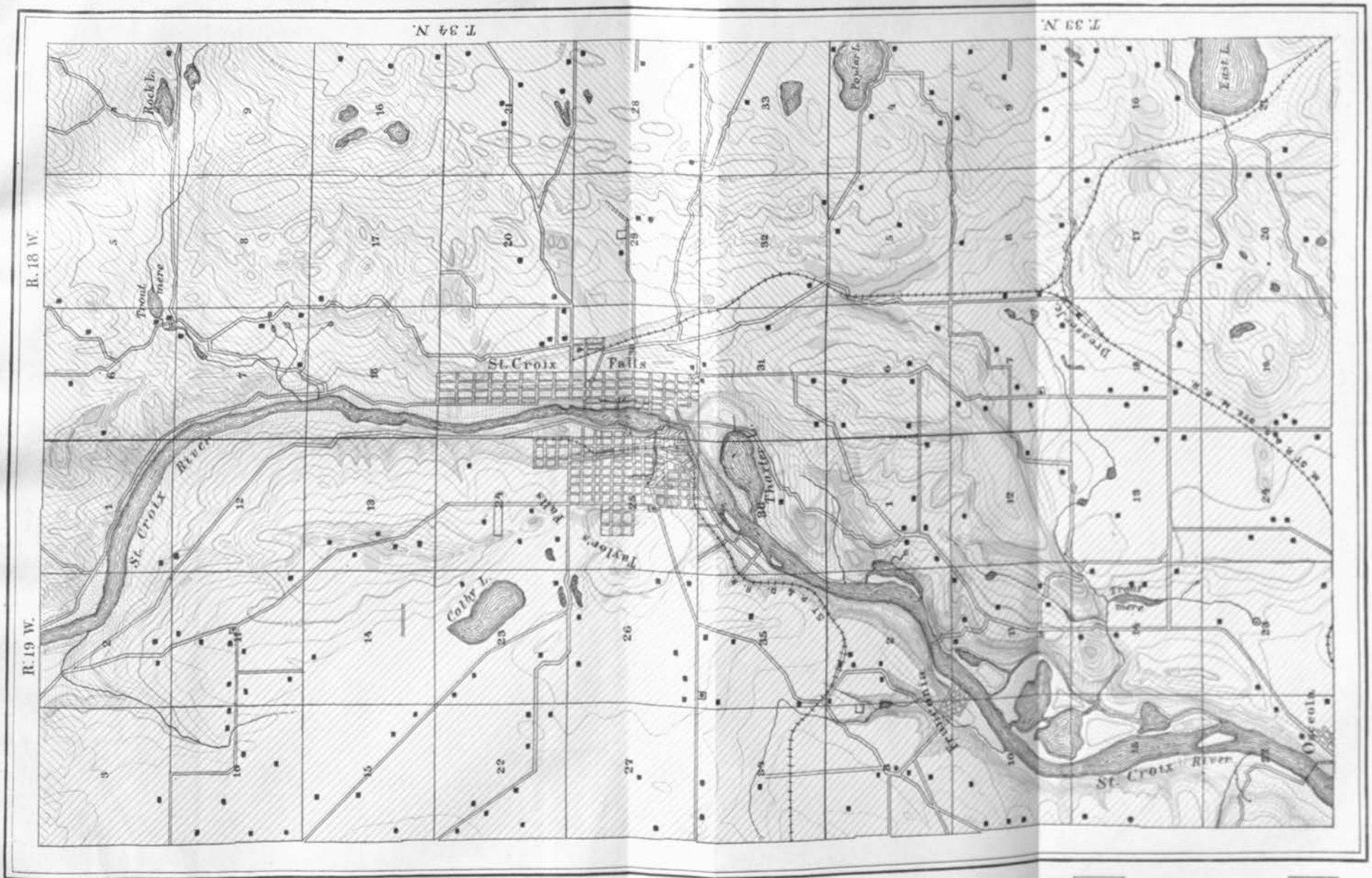


Keweenawan Diabase.

Cambrian Conglomerates.

Sandstones and Shales.

Eastern drift.

Western drift.

River debris.

Alluvium.

Map No. I. The St. Croix Dalles Area. (Contour interval 20 feet.)

From The American Geologist, Vol. XX, December, 1897.]

GEOLOGY OF THE ST. CROIX DALLES.*

By CHARLES P. BERKEY, Minneapolis.

Introduction.

The area described in this paper covers sixty square miles. It is ten miles long, north and south, and six miles wide. The St. Croix river flows through the district from north to south, dividing it into two unequal tracts. The portion on the west side of the river, comprising approximately twenty square miles, lies within the state of Minnesota; the eastern portion, approximately forty square miles in extent, belongs to the state of Wisconsin. The meridian of 92° 40′ longitude west from Greenwich and the parallel of 45° 25′ north latitude, pass through the district. The north line of town 34 forms the northern boundary, and the line between ranges 18 and 19 west of the fourth principal meridian passes lengthwise through the middle of the area. The villages of Taylor's Falls in Minnesota, and St. Croix Falls in Wisconsin, are centrally situated.

The southwestern extension of the Keweenawan copper-bearing rocks presents numerous outcrops at this point, and their erosion by the St. Croix river forms the well-known "Dalles of the St. Croix." On account of this prominent natural feature, the district has been called the *St. Croix Dalles Area.*

*A thesis accepted by the faculty of the University of Minnesota for the degree of Doctor of Philosophy, June, 1897.

SYNOPSIS.

PART I. *Geology.*

CHAPTER I. Topography and Special Surface Features.

1. Topographic description of the district, the elevation of prominent points, explanation of accompanying maps.
2. Surface features as modified by lakes, springs, abandoned river channels, river terraces, creeks and the smaller streams.

CHAPTER II. Glacial Geology.

1. The glacial drift, thickness, extent, character, origin.—The St. Croix moraine, the level tracts and valleys.
2. The effect of glacial action upon earlier formations.—On the diabases, glacial striæ.—Erosion of sandstones and shales, the glacial St. Croix river.—Summary.

CHAPTER III. Stratigraphic Geology.

1. Summarized statement of local geology.
2. Additional data.—The sandstone conglomerate, shales.—Subdivision of the lower sandstone into three members upon lithologic and paleontologic grounds.—The marginal conglomerates.—Classification.

CHAPTER IV. Geology of the Igneous Rocks.

1. Summarized statement.
2. Additional description and subdivision, jointing, dip.—The separate flows, profile at the Dalles, basis of division, number and total thickness.—Minor variations in character, breccia and volcanic ash.—Folds.—Unconformity.

PART II. *Mineralogy.*

CHAPTER I. Lithology of the Sedimentary Rocks.
Original constituents, alterations, local phases.

CHAPTER II. Lithology of the Igneous Rocks.
Original character.—Local variations, ophitic, porphyritic and amygdaloidal phases, flowage, tuffs, breccias.—Alteration phases and products.

CHAPTER III. Minerals.
Original and Secondary.—Analyses.

PART III. *Paleontology.*

CHAPTER I. Review of the Faunas Previously Described.

CHAPTER II. A New Fauna.
Favorable localities, principles of classification, general character of the fauna, lines of variation.—Description of new forms.

CHAPTER III. Summary and Correlation.
The Baraboo fauna.—Place in the Cambrian.

PART I.—GEOLOGY.

(Plates XX, XXI and XXII.)

CHAPTER I. *Topography and Special Surface Features.*

Topography. The elevation of each of the points established as a basis for the topographic map of the district studied was obtained by aneroid barometer readings. Published altitudes above mean sea level, determined by the surveys of the Saint Paul and Duluth and the Minneapolis, Saint Paul and Sault Ste. Marie railways, were used as primary stations. The existence of one road on each side of the river gave ample opportunity for correction of readings. About 900 aneroid readings were recorded and perhaps as many more taken at intermediate points and used for immediate correction of contour lines in the field. The following points were used as primary stations:

Taylor's Falls depot	791 feet
Taylor's Falls freight house	756 "
Franconia station	915 "
Steamboat landing at Taylor's Falls	687 "
St. Croix Falls depot	920 "
Summit of grade	1010 "
Dresser Junction	950 "
Osceola station	806 "

The following additional points have been selected from the list of those determined by aneroid readings, as representing different parts of the area:

Highest diabase knob—Taylor's Falls, S.W. ¼, N. W. ¼, S. E. ¼, Sec. 25, T. 34 N., R. 19 W.	1040 feet
Colby lake, Sec. 23, T. 34 N., R. 19 W.	940 "
Cemetery, Sec. 24, T. 34 N., R. 19 W.	960 "
Residence of Senator Deedon, Sec. 13, T. 34 N., R. 19 W.	1100 "
School house, Sec. 11, T. 34 N., R. 19 W.	980 "
Diabase knob, N. E. ¼, N. E. ¼, Sec. 1, T. 34 N. R. 19 W.	1120 "
Rock lake, Sec. 4, T. 34 N., R. 18 W.	1025 "
Trout mere, Sec. 6, T. 34 N., R. 18 W.	920 "
Fair grounds, Sec. 20, T. 34 N., R. 18 W.	1025 "
Summit of morainic ridge, Sec. 21, T. 34 N., R. 18 W.	1215 "
Summit of morainic ridge, Sec. 6, T. 33 N., R. 18 W.	1165 "
Poplar lake, Sec. 4, T. 33, R. 18 W.	1135 "
East lake, Sec. 16 and 21, T. 33, R. 18 W.	940 "
Trout mere, Sec. 14, T. 33, R. 18 W.	835 "

Picnic ground, Taylor's Falls	905 feet
Public school building, Taylor's Falls	900 "
Toll bridge, Taylor's Falls	725 "

The different topographic features are clearly displayed on the accompanying maps. The different surface features in their geological bearings are elsewhere discussed. It should be noted here that the morainic ridge and accompanying eastern plateau constitute the most elevated portion of the district. These attain an elevation of 1215 feet. The till plains, stretching through the western part of the district and from Dresser Junction southwestward, lie at an average elevation of 925 feet. The river gorge is an abrupt descent of more than 200 feet. Thus the difference in elevation of different parts of the area amounts to more than 500 feet.

Next to the glacial drift, the most potent factors in determining the topographic modifications of the surface features are the bold ridges of igneous rock.

