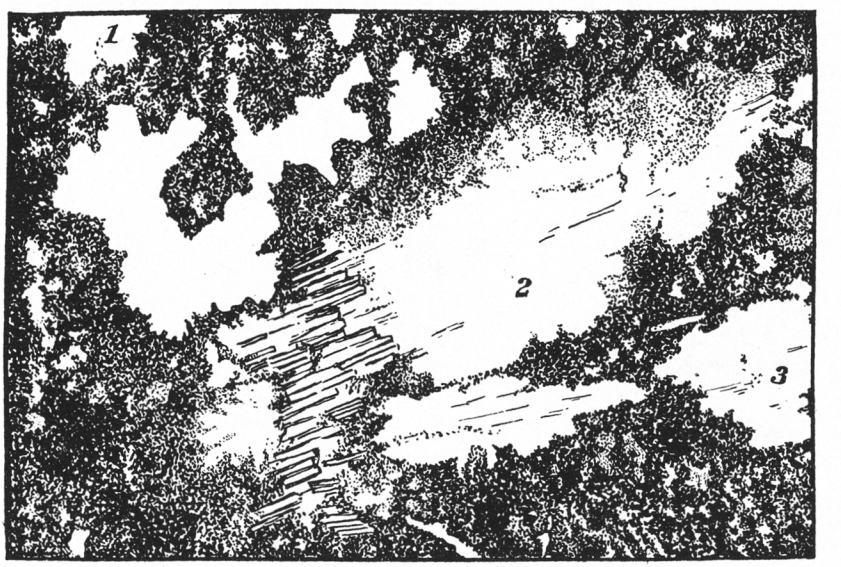


FIGURE 2.—*Hornblende Graywacke.*

The original grains of hornblende graywacke have almost completely disappeared. This figure shows hornblende developing in crystallographic continuity with larger areas of hornblende, also doubtless secondary, developed from original graywacke grains. 1, quartz; 2, hornblende; 3, feldspar. Banded portions, new hornblende.

graywackes of Thomson and Carlton as an interstitial mineral, in the region just named it has developed into the dominant rock constituent, placing even quartz in the background. The parallel position of the grains is usually seen, and the individuals elongated parallel to the axis *c*. Quartz is present in clear, well defined grains, bearing every indication of being secondary. Garnets and magnetite grains are rather numerous. It was observed that toward the surface at every exposure there was a greater proportion of biotite than at a few inches within the

rock, a suggestion leading to the belief that the biotite schists of the district are secondary after the hornblende rocks. There is not the slightest trace of remnants to demonstrate an earlier condition; hence stratigraphic relationships and lithologic condition are the data accepted in the interpretation given of the stages of alteration leading up to the existing completed schists.

The most marked macroscopic feature of these rocks is the uniformly schistose structure. Locally this is varied by the occurrence of more or less contorted veins and sharply lenticular masses of white quartz. Often associated with these are segregations of pink orthoclase, and more

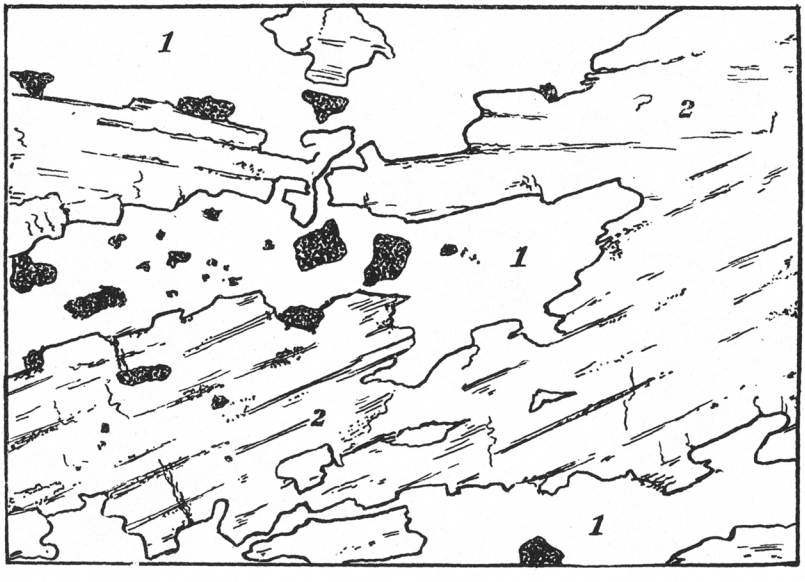


FIGURE 3.—*Hornblende Schists.*

The original clastic grains have entirely disappeared, and no trace is seen of the original condition of the rock. Hornblende quartz and magnetite are the minerals recognized. 1, areas of quartz; 2, hornblende.

rarely the dioritic lenses first noted by Kloos * at Little Falls, and since seen at many localities within the district. Very generally in these more altered phases garnets are abundant. They are especially numerous in those belts containing the lenticular masses of white quartz. At the log dam on Snake river, where the schists are greatly shattered by granite dikes, the texture is coarse.

Microscopically the quartz is in clear, perfectly transparent grains carrying few impurities, as minute crystals of hornblende and magne-

*J. H. Kloos: Neues Jahrbuch für Mineralogie und Petrefactenkunde, 1877, p. 36.

tite. The hornblende is in strongly pleochroic plates, with prismatic habit and generally parallel position. Figure 3 is from a representative hand specimen. Magnetite is present. Frequently its sections are quadratic, and they are strewn through every other mineral part of the section. Garnets show the usual tendency toward absorbing quartz in their growth to a considerable proportion of their bulk. Other minerals are rare. Staurolite appears farther westward as an important accessory.

