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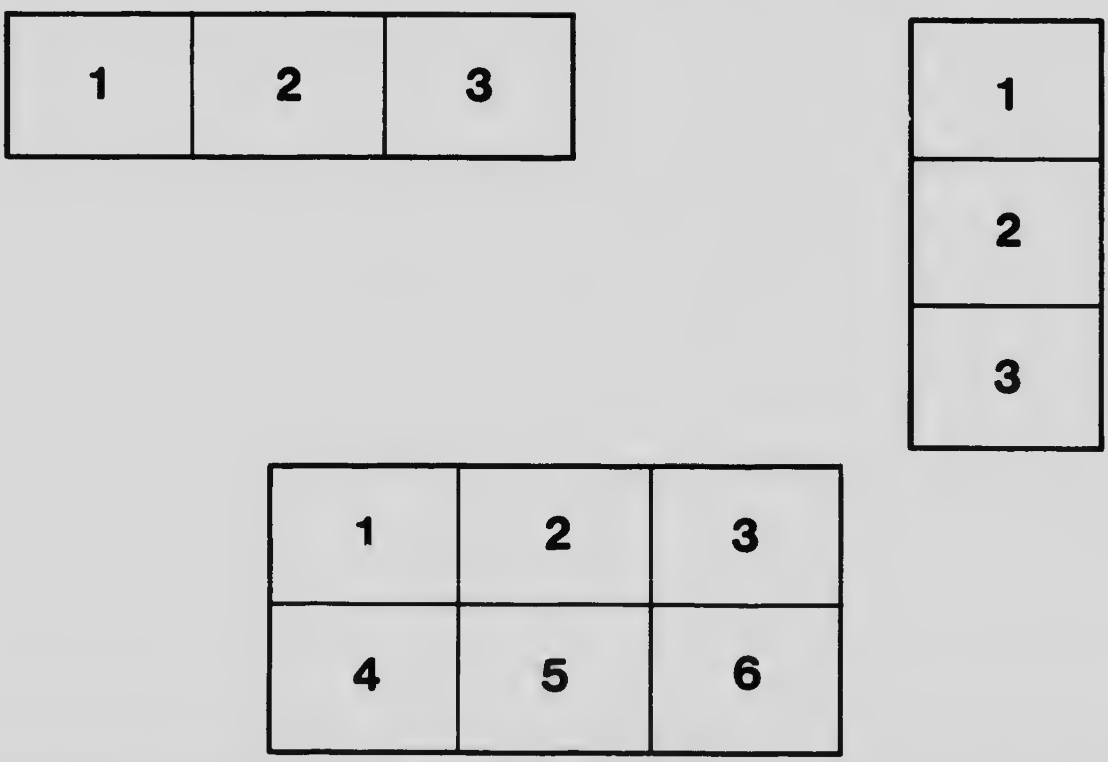
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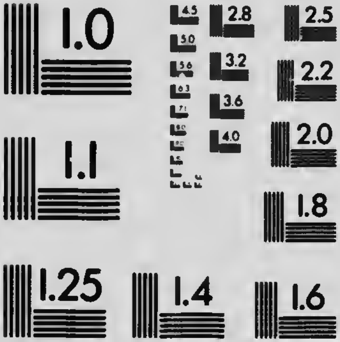

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PHYSICAL GEOLOGY
OF
CENTRAL ONTARIO

ALFRED W. G. WILSON.

PHYSICAL GEOLOGY OF CENTRAL ONTARIO.*

BY ALFRED W. G. WILSON.

(Read 20th April, 1901.)

CONTENTS.

* This paper was written as a thesis for the Doctorate of Philosophy at Harvard University, and was presented in May, 1901.

INTRODUCTION.

LOCATION.—That portion of the Province of Ontario desi CENTRAL ONTARIO is a triangular area with its base on Lake O to the south; the western arm is formed by the Niagara escarpm its extension from Hamilton to Collingwood; the northern bo follows the edge of the crystalline rocks from Georgian Bay to a on the St. Lawrence river a short distance east of Kingston.

Historical References and Sources of Information.—Previous institution of the Geological Survey of Canada, in 1843, there ha no systematic studies of the geology of Upper Canada, nc Province of Ontario. Before that date much even of the then un parts of the Province had been surveyed into townships, and m less accurate maps prepared. Admiral Bayfield's surveys of the Lakes were the most important work upon the shore-lines Province. The present available maps, though in part correct more recent work, are based largely upon these early surveys. D Bigsby had published (**1829**) a few papers in which reference is to certain features of the area under discussion. After the institu the Survey, the most important work is that of Alexander M Between 1843 and 1856 Murray had explored and mapped a portion of the present Province. His work in 1843 in the w portion of this area, and in 1852 in the eastern portion, forms the of our present knowledge of its geology. The first systematic ac in which all of Murray's work is summarized, was published l William Logan in 1863. This volume, entitled "The Geolo

Canada," is still the standard work of reference for the geology of "Old" Ontario. Since 1863 there has been little work in the area under the auspices of the Survey, except some work in 1886, the results of which have not yet been made public. Both previous and subsequent to Logan's summary there have been many shorter papers published upon various topics. Some of these will be noted in the text.

In the preparation of the present paper the writer has made use of many sources of information, and due acknowledgment will be made in the appropriate places. During the last few summers, as opportunity offered, the greater number of localities referred to in the context have been visited, and use has been made of the writer's own observations in the field.

The writer wishes to acknowledge his indebtedness to Mr. J. M. Clarke, of Albany, for the identification of a number of fossils; and to Professor W. M. Davis, of Harvard University, for advice and criticism while this paper was in preparation.

Résumé.—The area comprises, in all, about 6,500 square miles of territory. Within its limits are found rocks ranging in age from the Archean to the Niagara. These are overlaid by a great complex of deposits dating from the Pleistocene epoch. Everywhere along the northern boundary the various members of the crystalline series are found passing beneath the Cambro-Silurian sediments; in some localities outliers of the sediments are found upon the crystallines; again, inliers of the latter are found wholly or partially surrounded by the former. At one time the sediments extended much farther towards the north; their removal has revealed ridges, valleys, and residual monadnocks, the sub-mature topography of a well-dissected plain of denudation, a plain long antedating the Cambrian.

