TRAP SHEETS OF THE LAKE NIPIGON BASIN¹

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INTRODUCTION AND GENERAL REVIEW

DISTRIBUTION OF THE TRAPS

Along the north shore of lake Superior from the Slate islands to Pigeon river, and extending over an area reaching to more than 100 miles north of the Canadian Pacific railway, the most prominent geologic feature is the occurrence of large areas in which trap sheets predominate. Within this area practically every salient feature of the topography is found to be associated with these trap sheets. Along the southern edge of the district, and extending for about 40 miles north of the Canadian Pacific Railway line, the traps are constantly found in association with Keweenawan and Animikie sediments. In the northern part of the area, in the basin of lake Nipigon, residual patches of Keweenawan sediments are frequently found associated with the traps, but there are numerous localities where the igneous rock rests directly upon the older Archean rocks.

The variegated, bold, and picturesque topography seen along the line of the Canadian Pacific railway from Rossport to West Fort William, Red Rock at the mouth of the Nipigon river, McKay mountain at Fort William, Pie island, and Thunder cape are a few of the many salients familiar to any one who has journeyed by boat or rail to Port Arthur or Fort William. The gorge of the Nipigon river from north of lake Jessie is cut through one of these immense sheets, and the less well known but more picturesque canyon which forms Pijitawabikong bay, a few miles east of the Nipigon river, is also cut through the same sheet.

Usually these trap sheets are nearly horizontal and of great extent. The largest single continuous area, so far explored, lies in the basin of lake Nipigon, south and southwest of the lake itself. The sheets occur either as sills from 4 to more than 50 feet in thickness, intercalated within the sandstones, shales, or dolomites, or in the form of capping sheets from 12 to more than 500 feet in thickness. These caps stand at the summit of the local stratigraphic column and their upper surface usually is a tableland or mesa.

PETROGRAPHY OF THE TRAPS

As to the petrographic characters of the trap sheets it may be noted that diabase is by far the most abundant rock, olivine being present frequently in large amount. Structurally it may pass from a typical diabase, the prevailing rock, to a coarse gabbro or olivine gabbro, or locally to a fine grained porphyrite. The ophitic structure is the most prominent and widespread. The texture, except at the contacts with the

FIGURE 1.—Sketch Plan of Lake Nipigon Basin
Showing the areal distribution of the principal bedrock formations

earlier rocks, varies from medium to coarse; usually it is nearly uniform throughout the thickness of the whole sheet, except close or near to the basal and upper contacts, even where the sheets are several hundred feet in thickness. The sheets of diabase, with a few local exceptions, are remarkably constant in their petrographic characters over nearly the whole area. They are invariably holocrystalline and are never amygdaloidal.

VIEWS AS TO THEIR ORIGIN

The earlier students of the district regarded these diabase sheets, in whole or in part, as volcanic flows, the lower and thinner intrusive sheets being considered as contemporaneous with the sedimentary rocks with which they are associated, while the capping sheet was designated the "Crowning overflow" by Sir William Logan. Later work by Ingall² and by Lawson³ has combatted these ideas, and the view so admirably set forth by Lawson has come to be generally accepted.

Lawson's thesis is (page 29) :

"There are no contemporaneous volcanic rocks in the Animikie group.

"None of the trap sheets associated with the Animikie, whether of the nature of 'caps' or intercalated sheets, is a volcanic flow.

"These trap sheets are all intrusive in their origin and are of the nature of laccolitic sills."

Lawson further summarizes the data on which he founds this thesis in the following statement (page 44) :

"I. The trap sheets associated with the Animikie strata are not volcanic flows because of the combination of the following facts:

"1. They are simple geologic units, not a series of overlapping sheets.

"2. They are flat, with uniform thickness over more than one hundred square miles in extent, and where inclined the dip is due essentially to faulting and tilting.

"3. There are no pyroclastic rocks associated with them.

"4. They are never glassy.

"5. They are never amygdaloidal.

"6. They exhibit no flow structure.

"7. They have no ropy or wrinkled surface.

"8. They have no lava breccia associated with them.

"9. They came in contact with the slates after the latter were hard and brittle and had acquired their cleavage, yet they never repose upon a surface which has been exposed to subaerial weathering.

"II. They are intrusive sills because of the combination of the following facts:

² E. D. Ingall: "Mines and mining on lake Superior." Geological survey of Canada, 1888, vol. II, part 2, section H, pp. 42, 46, 79, 80, 99.

³ A. C. Lawson: "The Laccolitic sills of the northwest coast of lake Superior." Minnesota Geological Survey, Bulletin VIII, 1893.

"1. They are strictly analogous to the great dikes of the region : (a) In their general relations to the adjacent rocks and in their field aspect. (b) In that both the upper and lower sides of the sheets have the facies of a dense aphanitic rock, which grades toward the middle into a coarsely crystalline rock.

"2. They have practically a uniform thickness over large areas.

"3. The columnar structure extends from the lower surface to the upper surface, as it does from wall to wall in dikes.

"4. They intersected the strata above and below them after the latter had been hard and brittle.

"5. They may be observed in direct continuity with dikes.

"6. They pass from one horizon to another.

"7. The bottom of the sedimentary strata above them, wherever it is observable, is a freshly ruptured surface.

"8. Apophyses of the trap pass from the main sheet into the cracks of the slate above and below.

"9. The trap sheets, particularly at the upper contact, hold included fragments of the overlying slates.

"10. They locally alter the slates above and below them."

For purposes of discussion the diabase sheets may be divided into two great groups: That group of sheets both the upper and lower surfaces of which are known or can be readily inferred, and a group consisting of all those sheets whose under surface only is known—the group of sheets which forms the various topographic "caps" throughout the whole region.

With reference to the first group, the observations of the writer, conducted over a wider area, emphatically confirm Lawson's conclusions as outlined above. With reference to the capping sheets, the writer's observations are in accord with Lawson so far as the areas examined by both are concerned, but data obtained largely in the basin of lake Nipigon lead him to make a somewhat different interpretation of facts noted both by Lawson and himself, and to different conclusions.

SCOPE OF THE PRESENT DISCUSSION

The writer wishes to confine the present discussion wholly to the consideration of the nature of the relations which now exist, and possibly formerly existed, between that group of sheets of diabase which now form the "caps" and the underlying rocks. So far as all other masses of diabase within the area are concerned, his observations confirm in every respect those of Lawson. Hence that there are a group of diabase sheets in this region which are not volcanic flows but which are intrusive sills of a laccolitic type is *not* a subject of discussion in this paper.