THE HORNBLENDE-BIOTITE SCHISTS

These rocks differ in only a slight degree from the hornblende-schists just discussed. They carry biotite in addition to the minerals named in the preceding rock, are quite fresh looking in normal phases, and their texture is so fine that it is difficult to distinguish them from those carrying only hornblende as the bisilicate constituent. As a rule, the hornblende folia are very minute compared with the biotite. There are but few accessory minerals, garnet being the most conspicuous, while, microscopically, magnetite appears.

These rocks have every appearance of having resulted from the alteration of the hornblende schists. It must be admitted, however, that the evidence that such alteration actually occurred is incomplete. Specimens were not secured in sufficient quantity and from crucial points to establish the series or demonstrate the genetic relationship. In intermediate phases traces of the earlier constituents can be seen. Veins are frequent in these rocks. Their contents are made up partly of enlargements of the neighboring broken mineral grains, and thus point to the alteration processes as in progress.

THE BIOTITE SCHISTS

These rocks occur in several localities. In general field characters they are indistinguishable from the partially altered graywackes or the hornblende graywackes already described. The freshest phases show hornblende in small proportion; normally they carry biotite as the almost exclusive bisilicate constituent. Garnets are a characteristic feature of the entire series of rocks which have resulted through the complete alteration from the graywackes. In the biotite schists the garnets are altering into serpentinous products; some crystals having entirely disappeared, the resultant product, as a finely crystalline mass, presents the optical reactions of serpentine.

THE STAUROLITIC BIOTITE SCHISTS

These biotite-bearing rocks are characteristic along the Mississippi river for about 10 miles north and south of Little Falls. The strike is

north 10 to 30 degrees east, thus showing a strong deflection southward from the general direction around Carlton and along the Kettle river and its tributaries. The dip in places is northwestward—70 degrees at Swan river, 65 degrees at Muncys rapids, 70 to 75 degrees at Pike rapids, very nearly vertical at Little Falls, and finally, at the mouth of Little Elk river, the most northerly point where exposed, the dip varies from vertical to 80 degrees southeast, while the strike is north 40 degrees east, a notable variation from that at Little Falls. Quartz veins usually only an inch or two in width, lenticular masses of "quartz diorite," the occurrence locally of numerous staurolitic crystals from a half inch to two inches long, with numerous garnets occasionally filling the matrix, are the chief structural characters of interest. It is to be noted that these are characters peculiar to contact phenomena. Microscopically the typical rock is a biotite schist. A specimen from Pike rapids, one of the finest exposures on the Mississippi river, shows a groundmass of finely crystalline quartz grains with much coarser folia of biotite plentifully distributed. Crystals of staurolite and garnet are numerous, the former up to an inch in length scarcely differentiated from the quartz of the groundmass of the rock, while the light pink garnets are also full of quartzose inclusions. They seem to have rejected every other mineral save quartz in their crystallization. At the surface the biotite has undergone that physical change which in reflected light results in the lustrous golden yellow color so frequently observed in decaying drift boulders, namely, the deposition on the cleavage folia of films of iron oxide.

THE LIMESTONES

These rocks offer a wide range of varietal characters. In the creek to the north of the high exposures of fibrous hornblende schist southwest of Sturgeon lake, the limestone is remarkably free from mineral impurities. The texture is fine, color a clear, delicate pink, and structural planes distinct. The other exposures are less clearly carbonates. Where the abandoned gorge occurs, the rock gives every evidence of profound alteration. The surface is disintegrating mingled silicious and calcareous material in which the residual is a mass of incoherent quartzose fragments. Beneath the surface the rock is firmer; within 3 or 4 feet it is quite coherent and appears to be a mass of quartz grains of clastic habit imbedded in a matrix of dolomite. The contortion seen in the rock is apparently due to alteration under great pressure with more or less shearing. There is ferric oxide enough in all these layers in which the carbonates occur to give the red color to the rock on exposure.

An analysis made by Mr Levi B. Pease, of the University of Minnesota, of the samples which, both to the unaided eye and under the

microscope, seemed to be freest from impurities, gave the following result:

	Per cent.
SiO_2	5.02
Al_2O_3	14.20
Fe_2O_3	2.00
$CaCO_3$	60.52
$MgCO_3$	19.11
	100.85

Farther to the north, in the midst of the graywacke slates, the hornblendic graywackes, and the hornblende schists, bands of carbonates occur, varying from a few inches to several feet in thickness. They show numerous grains of quartz intermingled with the limestone. In short, the same characters, save in color and degree of alteration, distinguish these bands as have been described for the thoroughly crystalline limestones near Sturgeon lake.

THE GRANITES

These rocks are chiefly of the hornblende-biotite type. In Morrison country a light gray biotitic, rather finely textured outcrop occurs. At the now abandoned site of Granite City an unusual hornblende gneiss occurs. Gneissic features occur along the Rum river. At two or three localities on Snake river interesting dikes of granite break through the schists and make them more coarsely crystalline.

For miles along the Mississippi river, past Watab, Sauk Rapids, and Saint Cloud, exposures of these granitic rocks abound. Of the hornblende-biotite type, they once were augitic rocks, for in the freshest exposures augite cores still remain in the midst of the clustered hornblende individuals, while, as the rule of distribution, biotite individuals form a circle outside the hornblende clusters.