The basal members of the sedimentary series are destitute of fossils, and consist of more or less coarse detritus; above them thick deposits of fossiliferous limestone were formed, and in many localities this limestone rests directly upon the crystallines. These limestones are in turn overlain by bituminous shales.

A second cycle of slow depression, much greater than the former, resulted in the formation of a similar series of deposits, the upper members of which lie beyond the area under consideration.

In the long interval from the close of the last period of deposition within the area until the beginning of the Pleistocene epoch, during

which the northern portion of this continent is supposed to have, at different times, stood at different but undetermined elevations above the then sea-level, the rocks of this area were exposed to the atmospheric agencies of disintegration and degradation. The result was the development of a topographic system whose remnants, though partly obscured by the deposits of the Pleistocene epoch, are still recognizable.

Extensive climatic changes, by some supposed to be the product of, or accompanied by, elevation of this and adjacent portions of North America, interrupted these processes of dissection; ice, in the form of *sheet-glaciers*, modified the topography produced in previous epochs, and introduced large amounts of material from the adjacent crystalline area. During the close of the epoch, the time of melting of the glacier, the clay, sand, gravel and boulders which it carried were deposited. The waters collected in great lakes in front of the retreating ice. Around their shores deltas were built, beaches formed, and benches cut; and a new system of drainage lines was instituted.

Again, however, changes in relative elevations of different parts, and the withdrawal of the ice, led to the partial dismemberment of the drainage systems, to the definition of the present lake basins, and to the development of new lines of drainage, which are essentially the same to-day, though these and the lake levels are being slowly modified by secular changes of elevation.

TOPOGRAPHY OF THE PRE-SEDIMENTARY FLOOR.

Diverse Character of the Crystallines.—The crystalline series along the northern boundary of the area comprise rocks in greatest variety, crystalline limestones, micaceous and hornblendic schists, and gneiss, the latter very abundant. Associated with these are plutonic and volcanic rocks, acid, basic, and of intermediate varieties. The whole region has been one of complicated folding and intense metamorphism. The schistose structure of the rocks, throughout the area, is nearly vertical, and has a northeast southwest trend, with local variations from this general direction.

This great variety of rocks would necessarily offer different resisting powers to erosive agencies, and give rise to very diverse topography. In travelling through the region on foot one is continually ascending or descending. Even then he cannot fail to note the many small tarns, muskegs, and beaver-meadows found so frequently upon the upland areas.

Even-topped Character of the Uplands.—Almost anywhere in the region the ascent of a height, from which a good view can be obtained, will disclose a remarkably even sky-line, indicative of the even character of the upland surface, with occasional greater elevations standing out in relief. One of the best localities to see this is from the crest of the divide between Deer bay and Stony lake, almost the middle point of the northern boundary of the area. The waters of Deer bay lie 120 feet below; to the north-east is the small Lovesick lake; to the east, three miles away, is the basin of Stony lake, the water-level being thirty feet below that of Deer bay. The sky-line of the upland upon the opposite side of these basins is remarkably even. Almost directly east, twelve miles in an air line, are the Blue Mountains at the other end of Stony lake, rising above the general level. These ridges, locally called mountains, are syenitic masses which stand out nearly 200 feet above the rolling surface of the surrounding district.

A most striking view over the upland is that obtained from the summit of the cliff near the narrows of Haliburton lake, in the township of Harburn, forty-five miles north of Stony lake. Here the observer will be standing about 175 feet above the lake, and over 1,000 feet above Lake Ontario, this being one of the highest points in Central Ontario. The waters of Haliburton lake flow southerly. Within a radius of ten miles are a number of small lakes and streams whose waters flow to the west, north or east, eventually reaching the Georgian Bay or the Ottawa river.

Looking towards the east, south or west, the even upland plain appears to have a slight inclination to the south. Towards the north the direction of inclination is not so evident. Over the upland there are sometimes large, nearly flat areas of muskeg, a feature in which it is comparable to the uplands of Norway.

Dissection.—Though still in an early stage of the cycle, the region as a whole is much dissected. Minor ridges and valleys trending prevailingly northeast and southwest are the dominant topographic features of the upland areas; deep, steep-sided valleys, due apparently to later dissection, interrupt the continuity of the upland surface; slopes, frequently of almost bare rock, are common, and steep cliffs not infrequent. At the borders of the sedimentary series the difference in level between the general upland surface and the bottoms of the larger valleys would average about 150 feet; further north, in areas which have perhaps been much longer denuded, this difference is much greater. All the deeper valleys are now lake basins; many of the larger basins in the vicinity of Haliburton are deep, so that the depth of the valley bottoms below the level of the upland plain is frequently as much as 400 feet. The less-deep lateral valleys seem frequently to be graded with respect to the lake surfaces. In some localities, in small areas upon the upland, the topography is rolling, with only occasional low ridges and shallow valleys, except close to the present lake depressions.

Gradients.—The general even character of the skyline throughout the crystalline area justifies a comparison of the arithmetic gradients of the surface upon which the sediments rest, as ascertained by the differences between the elevations of a number of localities within the area. Data to institute a comparison along a series of parallel lines, outside of the sedimentary area, are not available. Radially from the upland surface in the vicinity of Haliburton lake to a number of points along the base of the Cambro-Silurian escarpment, between Georgian Bay and Kingston, the average gradient is nearly nine feet per mile.

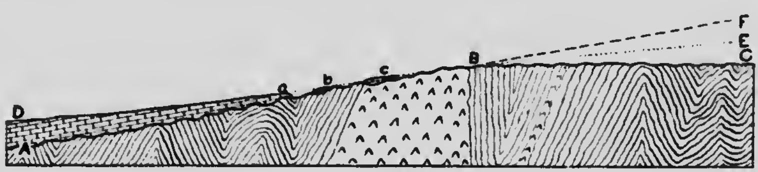

FIGURE 1.—AB represents the plain beneath the sedimentary cover ; BC, the plain north of the edge of the cover ; DB, the plain over the surface of the sediments ; *a*, the escarpment, *b* and *c*, outliers. Vertical exaggeration about forty times.