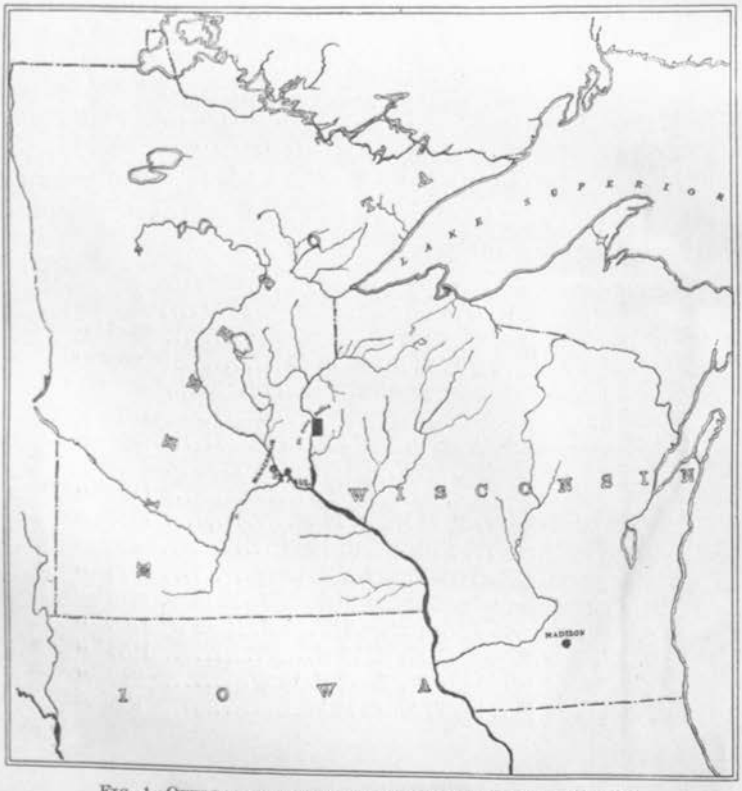


FIG. 1—OUTLINE MAP LOCATING THE ST. CROIX DALLES AREA.

Maps. Two maps have been drawn in illustration of the topography and geology of the area. The first includes the whole district of sixty square miles (see Plate XX, map No. I) while the other, comprising four square miles and including the greater part of the villages of Taylor's Falls and St. Croix Falls, represents the immediate vicinity of the Upper Dalles on an enlarged scale and with greater accuracy of detail (see Plate XXI, map No. II). Figure 1 is an outline map representing the location of the *Saint Croix Dalles Area.*

Lakes. The lakes occurring in the district are of two kinds: 1st, Glacial lakes; 2d, River lakes. In the first class there are two minor groups:

1st. Those which occupy many of the larger kettles of the glacial moraine which borders the northern and eastern sides of the district. These lakes* partly fill the larger and more favorably situated of the numerous depressions of the moraine and are doubtless much less abundant now than formerly. Many of the kettles may be seen in crossing the moraine at almost any point. Most of these lakes have no outlet, although it is probably these very lakes that feed so constantly the springs along the river banks nearly 500 feet lower down. The largest of these lakes are East lake, Poplar lake and Rock lake. All show a gradual subsidence.

2d. Those which remain from the rather extensive marshes or sloughs of the belt of till occupying a part of T. 34 N., R. 19 W. These lakes are now very shallow, and compared with their former extent, have almost disappeared. They once had outlet to the St. Croix river across the flat meadow land stretching northward and southward, but at the present time they are stagnant and muddy. Colby lake, with the four or five small lakes near it, are the representatives of this class.

Under River lakes have been included those now occupying abandoned channels of the St. Croix river. All of these lakes lie close to the present channel of the river, and most of them are directly connected with it and lie at the same level. The most prominent one is Thaxter lake in Sec. 36, T. 34 N., R. 19 W. It occupies a portion of the channel worn by a part of the river previous to the formation of the 750-foot terrace. A small swampy pond not deserving of the name of lake is

*Geology of Wisconsin, vol. III, 1880, p. 374.

found also in Sec. 36, occupying the rocky bed of the old channel used at the time of the formation of the 810-foot terrace. At this same time the erosion at the foot of the rapids following what now constitutes a rock-bound ravine or valley through the northern part of Sec. 1, T. 33 N., R. 19 W., was sufficient to form the basin now occupied by Folsom lake. The river lakes lying in sections 10, 11, 14 and 15 are probably of more recent origin, but date back at least to a time when the volume of water in the St. Croix river was much greater and the channel at this point much wider than at present. The igneous rocks, reaching the river at this place, introduced an obstacle to further erosion of the eastern portion of the channel, while the subsequent accumulation of river sand has barred off this chain of lakes.

Springs. The number of springs,* especially along the river, is very great. There are a few also farther back at either side of the river at a greater elevation. Those issuing at a low elevation along the river may be called river bluff springs; those issuing from the drift at a comparatively high elevation may in contrast be called drift springs.

The river bluff springs are almost without exception confined to the upper Dresbach shales and sandstones, below the 800-foot contour line. They owe their existence to the presence of the river gorge, which makes it possible for the saturated glacial sands and Cambrian sandstones to discharge the surplus water at the level of the more impervious shales and igneous outcrops. Locally, these sedimentaries are completely covered by recent debris of the river bluffs, but their true relations can scarcely be mistaken. At such points the springs seemingly issue from the glacial drift, but the drift in no case causes the flow. These springs are found continuously along the bluffs on both sides of the river. The most remarkable ones issue from the wooded slope lying between the 750-foot and the 810-foot terraces on the Wisconsin side of the St. Croix river in the village of St. Croix Falls. One also occurs in Taylor's Falls village at the same level. To these should be added the Franconia springs, which are the chief supply of Lawrence creek.

The glacial drift springs are all above the 800-foot contour

*Geology of Wisconsin, vol. III, 1880, p. 374.

line and most of them above the 900-foot line. They issue from drift areas, because of local impervious layers which check the underground escape of the descending waters. While such springs are numerous in Wisconsin, there are few on the Minnesota side of the river. The most notable examples are found in Sec. 7, T. 34 N., R. 18 W., where one of the number issues at an elevation of 1,000 feet. It is the water from these springs which is so much used in the maintenance of the several trout ponds or farms located within the district. The three now developed are in Sec. 6, T. 34 N., R. 18 W., Sec. 24, T. 34 N., R. 19 W., and in Sec. 14, T. 33 N., R. 19 W.

The water discharged from the springs of the district is, in most cases, exceptionally clear and wholesome. In a few places along the river much calcium carbonate is deposited from these waters in the form of travertine and crystallized calcite. In a few places iron is carried in considerable amount, and still more rarely, on account of local accidental contamination, the water is too impure for domestic use. But these are exceptional conditions.

Abandoned River Channels. There are several well-marked abandoned channels along the present course of the river. Two of these are referred to under the heading of terraces, but each will here be mentioned and their location noted:

1. The sandy bottom on which the wagon road runs through Sec. 2, T. 34 N., R. 19 W., on the west side of the river, appears to be a part of the ancient river bed, representing a stage marked farther to the south by a well developed terrace. This portion of the channel is separated from the main river gorge by a moderate rise of sufficient elevation to form a considerable island in the river during that stage.

2. The next attempt at cutting a channel outside the present one is found in sections 24 and 25 of T. 34 N., R. 19 W. This is in the northern part of the village of Taylor's Falls. The exact location is in the S. E. ¼ S. E. ¼ Sec. 24, and continuing through the E. ½ N. E. ¼ Sec. 25. This marks a stage coincident with the 780-foot terrace, and is in itself cut down nearly to the 760-foot contour line. At this stage of the river the rock outcrop lying in the S. W. ¼ S. W. ¼ Sec. 19., T. 34 N., R. 18 W., formed a bare, rocky island in the stream, reaching an elevation of 800 feet.

3. The third channel, and the most extensive and important one within the limits of the district, extends from the elbow in the Dalles, S. W. ¼ S. W. ¼ Sec. 30, T. 34 N., R. 18 W., through the W. ½ N. W. ¼ Sec. 31, T. 34 N., R. 18 W., and S. E. ¼ Sec. 36, T. 34 W., R. 19 W., to the river at Folsom lake in N. W. ¼ Sec. 1, T. 33 N., R. 19 W.

It extends slightly beyond these bounds at several places, but not to a considerable distance. The valley is entirely rock-bound, the erosion of which was checked at the 800-foot line. This abandoned channel is in places an eighth of a mile wide. Moses Strong mentions this depression* as probably an abandoned channel of the river St. Croix. There were two prominent rocky islands between it and the main channel at this stage. The first is now represented by the cliff south of the elbow, and the other is the prominent rocky hill in the middle of the S. ½ of Sec. 36, T. 34 N., R. 19 W. This channel marks the stage corresponding to the 810-foot terrace.

4. As the river cut its way into the rocks and sank below the level of the last named channel, the water plunging through the gap at the elbow formed a great whirlpool more than an eighth of a mile in diameter, which is still marked by the great bowl at the head of Thaxter lake in N. W. ¼ Sec. 31, T. 34 N., R. 18 W. The water from this whirlpool reached the main river again by way of the broad, easy channel, the fourth in the series of river channels, the course of which is now occupied by the river-lake, Thaxter, lying chiefly in N. E. ¼ Sec. 36, T. 34 N., R. 19 W. This, with the exception of the pot holes of the Dalles, is the most striking feature of the St. Croix river erosion.

5. The river-lakes lying immediately in contact with the river from Sec. 11 to Sec. 22 of T. 33 N., R. 19 W., represent a part of the channel of the older St. Croix river, which is now almost wholly abandoned.

6. There is a well marked, although not a deeply or evenly eroded valley, extending through sections 1, 12, 11, 14 and 23 of T. 33 N., R. 19 W., passing beyond the limits of the district and terminating in the very prominent abandoned gorge which separates the picnic ground and Eagle Point from the main river channel at Osceola. It is almost continuously divided from the present river gorge by a ridge from 20 to 75 feet high. The average elevation of the floor of this valley is 850 feet. This possibly represents an abandoned channel of the St. Croix at an early stage and probably during the time of a local glacial readjustment. Its persistence, almost parallel with the river for a distance of more than five miles, is the greatest evidence presented in favor of regarding it as an abandoned channel. It marks a stage corresponding to the development of the highest terrace noted near Stillwater, and the 905-foot terrace at Taylor's Falls commonly known as the picnic ground: and its later history, represented by the entire abandonment of that channel, is still marked by the 865-foot terrace of Upham.†

River Terraces. There are five river terraces within the boundaries of this district, marking stages in the erosion of the St. Croix valley. They are all well marked within the two villages, St. Croix Falls and Taylor's Falls. These terraces have been determined by various readings as:

*Geology of Wisconsin, vol. III, 1880, p. 416.