THE DIABASES

The dike rocks, of which two or three varieties are included under the more generic term diabase, occur throughout the entire district under discussion. They present some local phases of interest, and show a considerable range of special characters. They can not here be described in detail. It may be said that, as a rule, they are of the porphyritic type. Feldspar is usually in lath-shaped individuals, lying within a groundmass of feebly reacting minerals, finely crystalline in texture and to a great extent altered from their original condition. The feldspars are in some instances, as in a dike in the railway cut south of Carlton, extremely fresh crystals of labradorite, and in others so far altered into

finely crystalline kaolinic material as to be almost indistinguishable. At Little Falls and Sauk Rapids olivine is seen in partially decomposed crystals. In these dikes olivine was once a very important constituent.

THE GABBRO

Gabbro is mentioned here because it occurs in Little Falls at the western end of profile V, plate 30, from Little Falls to Taylors Falls, across the southern and southwestern portions of the area under discussion, and mapped on plate 29. A belt of gabbro bosses stretches from Little Falls into the southern half of Stearns county. They are believed to be post-Keewatin. They are throughout quite similar in lithologic characters; hence the Little Falls outcrop may be taken as a type. This rock is a biotitic gabbro. Labradorite, diallage, possibly hypersthene, olivine, magnetite, and several alteration products derived particularly from the decomposing hypersthene and olivine, mark the mineral habit of the rock species. The texture is medium, and alteration is marked.

VEINS AND VEINSTUFFS

Around Thomson and Carlton, and similarly throughout the Saint Louis River district, there occur a large number of veins. Most of them are thin, and, save as they point to structural conditions, insignificant. They are plainly veins of infiltration wherever any direct clue to origin can be seen. In plate 32, figure 2, is seen a quartz vein from one to three inches in width, which is involved in the crumbling of the rocks to an unusual extent. In many of the microscopically narrow veins quartz is the leading constituent, through which hornblende needles are projected into the veinstuff from the edges of broken hornblende individuals. The process was one of enlargement of the hornblende grains through the attachment in crystallographic continuity of fibers extending the prismatic axes of the old and disrupted hornblende.

There frequently are to be seen the attachments of quartz crystals to the walls of the minute fissures, with their axial or *c* directions pointed across the space, not in crystallographic parallelism but rather in one general direction. As veins become broader, the arrangement of vein contents becomes more complex, until when feet across they are made up almost entirely of granular quartz, pegmatitic masses, intermingled siderite, and in one or two instances segregated sulphides. An example of the first named is seen at the bridge across the Saint Louis river at Thomson. It stands nearly perpendicular and strikes quite nearly with the slates through which it breaks. It conforms therefore in position with the slaty cleavage of the region. Yet it is far from regular. Its thickness varies, both horizontally and vertically.

This vein is cut by dikes, showing its relatively great age. It is believed to extend past Barnum and to reappear on Kettle river, where a similar quartz vein has been explored for gold west of Sturgeon lake.

In the Blackhoof valley are several interesting veins. Quartz is the dominant constituent still, but associated with it is siderite, somewhat coarsely crystalline, which alters easily, leaving a soft, hydrous oxide of iron. The siderite is not confined to veins, but is scattered extensively through the neighboring schists in crystals and crystal clusters, weathering easily, leaving the iron-rusted pits more or less thickly scattered through the rocks. There is usually a film of dark green to black talc like material enveloping the veinstuff and separating it from the rockmass.

West of Sturgeon lake there is an enormous number of quartz veins. They are of the lenticular and gash-vein type. The rock becomes thickly studded with garnets; its texture grows considerably coarser; the veins are not wide, a few inches being the greater thickness. They frequently anastomose in a very complex manner.

Passing farther southwestward into the central Minnesota area the veins are partly quartz and partly of the granitic type. The latter are locally pegmatitic, with coarse and well developed feldspar individuals imbedded in a matrix of hornblende and biotite, while elsewhere they are finely textured, possess a reddish color, and are highly silicious in composition.

The veins are thus noted because their lithology and distribution are closely associated with the petrographic characters of the rocks under discussion. They carry evidence which, taken in connection with other lines, confirms in the writer's mind the close genetic relationship of the entire series.

Age of the Series

Earlier views

The age of these rocks has always been considered with reference to the occurrences at Thomson or where the staurolitic biotite schists cross the Mississippi river around Little Falls.

The Thomson series were regarded as Animikie, Upper Huronian, until Spurr announced in 1894, on what he regarded as sufficient evidence, his belief that they were at least as old as the Keewatin.* The grounds on which the earlier correlations were based were partly theoretic and partly lithologic. General composition and structural habit constituted the basis of determination.

When T. Sterry Hunt, in 1883, found the concretions of the slates and

* Amer. Jour. Sci., vol. 148, 1894, p. 162.

graywackes at Thomson, examination led him and J. W. Dawson to the conclusion that they must be evidence of keratose sponges.* That decision assigned the rocks containing them to an early Paleozoic terrane.