With reference to the "caps," it must be recognized at the outset that the only contact surfaces we can study are those at the base. The character of the upper surface and the nature of the contacts, if any, can be

a matter of inference only. Possibly a few of the "caps" belong to the first great group of sheets in which the character of the upper surface can be directly inferred from evidence available. The greater number of caps exhibit no direct evidence as to the character of their upper surface, and it is with these that the present discussion deals.

Negatively they exhibit none of those characteristics which are usually associated with volcanic flows—there are no pyroclastics, they are never either glassy or amygdaloidal, never exhibit ropy or wrinkled surfaces, have no associated lava breccias, and the nature of the contact with the underlying rocks shows that the latter were hard and brittle before traps came into the area. So far as negative evidence is concerned, they exhibit none of those features which are usually considered as characteristic of volcanic flows.

DESCRIPTIONS OF CRITICAL AREAS

IN GENERAL

The nature of the basal contacts of these sheets and the general character of the sheets can be best understood from the study of a selected few from a very much larger number of concrete examples. The examples which are cited in the succeeding paragraphs are only a few typical instances in which the relations of the traps to the adjacent rocks are clearly depicted. They have been selected because they are in localities readily accessible and because they are all, with the exception of Red Rock, within the Nipigon basin and are directly associated with the principal area of diabase.

GORGE OF THE NIPIGON RIVER

At Island portage, on the Nipigon river, about 5 miles above lake Jessie and in the heart of the gorge, Archean gneisses are exposed in the channel of the river. On the east there is a high cliff of gneiss rising about 350 feet above the river, which has, I believe, usually been mistaken for diabase, as it is nearly continuous with the diabase cliffs which swing in from the east at lake Jessie and continue up the east side of the Nipigon gorge almost to lake Nipigon. On the west side of the river, at Island portage, is a coarse pegmatitic granite rising about 250 feet above the water.

The area of Archean here exposed in the gorge of the Nipigon, completely surrounded and partly capped by diabase, is about 4 square miles. At lake Jessie the diabase is found nearly 300 feet lower, with possibly not more than 100 feet of sediments between it and the underlying Archean. The south edge of this sheet has been traced from a point

nearly 30 miles east of the Nipigon and for 12 miles west. The base usually rests on sediments throughout this distance of over 40 miles, the sediments in turn resting on a very uneven surface of Archean rocks.

The position and attitude of the Archean island in the diabase near Island portage suggest a pre-sedimentary monadnock, partly denuded before the advent of the diabase, buried by it, and subsequently uncovered by various erosion processes, the latest event in the geological history being the formation of the Nipigon gorge.

TCHIATANG BLUFF

At the southwest corner of lake Nipigon is a deep bay, lying between diabase headlands, called Grand bay. An inner bay at the bottom of Grand bay, on the route leading south to Black Sturgeon lake, is called Black Sturgeon bay. The south shore of this latter bay is bounded by a high bluff, the relief being over 700 feet. In the narrows between Grand bay and Black Sturgeon bay, a little more than half a mile from the base of the bluff, is a small island, known as Gneiss island, the bedrock exposed being gneiss. Between this island and the bluff soundings gave a depth of 66 feet. The entire bluff, to the summit, is diabase, and the highest point lies back from the cliffed front of the bluff (325 feet) about half a mile and stands about 650 feet above the lake. At three points on the face of this bluff masses of sandstone, now almost a quartzite, are found in the diabase. At least one of these is about 25 feet in thickness and stands nearly vertical. About $2\frac{1}{2}$ miles west of Gneiss island, at the foot of the bluff, another mass of gneiss outcrops, rising at least 150 feet above the lake, and capped by trap. Four miles south of here is a ridge of granite-gneiss which can be traced in a southeast direction, with varied expression and at times partly covered either by sediments or by diabase or by both for a distance of 20 miles, where it joins the large area of Archean rocks lying east of the Black Sturgeon river. The two small exposures of gneiss seen at Tchiatang bluff are topographically at a lower level than the main area to the south, and the second one noted probably represents the tip of the north end of a long ridge of Archean rocks.

Following the face of the bluff south to the narrows leading to the portage on the way to Black Sturgeon lake, there is a large mass of sandstone in the diabase just east of the narrows. This sandstone has a dip of about 80 degrees and is probably an inclusion in the diabase.

Four miles south of the bluff and about 1 mile east of Black Sturgeon lake, there is a large area of sediments resting directly upon the Archean, the actual contact and the lower basal beds being exposed. About 2 miles inland the diabase overlies these beds. It is not known

whether there are any sheets of diabase intrusive in these beds. East of the south end of Black Sturgeon lake the same sheet of diabase rests directly upon Kewatin rocks. Hence in the vicinity of Black Sturgeon bay and Black Sturgeon lake we find the upper diabase sheet resting directly upon Archean gneisses and granites, Kewatin schists and Keweenawan sandstones and dolomites, five different types of rocks of three formations, and in addition there are some inclusions of sandstones in the diabase standing in various attitudes from nearly horizontal to vertical.

SPRUCE RIVER GORGE

The main stream running southeast from Black Sturgeon lake is a river of the same name. Through most of its course from the lake to Black bay, on lake Superior, the Black Sturgeon river flows along a lowland bounded on the southwest by a cuesta formed of Keweenawan sandstones and dolomites, the strata having a slight southwesterly dip. On the northeast side of the lowland is an extensive area of Archean oldland.

FIGURE 2.—Section on Spruce River, 10 Miles southwest of Black Sturgeon Lake

The profile of the stream bed is shown at "a"

The cuesta on the west rises about 300 or more feet above the river, and in places it is capped by remnants of diabase sheets. At one point in the bed of the river there is also an outcrop of diabase, but the relations of this isolated mass to the surrounding rocks are unknown. The escarpment which forms the edge of the cuesta can be traced from just above the Canadian Pacific Railway bridge to a point some 15 miles west of the south end of lake Nipigon, where it terminates. Outlying remnants of the sediments are known in several localities still farther northwest.