At Toronto the crystallines are known to be about 1,100 feet beneath the present surface. Two other borings, one at Cobourg, and the other in the township of South Fredericksburg, indicate that the floor is over 500 and over 600 feet, respectively, below the surface at these localities. The average gradient beneath the sedimentary cover along a series of lines from the foot of the Cambro-Silurian escarpment to the bottoms of these borings indicates that the gradient beneath the cover varies from twenty-two feet per mile in the western portion of the district to over forty-one feet per mile at the eastern end. The relative attitudes of these two surfaces are represented in figure 1, where AB represents the edge of a cross section of the plain beneath, and BC the edge of a cross section of that outside the sedimentary area.

Upon the surface of the sediments toward the eastern part of the area, the gradient appears to lie between that beneath and that without the cover (figure 1, DB). In the vicinity of Toronto it, in part, approximately coincides with that upon the surface of the crystallines to the north. The surface is too irregular to justify any general comparison. In the area studied, that portion lying east of a line running a little to the east of north from the west side of Balsam lake is inclined towards the southeast. West of this line the inclination is towards the west.

The meagre data available thus indicate that beneath the sedimentary cover towards the western end of the area the average gradient is more than double that of the uncovered portions, while at the eastern end it is about four times as great. Near the western end, the gradient from the summit over the crystallines to the Black River escarpment, and over the surface of the Palaeozoic strata, is nearly the same. This gradient is less than half the average gradient of the northern side of the basin of Lake Ontario (23.7 feet).

The relative positions of the three plains suggest certain problems which may be summarized thus :—

1. Do these three plains represent three distinct periods of planation?

2. Are AB and BC of the same age, but now discordant by warping?

3. Did the plain AB formerly extend upward in the direction BF; is BC of the same age as DB, or is it younger?

4. Is the discordance between AB or DB and BC produced by warping?

The accordance of the plains DB and BC towards the western end of the area is suggestive of warping elsewhere. Data of a detailed character as to the gradient upon the uncovered crystalline areas and upon the sedimentary outliers of the plain AB between the point represented by B and the front of the escarpment *a* have not been obtained. Without them the evidence available is inadequate to solve the problems.

It should be added that the relative arrangement of the three plains, represented as meeting in a broad angle at B, is purely fortuitous. The data in hand are not enough to determine whether AB and BC represent two intersecting plains, or portions of a continuous arc, and whether all three have a common point of intersection.

Similar relations between two plains of denudation upon crystalline rocks, meeting at low angles, have been found by Van Hise in Wisconsin ('**96**), and by Smyth in the region south of Lake Superior ('**99**).

Darton has described a somewhat similar case in Virginia ('**94**, 582). In the Grand Cañon of the Colorado we have an actual transverse section of two such intersecting plains, both older than the Cambrian, but meeting at a much higher angle.

THREE PROBLEMS STATED.—Among the many problems which present themselves for consideration, three, which have reference to the character of the sedimentary floor, seem worthy of special attention :—

1. Have we here an ancient sub-maturely dissected plain of denudation, a kind of geographical fossil, or is this topography the result of post-sedimentary causes?

2. In either event is there any possibility of approximately dating its origin?

3. Is the plain wholly the product of sub-aerial processes, or have we here a plain of submarine abrasion, and subsequent dissection?

FIRST PROBLEM, PRE-SEDIMENTARY TOPOGRAPHY.—Turning now to a consideration of the first of these problems, it will be necessary to describe, with some detail, a number of special localities which seem to afford evidence for its solution.

Inliers.—In the township of Verulam, about midway between Sturgeon Point and Bobcaygeon at the foot of Sturgeon lake, conspicuous among the hills just north of the lake, is a ridge of aplitic granite known locally as Red Mountain. The exposed base is about sixty feet and the crest one hundred and ninety feet above the level of Sturgeon lake. The ridge itself is about 2,000 feet in length and 600 in breadth; the longer axis strikes N 23°E. The crest is rounded, but falls off at the northwest corner very abruptly, at an angle of about 80°; on the east the inclination, though less, is still too steep for a person to descend in safety. At the south end the descent on both sides, though steep, is less precipitous. The crest and sides, especially towards the north, are free from boulders; but the southern end, where the crest is lower, is strewn with large and small sharply angular fragments derived from the ridge itself, together with some large blocks of limestone. Forming a belt one hundred yards in width is marshy ground, beyond which are lower ridges of morainic material. Half a mile to the west of this ridge, occurs a second much smaller granitic ridge trending in the same direction. The deposits of drift seem to obscure any limestone deposits which occur in the immediate vicinity. Four and a half miles to the west, at Sturgeon Point, thin-bedded fossiliferous Trenton limestones are found dipping north at less than one degree. On the south shore of the lake other outcrops of limestone occur, with very light southerly dip. To the north, the edge of the Cambro-Silurian escarpment, looking out over the main body of the Archean, is found at a distance of about 11.5 miles (as measured on the maps).

Is this the summit of a monadnock, buried when the sediments were deposited, and since uncovered in the progress of denudation; or have there been granitic intrusions since the formation of the stratified deposits? In this locality positive evidence either way seems to be lacking.

Further east, just north of Varty lake, and four miles from the edge of the escarpment, is a small oval dome of pink gneiss. Towards the north end of the dome four shafts, on a line transverse to the longer axis, penetrate the overlying limestone and show that the dip is nine degrees east on one side, and very much less on the other. A short distance away from the dome the strata have a dip of less than one degree. Near the southern end, where the gneiss is exposed, the limestone strata, quite close to the contact (the last few feet are covered with sod) are in an attitude which indicates that they abut against the gneiss. The higher strata, which once must have overarched the dome, have been eroded away. Here then we have beds of limestone strictly conformable with each other, and parallel to the surface upon which they rest, where seen in the shafts, arching over a dome of gneiss. So far as could be ascertained there is no evidence of post-sedimentary elevation.