The geologists of the northwest for more than 20 years have held to the Huronian age of these rocks, using the term Huronian in its broad sense. This assignment has had as the strongest argument urged in its favor a general lithologic resemblance, reinforced by geographic situation. Spurr writes one paragraph in the history of correlation so well that he may be quoted in part:

"In the Third Annual Report of the United States Geological Survey, Irving† first hinted at the correlation of the 'Saint Louis slates' with the Animikie of northeastern Minnesota, as observed at that time around Gunflint lake and Thunder bay. He pointed out the general lithological resemblance between the two series and noted the difference in that the 'Saint Louis slates' are cleaved. In the same report, however, he‡ suggested the correlation of the uncleaved Animikie slates with the folded schists lying further north, and his descriptions and accompanying diagram clearly show that he included among these schists the larger part, if not the whole, of what we now know as Keewatin (Lower Huronian). In the Fifth Annual Report§ he first confidently assigned to the Thomson (Saint Louis) series a place equivalent to that of the Animikie. . . . In the Seventh Annual Report‖ he again refers to the Saint Louis slates as Animikie, and here first hints as to what horizon of the Huronian they were believed by him to belong—that is, the same as that of the upper slates of the Animikie series as represented by the Mesabi range."¶

In the paper referred to (page 163) Spurr noted in the Virginia area of the Mesabi range a transition from the holocrystalline mica and hornblende schists, so pronounced in their habit in contact with the granites, to easily recognizable sedimentary and only slightly altered silicious and clay slates and graywackes at the most southward lying points where exposed, which are also most distant from the granite contact.

These Keewatin rocks, Spurr adds,** "possess a strongly marked regional cleavage or schistosity not far from vertical," trending north 70 degrees east. This east-northeast to west-southwest direction, with generally southward dip, it may here be emphasized, is a very common attitude of the Keewatin schists and slates from the gold-mining district north of Rainy lake to the southernmost exposures now known on the Snake river of east-central Minnesota, an air-line breadth of 200 miles.

* Transactions Royal Soc. Canada, vol. i, ser. iv, p. 250.

† Roland Duer Irving: Copper-bearing rocks of lake Superior. Monograph v, U. S. Geol. Survey, 1883, p. 162.

‡ Op. cit., p. 170.

§ Archean Formations of the Northwestern States, p. 196.

‖ Classification of Cambrian Formations, p. 422.

¶ Amer. Jour. Sci., vol. 148, pp. 160, 161.

** Ibid., p. 163.

Noting the characters of the less altered phases of the Virginia Keewatin, Spurr, on lithologic grounds, correlates these with the Cloquet rocks because almost every phase can be duplicated, the only difference being the presence in the latter of a minor transverse cleavage, while the resemblance of the Stony Brook exposures in section 27, township 51, range 19 west, and the Mesabi graywackes is complete.* Touching the staurolitic schists along the Mississippi river, usually regarded as the Thomson series changed by becoming crystalline, Spurr adds that they correspond exactly to the green schists and crystalline schists of the Mesabi district.

Turning to dynamic characteristics, Spurr says that one of the greatest differences between the least altered Keewatin near Virginia and the Mesabi (Animikie) slates is the steeply dipping cleavage in the former. This cleavage is for northeastern Minnesota a distinctly pre-Animikie character. It is seen in many localities within the Keewatin between Saganaga lake and lake Vermilion, and is a strongly imprinted character at Virginia, Stony Brook (lying 40 miles south), Cloquet, Carlton, and Thomson, and eastward into Duluth.

On the foregoing lithologic and structural grounds Spurr correlates the rocks around Carlton and Thomson with the Lower Huronian rather than with the Upper. With this correlation every geologist who, within the knowledge of the writer, has subsequently worked in this region has come into general accord.

THE PRESENT VIEW

The studies of recent years, as set forth in the foregoing summary of petrographic characters, have led the writer to the conviction that the basal rocks of the district described all belong to a single unit of geologic time. This unit or period was terminated by a series of volcanic disturbances resulting in extensive accumulations of granite in the Mississippi River region, a large number of granitic dikes in the district crossed by the Rum and Snake rivers, and a complete metamorphism of the vast series of silicious clastics along the Kettle River valley. The petrographic characters of the sedimentaries have been thereby so changed that no positive recognition of their clastic character is to be seen until Mahtowa and Carlton are approached as one traverses the state from the Mississippi river toward Duluth.

It has been shown in the foregoing discussion that the rocks exhibit for some miles, in a succession of stages which can be followed step by step from Thomson southward, the graded alteration of coarse and fine graywackes into sharply crystalline hornblende and hornblende-biotite schists to the west of Sturgeon lake.

*Loc. cit., p. 165.

The observations of Spurr and his interpretation of them are accepted by the writer, inasmuch as the writer's own studies lead to the conclusion that the rocks from Cloquet to the exposures west of Sturgeon lake belong to the same series, which series, in the nomenclature of this paper, is designated Keewatin.

The schists, still followed for miles southwestward from Sturgeon lake, present no further variation than an intenser metamorphism would bring about, namely, the occurrence of a coarser texture, the introduction of quartz veins and lenses, and the presence of garnets, both minerals giving proof of great alteration, and the latter particularly an index of contact metamorphism, as in the Crystal Falls iron-bearing region,* and "due to the reactions between solutions passing between the intruded and intruding rocks and carrying dissolved salts from the one into the other."† In many localities, literature shows, garnets are a frequent contact mineral, and their presence and distribution are a guide in structural problems.

It is recognized that southwest of Sturgeon lake step-by-step determination of the rock- and time-continuity, so clearly traced from Stony brook to that point, can not be followed, owing to the covering of glacial drift, which leaves only occasional exposures in view. The rock relationship of these isolated exposures must for the present be a matter of opinion rather than actual demonstration. The opinion of the writer is that westward from Sturgeon lake to the Mississippi river and beyond the rocks are a continuation of the same Keewatin schists as occur in the Saint Louis and Kettle River valleys, broken, displaced, folded, and altered by crustal movements and the intrusion of the dikes, bosses, and laccolites of hornblende and hornblende-biotite granites. These granites have gradually replaced the schists, until in Benton, Sherburne, and Stearns counties not an exposure of the schists has yet been reported. Profile II, plate 30, shows this displacement.