About 10 miles southwest of the Black Sturgeon lake the Spruce river, an important tributary of the Black Sturgeon river, flows down the face of the escarpment through a gorge cut in diabase, and eventually it reaches Black Sturgeon lake. Above the gorge the river flows in a channel cut in red Keweenawan dolomites. On approaching the edge of the

escarpment it enters a gateway formed by the edges of one of the diabase sheets, which here rises fully 350 feet above the upper surface of the sediments in which the upper part of the channel of the river is carved. The stream in flowing through the gorge cascades and falls over diabase. Near the foot of the principal falls, about 90 feet below the level of the river above the gorge, greenish dolomites are exposed in the bottom of the channel and the sides are bordered by diabase. Down stream about 2 miles from the head of the gorge and probably about 170 feet below it, no further sediments are encountered and the stream channel is located on diabase. Numerous exposures of diabase between this point and Black Sturgeon lake make it seem probable that below the escarpment the whole area is immediately underlain by diabase. Sediments again appear from beneath the diabase not far from the point where the river enters Black Sturgeon lake. There can be no question but that in this locality a diabase sheet (at least 300 feet in thickness) lies along the edge of the cuesta, descends its front, and overlies a very large portion of the lowland in the immediate foreground and probably as far east as Black Sturgeon lake.

NIPIGON HOUSE OUTLIERS

Just north of Nipigon House, on the side of a hill of granite porphyry, and covering an area of less than half a square mile, is a small detached mass of diabase lying in a local hollow, the main part of the hill rising behind it. In other hollows on the same ridge are two small patches of basal sandstone and a second area of diabase. On the west end of Jackfish island, less than half a mile away, diabase is found at water level in immediate contact with the same granite porphyry.

About 6 miles north of Nipigon House, on the Inner Barn island, in Wabinoosh bay, the remnant of the same diabase sheet has a thickness of about 600 feet. On the mainland south of the island other contacts between the diabase and the underlying granite are found, and some boulders of granite were also found in the diabase near the bottom of the sheet.

WABINOSH VALLEY

About 8 miles northwest of Nipigon House the Wabinoosh river enters Wabinoosh bay on lake Nipigon. Ascending the Wabinoosh river toward the northwest, at Waweig lake, about 8 miles upstream, granites and gneisses are exposed near the shores of the lake and at a number of points in the bottom of the valley in which the river runs for the next 12 miles of its course. On either side diabase bluffs rise to an elevation, in round numbers, of 300 feet above the valley. Ascending these bluffs on the

north side of the river valley and descending on the other side, at a distance varying from 1 to 2 miles from the river and at a height of between 145 and 160 feet above it, the granite gneiss is again encountered. The north edge of the diabase sheet thus is shown to abut against the side of an ancient valley in the Archean, and the depth of this valley was at least 150 feet. The preserved portion of the diabase sheet between the valley of the Wabinoosh and the Archean highlands to the northeast of it now lies on the side of this old Archean valley.

OMBABIKA NARROWS

At the northeast angle of lake Nipigon is found one of the most interesting contacts of the district. The remnants of the diabase sheet have, in the vicinity of Ombabika narrows, a thickness of about 400 feet. On the north side of the narrows, just opposite the small island which divides the channel into two parts, the diabase flowed over rocks which had previously been eroded in such a way as to produce an undulating surface (or a warped surface). Subsequent erosion and glaciation have removed almost all of the diabase. Because of the position of the high ridges of diabase on either side of the narrows and because of the relations which the fronts of these cliffs bore to the direction from which the movement of the ice-sheet took place, erosion was especially active at this point, and the present surface, also a warped surface, is remarkably smooth. It has happened that over an area of several hundred square feet glaciation stopped at such a point that the present surface intersects the old pre-diabase warped surface in such a way that small areas of trap now occupy small hollows in the old surface, and, in a low cliff, sections of contacts in both vertical and horizontal planes are exposed.

At the west end of the island, in the narrows, there are a number of large and small granite boulders, derived from the immediately underlying Archean rocks, included in the diabase, with their upper surfaces planed off by the glaciation.

Within 2 miles of the narrows, toward the south, there are at two points very small exposures of a white quartzite with the diabase overlying, actual contacts being observed. Along the shore for 8 miles south of the narrows there is a narrow but nearly continuous strip of granite-gneiss exposed along the shore, the diabase rising in a ridge behind it.

On the northwest side of Humboldt bay, 8 miles southeast of the narrows and across the ridge of diabase which forms the main axis of the South peninsula of Ombabika, there are several areas both of granite-gneisses and Kewatin schists overlain by traps, actual contacts being seen.

On the east side of the north arm of Humboldt bay, about 2 miles from the contact between Kewatin schists and the diabase, the remnant of the trap sheet rests on Keweenawan sandstones; these in turn rest on granite. This area of sandstone is an isolated patch, with a minimum thickness of 50 feet. Since the diabase is found in actual contact, not only with the sandstones but also with the underlying rocks in adjacent areas, the contact is an unconformable one.

POSSIBLE REMNANTS OF OLD SOILS IN SITU

Within the Nipigon basin the greater number of contacts noted between the base of the remnants of the capping sheets of diabase and the underlying rocks were in areas where the Keweenawan sediments had largely been removed prior to the volcanic extrusion. In some four places, two of which have been mentioned above, boulders of Archean rocks have been found within the diabase close to the basal contact. Contacts between Keweenawan sediments and the igneous rock are also frequently found, but the best examples lie to the south of the Nipigon basin, along the line of the Canadian Pacific railway, in the area that is underlain chiefly by these sediments and the area in which the intrusive sills are so abundant.

Near the mouth of the Nipigon river, 3 miles southwest from Nipigon station, the railway track skirts the foot of a diabase-capped bluff known as Red Rock (from the characteristic color of the underlying sediments). At this locality (mile post 66, from Schreiber) the diabase sheet ascends across the beds to a height of about 140 feet, and the upper part of the sheet seems to rest nearly conformably on the upper beds. Where the diabase crosses the truncated edges of the lower beds, close to the railway track, between the base of the sheet and the undisturbed portion of the beds is a mass of broken rock at least 10 feet in thickness at one point and probably thicker elsewhere. This breccia consists of small fragments of the sediments, many of them partly rounded and the whole now recemented and bleached to a color lighter than that of the parent beds. The recemented beds seem to have a slight downward dip toward the ascending trap sheet.