In the valley of Mill creek, a small stream, the outlet of Sydenham lake, about five miles from the main area of the archean, is a small ridge of gray micaceous gneiss. The valley of the creek is about one mile in width, and flat floored; the nearest of the two bounding escarpments is 400 yards away, and the crest is 105 feet above the valley floor. The small crystalline ridge has evidently been exposed by the agency which carved the deep broad valley. Similar exposures of gneiss are found in the depressions occupied by many of the lakes of the Trent river system, on the Moira river, and elsewhere in like situations.

Still further east, at Kingston Mills, just west of the bridge across the gorge of the Great Cataraqui creek, there is a railway cut transverse to a granite ridge. The west end of this cutting passes through a small mass of calcareous quartz conglomerate, lying in a hollow upon the flank of the granite. The contact between granite and conglomerate shows in cross section on both sides of the cutting. There are, in all, about twelve feet of strata, dipping lightly to the west. The contact plane between these strata and the granite has, for the upper two-thirds of its length, a dip of about thirty-five degrees to the west. Towards the base this dip flattens out, and just where the line of contact passes beneath the material of the railway bed, the bedding of the sediments and the surface of the granite seem to be parallel (figure 2).

In this calcareous conglomerate are found fragments of crinoid stems and the casts of a Cameroceras. Several specimens of the latter, composed of white crystalline calcite, were taken from one of the lower beds at a point six inches from the granite. Other specimens more than five feet distant from the granite are identical in appearance with

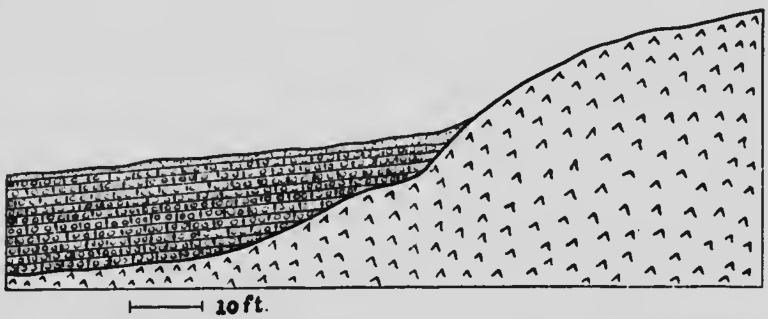

FIGURE 2.—Diagram to show the relative positions of the calcareous quartz conglomerate and the granite at Kingston Mills railway cut. Horizontal and vertical scales equal.

those obtained close to it. Neither rock has undergone any changes such as might be expected were the granite a post-sedimentary intrusion.

On the southwest flank of the same hill, at a slightly higher elevation, is a small exposure of a compact, fine-grained, gray limestone, with a conchoidal fracture, and in close proximity to the granite, which can be followed around it. A quarter of a mile west the limestone beds in the valley are fifteen feet in thickness.

Three and two-thirds miles almost directly south of this, at Fort Hill, on Barriefield common, midway between the Gananoque road and the river shore, occurs an ovoid quaquaversal dome with a gneissic core. The direction of the main axis of the dome is about northeast. The strike of the gneissic structure is about east and west, while the dip is almost vertical. The limestone forms a low infacing ridge, in places broken down. The maximum dip, sixteen degrees, occurs on the southwest side of the dome, but rapidly becomes less as one recedes from the central core. On the northeast side the dip is five and a-half degrees to the south of east, but away from the core, this also diminishes. The limestone is compact, fine-grained, and fossiliferous. In texture it much resembles that found upon the higher exposures on the southwest flank of the granite ridge at Kingston Mills. (figure 3.)

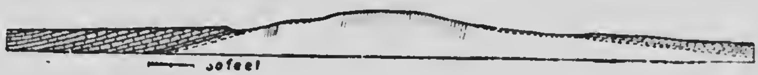

FIGURE 3.—Transverse section of the quaquaversal dome at Fort Hill, Kingston. Horizontal and vertical scales equal.

One-third of a mile east of the dome, the nearly horizontal limestones form an easterly-facing escarpment, talus covered, facing a large area of crystallines, partly gneiss, but mainly a dark red granite. The valley between is about one hundred yards in width, but towards the northeast the depth and width diminish, and the limestones, still almost horizontal, outcrop near the granite (figure 4). This granite is itself a

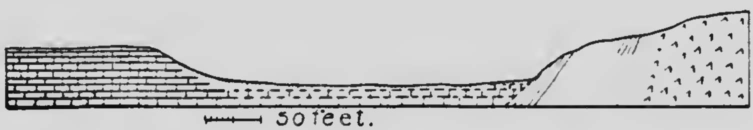

FIGURE 4.—Diagram to show the apparent relative positions of the limestone and crystallines east of Fort Hill. Horizontal and vertical scales equal.

large inlier from the western side of the arm of the crystalline series which connects the Canadian archean with that in New York. East and north, through the township of Pittsburg, there are many ridges of gneiss with a general northeast trend, thes trikes being sympathetic with the direction of the ridges, and the dips nearly vertical, or when inclined, the inclination is generally the same on both sides of the ridge in question. Between some of the ridges long tongues of horizontal strata extend northeastward, frequently, though not always, with an escarpment facing the gneiss. In no place does the limestone show a dip sympathetic to the inclination of the ridge adjacent, though there are cases where the relative positions of the two are such that the dip ought to be nearly thirty degrees, if the gneissic ridge were elevated after the deposition of the sediments.

With reference to these ridges of gneiss, and to the unroofed dome at Fort Hill, Dr. Drummond writes: "The Laurentian strata have been here elevated into these great ridges at a period subsequent to the

Black River times" ('**92**, 110). So far as indicated in the context, the only evidence upon which this deduction is founded, is the occurence of the limestone strata "at a high angle," dipping outward from the central dome of gneiss. The evidence, as stated, seems inadequate to admit of the broad conclusion reached.