This opinion is hesitatingly put forth, although it has been held by the writer for several years. Other discoveries are probable, and other rock formations may be brought to light. Archean knobs may be found protruding through the complex here assigned to the Keewatin. The local reasons for this assignment have been sufficiently dwelt upon, if not with convincing clearness or array of proof. Within any geologic region there are certain rock associations and relationships that, once recognized, are usually reliable. The observations in central and eastern Minnesota, on which the age relationships are herein based, are rein-

*Clements, Smyth, Bailey, and Van Hise: The Crystal Falls iron-bearing district of Michigan, etcetera. Monograph xxxvi, U. S. Geol. Survey, 1899, p. 415.

†Van Hise, Bagley, and Smyth: Marquette iron-bearing district of Michigan. Monograph xxviii, U. S. Geol. Survey, 1897, p. 514.

forced by the lithologic results already cited (*ante*, page 357), for the Penokee range, lake of the Woods, Rainy lake, Black hills, Virginia, Minnesota, and the personal observations of the writer along the northern boundary of Minnesota, where bosses of granite, dikes of the same rock, and diabase dikes break through the schists, which a few miles to the eastward give place to clastic rocks either through the waning strength of alteration processes or by superposition in identically the same manner as seen in this region under review.

The further proposition is proved: Much later than these events another period of volcanic activity occurred, in which basic eruptives in the form of dikes of diabase porphyry were intruded into the uplifted and eroded schists and acid eruptives, and a great fault line was developed which marked the line of weakness, defining the line of volcanic vents, out of which poured the enormous lava flows of the Chengwatana series of the Keweenawan.* No trace of these dikes has yet been found in the Cambrian.

SUMMARY

Along the eastern border of Minnesota, and extending westward beyond the geographic center of the state, lies a belt of graywackes, schists, and both acid and basic eruptives. Around Thomson, Carlton, and Cloquet the rocks are chiefly graywackes and graywacke slates. Clay slates, carbonate schists, and diabase dikes are associated with them. Southward rocks occur which are plainly altered from the graywacke type just named. As shown by a very continuous series of exposures, these extend with practically no change in lithologic characters well into the Kettle River valley. Their attitude is practically without change—that is, they slope continually southward at an angle varying between 5 and 20 degrees until the district west of Sturgeon lake is reached. At this point the rocks are hornblende and hornblende-biotite schists carrying minerals of contact significance and interbedded with an interesting body of limestone which to a considerable extent is quartzose.

To the west of Sturgeon lake the attitude of the rocks is changed. Passing to the Snake River valley, schists occur gradually broken by granite dikes. From the Snake river westward to the Mississippi, granite becomes of growing importance until, west of the river, no known exposures of schist occur, the rocks being wholly hornblende-biotite granites, with which are associated dikes of diabase porphyry and bosses of biotitic gabbro.

The petrographic characters of the rocks are named. They correspond precisely with the stratigraphic and structural characters just stated in

* This Bulletin, *ante*, p. 327.

the interpretation they afford of the genesis and stratigraphic relations of the rocks under discussion. The regions named as affording similar petrographic conditions are the Black hills of South Dakota, Penokee-Gogebic iron range of Michigan-Wisconsin, the lake of the Woods, Rainy lake, the International boundary, and the Mesabi iron range at Virginia; which conditions point to these genetic states:

1. A period of sedimentation took place, during which mediumly coarse to fine silicious deposits were laid down over a large area and to a great thickness, estimated not less than 20,000 feet.

2. Following this came a period of volcanic activity, during which enormous quantities of hornblende-biotite granite, originally augitic acidic rocks, were poured out to the westward, probably contemporaneous with the granitic intrusions of the Mesabi range and Rainy lake. These intrusions faded out into a series of minor bosses and dikes to the eastward and in the central part of the area described.

3. Farther away from this center of volcanic activity the schistose condition of the sediments becomes less distinct until typical and slightly altered graywackes prevail.