†Geol. and Nat. Hist. Surv. of Minn., Final Rep. vol. II., 1888, p. 417.

Diabase. Conglomerate. Sandstones and Shales. Eastern drift. Western drift. River debris. Alluvium.

Map No. II. The Village of Taylor's Falls and a Portion of St. Croix Falls, Including the Upper Dalles and the Inter-State Park.

An area two miles square drawn on an enlarged scale.

(The Park boundary on the west side of the river is represented by an interrupted line.)

The first or 905-foot terrace.

The second or 810-foot terrace.

The third or 780-foot terrace.

The fourth or 750-foot terrace.

The fifth or 725-foot terrace.

Traces of all five are found north of the villages along the river. The sand covered flat in Sec. 2, T. 34 N., R. 19 W., is a terrace flat.

The 905-foot terrace belongs to the period of ice retreat and is discussed under Glacial Geology.

The 810-foot terrace is most prominently marked in the village of St. Croix Falls, where it is coincident with the main business street and forms a striking bench extending for more than half a mile along the river. This terrace marks the stage of the river corresponding to the development of the abandoned channel in Sec. 36, T. 34 N., R. 19 W., and doubtless indicates a check in the erosion of the river gorge. The river was held at this level until an entirely new channel had been developed toward the west through the sandstones and shales. These formations permitted a more rapid erosion than the volcanic rocks which formed the floor of the abandoned river bed.

The 780-foot terrace is prominently marked northward from St. Croix Falls along the wagon road for a distance of two miles. The arrest in erosion causing the terrace comes from the two barriers or dams of diabase, one at the elbow of the present Dalles and the other a mile north at the present St. Croix falls. At the time of this terrace building the river made use of an abandoned channel plainly marked through a part of the northeast ¼ Sec. 25, T. 34 N., R. 19 W., in the village of Taylor's Falls, now occupied by the St. P. & D. freight depot and tracks. The northernmost barrier was so readily destroyed that further erosion of this channel was checked, although a portion of the river used this side until it had cut below the 760-foot contour.

The 750-foot terrace is easily traced on both sides of the river for a mile above the Dalles. It is the most pronounced of all and marks probably three events: 1st, it awaited the erosion of the narrow gorge from the elbow to the toll bridge, which made it possible for outflow at a lower level; 2d, it marked the period of most prominent pot hole erosion; 3d, it seems reasonable to conclude that it marked at least the beginning stage of a very considerable decrease in the amount of water discharged by the St. Croix.

The 725-foot bench on the Wisconsin side marks a stage claiming a place among the group of terraces. It is developed at no place so well as immediately above the toll bridge. And it marks the last serious check in the erosion of the present very narrow channel through the Dalles.

On the Minnesota side of the river opposite Hudson, Wis.,

20 miles south of this district, two prominent terraces with several minor ones are described.* The lowest of these is 70 feet above the river. The river level is 672 feet above the sea,† making the elevation of the terrace 742 feet. The second of these Hudson terraces is 200 feet above the river, making an elevation of 872 feet above the sea. I do not know of any corresponding terraces in the St. Croix Dalles area, unless we may consider the 905-foot terrace, which is so prominently marked in the village of Taylor's Falls, as such representative. This, I am inclined to think, is a proper correlation. At a time when such a terrace must have been formed it is not probable that any considerable fall was encountered within the distance. It is reasonable to suppose that a descent of 30 feet between the two points would not be excessive for the glacial river. This terrace-like development at 905 feet on both sides of the river is further discussed in the chapter on Glacial Geology.

There is evidently no connection between the 742-foot terrace at Hudson, Wis., and the terraces of this district. It is believed that a considerable fall was developed below the Dalles, where the soft sandstones were reached. If this be accepted, it must also follow that, from the time of their beginning, the terraces above the fall would be entirely independent of those below, not only in the matter of elevation, but also in the point of origin.

There have been two other terraces noted in previous geological reports by Mr. Upham. These extend‡ from Sec. 2 Shaffer northward and are very pronounced terraces. Mr. Upham estimated them respectively 90 and 125 feet above the river. These estimates would indicate at this point elevations of 830 and 865 feet above sea level. It is therefore probable that the first one of Mr. Upham's terraces corresponds to the 810-foot terrace of the Dalles district. The 865-foot terrace has no corresponding development in the 10 miles immediately south of it, unless the 850-foot side channel mentioned before may be related to this stage of the St. Croix river.

The smaller streams and their erosion effects. There are

*Geology of Wisconsin, vol. IV, 1882, p. 134.

†U. S. G. S., Bulletin 72.

‡Minn. Geol. and Nat. Hist. Survey, vol. II., Final Rep., 1882, p. 417.

numerous small streams in this area, the largest being utilized for water power for several manufacturing establishments. Most of them originate in the springs issuing from the river bluffs and flow at once to the river, only a few rods away. Their erosion effects are not very pronounced in any single case, although the combined effect is to remove a comparatively large amount of rock material. Those streams which originate in the springs located in the drift hills, or in similar situation, have eroded quite extensive gorges and frequently exhibit exceptional exposures of the underlying sedimentary rocks. Several streams whose entire supply of water in dry seasons comes from the springs along their courses are in wet seasons the outlets of the lakes of the district. The most notable of these streams are:

1. Rock creek, originating in the morainic lakes near the northeast corner of the area, and following a glacial valley to the river.
2. Dresser creek, following the old glacial overflow plain from near Dresser Junction to the river.
3. Brown creek, originating in the sloughs north of Colby lake and following a tortuous course to the river in Sec. 2, T. 34 N., R. 19 W.
4. Lawrence creek, situated in the western portion of the district, the most notable one, on account of the gorge it has cut through the sandstones at Franconia. During part of the year it is dry in a portion of its course, but the springs originating at the head of the gorge always furnish a considerable flow of water in its lower course. Its erosion effects are entirely disproportionate to the present size of the stream. This creek is the natural drainage for many of the sloughs, which were once lakes of considerable size on the flat till plain lying in the western part and even beyond the bounds of this district. It, no doubt, had a much greater volume of water at that time. The effect of this stream has been to cut a fine gorge from the river at Franconia along the line between sections 2 and 3 of T. 33 N., R. 19 W., for more than one-half mile in length and to a depth of from 150 to 200 feet below the surrounding surface. No such erosion is elsewhere to be found outside the St. Croix gorge itself.

Chapter II. *Glacial Geology.*

I. *The Glacial Drift.* Most parts of the district are heavily covered with drift. The only portions lacking it entirely are the more prominent outcropping ridges of igneous rocks. The parts most thickly covered are the preglacial valleys, and probably the tract now occupied by the moraines at the eastern side of the district. Exact measurements are obtainable in but few places.

Taylor's Falls, ravine road, gray drift, 50 ft., modified drift, 3–5 ft., red drift, 75 ft.

Franconia, Lawrence creek gorge.* yellow drift, 20 ft., modified drift, 50 ft., red drift, 50–75 ft.

Senator Deedon's well, drift, 12–15 ft.

Well, N. E. ¼, S. W. ¼, Sec. 1, T. 33 N., R. 49 W., drift, 17 ft.

St. Croix Falls, 2 blocks E. of toll bridge, red drift, 70 ft.

Sections showing the thickness and character of different beds are represented by figs. 1, 2, 3 and 4, plate XXII.

The northwestern part of St. Croix county, Wisconsin, is covered with glacial drift 40 to 60 feet in thickness in which kettle holes are a common feature.†

The glacial debris lies in flat plains of modified drift, flat sand plains, rolling plains of till and a belt of characteristic morainic hills.

Character. There are two sharply defined kinds of material represented in the drift of this locality. In certain respects this area is especially favorable for the study of these two kinds, which are called the eastern and western drift.‡. They occur in three layers. In most of the sections but one or two of these layers occur. That drawn for Taylor's Falls exhibits all three of them, however, and a correlation of this section with those at other points makes such a division advisable. Of these three layers the upper and lower are similar in character and probably identical in origin; the middle layer is distinct from those above and below, and shows the characters that are ascribed to the western drift. For the area on the west side of the St. Croix and a large part of the southern portion of the district on the east side of the river, the prevailing downward succession in the drift is: first, a rather thick surface sheet of western blue or gray till; second, a variable layer of modified drift; third, red eastern drift lying upon the eroded preglacial rock surface. In the northern and eastern portions of the district, especially those portions lying north and east of the village of St. Croix Falls, the prevailing character is that of the eastern drift. No exposure seen shows any of the western material. But on the west side of the St. Croix river at Taylor's Falls and, as appears from the relative

*Geol. and Nat. Hist. Survey of Minn., Final Report, II, 1888, p. 412.

†Geology of Wisconsin, vol. IV, 1882, p. 132.

‡Geol. and Nat. Hist. Survey of Minn., Final Report, vol. II, 1888, p. 410.

position, also further north, along the high diabase ridge, there is a much more complicated succession. The most complete section is shown at the picnic ground, in Taylor's Falls, and on the side of the drift ridge back of the village.

Upon the lower shales, at an elevation of 770 feet (see fig. 2, plate XXII), rests partially stratified till of characteristically eastern material, which continues uninterruptedly along the ravine, at the side of the street, to an elevation of 845 feet. At the same time the shales are traceable in the same ravine to an elevation from 800 to 825 feet, and then become concealed beneath the debris. A bed of gravel and small boulders about 2 to 3 feet in thickness lies immediately upon this red stratified deposit and separates it from the overlying accumulation of typical western bluish gray material. This western drift is a till in which boulders, pebbles, gravel, sand and clay are promiscuously intermingled, and in which, compared with the lower member, regarded as eastern drift, the presence of numerous limestone boulders and an abundance of calcareous material is the most conspicuous feature. This upper member is not so markedly stratified as is the lower one. On the exposed surface, however, it has a tolerably compact appearance due to the great amount of calcareous material available as a cementing substance. The result is, in some places, a kind of crag. The thickness of this gray and bluish gray drift layer is 35 to 40 feet, reaching an elevation of 885 feet. From this point the character of the material changes somewhat, becoming chiefly sand and gravel with a covering of soil to the top of the bluff, at an altitude of 905 feet. This forms the highest river terrace, which continues westward as a sandy plain for a thousand feet, to the high ridge back of the village. Here, at an elevation of 935 feet, ten hundred and fifty feet east of the Swedish church, a large patch of red till 10 feet in thickness is found exposed. Above this there is sand and gravel to the highest, or 1,100 foot contour line. This red patch is believed to represent a later advance of the eastern ice lobe upon the western drift area, rather than a remnant of an earlier accumulation left unmolested by the western invasion. Additional support is given to this view by a similar exposure of red till occurring on the same ridge farther north, in the S. E. $\frac{1}{4}$, S. W. $\frac{1}{4}$, Sec. 13, T. 34 N., R. 19

W., along the road near senator Deedon's farm. (See plate XXII, fig. 1.)