If the ridges were elevated subsequently to the deposition of the strata, *i.e.*, were ridges of deformation, certain necessary results would follow. Over large areas the gneissic structure is frequently parallel. If, in such an area, a ridge is formed by elevation without faulting, in a region where the dips are not exactly vertical, the inclination on the side of the new ridge towards which the structure hades would be steepened, and that on the side opposite lessened. A traverse across the ridge in the direction of hade would show a decrease to a minimum where the grade was greatest, followed by an increase through the normal at the crest, to a maximum where the grade was at a maximum upon the opposite side, and then decrease to the normal (figure 5). In a series of such ridges this *diversity of dip* would occur *uniformly* across the ridges.

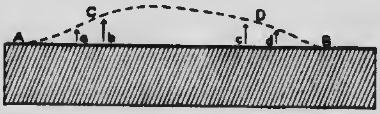

FIGURE 5.—If AB represent the position of the surface of the gneiss before upheaval, and ACDB the position of the surface of the dome after upheaval, then that portion that moves upward at *a* will have a less distance to rise than that at *b*. Therefore the dips between *a* and *b* will be steepened. Similarly, on the opposite side the dips will be lessened. Beneath the crest the uplift will be uniform, and hence there will be no alteration of dip. Where the grade of the new ridge is steepest the change from the original dip will be greatest.

Secondly, strata adjacent to *all* the ridges would be inclined in sympathy with the elevation, the greatest inclination being nearest the steepest and highest ridges; where the inclination of the ridge is very steep the strata would be affected for a longer distance away from the centre of elevation, or if the uplift did not affect the strata at any great distance, faulting and slipping would occur.

If the uplift took place gradually, or rapidly, during the period of deposition of the strata, the *uniform diversity of dip* in the structure of the ridges would be as in the first case. The strata would tend to thin out over the crest, if the material were somewhat coarse. If the uplift were very great some of the beds might even end in wedges against the sides of the ridge. The other necessary results would be as in the former case, though faulting and slipping are less likely to occur, owing to the softness of the beds. In the sections as usually exposed it would be very difficult to distinguish between intersedimentary and post-sedimentary uplift.

Had the ridges existed prior to the deposition of the sediments, having been the product of erosion, the structure of ridge and valley would frequently have the same dip; in cases where the dips varied the diversity would not be systematic. The position assumed by the sediments would depend upon three factors, two of which are, in practice, determinable by observation, the third by inference only. The steepness of the grade of the ridge would necessarily be an important factor. Where the grade was light the sediments would be deposited evenly over the inclined floor. As the inclination of the floor increased the tendency would be for the beds to wedge out and finally to abut against, rather than to rest upon the incline. The fineness or coarseness of material and the degree of agitation of the water would be important varying factors. Where the waters were quiet, and the sediments coarse, the deposition could take place upon slopes down which the materials would readily move if the waters were agitated. If the sediments were fine, the slopes upon which they could rest would be much steeper. The angle of repose for the sediments will then vary as each factor varies, and hence numerous variations are possible and many of these are also probable.

The deduction leads to inquiry as to what is the maximum angle of repose at which, under what may be called normal conditions of deposition, strata of different compositions may be deposited, for obviously this must be known before we can determine, from the dip alone, whether strata were deposited in an inclined position. The number of variants is too great to permit of a complete reply to the question; it seems advisable rather to apply the criteria already deduced to the facts under consideration, and indirectly to obtain a partial answer to the last problem.

In the areas where the gneiss is not obscured by a cover in the bottoms of the valleys, we frequently find the dips the same over large areas of ridge and valley; sometimes there is diversity, in the valley it may be vertical while in the ridge it is inclined, or vice versa, but *uniform diversity* is not found. This *uniform continuity* and lack of *uniform diversity*, particularly in areas where the structures are inclined away from the vertical, would alone indicate that these are not ridges of deformation, but on the contrary, would lead us to infer that they are the result of erosion.

Attention has already been called to the lack of sympathetic dip in limestones adjacent to steep gneissic ridges. At Kingston Mills cut the upper part of the granite face was too steep for the coarse sedimentary deposits to rest upon it under the then existing conditions. Consequently they moved down, as deposited, to a position of stable equilibrium, producing in the slipping, the slight upward drag seen in the beds just at the contact. At the ridge near Varty lake, and at that one now fronting the escarpment east of Fort Hill, similar conditions probably prevailed. The steep face of the ridge in the latter case has a slope of about thirty-five degrees, in some places it is even steeper, yet the limestones show no sympathetic dip, (figure 4). At Fort Hill, where the grade indicated by the strata is *now* sixteen degrees, the water would probably be somewhat deeper, and the calcareous sediments were very fine grained. The inclined position of the much coarser sediments at Kingston Mills, and the state of preservation of the fossils in these coarse sediments, indicate that the water was moderately quiet so there seems no adequate reason why the finer material should not have been deposited in its present inclined position at Barriefield common, (figure 6). With reference to the other criteria, thinning out of

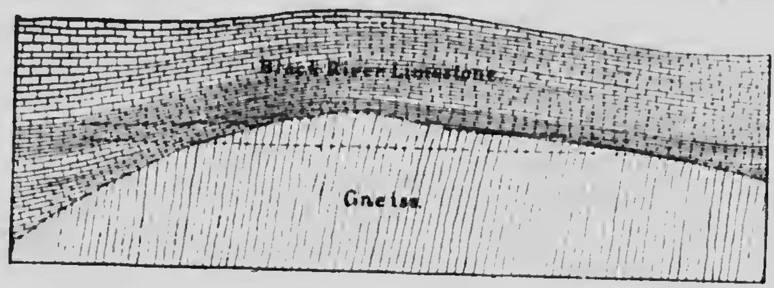

FIGURE 6.—An ideal section to show the probable conditions at Fort Hill before degradation and denudation. The dotted lines show the bottom and top of figure 3.

beds, faulting and slipping, so far as known the two latter are abseat, and the first can only be applied rarely.