At mile post 67, on the opposite side of the same ridge, are more exposures of a similar breccia, not in immediate contact with the diabase sheet. Nearly midway between these two points one of the railway cuttings passes through a dome in the sediments in which many of the thin shaly beds are crumpled, while the heavier beds are folded or faulted locally. While there are no exposures of diabase in the exposed portion of the core of the dome, its form and structure strongly suggest that the strata are arched up by a laccolitic mass below.

Lawson cites the local unconformity between the diabase and the sediments as an example of the intrusion of a laccolitic mass of the diabase across the beds. We have, however, no information as to the actual character of the upper portion of the capping sheet, and in the absence of this positive information the writer would interpret the section differently.

At first sight the apparent downward dipping of the edges of the beds at the contact with the diabase suggests monoclinal faulting. Directly opposite, across the river, similar sediments also capped unconformably by diabase, form a similar bluff, standing at almost precisely the same level, the distance between the two bluffs being less than a mile. If there were monoclinal faulting, accompanied by the intrusion of the diabase along a plane in the fault zone, not only would the occurrence of escarpments of nearly equal height on opposite sides of the fault plane be improbable, but the lifted block would be the block *above* the trap sheet,

FIGURE 3.—Section at Red Rock at the Mouth of the Nipigon River

Intersection of Keweenaw strata by diabase, showing a small mass of supposed old soil breccia at the base of a pre-diabase cliff. One hundred and forty (140) feet of sediment are capped by 125 feet of diabase.

not the one *below*, and in this case both blocks are *below* trap sheets. Again, if the molten diabase had been forced upward from below along a fracture plane, it seems probable that if it disturbed the edges of the strata through which it passed it would tend to bend them *upward*, in the direction of flow, rather than downward. Where the diabase was in a very fluid condition, as presumably it was in this case from the nature of the crystalline structure of solidified magma, where fracturing was produced along the line of the intrusion, small fragments would almost certainly have been washed out into the diabase, and it would have insinuated itself between other fragments nearer the parent beds, but in no case were phenomena of this character noted. The fragments are fairly uniform in size, no very large blocks being noted, and are frequently rounded at the corners and edges, the whole mass being recemented with a material that was probably derived from the beds themselves.

The block of sediments now exposed in section above water level very strikingly resembles such a ridge as could be duplicated many times among similar sediments, a flat-topped ridge fronted by a nearly bare

sandstone cliff with a small talus at the base. The apparent downward drag of the beds at the contact between the breccia and the diabase is precisely similar to the soil drag found on steep faces of escarpments or slopes where the edges of thin beds containing shale members are exposed.

The writer is thus inclined to regard the breccias found only along the base of the hill as old soil breccias and the unconformity at this point as evidence of extensive erosion previous to the incursion of the trap.

An almost precisely similar breccia, in which many of the fragments are distinctly rounded, occurs near the post-office about $1\frac{1}{2}$ miles east of Ouimet station (between mileposts 87 and 88), where it is also associated with, but only partially concealed by, a trap sheet—both at the foot of a slope and at its summit.

Again, at mileage $97\frac{3}{4}$, is a mass of very similar material consisting of fragments of red arenaceous dolomites lying in a hollow in granite and not now associated with any trap sheet.

The breccia found at the base of Red Rock, on the east side of the ridge, is in immediate contact with diabase and is only a small fragment of material similar to that which is found in several other localities not always associated with diabase sheets at the present time and not necessarily occurring at points where an intrusive mass has forced its way across strata. Under any other circumstances these fragments of waste rocks would unhesitatingly be regarded as remnants of an old soil cover. Except for the fact that they are recemented, they are almost precisely similar to the waste masses found in many other places associated with these same rocks today.

DISCUSSION OF THE EVIDENCE

SURFACE FLOWS VERSUS INTRUSIONS

Obviously the "capping" sheets of diabase, the group under consideration here, must have been either surface flows or intrusions. Were the original upper surface of the sheets preserved, it is extremely probable that there would be no difficulty in determining to which group they belonged. If they were surface flows we would expect to find the upper layers glassy, amygdaloidal, with traces of flow structure, occasionally perhaps associated with lava breccias or other pyroclastics. If intrusions, we could expect to find traces of the overlying sediments, or, internally, at or close to the former upper contact, the diabase would at times contain fragments derived from the old cover, and would always show a progressive diminution in the size of the grains of the constituent minerals as the contact was approached, precisely the same as is shown in all cases where both upper and lower contacts are known. Unfortunately

it happens that all traces of the actual character of the upper portion of these sheets has been lost. In the Lake Nipigon basin alone there can be no question but that more than 80 per cent of the original volume of the mass of diabase that once was present has been removed, assuming that it had even a minimum thickness of between 600 and 700 feet (600 feet being the actual thickness of the remnants of the sheet in several places). When it is remembered that at the very summit of the thickest sheets known we find no change in texture indicating that an upper limit is being approached, it seems conclusive that before erosion began the sheets were very much thicker than their thickest remnants are today. While it would be rash to give any figure as a possible maximum based on the data now available, still if a minimum of 1,000 feet is allowed it would be found that more than 90 per cent of the volume of the original sheets has been removed from the area of nearly 6,000 square miles here under discussion.

Whatever may be the accuracy or inaccuracy of the approximations given above, an enormous amount of erosion undoubtedly has taken place, and in view of the fact that no record has been preserved as to the actual character of the upper part of the upper sheets, even if intrusive, the non-occurrence of any phenomena that can be associated with a volcanic flow must be regarded as a negative argument of very slight weight. In this case it is an argument of equal weight for both types of invasion, since each type has a characteristic upper surface under normal conditions. In fact, the preservation of upper layers that were more or less glassy and porous—the characteristic feature of most surface flows—would be extraordinary in a locality where the erosion has been so extensive, for such a surface would be even more susceptible to the action of erosive agents than either sediments or the upper surface of an intruded sheet.

It must also be considered that the features characteristic of the upper portion of a flow are confined to a few feet of the upper parts of the sheet. If there were a number of successive flows, following one another at intervals, so that the upper surfaces of the earlier ones had had the opportunity of cooling before the next flow came upon it, it is very probable that remnants of these surfaces would have been preserved.