In all essential respects this last named exposure resembles the Taylor's Falls occurrence with the exception that it lies at an elevation of nearly 1,050 feet, or more than 100 feet higher than that. The two miles intervening between the two areas shows continually a sandy modified drift. The drift encountered on the Wisconsin side of the river, along the wagon road eastward from the toll bridge and upon the shales, as shown in plate XXII, fig. 4, is typical eastern till. It is first seen at an elevation of 880 feet and continues to an elevation of 950 feet, where it suffers an interruption preventing further accurate observation. A quarter of a mile further south, on the road in the northern portion of Sec. 31, T. 34 N., R. 18 W., a slight removal of the soil again reveals the red eastern till at an elevation of 1,000 feet. This is regarded as a continuation of the section of eastern till resting upon the sandstones and shales as represented in fig. 3. The western drift has not been observed east of the river at this point. The characters indicating the presence of the eastern drift can be followed still further southward and to a still greater elevation. In the N. E. ¼, N. W. ¼, Sec. 6, T. 33 N., R. 18 W., the road crosses the crest of the ridge. At this place, which is one mile south of the exposure in Sec. 31, red till is again exposed. The elevation at this point is 1,150 feet.

A mile still farther south the road descends into the broad valley near the head of which is Dresser Junction. At that point the drift material changes very noticeably and the characters of western drift predominate in the surface exposures. This is true of the whole valley, although some portions are much more sand covered than others. How far this western aspect extends into the bordering moraine is not determined, but the material observed upon the ridge is of eastern origin, which would seem to limit the western invasion at its western border. It is probable that this extensive moraine was not to any considerable extent developed by the western invasion of the ice sheet. For the continuation of the moraine further northward seems wholly independent of western influence and is composed of eastern material.

Origin and Periods of Accumulation. As to the origin of

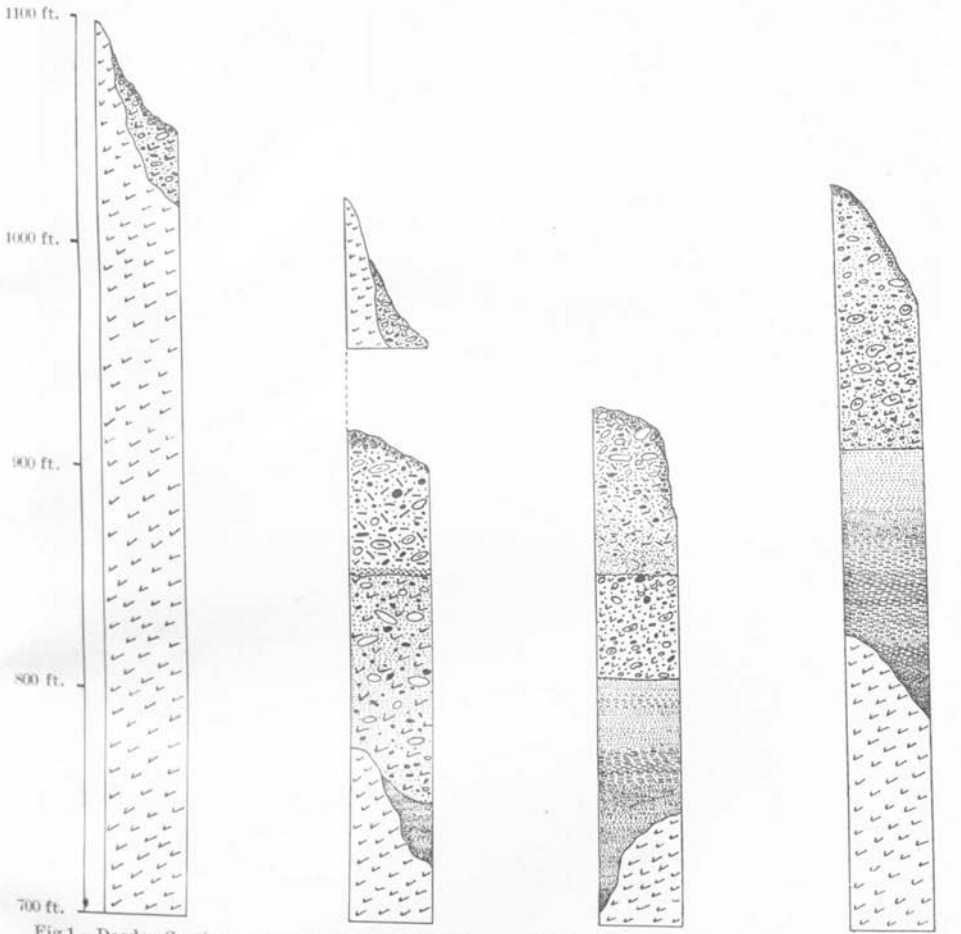


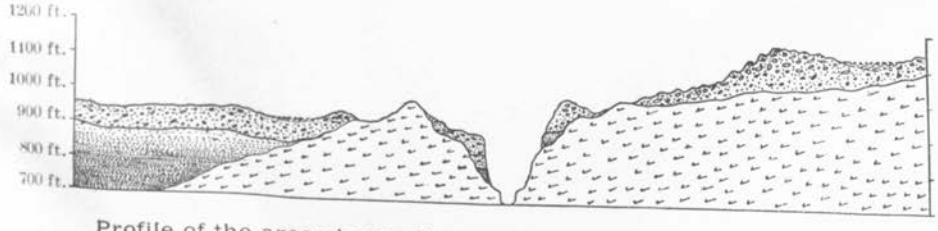
Fig.1.—Deedon Section. Red drift on the Diabase.

Fig. 2.—Taylor's Falls Section. Red, gray and red drift.

Fig. 3.—Franconia Section. Gray and red drift.

Fig. 4.—St. Croix Falls Section. Red drift on the sandstones

Sections of the Glacial Drift and Underlying Rocks.



Profile of the area along a line drawn through Colby and Poplar lakes, showing Glacial Drift, Cambrian Sedimentaries and Keweenawan Diabases.

the different materials of which the drift is composed, the character of rock from which it was derived, and the source of supply, there is but little variation from observations made by Minnesota and Wisconsin geologists. The following statements are intended to summarize these points:

1st. The eastern drift was derived largely from the igneous and iron-bearing rocks of the Lake Superior basin. The most abundant rock species noticed are: melaphyr (occurring in rather large boulders); granite; amygdaloidal diabase; gabbro; quartz porphyry; diabase porphyrite; together with the sedimentaries, quartzite, red and yellow sandstone and a considerable admixture of highly ferruginous pebbles and fragments. The clayey material is red in color. Sand and gravel are abundant.

2d. The so-called western drift carries many of the same rock species as the eastern. In addition, however, limestone boulders and pebbles are abundant. The till and clay are usually gray or bluish gray in color and contain considerable finely ground calcareous material.

It is evident that two such characteristically different deposits must have been derived from two very different sources. Either the characteristic constituents of the gray drift were exhausted in a certain direction and were therefore of necessity succeeded by a quality very different on account of that lack; or we must suppose that there are at least two different areas of supply furnishing the material by two independent ice streams. The latter view is the more reasonable. In accord with the known character of the rock formations in different directions from this area, the red drift is believed to have come from the north and northeast, while the gray and blue has come from the west and northwest.*

As to the periods of deposition, evidence shows that there were two and perhaps three different periods of accumulation. Whether any of the drift represented here was accumulated earlier than the Iowan stage of re-advance may be doubted. Correlation with subdivisions accepted in other districts is difficult since this is so far removed from typical localities. The time intervals were comparatively short, indeed the ice fronts were, during a part of their duration, in actual contact. The eastern lobe, however, persisted longer than its western companion-lobe, and accumulated the extensive deposits credited to the Wisconsin stage of advance.

The Moraine. The Kettle range of the Wisconsin geologists† includes in many parts of its extent several quite dis-

*Geol. and Nat. Hist. Survey of Minn., Final Report, vol. II, 1888, p. 410.

†Geology of Wisconsin, vol. I, 1883, pp. 275-281.

tinct and nearly parallel morainic ridges, which may quite properly be treated as independent moraines.

These ridges or moraines mark the halting places of the glacier in its first stages of retreat after the so-called Wisconsin re-advance. One of them lies within the St. Croix Dalles area and extends throughout its length, from sections 19, 20 and 21, T. 33 N., R. 18 W., to sections 1 and 2, T. 34 N., R. 19 W., coming in its northern development close upon the river in Sec. 2. This is an especially important moraine, not so much because of its relation to the Kettle Range, as because it follows the dividing line between the eastern and western drift. The western material cannot in all places be traced eastward to this morainic ridge, but generally it can be thus traced, and nowhere has the western material been found to the east of this moraine.

The name St. Croix moraine is proposed for this ridge, since it passes in its typical development only a short distance to the east of the village of St. Croix Falls, and follows almost parallel with and at certain points encroaches upon the river St. Croix, and because it apparently marks a stage of ice lobe adjustment and drift accumulation that was the chief factor in causing the St. Croix river to flow in its present channel.

The St. Croix moraine varies in width from one mile to two and a half or even three miles. It is bordered on the east by a high rolling plain extending several miles beyond the district. The moraine is bordered on the west by several valley and plain areas, all of which will average 200 feet lower than the corresponding highest parts of the moraine itself. This ridge is characterized by a very hilly and irregular contour. The surface is alternately a knoll and a kettle or a short ridge and a blind valley. Many of the larger kettles are small lake basins.

Drainage courses are not sharply marked, and many of the lakes have no outlet. Most of the drainage is underground. The kettles sink frequently 100 feet below the lowest possible outflow. The knolls often rise 100 feet above the average level. The whole effect is to produce an almost continuous succession of knobs and ridges which are simply bewildering in any topographic determinations. The materials of the St. Croix mo-

raine are largely sand, gravel and small boulders, and the origin is the same as is that of the red drift.

The Level Tracts. Three well developed plains covered mostly with till, occur partly within and partly without the St. Croix Dalles area. These will be referred to as the eastern, western and central plains.