The balance of evidence thus seems to indicate that the ridges are of pre-sedimentary origin, and that the sedimentary strata were deposited essentially in the positions in which we find them to-day. It is interesting to note that at the base of the cliff on Deer bay, in the distance of a little over a mile, there is a continuous transverse section of no less than five light anticlinal domes in strata which are only removed a few feet from the gneiss, here below the water level. The arch dies out in about the first twenty feet of strata. Above that, so far as the eye can judge, they are nearly horizontal.

Logan ('63, 98), refers to strata near Millburn (then, Daly's Mills) having comparatively high angles of dip near the junction with the

Laurentian, where they seem "almost always to be slightly accommodated to the worn surface." Laflamme (**'84**, 15; **'86**, 43) has noted similar features in the Lake St. John region; and Adams (**'93**, 338) has drawn attention to the fact that the *roche moutonnée* character of the Laurentian rocks was impressed upon them in pre-Cambrian times.*

Outliers.—Similar evidence as to the character of the pre-sedimentary surface is offered in the vicinity of the numerous outliers upon the crystallines.

Conclusions.—In Central Ontario, from the evidence afforded by the inliers of Archean within the area of Palæozoics, and of the outliers of Palæozoic strata upon the Archean, it seems that the sediments were laid down upon an uneven floor essentially the same as that presented at the present day by the Laurentian areas along the borders of the Cambro-Silurian escarpment.

Examples elsewhere.—These buried oldland surfaces are found in many other localities. Sometimes the eroded surface is almost a plane, as seen in the Grand Cañon section of the plain upon which the lower Palæozoic deposits rest. Again the surface may have had irregularities many hundred feet in height, as shown in the Baraboo ridge in Wisconsin, or as seen in an area in the Scottish Highlands, described by Geikie. (See Newberry, **'58**, 57; Irving, **'72**, 99, and **'77**, 427; Dutton, **'82**, 209; Geikie, **'88**, 400; Bell, **'94**, 362; Keyes, **'95**, 58; Van Hise, **'96**, 59).

SECOND PROBLEM, DATE OF EROSION.—The second and third problems for consideration have reference to the time and conditions of erosion by which this pre-sedimentary topography was produced.

From the writings of the earlier geologists the prevailing view seems to have been, that the Palæozoic sediments were laid down upon a rising sea bottom, and that the Archean areas in Canada represent the first emerged land. The more recent view is that the sediments were accumulated on a sinking land surface.

In this area, the granites, gneisses, and schists date from Archean time. The evidences of a vast amount of denudation afforded by the truncating surfaces, and the absence of lower and middle Cambrian sediments from every portion of the area, make it improbable that during the deposition of these sediments elsewhere the land here was below sea level. The consensus of opinion, based upon the study of

* See also Lawson, **1890**.

the conditions of the pre-Cambrian floor, and upon the distribution of the Cambrian sediments over North America, is that during the interval of the deposition of early Cambrian sediments there was a great interior continent, of which Central Ontario would form a part.

Walcott ('91, 567) thus sums up the conclusions from his studies on "North America during Cambrian time":—1. "The pre-Cambrian Algonkian continent was formed of the crystalline rocks of the Archean nuclei, and broad areas of superjacent Algonkian rocks that were more or less disturbed and extensively eroded in pre-Cambian time. Its area was larger than at any succeeding epoch until Mesozoic time."

* * * * * * * * * * * * *

4. "The interior continental area was, at the beginning of Cambrian time, an elevated, broad, relatively level plateau between the Paleo-Appalachian sea on the east, and the Paleo-Rocky Mountain barrier on the west."

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7. "The Cambrian Sea began to invade the great Interior Continental area in late Middle Cambrian time, and extended far to the north toward the close of the period."

8. "The depression of the continent in relation to sea level began in pre-Cambrian time and continued with a few interruptions until the close of Paleozoic time."

Many conclusions with reference to events which occurred so long ago must necessarily be somewhat uncertain. With our present knowledge of the evidences, it seems that during Archean and early Cambrian times this area formed part of a continental area. The processes by which the even-topped upland was produced operated so long ago that it is impossible to determine their precise nature. The character of the subsequent dissection appears to indicate that the present topographic features of the uplands were, in the main, the product of subaerial erosion during a pre-Potsdam period of elevation.

The balance of evidence thus leads to the conclusion that the present surface features of the crystalline area, at least along the borders of the Palæozoic sediments, are essentially the same as they were in pre-sedimentary times. The problem now arises as to the process by which the degradation and the denudation produced the even-topped upland and the varying features of the present topography.

It would be well to note with reference to the term *even-topped*, that a personal equation must be considered. The expression is used here to describe the sky-line of the upland plain, where for long distances, so far as the eye can judge, it appears with no marked irregularity. In many parts of the area the surfaces of large lakes offer horizontal lines for comparison. Occasional irregularities occur, and these frequently make abrupt changes in the otherwise even line. *Upland plain* has been used to indicate that imaginary surface whose elevations accord with the elevations of the even sky-lines, as seen in many parts of the area. *Upland* indicates portions of the present land surface whose elevation accords closely with the upland plain, and whose surface presents only minor irregularities, as compared with the greater irregularities of the surface of the region as a whole (figure 7). The present

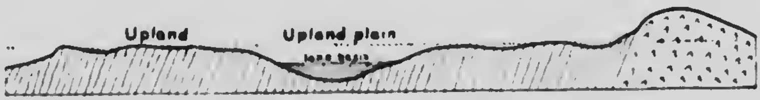

FIGURE 7.—Diagram to illustrate the definitions of terms.

topography is such that although the slopes are frequently graded, there are few areas to which the corresponding term lowland should be applied. The change in gradient from the valley side to the upland is frequently so marked as to justify the use of the term *shoulder* to describe the place where the change occurs.