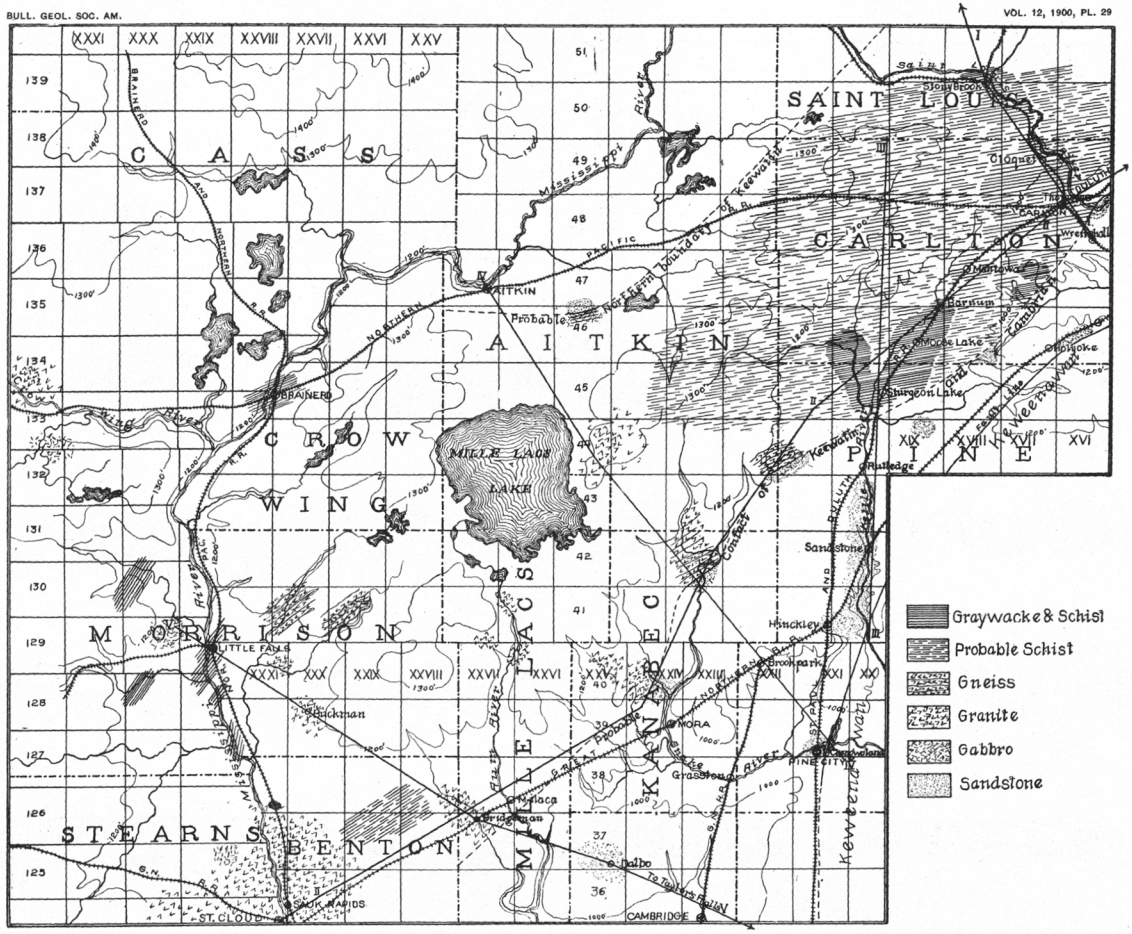
4. After an era of uplift and erosion, the entire area was subject to further volcanic invasion, when extensive dikes of diabasic rocks were forced into graywackes, schists, and granites alike; the southeastern edge of the intruded rocks was forced down by the development of a fault line and became covered with hundreds of feet of sandstone sediments, when the great Cambrian transgression of the sea took place.

The age interpretation accepted for the rocks under discussion is that of Spurr, who regards the rocks along the Saint Louis river as Keewatin, basing his correlation on their relations, geographic, structural, and lithologic, to the Keewatin schists in the neighborhood of Virginia, on the Mesabi iron range.

The series along the Saint Louis river is shown to continue through the Blackhoof valley and into that of the Kettle river as far as the exposures west of Sturgeon lake as a series of finely crystalline hornblende and hornblende-biotite schists. These Blackhoof and Kettle River schists are therefore held to be of Keewatin age.

The rocks stretching southwestward from Sturgeon lake across Snake and Rum rivers into central Minnesota are, on account of their geographic continuation and lithologic and structural habit, assumed to be a continuation of the same schists as were followed from the Saint Louis into the Kettle River valley—that is, Keewatin.

If the investigations and opinions herein set forth prove in their general features to be correct, the eastern and central portions of Minnesota must be mapped as Algonkian rather than Archean, as has hitherto been done.



MAP OF CENTRAL-EASTERN MINNESOTA

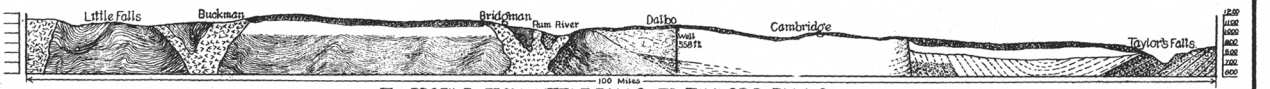
Showing distribution of Keewatin graywackes, schists, and associated eruptions

I. PROFILE–FROM THE GIANTS RANGE TO WRENSHALL.

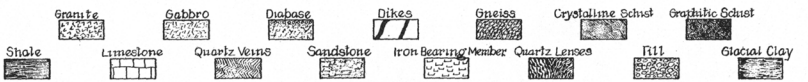
II. PROFILE–FROM DULUTH TO SAINT CLOUD.

III. PROFILE–FROM CLOQUET TO HINCKLEY ALONG THE KETTLE RIVER.

IV. PROFILE– FROM AITKIN TO CHENGWATANA.



V. PROFILE–FROM LITTLE FALLS TO TAYLORS FALLS.



PROFILE ACROSS THE KEEWATIN OF EASTERN MINNESOTA

Explanation of Plates

Plate 29.—*Map of Central-Eastern Minnesota*

On this map are represented all the rock exposures known. The conventional expresses the type of rock. The northern part of the map is probably Animikie; it is generally believed to be underlain by the southward stretching beds of the Mesabi iron range. The southeastward border is determined by the exposures of several localities and the deep well at Dalbo. The fault line defines the northwestward limits of the Keweenawan of eastern Minnesota. Topography from maps of Geological Survey of Minnesota.

Plate 30.—*Profiles across the Keewatin of Eastern Minnesota*

I.—Profile from the Giants range to Wrenshall.

This is a general section of the Mesabi Iron range (after J. E. Spurr), and the clastic series from Stony brook to Wrenshall. To the south of the Mesabi lies the series of more or less folded graywackes and associated rocks north and south through Cloquet and Carlton, where the rocks are in almost continuous exposure.

II.—Profile from Duluth to Saint Cloud.

The rocks are in exposure at all points named on the profile. A small area of Cambrian sandstone lies between the Snake River and Ann River crystallines.