The eastern plain extends from the St. Croix moraine eastward for several miles. Only a narrow strip comes within the territory examined, but enough of it has been seen to disclose its prevailing characters. It is rolling or undulating in surface, but does not vary much from the 1,200 foot elevation. There are numerous small lakes and sloughs, and it is an area of excellent farming land, thickly settled. Its material is a till with characters which belong to the eastern drift.

The western plain lies upon the west side of the St. Croix river. It extends from Franconia station westward and northward, including the whole west central portion of the district. The northeastern boundary is formed by the diabase ridge extending from the village of Taylor's Falls northward. This plain also extends far beyond the bounds of the area. Only occasional irregularities break the prevailingly level contour, varying in elevation from 915 feet at Franconia to 950 feet a few miles further north. It is a till covered area of western drift, the character of which can be studied in many places. The drift on this area* has been noted and approximately mapped by Mr. Upham.

The prominent bench in the village of Taylor's Falls, known as the picnic grounds, is in character of materials intimately connected with the western till plain. The considerable accumulation of sand and other modified drift bounding it on the west does not apparently owe its origin wholly to river action; it is no doubt derived from the adjacent esker-like ridge.

The central plain is a peculiar glacial accumulation situated immediately to the east of the village of St. Croix Falls. It occupies a large part of the S. E. ¼, Sec. 19, and a portion of Sec. 20 adjacent, the N. E. ¼ of Sec. 30 and the adjacent portion of Sec. 29, T. 34 N., R. 18 W. This accumulation is con-

*Geol. and Nat. Hist. Survey of Minn., Final Report, vol. II, 1888, p. 412.

nected somewhat brokenly with a prominent level valley averaging a half mile in width, which follows quite closely the boundary line between sections 31 and 32 of the same township. The northern third of this plain, viz., those portions lying in sections 19 and 20, lie at an elevation of from 1,020 to 1,025 feet, and is almost level but somewhat depressed centrally. It drains northward to the St. Croix river. On the west this plain is limited abruptly by the river gorge which is a sharp descent of over 300 feet within a distance of less than half a mile. In most respects this level area resembles a terrace; it also reminds one of the similar development on the opposite side of the river, in Taylor's Falls, known as the picnic ground. But the difference in elevation of the two is more than 100 feet, while the differences in character are equally striking. The St. Croix moraine forms its eastern boundary. Southward it is somewhat broken, but still it shows the same character, and near the south line of Sec. 29 it is too much cut up to be recognized. From this southern portion of the plain a very prominent erosion valley leads toward the N. N. W., and follows its edge for nearly a mile to the railway station in St. Croix Falls. Southward still further, in Secs. 31 and 32, the plain again becomes prominent, this time, however, as a very distinct valley lying between the St. Croix moraine on the east and the high diabase ridge on the west. This level tract narrows rapidly near the south line of Sec. 32, where it merges into a rock bound gorge. The walls of this gorge are precipitous on the west and rise gradually toward the east. The bed of the channel is solid igneous rock. This southern termination of the valley has an elevation of 1,010 feet. From this point southward another area is developed partly as a resultant of the first, but of very different character. All points necessary for decisive conclusions are not at hand. The only ones lending any weight toward conclusions as to origin are the following: The material is of eastern origin; it slopes gradually toward the south and leads to a well marked late glacial river gorge; the western boundary is in part the present river gorge which is, at this place, the limit of the western drift; the eastern boundary is at all times the St. Croix moraine which represents an eastern drift accumulation.

The facts suggest the following statement of conditions obtaining during and immediately preceding the withdrawal of the latest glacial ice lobes at this locality. The western ice lobe advanced spreading the western drift to the very position now occupied by the central plain. Here it was met and energetically opposed by a northeast lobe carrying much debris and rapidly accumulating the thicker eastern drift deposits. The eastern advance was even energetic enough to override the edge of the western lobe, and left a few patches of characteristic material within western territory. With the melting of the ice the two lobes separated and a lake formed on the present site of the plain, which was drained by the development of the channel at its southern extremity.

An early halt in the eastern lobe developed the St. Croix moraine and served to furnish immense floods to the rivers of that time, of which there are traces of at least two more within the district. As the western lobe retired it uncovered an additional line of drainage represented by the present river gorge and the narrow valley extending northward along the railroad to St. Croix Falls station.

The level floor of this narrow erosion valley for a distance of at least a quarter of a mile indicates that at this elevation, 905 feet, deeper water was reached, which effectually checked extensive erosion.

It is important to note in this connection that the Taylor's Falls picnic grounds bench across the river is of the same elevation, and equally level, and equally suggestive in the character of its material of river or lake influence. If it be river influence, they mark the highest prominent river terrace; if it indicate the position of an ice-dammed lake, the fact still remains that such a lake occupied the place of the later river, and upon its subsequent drainage left, as its eastern and western limits, these two terrace-like deposits in evidence of its existence.

The central plain just described is intimately connected with a more extensive tract which may be referred to as the Dresser Junction flood plain.

The rock bound gorge connecting these two plains is clearly a glacial river channel. It broadens into a sand covered valley at an elevation of 965 feet, following closely the west

line of section 5, T. 33 N., R. 18 W. The valley in its southern extension, includes the greater part of sections 7 and 18, T. 33 N, R. 18 W., and sections 13, 14, 23 and 24 of T. 33 N., R. 19 W., and is continued beyond the bounds of the St. Croix Dalles area. Western material is found abundantly strewn among the pebbles around Dresser Junction. The greater portion of the plain is composed of modified drift. This valley seems to mark the farthest advance of the western ice lobe. And, as the ice melted back, it became the course of a river which carried away the later glacial floods. All parts of this valley near the moraine are deeply covered with coarse sand. Farther away from the morainic source of supply the more level stretches of the plain have comparatively good soil. A second tributary to the plain stretches through section 18 and develops into a deep, sandy ravine leading into section 4, toward Poplar lake, which nestles among the morainic hills. Except for the igneous rocks encountered in the former channel, this old drainage course seems to be as important as that, and has no doubt been in more constant use since those conditions which produced them both disappeared.

Rock Creek Valley. The largest stream tributary to the St. Croix in this area, is Rock creek. Rising beyond the boundaries of the district it occupies a deep valley extending westward near the south line of sections 4 and 5, T. 34 N., R. 18 W., and then swings quite abruptly to the southwest through section 7 to the river. It is not wholly a late erosion valley. The kettles and knobs which characterize the moraine extend also into this valley. On either side the knolly ridges rise to 1,100 feet, and toward the north and east they are immediately merged into the plateau, more than 1,200 feet in altitude. The bottom of the valley lies for the greater portion of its extent above the 900-foot contour. Below that line, however, there are abundant erosion phenomena—sand flats, benches and terraces. The extensive level tract in S. E. $\frac{1}{4}$ of Sec. 7 seems to indicate terracing, and should be correlated with the 905-foot terrace at the Dalles.

A slight bench at 860 feet, along the wagon road, may be the local development of the 865-foot terrace of Upham* described as lying two miles further north.

*Minn. Geol. and Nat. Hist. Survey, Final Report, vol. II, 1888, p. 417.

This 300-foot valley, from one-fourth to one-half a mile wide, extending back among morainic ridges for several miles, and showing undisturbed terminal accumulations almost to the bottom, constitutes a somewhat unique feature in the surface geology of the district. It probably lies in the direction of movement of the latest ice advance, and is partially due to glacier erosion of an older drainage course.

II. Effect of Glacial Action upon Earlier Formations. The glacial action left distinct marks upon both the igneous and the sedimentary rocks. On the diabase the effect is much more easily observed at this time, although the action was very much more effective on the sedimentary rocks. Glacial striæ, smoothing of exposed surfaces, the breaking down of ragged cliffs, fluting and glacier erosion can be seen. All these except the last are more successfully preserved and therefore more readily seen on the igneous outcrops.

Glacial striæ are not found at every outcrop, although one or more of the above mentioned evidences of glacial action are to be seen at any extensive exposure. Those showing striæ most plainly and abundantly with their bearings are the following:

1. N. E. ¼, N. E. ¼, Sec. 1, T. 34 N., R. 19 W.

Near road—few striæ bear S. to S. E.

West side of outcrop—striæ bear almost E. and W., as an average direction. Of the variable ones, the greater number run N. E. and S. W. —angle of variation nearly 90 degrees.

Most of the striæ are along the extreme western border of the outcrop. Of those noted the majority had a direction N. of E. to S. of W., between 15 and 20 degrees, a few were found from W. of N. to E. of S. about 20 degrees, and still others were E. and W.

2. S. W. ¼, N. W. ¼, Sec. 6, T. 34 N., R. 18 W.

West slope of outcrop—striæ found only on the smooth, close grained portion of the exposure. They bear E. and W., also N. of W. to S. of E.

3. N. W. ¼, Sec. 5, T. 33, N., R. 18 W.

Markings on the very smooth polished surfaces of the diabases of the old channel from which the soil has been removed by the building of the M. St. P. & S. Ste. M. railway, bear almost N. and S. These markings may have other origin.

4. Sec. 31, T. 34 N. R. 18 W., near the center of the south half of the section, in the public road, are some low, evenly polished exposures of diabase on which markings occur.

5. In the village of Taylor's Falls, near the Swedish church on the highest exposed portion of the igneous rocks, glacial markings may be

seen. The following directions were noted in different places at this locality:

Well preserved striæ bearing N. 25 degrees E., a few other faint marks at an angle of about 45 degrees to these.

Well preserved striæ N. W. to S. E. and several bearing a few degrees more westerly.

Near the church—strongest marks N. 20 degrees E., faint marks exactly N. W. and S. E.

A few more were seen varying at small angles from the directions given above.

Former observers* have noted glacial striæ at the following points:

Sec. 36, T. 35 N., R. 19 W., bearing S. 40 degrees E.

Sec. 29, T. 34 N., R. 18 W., shallow flutings, bearing about S. 45 degrees E.

At Hinckley† the glacial striæ bear S. and S. 5 degrees W.

Very few places show striation of a persistent character, and readily escape observation. At nearly every place the bearing of the striæ is extremely variable, the directions being frequently at right angles to each other, with many intermediate degrees of variation.

The igneous flows dip in general toward the S. W. and W. S. W. This, with the tendency toward columnar structure gave opportunity for extensive destruction of the original cliffs. At such points as developed particular concentration of glacial abrasive action, which would be the case in those valleys lying between two ridges of eruptive rocks, or at a gap in an opposing ridge, the destructive influence should be strongly marked. This influence is especially noticeable at the old glacial channel in Sec. 6, T. 33 N., R. 18 W., and in the village of Taylor's Falls, at the Dalles. The rock exposures above the 800-foot contour, at the last named locality, bear evidence of ice abrasion as a factor in widening this gap between opposite cliffs, while the lower benches exhibit sufficient evidence of water action to explain all the erosion at that point.