THIRD PROBLEM, CONDITIONS OF EROSION.—Two hypotheses have been offered to account for the origin of topography of this nature. The one would consider it as the product of a single cycle, the other as the product of two or more (n + 1) cycles. The first, the "bevelling" hypothesis, would consider the present features as those of an ancient mountain system reduced to maturity and possibly re-elevated and made more rugged. The second would consider that the even uplands (produced during a long interval of time, at a period when the land stood relatively near base level) are remnants of the upland plain, and that the present valleys and lowlands were due to an increased activity of the agencies of degradation and denudation because of subsequent elevation.

If the area is part of an old mountain system reduced to its present form by bevelling, the present elevations must have once been higher and more rugged than they now are (figure 8, ABCDEF). In the process of degradation the ruggedness would be reduced and the slopes become graded by the removal of waste from the mountain sides and its transportation to the valleys, where it would either remain or be removed according to circumstances. Eventually, there would be a uniformly graded slope from stream bed to mountain top (AGCDHF). After the production of this slope the process will continue, but more slowly, with the gradual reduction of the crest, and corresponding

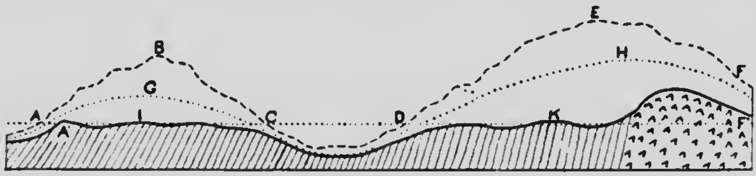

FIGURE 8.

decrease in grade, approaching but never reaching complete horizontality. Of necessity there will always be one point, or a series of points in line, higher than all the rest. From here the gradient would be downwards in all directions. In the late mature stages, when there is some approach to a nearly smooth surface over the whole mountain, there will be no abrupt change in slope.

Such an explanation of the process of degradation makes no provision for the occurrence of areas of greater or less extent with almost identical elevation, (A' IC, DK); nor for the abrupt changes in gradient such as occur at the shoulders before mentioned (A', C, D.) Hence, in the writer's conception of the process, it seems inadequate to explain significant facts of the present case.

The two-cycle (n + 1 cycle) hypothesis would explain these peculiarities by postulating a previous cycle (or cycles) of erosion in which the land was cut down to a surface of very faint relief and subsequently elevated and dissected, the new valleys not having yet extended their graded slopes far enough to completely obliterate the plain of the former cycle. The shoulders were produced where the change in gradient from the present valley side to the older plain occurs.

In almost every locality where the Cambro-Silurian sediments are seen in contact with the crystallines, the surface is seemingly quite fresh. Except in one known locality, where a distinct arkose of angular material is found, the old soil cover seems to be completely gone. The process by which this cover was removed and the surface of the Archean freshened, is at present undetermined.

SUMMARY.—The present topography of the pre-sedimentary floor may be regarded as the product of a degradation which produced a planation surface, and the residual monadnocks, as indicated by the even-topped upland. This surface was uplifted to permit of the renewed activities that carved and denuded the ungraded, or partly-graded slopes of sub-maturity, now presented wherever it has been freed from the Palæozoic cover. This latter dissection and denudation antedates the sediments, within this area, commonly called Potsdam, and may well have taken place in early and middle Cambrian times.

The ancient pre-sedimentary surface may be conveniently described as a sub-maturely dissected and denuded peneplain dating from before early Cambrian times.

THE PALÆOZOIC SERIES.

A Question of Correlation.—In tracing the geological history of this area, by means of the nature and relations of the different deposits found adjacent to and within its boundaries, there is a question that must not be disregarded, as to the correlation of partly eroded stratified deposits, at a low angle of dip, around the margin of an oldland area. In the formation of a series of deposits upon a slowly sinking land surface, the normal distribution of material is the formation of sand and pebble beds at the shore line, grading gradually into clays and muds, and thence into calcareous deposits (figure 9). Any given stratum must have three synchronous members, each merging gradually into the

FIGURE 9.—Diagram to represent the normal distribution of sediments. A, oldland ; B, sandstone and conglomerate zone ; C, shale zone ; D, limestone zone. Transition zones are indicated by lines.

adjacent member. The beds composed of strata which have been deposited successively must also each consist of these three members. During the time of the formation of any given bed the forms of life existing at that time will be distributed over the surface of that bed, each in its appropriate locality. The sand-loving forms will be near the shore, the mud-loving forms in the areas which afterwards become converted into shale, and the forms which thrive best in deep clear water will be found further seaward. At the transition zones where there is a merging of conditions there will be a merging of forms. Accidents may happen by which the normal distribution is slightly disturbed; and some few forms may exist in all three zones.

Since the production of the deposits, their thickness, and their other relations depend upon the two factors, *rate of depression* and *rate of supply of detritus*, with varying conditions as to depth of water, there are many possible variations from the normal arrangement. The result of one such variation is represented diagramitically in figure 10, where the rate of supply of detritus has been sufficiently in excess of the rate

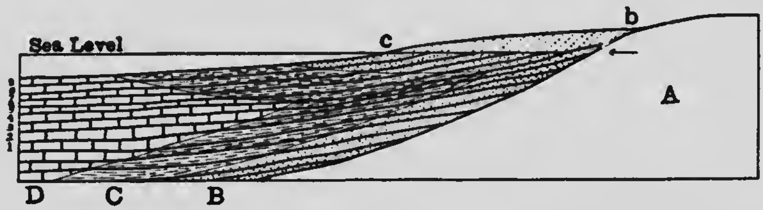

FIGURE 10.—Diagram to represent a special variation in the distribution of sediments. A, oldland; B, sandstone and conglomerate zone; C, shale zone; D, limestone zone. Transition zones are indicated by lines. *bc*, sub-aerial deposits.

of depression of the land, to permit of the transgression of the sands over the seaward zones. If a rapid variation had taken place in the opposite direction, the muds and sands might become mingled along the shore, and eventually the limestones might rest directly upon the oldland surface. Irregularities in the variations of each factor will lead to many irregularities and overlaps along the zones of transition.