III.—Profile from Cloquet to Hinckley along the Kettle river.

Beginning west of Cloquet the profile passes through the quarrytown of Sandstone to sections 22-23, township 41, range 20, where the great Keweenawan fault line lies. The Cambrian completely covers the underlying Algonkian rocks from Rutledge southwards.

IV.—Profile from Aitkin to Chengwatana.

The glacial Lake Aitkin clays are assumed to overlie the westward extension of the Mesabi, since to the southeast of Aitkin quartzite has been discovered. Cambrian sandstones exposed on the Snake river and penetrated to 700 feet at Pine City near Chengwatana are assumed to be continuous between these points.

V.—Profile from Little Falls to Taylors Falls.

To the east of Dalbo this profile passes outside the area mapped.

All of these profiles are partly generalized.

PLATE 31.—*Slate Quarry and Graywacke Exposure*

FIGURE 1.—Slate quarry at Thomson, Minnesota.

The slate dips strongly southward. The diagonal lines across the face of the quarry represent the bedding planes. Lenticular nodules of sideritic material lying along these lines have assumed a vertical position conforming with the slaty cleavage. This cleavage can be seen on the left of the picture above the hammer. Photograph by C. P. Berkey.

FIGURE 2.—Shattered surface of graywacke and graywacke slate, Thomson, Minnesota.

The dip is southward. In these rocks also the carbonate nodules have been squeezed into a vertical position. These are well shown on the knob to the right. Near the middle of the picture is a finely carved glacial groove whose wearing is in the direction of the bedding of the rocks. Photograph by C. P. Berkey.

PLATE 32.—*Graywacke Slate and Graywacke*

FIGURE 1.—Exposed surface of graywacke and graywacke slate near Thomson, Minnesota.

The rock is thoroughly jointed, and occasionally some displacement is seen. This fracturing was probably produced coincident with the production of the slaty cleavage seen in neighboring clay slates. Surface produced by glaciation. Photograph by C. P. Berkey.

FIGURE 2.—Graywacke with contorted quartz vein, Carlton, Minnesota.

This view is from the railroad cut south of Carlton, Minnesota, and shows a greatly contorted quartz vein one to three inches wide. The graywacke is quite compact and free from the sideritic nodules characteristic of the exposures at Thomson, as shown on the preceding plate. Photograph by C. P. Berkey.