On the sandstone and shales the effect of the glacial erosion was almost wholly confined to scooping out valleys between parallel igneous ridges, resulting in the removal of the comparatively soft sandstone to a level from 10 to 300 feet lower than the adjacent crystalline outcrops.

*Geol. of Wisconsin, vol. III, 1883, p. 382.

†Warren Upham, Geol. and Nat. Hist. Survey Minn., Final Rep., vol. II, 1888, p. 642.

The localities illustrating this erosion are so numerous that it is scarcely necessary to do more than call attention to the map of the district. The most important example is that of the valley now partially occupied by the St. Croix river above the Dalles. The stream lies for nearly five miles almost without a break, between parallel ridges of diabase, standing, on an average, one mile apart and reaching an elevation of from 100 to 300 feet above the adjacent sedimentary rocks. This difference of elevation is believed to be due not so much to preglacial land erosion as to the direct action of the ice during the glacial period itself.

The effect of the glacial erosion upon the drainage of this portion of the St Croix valley may be traced to a limited extent. Almost nothing can be claimed to be added to our knowledge of the preglacial St. Croix. The present channel is not believed to represent the original location of the river, although smaller streams may have occupied portions of it. The rock wall which occupied the site of the present Upper Dalles was an effectual dividing ridge, and to the north of this, small streams, occupying the present positions of the St. Croix river and Rock creek drained northward until some river was reached which probably emptied into the Mississippi.* In the southern portion of the district all evidences indicate that the present St. Croix river gorge is postglacial.

The inter-glacial St. Croix, up to the time of the invasion of the western lobe, at the beginning of the Wisconsin epoch, seems to have followed the preglacial drainage lines as understood above. But with the encroachment from the west a new connection with the Mississippi was made, and it at that time followed the extreme front of the invading ice.

The channel at present occupied by the St. Croix river varies but little from that just mentioned. An impracticable early course in the vicinity of Dresser Junction was abandoned. The river fell back finally with the retreat of the ice to its present more favorable course. The chief factor in making the present channel the most available and permanent line of drainage was the glacial erosion accomplished at this locality. There is little doubt but that the considerable bend toward

*Mr. Upham, Report of the Park Com., State Park of the Dalles of the St. Croix, 1897, p. 45.

the east which is continued for a short distance into the northern portion of the area, is chiefly due to the opposition of the ice and its accumulated debris coming from the west. The whole effect of postglacial erosion has been to deepen the chosen course of the stream. Any variation from it is seen solely in the slight shifting from the minor abandoned channels in its later development.

If this be the true explanation of the evidence at hand it argues that the remarkable erosion phenomena, which are so noticeable in the gorge in the vicinity of the Dalles, are all of late glacial and postglacial age, the larger part of which was accomplished at the immediate close of the glacial period during the time that the river served as the overflow channel for the West Superior glacial lakes.*

At this time the volume of water discharged was abundantly sufficient to account for all the erosion phenomena which seem so superior to the amount now carried by the St. Croix river. Chief among these phenomena are the enormous pot holes worn in these rocks at St. Croix Falls and Taylor's Falls.

Summary. The foregoing discussion, dealing with phenomena observed in this district, has a bearing upon some of the questions receiving present attention among northwestern glacialists.

Among these is the question of single sheet as opposed to several independent lobes, the latter of which is more agreeable to accumulating evidence.

The marked variability in the bearing of the glacial striæ, the peculiar character of certain areas of drift accumulation, and the change from a surface drift of western character to one of eastern origin, suggests that the district is one of the critical areas for the study of glacial geology.

Mr. Upham's determination of the northern limit of the blue till† at about the course of Snake river, and its southern limit, through the northern part of Washington county, no doubt accords with the limit noted in this district, and is consistent with the facts presented in this discussion.

Mr. Upham's attempt to correlate the farthest advance into

*Geol. of Wisconsin, vol. I, 1883, p. 286 and p. 261.
Upham, Geol. and Nat. Hist. Survey of Minn., Annual Reports.

†Geol. and Nat. Hist. Survey of Minn., Final Report, vol. II, 1888, p. 412.

Wisconsin with the 4th or Kiester moraine,* is not necessarily substantiated by the evidence herein set forth. In fact the morainic development due to western accumulation seems to disappear gradually as it approaches this area.

Wisconsin geologists refer to the Kettle range, of which the moraine immediately east of St. Croix Falls is a part, as probably belonging to the same stage as the accumulation known as the Leaf Hills moraine in Minnesota.† Such correlation is not yet substantiated and can not be so long as the glacial accumulations immediately south and southwest of the extremity of lake Superior are so imperfectly known.

Observations in this district indicate that the erosion of the St. Croix Dalles is post-glacial.

Chapter III. *Stratigraphic Geology.*

The exposed sedimentary rocks in the St. Croix Dalles area vary from a few feet to 225 feet in thickness. An equal thickness probably lies below the level of the St. Croix river, upon the very irregular floor formed by the Keweenawan rocks. If the dip of the igneous rocks were constant, however, a thickness of 1,500 to 2,000 feet could be attained along the western margin of the area.

The dip of the several subdivisions is fairly uniform southward at a very gentle inclination, amounting to 50 to 75 feet per mile.‡ While varying slightly at different places, the dip is fairly constant to a considerable distance beyond the bounds of the area. Approaching the district from the south and west, it is noted that the successive members of the Magnesian series disappear one by one until, at Eagle Point, near Osceola village, the Oneota dolomite constitutes the cap and surface formation. Within the bounds of the district this formation also is lacking, and the Jordan sandstone becomes for some distance the uppermost formation. No attempt to follow the subdivisions toward the north beyond Osceola has heretofore been attempted. The subdivisions of the Magnesian series§ recognized at Osceola are, approximately: Oneota

*Geol. and Nat. Hist. Survey of Minn., Final Report, vol. II, p. 415.

†Geology of Wisconsin, vol. III, 1880, p. 385.

‡Geol. and Nat. Hist. Survey of Minn., Final Report, vol. II, 1888, p. 409.

§The Magnesian Series of the N. W. States, by Hall and Sardeson. Bull. Geol. Soc. of America, vol. 6, 1895, pp. 167-198.

dolomite, 30 feet, Jordan sandstone, 75 feet, St. Lawrence dolomites and shales, 40 feet. At this place the Oneota and Jordan formations are rather sharply separated, as are likewise the Jordan and St. Lawrence; but the lower limit of the St. Lawrence is not prominently marked.

Below the St. Lawrence formation a series of more or less clearly defined beds of sandstone, shales, greensands, calcareous shales, pyritiferous shales and conglomerates has been included by geologists in the terms,—Lower sandstone,* Potsdam sandstone,† St. Croix sandstone,‡ Basal sandstone,§ and Dresbach and Hinckley sandstones,‖ without subdivision. The fauna, which seems largely confined to the lowest shales, was considered too meagre for a satisfactory correlation of the formation, and a discouragement at the outset to any successful subdivision.

Additional Data. Explorations of the writer have brought to light several facts which bear directly upon the question of correlation and subdivision of the lower sedimentary rocks of this district. They are the following:

The existence of a well-marked sandstone conglomerate has been determined: and St. Lawrence shales have been found to occur in Sec. 1, T. 33 N., R. 19 W.

The persistence of certain lithologic characters have been shown.

The discovery has been made of an extensive fauna in the marginal conglomerates.

The Sandstone Conglomerate. Along the wagon road through the N. E. ¼, N. E. ¼, Sec. 1, T. 33 N., R. 19 W., there is exposed, to a limited extent, an interesting conglomerate, of which specimens are readily obtained. The significance of the occurrence lies in the fact that the worn pebbles of this conglomerate are of sandstone, which are enclosed in a matrix of sandstone. The pebbles are little more compact and resistant than the matrix sand itself, are perfectly worn and range

*Owen: Geol. Survey of Wis., Iowa and Minn., 1852.

†Chamberlin: Geol. of Wisconsin, vol. I, 1883, p. 123.

Hall and Sardeson: Bull. Geol. Soc. of America, vol. 3, 1892, pp. 331-368.

‡Upham: Geol. and Nat. Hist. Survey of Minn., Final Report, vol. II, 1888, p. 407. Winchell: Final Rep., vol. I, 1884, p. 257.

§Norton: Iowa Geol. Survey, vol. VI, 1897, p. 140.

‖Winchell: Final Rep., vol. II, 1888, p. xxii, and 21st An. Rep. Geol. and Nat. Hist. Survey of Minn., 1892, chart, p. 5.

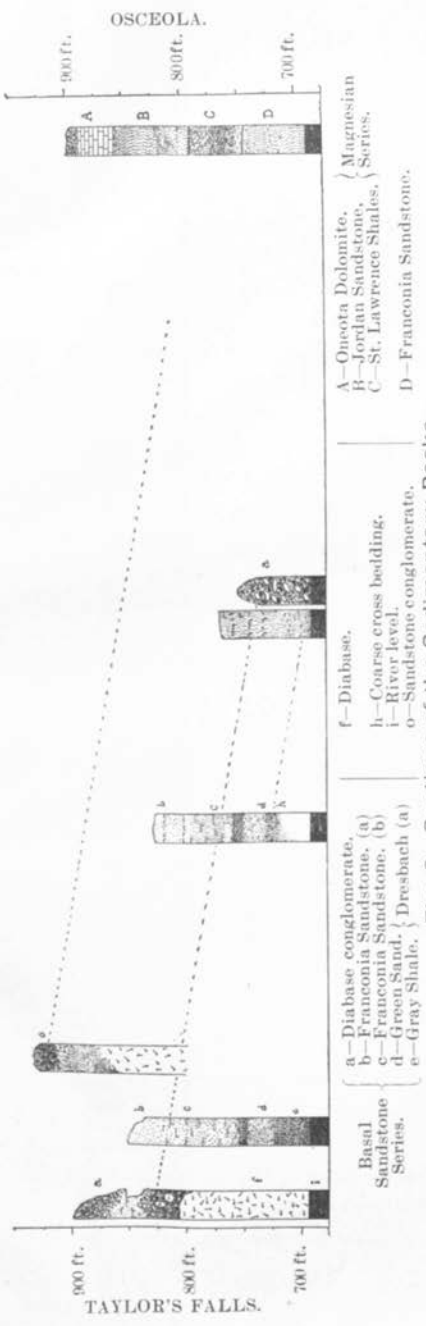


Fig. 2.—Sections of the Sedimentary Rocks.

in size upward to three inches in diameter. They show no fossil content, although the matrix carries abundant fragments of trilobites. An outcrop of igneous rock lies in the immediate vicinity, but the intervening distance between it and the conglomerate is covered by soil and drift. Sandstones and shales are exposed at numerous places along this same road at lower levels, and presumably at lower rock horizons, but a continuous section is not obtainable. The friable nature of sandstones makes them especially liable to mechanical destruction and for this reason a sandstone conglomerate is a rarity among rocks. This circumstance makes the occurrence an interesting one, and the evidence which it gives in support of the view that a considerable erosion interval occurred at this point makes it of additional importance. To what formation the sandstone conglomerate belongs, and what this break in sedimentation may mean are questions which deserve attention.