A comparable instance is that of the Columbia lava fields, which cover an area of 200,000 square miles. The lava fields are built up by a number of separate flows, and the thickness varies from between 300 and 400 feet along the edge of the canyon of the Columbia to 3,700 feet, according to Le Conte, in the Cascade mountains near Dalles.⁴ Russell de-

⁴ *American Journal of Science*, series III, vol. 7, 1874, p. 168.

scribes the rock as usually a compact bluish black basalt with frequently a well defined columnar structure, "but also at times it is vesicular and scoriaceous, especially on the surface of sheets."⁵

If, in the Lake Nipigon area, the lavas were very fluid, and if the flows followed one another closely, so that the earlier flows had not had time to solidify before the later followed upon them, or if there were only one large flow, the fluid lava would tend to accumulate in the basins and hollows of the invaded district, would heat the underlying rocks, possibly even re-fusing parts of the lava that had cooled on the first contact with the cold underlying beds on which it rested, and would remain fluid for a very long time, giving ample opportunity for the development of the crystalline texture so characteristic of the basal portion of the remnants of the sheets.

In this event the characteristic upper surface would be confined to the highest members only, and below a certain limiting depth the cooling of the mass would proceed as if it were a laccolitic mass below a sedimentary cover. For this reason also no argument as to the nature of the upper surface and as to the character of the intrusion can be based on variations in the texture of the crystalline rock. While the marked uniformity of the grain of the rock, except that close to the base of the sheets, suggests slow cooling, nearly simultaneous solidification throughout the greater portion of the mass of the sheet, and the existence of a cover, it offers no evidence as to the character of that cover.

UNCONFORMITIES OF THREE TYPES

General characteristics.—The occurrence of numerous unconformities is an established fact. Broadly, they are of three types:

The diabase sheet appears to truncate the edges of the nearly horizontal beds of sedimentary rocks *in situ* on Archean rocks.

The diabase rests on an erosion and uneven surface which truncates the structures of metamorphic Archean rocks.

The diabase rests on an uneven surface which truncates both Archean metamorphics and overlying later sediments—rocks of two or more formations.

Examples of each type.—Contacts of the first type are particularly numerous along the line of the Canadian Pacific railway. Reference has been made to the unconformity at Red Rock. A number of other examples are described by Lawson, more particularly, however, with respect to contacts between the diabase and underlying Animikie rocks. One of

⁵ I. C. Russell: A geological reconnaissance in central Washington. U. S. Geological Survey, Bulletin 108, p. 21.

the most striking of Lawson's illustrations is reproduced here.⁶ The unconformity in the gorge of the Spruce river also belongs to this group.

The explanations offered by Lawson and Ingall on the one hand and by the writer on the other, so far as they apply to these major unconformities, are diametrically opposite. In so far as these unconformities alone are concerned, the writer's verdict would be "not proven;" but when the various other unconformities are also considered, the balance of evidence seems to be strongly in favor of the latter explanation.

Contacts of the second class are numerous all around lake Nipigon. One of the most striking, that at Ombabika narrows, has been described in some detail, and attention has been called to the inclusion of boulders of the underlying rock in the diabase. Another example from near

FIGURE 4.—*Diagrammatic Section near the Extremity of the Point between Big Trout and Pigeon Bays*

Showing the relation of the trap sills to the Anlmikie strata. (After Lawson)

Nipigon House has also been cited and the occurrence of included boulders noted. There are also a number of other localities where masses of diabase, covering areas varying from about 1 acre to over 10 square miles, show actual contacts with an eroded Archean surface, and in some instances they contain detached blocks of Archean rocks similar to the bedrock on which they rest. The diabase masses occur on the tops of ridges and on the sides of valleys cut in the Archean (as at Wabinosh river, Nipigon House, and Tchiatang bluff) as well as in the bottoms of valleys. Archean valleys with a relief of a minimum of 150 feet are found to have masses of diabase located on their sides.

The contacts of some of the smaller remnants of diabase sheets and the underlying rock show in detail the nature of the surface over which the diabase flowed and show that it was very intricate. There are many instances in which it can be shown that what appear to a traveler in the

⁶ Lawson: *Op. cit.*, figures 1, 2, 3, 4, and 5.

valleys to be high ridges of diabase rising above the adjacent depression are merely the edges of a dissected sheet of diabase, the present remnants now lying on the sides of old valleys cut in Archean rocks. Since the diabase is harder and more compact near contacts with other rocks, a reasonable explanation of the occurrence of this type of ridge is that the remnant of diabase is preserved where it lies largely because of its relation to the underlying rock and because of the texture thereby developed in this part of the sheet in the process of cooling. The high cliffs at Tchiatang bluff, where there is a relief of over 700 feet and diabase for at least 650 feet of this height, may be a case in point. The whole core of the bluff may possibly be Archean and the diabase only occur as a sort of plaster over its face.

The third type of unconformable contact has been illustrated by the description of the vicinity of Island portage, on the Nipigon river. Other examples cited are Tchiatang bluff and Humboldt bay, the latter being mentioned in connection with the Ombabika Narrows area. About ten contacts of this type have been examined by the writer, well distributed over different parts of the area, and it has been definitely established that the unconformity they indicate is not confined to any specific locality.

Discussion.—As has already been pointed out, the first type of unconformity has been explained either by the theory of a flow over an eroded surface or by assuming that the diabase was intruded across the beds. In the latter event it appears to the writer that certain evidence of this intrusion would be found at the contacts in the relationships which would then exist between the intruding rock and the edges of the fractured strata. This direct evidence is lacking, and, so far as the first type of unconformity is concerned, conclusive evidence has not been cited.

The second and the third types of unconformity have not, so far as the writer is aware, been previously discussed in print. There are but two possible ways in which they can have been brought about. The diabase must have flowed over an eroded surface or it must have been forced in to its present position along the surface of contact between an overlying cover and the rocks with which it is in contact.

Naturally the surface of contact between the sedimentary rocks and the underlying Archean would have been the locus of a number of lines of least resistance (or a plane of least resistance). Had the Archean surface been only moderately even, it is possible that it would have lain in the plane of least resistance; but the surface is an undulating one, with a moderate relief of at least 300 feet and in places more than this. In detail some parts of the surface are extremely intricate, yet we find

numerous instances in which the diabase occupies not only major depressions in the surface, but has even insinuated itself into minor irregularities. It has done this not in a few localities, but in many places widely distributed. Had it insinuated itself between an overlying cover and the rock on which it now rests, normally one would expect to find numerous small remnants of the sediments in the bottoms of the major hollows, at least, rather than to find so complete a stripping as seems to have taken place. In the second place, the edges of the sheets, with the sediments underlying, have been followed and examined for many miles and by many observers, and no single instance has been recorded where an intruded diabase sheet has followed the sinuosities of the contact surface between the sediments and the underlying Archean. In other words, while in the whole area numerous sheets have been intruded into the sediments in addition to the sheets that now form the "caps," yet in no instance has one of them been found to have intruded itself along the supposed plane of weakness at the contact between the sediments and the underlying rocks.