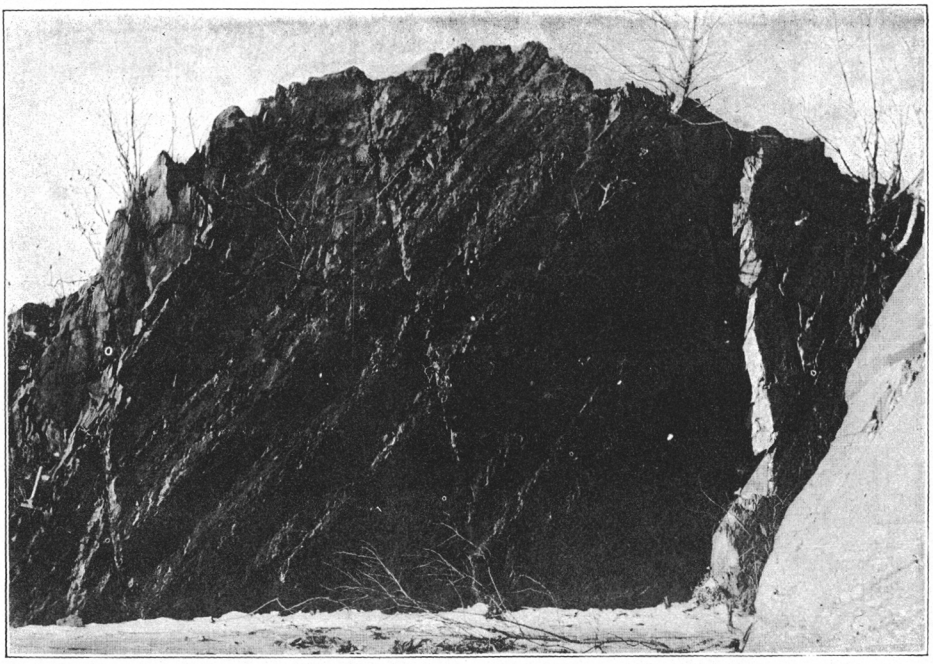


FIGURE 1.—SLATE QUARAY AT THOMSON, MINNESOTA

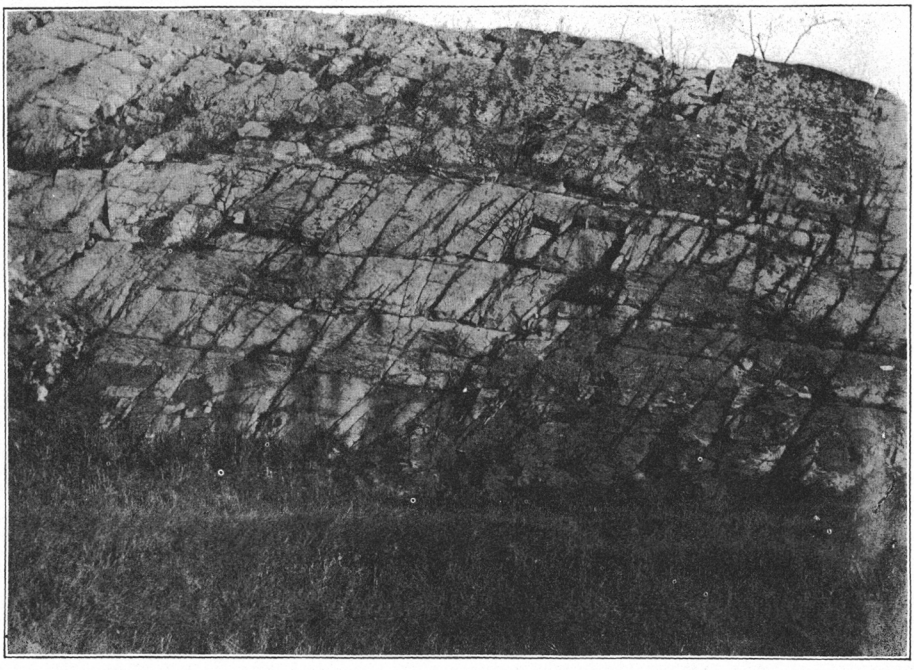


FIGURE 2.—SHATTERED SURFACE OF GRAYWACKE AND GRAYWACKE SLATE, THOMSON, MINNESOTA

SLATE QUARRY AND GRAYWACKE EXPOSURE

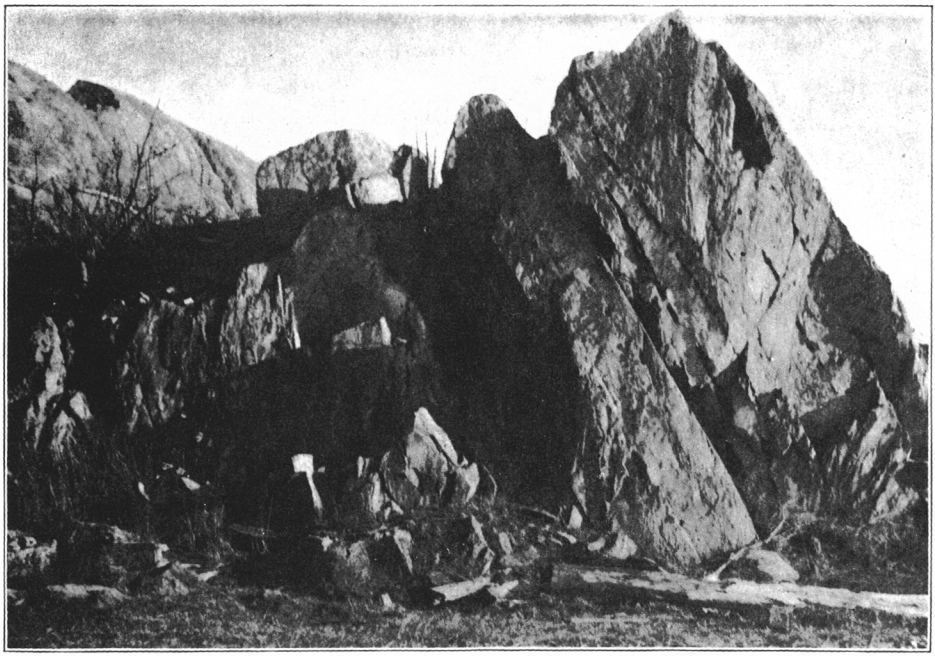


FIGURE 1.—EXPOSED SURFACE OF GRAYWACKE AND GRAYWACKE SLATE NEAR THOMSON, MINNESOTA

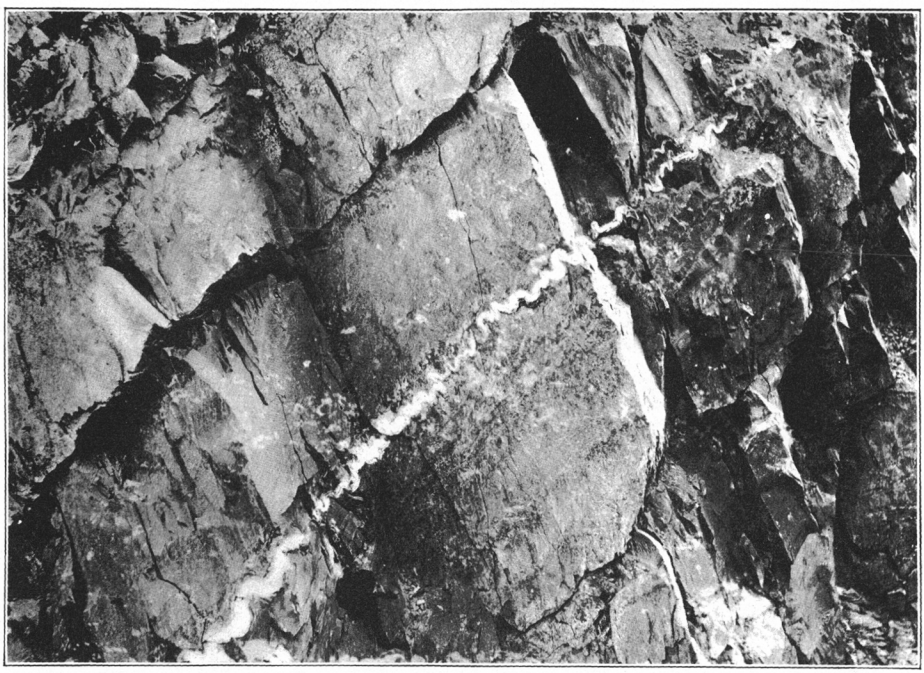


FIGURE 2.—GRAYWACKE WITH CONTORTED QUARTZ VEIN, CARLTON, MINNESOTA