Fig. 2 was drawn to illustrate this occurrence and to correlate the subdivisions of the Cambrian sedimentaries of this locality. By reference to this chart, it is seen that the average dip of the sedimentary strata, as they appear in the river gorge, makes the sandstone conglomerate correspond to the well known break between the St. Lawrence and the overlying Jordan. Further, this St. Lawrence-Jordan* interruption in the continuity of the strata, is the only one thus far known commensurate with the formation of such a conglomerate. The lithologic characters and faunal content of the matrix are more closely allied to those of the Jordan than to any other formation. For the Jordan is an extensive sandstone formation, characterized by thick, coarse cross-bedding, well agreeing with the abundant supply of material, derived, in part at least, from the destruction of the St. Lawrence and earlier strata. It appears then that this sandstone conglomerate represents the extreme northern limit of the Jordan sandstone, with which it should be correlated: and the time break indicated was great enough to secure a solidification of earlier formations sufficient for the construction of a conglomerate from their debris.

The St. Lawrence Shales. From a well in the S. W. ¼, S. W. ¼, S. W. ¼, Sec. 1, T. 33 N., R. 19 W., were obtained two specimens of a sandy shale which resembles, in lithologic characters, the St. Lawrence shales found at Osceola Falls. This occurrence is 850 feet above sea level, and therefore would agree in altitude with a continuation of the St. Lawrence shales in this direction. It must be admitted, however, that with the approach of all of these formations to the immediate vicinity of the cliffs of igneous rocks, beyond which none of them are known to extend, the lines of separation between shales and sandstones become less sharply defined.

The Basal Sandstone Series. Among all of the terms that have been used from time to time to designate certain formations and groups of formations in southeastern Minnesota, not a single one has been limited to the sandstone and shale series, lying between the St. Lawrence formation and the Keweenawan rocks, with sufficient constancy and definiteness to warrant general acceptance. A recent reference to these rocks

*Bull. G. S. A., vol. 6, 1895, p. 173, Magnesian Series, N. W. States.

by Norton* under the name *Basal sandstone* is the most acceptable yet offered. But the fact that this formation, instead of being uniform as the name would indicate, is made up of a succession of separable subdivisions, makes a slight modification of the term advisable. The term St. Croix series is a much better name, but as restricted by Winchell,† was not originally proposed for the whole group of rocks now under discussion and has not been uniformly applied by writers. Accordingly the term *Basal sandstone series* has been determined upon as a convenient name. It is intended as the coordinate of *Magnesian series* as used by Hall and Sardeson.‡ A prevailingly arenaceous character gives this basal formation a unity similar to that secured in the *Magnesian series* by its dolomitic development.

This series of sandstones, shales and conglomerates between the base of the overlying St. Lawrence formation and the Keweenawan floor, exhibits certain characters sufficiently constant to merit subdivision into at least three distinct parts.

The uppermost subdivision is a sandstone exhibiting two phases: (*a*) an incoherent fine sand, which is underlain, (*b*) by more compact and thick-bedded layers. Thin seams of green shale occasionally appear in this bed. Its thickness is about 100 feet at its most favorable exposure. Fossils are not well preserved within it, and they are not abundant except in one horizon. Because of the exceptionally fine exposures of this formation in the vicinity of the small village of Franconia, this uppermost division of the series is called the *Franconia sandstone.*

The second subdivision has a persistently shaly development in its uppermost and lowest members, between which is a green-sand bed, which is coarsely arenaceous. A typical section exhibits, in descending order:

Shaly sandstone, 10 feet.
Green-sand, 20 feet.
Gray shales, 40 feet, to the river, below which its extent is unknown.

The green-sand is a glauconitic mixture. Broken frag-

*Geol. of Iowa, vol. VI, 1897, p. 140.
†Geol. and Nat. Hist. Survey, Final Report, vol. II, 1888, p. xxi.
‡Bull. Geol. Soc. of America, vol. 6, 1895, pp. 167-198.

ments of Lingula shells are abundant. Cross-bedding characterizes this bed at Franconia. Fossils other than Lingula are not abundant within this formation. The conglomerates, however, that belong to this part of the Basal Sandstone series carry *Obolella polita* Hall, and *Lingulepis pinnæformis* Owen, besides other fragments not identified. Dresbach (a).

The third subdivision of the series is observable only above the Dalles, at Taylor's Falls, and at St. Croix Falls, in numerous exposures adjacent to the river channel. About 50 feet of this stratum is exposed, and the lower limit is always within reasonable estimate, since it occupies the comparatively shallow basin through which the river flows. This formation consists of sandy shales at several places; loose clayey shales extending farther up the river; calcareous shales in which thin layers of limestone one to three inches thick occur; and pyritiferous shales in which secondary iron sulphide in little pellets and grains make up almost one-third of the mass. Among these beds fossils are most abundant in the calcareous shales. The fauna is meagre in variety of species, but the number of individuals is unlimited. The species always obtainable is *Lingulepis pinnæformis* Owen. The pyritiferous shales also carry a few fossil species, the pyrite serving as the fossilizing agent, while other beds of the formation carry almost no fossil forms. Dresbach (b).

For these last two subdivisions as now limited the name Dresbach* of former writers is adopted. Dresbach, Minn., is the type locality where the succession was described by N. H. Winchell. Further proof of the correctness of the present correlation will be undertaken in the chapter on paleontology.

The Conglomerates. The diabase conglomerates of the Cambrian age, lying alongside some of the igneous cliffs and ridges, are both the most interesting of the local phases and at the same time the most responsive to investigation. Among the localities of most ready access are the following:

1st. At the water's edge, along the river, S. E. ¼, N. W. ¼, Sec. 15, T. 33 N., R. 19 W., where the conglomerate stands as a cliff 50 feet high with no visible ledge accompanying it at either side; 2d. On Mill street, in the village of Taylor's Falls, at the railway crossing, and at the brow

*Geol. and Nat. Hist. Survey of Minn., Final Rep., vol. II, 1888, p. xxii.

Bull. Geol. Soc. of America, vol. 6, 1895, p. 170.

of the hill as the street approaches the public school building. Other localities where contact of the Cambrian strata and the Keweenawan is marked by a conglomeratic tendency are:— At the river bank, St. Croix Falls, and at the test pit in N. W. ¼, S. W. ¼, N. E. ¼, Sec. 1, T. 33 N., R. 19 W., near the highway, three-eighths of a mile S. W. of the sandstone conglomerate outcrop.

At none of these places, however, is there any such extensive exposure as at the first two named.

The first mentioned locality is a prominent landmark on the river between Franconia and Osceola.* A narrow ridge runs out from the main river bluff squarely to the stream, where the vertical face, 40 feet in hight, reveals the cause of its successful resistance to the erosion which has worn back the sandstone bluff several rods. There is at this place an apparent absence of the rocks from which this conglomerate could have been derived. No outcrop of these rocks is to be seen on the same side of the river, although it is possible that the adjacent higher river bluff encloses or covers such a ledge. That this conglomerate has outlasted the parent cliff beside which it must have been formed seems to be a necessary conclusion. There is, however, an almost unbroken ridge of diabase extending from the railroad, two miles north of Dresser Junction to the river just opposite the conglomerate exposure and no doubt at one time was connected with it. River erosion has destroyed all connection which once existed between the two and which still may exist beneath the bed of the river. In such a way, indeed, an adjacent cliff may have been destroyed while favorable conditions saved a part of the conglomerate beside it.

The same fossil species occur in this conglomerate as are found in the adjacent shales. It belongs to the upper bed, the green shales, of the Dresbach formation.

Two outcrops of conglomerate on Mill street in Taylor's Falls, are probably continuous beneath the drift. Their marked differences in color, hardness, and compactness of the matrix are not of great taxonomic importance. The exposure at the brow of the hill is near the 875-foot contour line, and for convenience of reference will be called the upper conglomerate. The one at the railroad crossing is at about the 810-

*Owen: Geol. Survey of Wis., Iowa and Minn., 1852.
Section 4, from Marine Mills to the falls of St. Croix.
N. H. Winchell: Tenth annual report, Minnesota survey, 1881, p. 120.

foot line and will be referred to as the lower conglomerate. All differences noted between the two are satisfactorily explained by the fact that the upper conglomerate lies in immediate contact with the parent ledge, while the lower one represents the limit of the conglomeratic accumulation as it merges into the sandstones; the upper is thoroughly saturated with ferric oxide, while the lower contains more of the carbonates; the upper has been more effectually drained of the destructive alteration reagents which permeate the waters of such great reservoirs as sandstone strata become, while the lower has been more completely within their reach, so that its pebbles and boulders show both more extensive disintegration and a greater variety of secondary products. The cause of this difference between the upper and lower conglomerates at Taylor's Falls is still more strongly enforced by a comparison with that below Franconia, already described. In this latter exposure almost every boulder is well advanced toward the last stages of decay. Some of them are little more than an earthy compact mass—all now left of a once fresh, lustre mottled diabase, as is shown by the alternating blotches of green, gray and brown still to be seen upon the broken fragments. Still there is no evidence of any considerable time break between these conglomerates; and the differences of surrounding conditions due chiefly to their position, are believed to constitute the most potent cause of their variation.

All boulders of the conglomerates are of the same petrologic character as the eruptive rocks now, or at one time, in place in the vicinity. No specimen of any rock belonging outside of this group of diabases was found among them.

The conglomerate at Taylor's Falls belongs stratigraphically to the lower part of the Franconia sandstone member of the Basal Sandstone series, and extends downward into the next underlying member, the Dresbach sandstone. The diabase conglomerate at St. Croix Falls belongs to the lower shales member, and that before noted in Sec. 1, T. 33 N., R. 19 W., apparently belongs to the St. Lawrence formation.