In the case of unconformities of the third type, under the intrusive theory the diabase must have occasionally been unable to insinuate itself along the intricate surface of the Archean and must have broken across the beds of the sediments to a higher horizon, leaving a remnant firmly attached to the original basement, and again descending after the obstructing mass was passed—an improbability not only because of the physical difficulties involved, but also because at the contacts, so far as recorded or examined, no evidence of violent disruption or intrusion has been found.

Again, numerous contacts between the sediments and the Archean show that usually the basal beds are arkoses or conglomerates, and contain at least a few pebbles, cobbles, or boulders, derived from the underlying rock. In four widely separated localities, yet each in the vicinity of unconformable contacts between the diabase and two other formations, boulders of the underlying Archean have been found in the diabase at or close to the contact. The diabase in actual contact with these boulders is fine textured, but it is not glassy, and the zone of alteration, even in the immediate vicinity of one boulder about 5 feet across, is very narrow, from which one can infer that the boulder lay in the fluid or semifluid diabase long enough to become heated through, and that it had but little effect on the cooling of the diabase magma in its immediate vicinity.

No fragments of any sandstone or other cement material similar to that found in the basal conglomerate was found either in the diabase or clinging to the boulders, so far as seen.

It seems very improbable that the several masses of diabase in which these boulders now lie were intruded between the basal beds similar to those in adjacent masses of sediments and the Archean rock on which the trap containing these boulders now rests.

COLUMNAR STRUCTURE

Columnar structure is a feature characteristic of all the sheets, whether distinctly intrusive or possibly surface flows. In nearly every instance it extends from the lower surface to the upper surface, as it does from wall to wall in dikes. Structures of this type, however, are not confined strictly to sills. We find that the flows of both the Snake river and the Columbia river lava beds exhibit the same type of structure. It must also be pointed out that with respect to the capping sheets we know only the base of the sheet and possibly its middle parts, the upper part having been removed. There are also many localities where horizontal jointing is as well developed as the vertical jointing by which the columnar structure is produced. In very many instances (three localities are: east side of Pijitawabikong bay; near Speke point on the east side of lake Nipigon; and the west side of the portage into Waweig lake from the south) this double system of jointing is well developed, and a moderate amount of erosion along the fissures has slightly rounded the exposed corners of the joint blocks, so that the face of the cliff, sometimes for many hundreds of square feet, closely resembles an ancient wall. The resemblance to a wall is very close and remarkable, because the individual blocks are strikingly uniform in size and are usually oblong in section, the horizontal joints being usually closer to one another than the vertical ones.

On many of the thicker sheets so well is horizontal jointing developed that the vertical columnar structure which the cliff faces of these sheets present is largely due to the accident that gravity—which causes some of the joint blocks to fall down the fronts of the cliffs while others remain standing as columns—happens to act in a vertical direction only.

SUMMARY OF THE EVIDENCE AVAILABLE

IN FAVOR OF INTRUSIVE SILLS

The arguments in favor of regarding the “caps” as intrusive sills may be briefly summarized as follows:

1. Entire absence of any of those features that are usually associated with the upper parts of a surface flow—glassy matrix; amygdaloidal, porous, or basaltic texture; flow structure; associated volcanics, either lava breccias or pyroclastics.
2. A medium to coarse crystalline texture, usually indicative of a slow

rate of cooling, such as would normally take place only at some considerable distance below the surface.

IN FAVOR OF SURFACE FLOWS

1. The very widespread occurrence of unconformities between diabase sheets and underlying formations.

2. The occurrence of boulders of granite and gneiss and schist in diabase, the latter resting on similar rocks *in situ* in localities where there is direct evidence that before the advent of the trap the underlying rocks were buried beneath the sediments similar to those now present, near by, under the same diabase sheet.

3. The occurrence of old soils *in situ* at the bases and on the sides of sedimentary ridges, the whole being covered in places with a diabase cap.

4. The nicety of the adjustment by which the diabase sheets have fitted themselves to the underlying topography. While the upper surface⁷ of the residuals of the capping sheets are everywhere fairly uniform in height, the base of the sheet has adjusted itself to a topography where the relief was at times as much as 300 feet.

5. The mechanical problem which arises in explaining the numerous unconformities, especially those on the embossed Archean surface, by the theory of intrusion vanishes completely on the theory of surface erosion prior to surface extrusion.

6. The features characteristic of the upper surfaces of sills—the occurrence of overlying beds or fragments thereof, aphanitic structures, included fragments in the upper part of the sheets—are not found.

7. The medium to coarse texture, which characterizes the sheets, would be found at the base of thick surface flows as well as in sills, being dependent not on the nature and thickness of the cover so much as on the rate of cooling.

8. A glassy matrix, amygdaloidal or porous structure, basaltic texture, flow structure, and associated volcanics would not be characteristic features of the under parts of surface flows, and the upper parts of these sheets are unquestionably removed, without a single exception.

BALANCING THE EVIDENCE

It seems that we have no data relative to the actual character of the upper surface of the trap sheets. Such negative evidence as is available is equally applicable to both theories. With regard to the texture of the residual basal portions of the sheets, there are no recorded differences

⁷ It is recognized that this even upper surface is now an erosion surface and does not necessarily owe its even character to an original uniform structural surface.

which would indicate that it belonged to a flow and not to a sheet. On the other hand, numerous unconformities exist and the diabases are known to rest successively upon Laurentian, Kewatin, Huronian (possibly Middle and Lower, certainly Animikie), and Keweenawan, and these unconformities are very widely distributed. Owing to the mechanical difficulties involved by any other interpretation, it seems to the writer that the balance of evidence available is distinctly in favor of considering these capping sheets as the basal residuals of a once very extensive flow or series of flows of a very fluid diabase over the well dissected topography of a previous cycle.

SOURCE AND NATURE OF THE FLOWS

Information about the source of the diabase is scant. No specific centers of eruption are known. Some of the sills in the sediments are found associated with dikes of similar rock. Instances where the actual connections between the two have been observed are rare, and the writer has never had the opportunity of studying one in detail. Two localities have been found where the writer thinks he has located a connection between a dike from below and the overlying diabase cap. In both instances only one side of the supposed dike in contact with the adjacent rock was found, though the connection with the sheet is distinct, and it can not be regarded as certain that the intrusive is a dike from below.

One of these lies east of the south end of Black Sturgeon lake, about 3 miles from the lake, near the head of a dry canyon cut in Kewatin schists. Near the head of this gorge, on the north side, the schists are found to *overlie* the diabase, an actual contact having been found. The contact occurs in the face of the cliff which forms the north wall of the canyon, and rises upward at an angle of about 20 degrees from the horizontal, the exposed portion being about 125 feet in length. This diabase, here lying *below* Kewatin schists, is directly connected with the main sheet of diabase that covers all that section of country south of lake Nipigon and extends eastward beyond the Nipigon river. If this is a feeding dike, the other contact lies farther east, beneath the diabase sheet, and would not now be accessible.

The second locality is near the head of Pine portage, on the Nipigon river, at the north end of the area of gneiss exposed in the gorge. Opposite the head of the portage are high bluffs of diabase, rising over 300 feet above the river. Near the summit we found a large mass of gneiss overlying the diabase, which forms the whole front of the cliff facing the portage. No actual contact could be found, though the two rocks were traced to within about 10 feet of each other. A small intervening hol-

low, filled with loose soil, obscures it. The contact seemed to dip away from the cliff face and stands approximately at an angle of 45 degrees, dipping toward the northeast. Since the gneiss here is part of the Archean ridge to the south, that has unquestionably been buried in a flow of diabase, it is possible that the preexisting topography was such as to bring about the relations here described without any intrusion from below in this locality.

A third locality of interest is at Camp Alexander. About one mile below the steamboat landing, at the mouth of Bass creek, on the west side of the river, a nearly vertical contact between diabase and granite occurs. Since the granite outcrops on the east side of the river, the width of the diabase mass is about 400 yards, or less than a quarter of a mile. A number of outcrops show that it extends northward for about 2 miles. At the north end, part of it is spread out over granite as a capping sheet. No conclusive evidence was found to show that the diabase at Camp Alexander and vicinity occurs as a dike. There is independent evidence to show that it occurs at the bottom of an old Archean valley and there is reason to suspect that the mass of diabase here preserved occupies a depression that was once a gorge in the valley floor.

Adjacent to the shores of lake Nipigon there are several localities where wide dikes of diabase similar to that in the sheets occur. There are also numerous outlying large and small masses of diabase on the summits of Archean ridges, on their sides, and in the valley bottoms. In many instances it was impossible to find any actual contacts. In quite a few cases, particularly where the diabase lies at the summit or on the side of a ridge, sufficient actual contacts were found to show that the remnants were parts of sheets. With regard to some large masses of diabase, very coarse in texture (in one instance we found olivines more than one inch across), no contacts were found. While the coarse texture suggests slow cooling, the mass may have cooled slowly, because it lay at the bottom of a hollow and was thus deeper below the surface than the portions of the sheet lying above the adjacent hills; or it may have been more closely associated with a feeding dike and been the last to cool and solidify. In the majority of cases the textures of the more or less isolated and outlying masses of diabase are neither coarser nor finer than the textures of the different parts of the sheets in the main area.

While it seems probable that the diabase flowed out over the area from many fissures, very few of these fissures are known. The numerous outlying masses and ridges of diabase, scattered everywhere over the Archean, to the north and northeast of the main area close to the bed of the present lake Nipigon, are often supposed to be remnants of an extensive system of dikes. Detailed examinations of many of them have shown

that, so far as accessible contacts are concerned, they are probably parts of sheets. Of course nothing is positively known about their cores, but one is justified in assuming uniformity on the Archean topography. In many cases, between the detached remnants of sheets or between these remnants and the main mass of diabase, are wide dikes now unconnected with any sheets, but of similar rock. These dikes probably mark some of the channels through which the molten diabase ascended.

The diabases are so widespread that we must infer that they were intruded at many different points, either simultaneously or successively. While only a few possible points of intrusion are known, we can infer the existence of others. Still it must not be forgotten that in the Snake River fields flows of between 50 and 60 miles are recorded for lavas which solidified into basalt. Where the lava was fluid (as is indicated by the coarse crystalline structure and absence of flow structure) and remained quiescent for a long time subsequent to extrusion, and where the outflow was so great that even the small remnants of the sheets now left show a minimum thickness of over 600 feet for a belt more than 60 miles in length—under such conditions, very few openings would suffice.

CHARACTER OF THE PREEXISTING TOPOGRAPHY AND DATE OF DENUDATION

Previous to the extravasation of the diabase the section of country lying south of the present lake Nipigon was underlain largely by Keweenawan sedimentary rocks, with here and there exposures of older crystallines. In the basin of lake Nipigon and northward there were numerous sedimentary remnants, outliers upon the Archean. The Archean itself presented that undulating and mammillated topography so characteristic everywhere along the margin between the sedimentaries and the earlier rocks.

In fact, the topography was that of a belted coastal plain with the Archean oldland to the northeast with numerous sedimentary outliers in the basin of lake Nipigon. The southwest part of the present basin represents a portion of the inner lowland. The main area of sediments lay south and southwest of the lake, and the first cuesta, that facing the oldland, can be traced from near the Canadian Pacific Railway line, lying to the west of the present Black Sturgeon valley, and continuing northwest to a point about 20 miles southwest of Nipigon House, where it turns southwestward again. The present Black Sturgeon river runs along the lowland in front of the cuesta to within a few miles of the present Canadian Pacific Railway bridge, where it turns and enters the cuesta, crossing to lake Superior through a gorge similar to that of a consequent stream.

The ancient belted coastal plain of North America, so well and characteristically developed nearly continuously around the whole convex southern, southwestern, and western border of the Archean oldland, is usually considered to be of post-Cretaceous age, it being inferred that the dissection by which the belted features of the topography were developed took place subsequent to that long period of post-Paleozoic planation which continued to the close of the Cretaceous.