Thus the conglomerates as a whole, do not belong to any single member or formation, but are accumulations, resulting from special surroundings, which may, and no doubt do, occur at all horizons from the first one laid upon the Keweenawan

floor to the uppermost member of the sandstone present in the St. Croix valley. Therefore each outcrop must be studied by itself and its position determined independently of the mere fact of its conglomeratic character or the proximity of other exposures.

The reason for the extended attention given to the conglomerates in proportion to their geographical extent, lies in the fact that within them is preserved the richest fauna thus far discovered in all the formations. The loose sandstones which constitute so great a part of the sedimentary strata are unfavorable for the preservation of fossil forms. The greater part of the shales is almost as barren as the sandstones, and such layers as do carry fossils, whether sparsely scattered or in multitudes, exhibit a narrow range of species. It is only in the conglomerates, as recent observations prove, that there existed comparatively favorable conditions for preservation. Among these rocks a remarkably abundant and new fauna has been discovered. Further description of these new forms will constitute a separate chapter of this paper.

Classification. A detailed study of the area at and adjacent to the Dalles of the St. Croix suggests the following formational subdivisions:

Magnesian series. (Hall and Sardeson.)	Shakopee dolomite.			
	New Richmond sandstone.			
	Oneota dolomite.			
	Jordan sandstone.			
	St. Lawrence dolomites and shales.			
Basal Sandstone series. (Modified from Norton.)	3. Franconia sandstone (100 feet).			The St. Croix Formation. (Winchell.)
	2. Dresbach shales (150 feet).	Obolella polita zone	Greensands and shales	
		Lingulepis pinnæformis zone.	Calcareous & pyritiferous shales.	
	1. The lowest formation of this series is not exposed in the Dalles area, but it includes the lowest sandstone beds and possibly also the "Hinckley sandstone," (0 to 1,000 feet).			

Chapter IV. *Geology of the Igneous Rocks.*

A majority of the outcrops of igneous rocks lie within the erosion valley of the St. Croix river and thus owe their pres-

ent exposure to that stream. Notable exceptions to such distribution of the exposures are the prominent ridges, one to three miles distant from the river on either side, rising considerably above the surrounding drift. On the accompanying maps the location and surface extent of these rocks are given. The total area of their outcrops is about two square miles. In general, the occurrence and characters of the igneous rocks of this region have already been described by geologists.*

Many of these early descriptions are accurate and followed by logical conclusions. Present opinions of geologists are summarized in the following statements:

The igneous rocks of the St. Croix valley represent the southwestern extension of the volcanic flows and sedimentary strata known in the lake Superior region as the Keweenawan or Copper Bearing series. Irving insists upon the identity in essential characters of the igneous rocks of Keweenaw point and those of the St. Croix valley,† and this is considered by geologists the true correlation.

Keweenawan sedimentaries have not yet been observed in these southwesterly areas. The rock has been called most frequently a melaphyr. A serrate outline‡ of some of the outcrops and a step-like appearance of others has been referred to as indicative of the dip of these beds. A system of jointing planes is regarded as evidence of separate and perhaps numerous flows of molten matter. The vertical planes of this system represent an essentially basaltic fracture approximately perpendicular to the cooling surfaces; while the more persistent though somewhat irregular planes, more nearly horizontal, suggest lines of separation between successive flows. The dip of these planes, which is fairly uniform throughout the area, is, in the vicinity of St. Croix Falls, an average of 15 degrees W. by S.§

Differences in physical and mineralogical character corresponding roughly with the above mentioned separation planes, have been noted by the earlier geologists but not fully described. Conglomerates in contact with the volcanic rocks at numerous places are regarded as belonging to the next geologic age—the Cambrian.‖

---

*Owen: Geol. Survey of Wisconsin, Iowa and Minnesota, 1852.
Chamberlin (Strong): Geology of Wisconsin, vol. III, 1880.
Upham: Geol. and Nat. Hist. Survey of Minn., Final Report, vol. II, 1888.
Winchell: 10th An. Rep. Geol. and Nat. Hist. Survey of Minn., p. 120.
Kloos and Streng: Neues Jahrbuch für Min., Geol. und Paleont., 1877. (Translation in the 11th Report of the Minnesota Survey.)
Kloos: Zeitschrift d. Deutsch. Geol. Gesells, 1871. (Trans. in 10th Minn. Rep.)
Irving: U. S. Geol. Survey, Monograph v, 1883.

†Monograph v, U. S. G. S., 1883, pp. 239, 240.

‡Geology of Wisconsin, vol. III, 1880, p. 369.

§Compare Geology of Wisconsin, vol. III, 1880, p. 420.

‖Geology of Wisconsin, vol. III, 1880, p. 417.

Additional Data and Discussion. Vertical or basaltic cracks and fissures are more numerous in some outcrops than in others. Outcrops west of the river and especially those in the immediate vicinity of Taylor's Falls, show this character in its highest development. Certain parts of the flows exhibit these joints to a more marked degree than others, the supposed upper portions of certain flows being singularly free from them. It is possible that the vicinity of the falls has suffered from additional disturbance, for jointing planes are especially abundant at the Dalles accompanied by large fissures. One of these large fissures has exerted a powerful influence upon the course of the St. Croix river at this place.

If one proceeds up the river toward the elbow without change of course so far as to the enclosing wall on the east side, it can be observed that there is an immense fissure in that wall extending without change of direction, but with converging sides back a considerable distance from the river. The vertical sharply cut walls of this fissure stand apart about 20 feet and widen in the direction of the river's course. At present the St. Croix turns almost a right angle at the elbow in the Dalles and flows westerly in a straight line between walls of solid rock for a distance of almost half a mile, while a continuance of its original southerly course in a channel through the same kind of rock for only 20 rods would have accomplished the same purpose. Such freakishness can be explained only on the ground of some structural aid in the misdirection of the river. The columnar structure of the rocks has made it possible to preserve almost vertical cliffs throughout the history of this river. The heat of summer and the frosts of winter levy contributions from year to year for the accumulating piles of debris at the foot of the cliffs. Some of these blocks drop into the river whose maximum depth, now 160 feet, is gradually but certainly diminishing. In view of the erosion effect above the falls it is scarcely possible to believe any such depth attainable in this extremely hard diabase rock without the acceptance of one of the following conditions: either the complete undermining of the igneous rock at its edge by the erosion of the underlying formation, or the occupancy of an original fissure line and plane of weakness by the river, making it necessary only to main-

tain a depth already secured. Of these two courses the latter seems the more reasonable. Any subsequent filling of this fissure by sandstone, shales or loose debris would present comparatively slight opposition to erosion.

The Lava Flows. Figure 3 is intended to represent a profile of the igneous rock surface including the river gorge immediately above the elbow at the Dalles. The profile is extended on the west side of the river to the Swedish church at the top of the ridge fifty rods south of the center of Sec. 25, and on the east to the top of the diabase cliffs. By this profile it will be seen that seven very prominent steps constitute the ascent on the west side of the river. At each step there is a repetition of certain easily recognized physical and structural characters.

These characters may be grouped as follows: At the summit of each step there is a persistent highly epidotic zone, possessing in many cases none of the original mineral characters of true diabase. Structures resembling flowage lines are observable only in this zone. In position and bearing these lines correspond closely to the previous statements of dip. A more persistent lateral plane of separation coincides with this zone, as will be noted by the wide bench leading in each case to the

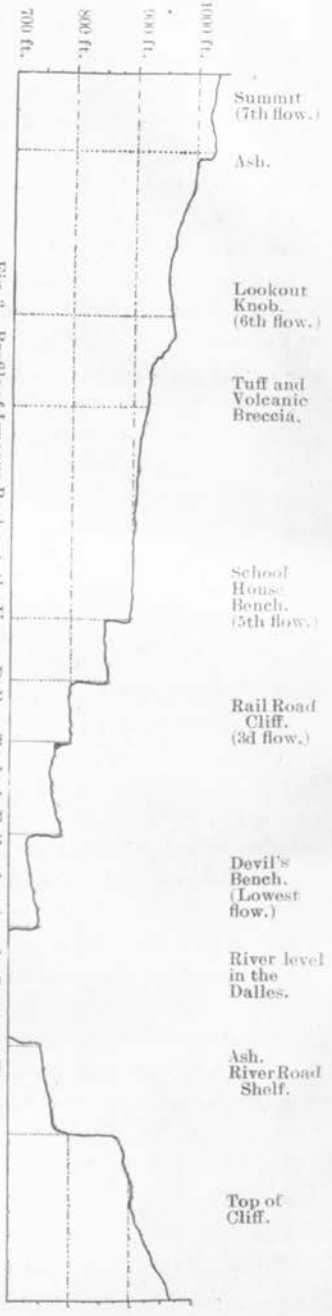


Fig. 3.—Profile of Igneous Rocks at the Upper Dalles, Taylor's Falls, showing the Separate Flows.

foot of each step. In some instances also there is a zone of greater porousness at the top of each step than is usual in other parts, and greater local differences are developed in the rock. Greater hardness in places separated by areas more readily destroyed has given rise on one of these benches to one of the most magnificent exhibitions of pot-hole erosion anywhere to be found. In at least two places a decidedly schistose character has been developed at the immediate line of separation. In a good hand specimen the bands and veins show a considerable crumpling of the layer.

On the bench east of the river below the toll bridge the so-called flowage structure is extensively displayed. On certain portions of the bench above the public school building and at least at one point on the east side of the river a distinctly brecciated structure has been preserved. This is offered as an addition to the evidence of the complete independence of these successive steps and a proof of the theory of separate surface flows.

In this zone occurs a limited development of the tough blue diabase and the still more limited tufaceous rock which has been found at three different horizons at Taylor's Falls. (See chapter on the lithology of the igneous rocks.) In this zone secondary quartz is so abundantly formed in places as to make up almost one-half of the rock although secondary quartz is by no means confined to this plane.

Quartz veins, secondary feldspar, grains and threads of metallic copper occur. In no other corresponding portions of the flows are there any correspondingly great variations. At one point a quartz segregation, filling one of these lateral separation planes, has been worked for copper, but with no success.

The set of joints and columns is usually interrupted at these separation planes. Below this zone in every case the typical flow shows a considerable uniformity of adjacent areas, a stronger tendency to the formation of joints and columns, a very dark color and a typical diabasic texture. Lustre, mottling porphyritic development and chloritic alteration products are also more common.

The thickness of the several flows as thus separated varies between 30 and 60 feet. That they may include other thinner