As the Nipigon belted coastal plain—only a mere remnant clinging to the edge of the Laurentian peneplain, it is true—lies midway between the coastal plain of the Great lakes of the Saint Lawrence system and the similar coastal plain of the Mackenzie and Saskatchewan river systems, it seems not unreasonable to suppose that the conditions which were so uniform and similar on all sides of this area (for a similar belted coastal plain seems also to have developed north of the Archean oldland in the Hudson Bay basin) should have also prevailed here, and that the Nipigon coastal plain remnant may also be of post-Cretaceous age.

The incursion of diabase, judging by the nature of the contacts and from the character of the pre-diabase dissection and relief, took place at a time when the relief was at its maximum development. Numerous outliers lay in front of the main cuesta on the newly uncovered lowland, and remnants of many of these outliers are still preserved as lava-capped mesas standing well out on the lowland or even on the oldland. Had it not been for the protecting lava cover, it is very probable, in view of the enormous amount of erosion that has certainly taken place since the advent of the diabase, that the number and area of these outliers would be much less. In fact, it is quite possible that little, if any, of the Keeweenaw sediments would have been preserved north of lake Superior.

DISTRIBUTION OF THE DIABASE

The main sheet of diabase occupies the ancient lowland depression of the Nipigon coastal plain, and roughly forms a crescentic mass bounding lake Nipigon on the south, southwest, and west. With small gaps where subsequent dissection has curved deep valleys,⁸ in the bottoms of which the earlier rocks are exposed, it extends in a crescent form from Gull lake on the east to beyond the Wabinoish river on the west. Southward and southwestward remnants of the sheet form mesa caps on many of the prominent ridges found scattered widely over the area on which the main mass of the sediments is still preserved, between lake Nipigon and lake Superior. Northward, practically the whole of the basin of the

⁸ Pijitawabikong bay, Nipigon River gorge, Black Sturgeon passage, and several minor passages.

present lake Nipigon is underlain by diabase, and beyond the lake as far as the Hudson Bay divide, mesas occur. Northeast of the lake the principal remnants of the main sheet forms the north and south peninsulas of Ombabika, and another large area, possibly a part of this sheet, occurs 12 miles farther northeast, at Grass lake. Since the oldland gradually increases in elevation northeastward, it is doubtful if the northeast edge of the sheet extended many miles beyond Grass lake.

At the south end of Pijitawabikong bay the remnant of the sheet is at least 600 feet thick. Near the middle of the crescentiform main mass of diabase, at Tchiatang bluff, on Black Sturgeon bay, it is at least 650 feet from base to summit. The remnant at Inner Barn island, in Wabinoosh bay, is 600 feet thick. In all these localities and in numerous other places not here indicated specifically a careful examination was made of the sheet from base to summit, and, apart from the fact that at some points erosion has developed great benches, no noticeable change in the holocrystalline texture of the rock was observed and no indication was found that would lead one to think that the sheet consisted of successive flows.

At the northeast angle of lake Nipigon, on the peninsula of Ombabika, and at Livingstone point the thickness of the remnant of the sheet is about 300 feet, thinning to about 250 feet where masses of sediments underlie it. At various points around the margin of the oldland, remnants on the adjacent uplands vary in thickness from 12 feet in one noted instance to 150 feet. With regard to the masses of trap capping blocks of sediments on the cuesta to the southwest of the lowland, unless there is specific evidence to the contrary, it can not always be decided whether they are remnants of an original capping sheet or are parts of a sheet that had been intruded between sedimentary beds, the overlying beds and the upper parts of the sheet having since been removed by erosion.

The relations of the thinner capping sheets around the lake basin on all sides of the lowland to the main mass in the lowland can be well comprehended by inferring that the molten diabase probably filled the lowland basin to overflowing and then spread out on the adjacent higher ground on all sides. Undoubtedly some of the diabase came to the surface through fissures on the margin, but not within the basin, but the tendency would be for it to move toward the lower ground. Eventually the diabase from its several sources probably filled the whole basin and spread far out on the adjacent uplands on all sides.

As to the maximum depth of the molten diabase over the lowest parts of the flooded lowland, no accurate figures can be given. An approximation based on the thickness of the remnants in the basin and of some out-

side it, but immediately adjacent on the neighboring upland, would place it at a minimum thickness of more than 1,000 feet.

SUMMARY OF THE POST-CRETACEOUS GEOLOGIC HISTORY⁹

Following the period of elevation which succeeded the Cretaceous peneplanation epoch, a belted coastal plain topography had reached a mature stage of development in the lake Nipigon basin. There were still many remnants of the lower members of the coastal plain sediments, scattered over the main lowland between the Archean oldland and the (probably) paleozoic sediments. At a number of different points in this and in the adjacent areas, huge masses of molten diabase were forced upward from below through fissures. In those parts of the district where the cover of Paleozoic sediments was not removed the diabase was forced between many of the beds in laccolitic masses or broke across the beds as dikes. Near the edge of the cuesta some of the laccolitic masses probably forced their way (horizontally) to the edge of the escarpment and the molten diabase poured down upon the lowland. Through other fissures passing only through the Archean rocks of the lowland, fluid diabase was also forced upward. The flows followed each other with sufficient regularity and so closely that a large amount of liquid rock collected in the lowland basin in front of the inner cuesta, between it and the oldland, eventually reaching such a height that it overflowed upon the adjacent uplands. Owing to its depth, the rock cooled very slowly except in the lower basal portions and in the upper part. Probably the middle portions congealed nearly simultaneously throughout the whole mass, after a long period of slow cooling.

Subsequent erosion has removed over 90 per cent of the diabase (possibly 95 per cent) and a considerable portion of the underlying sediments. Here and there, however, portions of the fossil post-Cretaceous coastal plain have been preserved by its diabase cover. The post-diabase degradation has developed a type of topography very similar to that of the original coastal plain. Subsequent to the outpouring of the diabase a system of block faulting has slightly affected the region, disconnecting contiguous portions of the diabase sheets and sills, modifying locally the type of topography developed, and differentially affecting the rates of erosion in different parts. The presence of laccolitic sills and capping sheets of diabase, much harder and more compact than the underlying sediments, has resulted in the development of the numerous mesas and buttes so characteristic of the region.

⁹ Post-Cretaceous on the assumption that the Great Lake basins (except Superior) are of this date.

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Trap sheets of the Lake Nipigon Basin

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Notes