By subsequent processes, after a greater or less interval of time, these deposits will become indurated and form sandstones and conglomerates, shales, and limestones. If, after uplift, the greater part of the sediments are eroded away, and small remnants, perhaps as outliers, remain in protected areas, we may find limestone in one place which is contemporaneous with sandstone in another, though the fossils in each are wholly unlike. Moreover, deposits, of entirely different epochs, may be almost identical because derived from the same source.

SANDSTONES.—In Central Ontario, particularly towards the eastern end, where the sediments occur in ellipsoidal basins, and with a very slight and irregular dip, the sandstones and some of the other beds entirely without fossils, there is a strong a priori argument for considering that the *sandstones* and *some of the limestones* are contemporaneous. The oldest sediments, within the area, which can be identified by fossils, are the Black River limestones. Conformably below these are beds, which in some cases carry fossils that are supposed to mark a transition vertically from the Chazy at least, but which equally well may mark a transition horizontally. Chiefly as outliers, but occasionally passing beneath the non-fossiliferous beds below the identified beds of the Black River formation, are a series of sandstones usually termed Potsdam. (The maximum thickness is, locally, sixty feet). As no fossils, except some very obscure Scolithus borings, have, so far as the writer knows, ever been found in these beds; and as *Potsdam* is a term introduced to describe rocks where certain definite stratigraphic and faunal relations hold, it is inadvisable to apply the term until these well defined relations are proven to exist here. Even were fossils found in the sandstone, the possibility of their being, *in this locality*, contemporaneous with the lower limestone beds, would not be diminished.

Much of the sandstone of these deposits, in this area, occurs in depressions between pre-sedimentary ridges. There are many angular fragments of gneiss and quartz, both large and small, included in the sandstone. In many places there are no known beach-worn pebbles, and no fossils, even in very thick beds; the material has been well sorted and consists almost wholly of quartz grains; the beds are frequently very massive and obscurely cross-bedded; ripple marks are absent or very obscure in many localities. There thus seems to be good reason for thinking that much of this sandstone may be waste which was laid down here, possibly by streams, after the crystalline surface had been smoothened and freed from its residual soil, if such ever existed, but before the advent of the sea, and that the shoreline of that time is now concealed by the overlying deposits. Subsequently, in the rapid depression of the land immediately preceding the time when the limestones overlapped upon the crystalline area, the surface of these sands may have been evened off, and perhaps a small amount of new material was added.

ARKOSE.—There is one known locality in which the non-fossiliferous sediments beneath the identified Black River limestone are especially interesting. At the foot of the escarpment on Deer bay, just at water level, a few well marked beds of arkose are exposed. The beds average about ten inches each, the whole deposit being an unknown amount over six feet in thickness. This arkose consists of translucent partly worn crystals and fragments of quartz and angular fragments of pink orthoclase feldspar, cemented with a dark reddish-purple feldspathic and calcareous cement, with occasional patches which resemble the argillaceous portions of some of the succeeding beds. The rock is readily friable and forms a beach of small gravel just at the foot of the cliff. The constituents of this arkose are distinctly different from those of the adjacent gneiss. The nearest outcrop of gneiss is one hundred yards away, and the water between reaches a maximum depth of nine feet, but, from the conformation of the bottom, the exposed portion of the deposits must evidently be within a very few feet of the gneiss immediately below it. The deposits may be regarded as a remnant of the old soil cover of pre-sedimentary times, slightly rearranged.

BLACK RIVER AND LATER FORMATIONS.—Succeeding these unidentified beds are the Black River limestones, which form a cuesta, whose northern boundary forms an escarpment extending from Georgian Bay to Kingston. The Black River beds are succeeded by the Trenton limestones with a thickness, as calculated from the dips near the eastern end across Prince Edward county, of over 1,400 feet. These are overlain by about 100 feet of Utica shales. Above this are nearly 800 feet of Lorraine shales and sandstones, overlaid in turn by 545 feet of Medina marls and sandstones. The upper bed of the Medina is, in Central Ontario, a heavy gray sandstone, about twelve feet in thickness, but occasionally thicker. The beds above this, found in the Niagara escarpment, consist of Clinton dolomitic limestones and shales, overlaid by the Niagara limestone. Throughout the region, so far as known, there is no observed unconformity between the beds of the various formations.

SUMMARY OF THE PALÆOZOIC HISTORY.—The geologic history of the area, subsequent to the period of denudation and dissection of the crystallines, was begun by a depression of the land, during which some small amounts of sand were deposited along and near the shores, with deposits which formed shales and limestones in the deeper waters. This depression continued somewhat faster than the rate of supply of detritus, and finally limestones, which, however, contain siliceous material, were deposited over the whole area. The waters were "richly tenanted by a great variety of forms of invertebrate life, and representing the culmination of invertebrate animals in the Lower Palæozoic" (Dawson, '89, 73). The great thickness of the deposits indicates that the Trenton epoch was of considerable duration. Towards the close of the limestone-forming epoch a variation took place, the new material supplied to this area was in the form of clays and muds. The change in the character of the deposits was accompanied by a change in the types of animal life here present. This change, marked by the Utica shales, was probably caused in part by a decrease in the rate of depression of the land. That it did not cease is shown by the thickness of the deposits.

Throughout the Lorraine epoch the area has been one of large sandy mud flats, alternately bare, exposed to the sun and rains, and submerged. The shallow sea appears to have endured for some time, since these deposits gradually give place to the sandstones of the Medina epoch. During the Medina there has been an alternation of the depth of the ocean here, as evidenced by the mingled sandstones and marls, the former with mud cracks, ripple and current marks. The final stage of the Medina led to the accumulation of a broad thick band of fine-grained siliceous sandstone, free from ferric oxide, in marked contrast to the majority of the lower beds.

The succeeding epoch must have begun with a relatively rapid depression of the land, since the overlap of the Clinton dolomitic limestone upon the upper sandstone of the Medina is abrupt. The depression seems to have continued rapidly enough to permit of the overlap of the succeeding Niagara rocks upon the crystalline areas far to the north. From the purity of the limestone, and from the types of organic remains, and their abundance, it is inferred that the waters of this epoch were clear and warm. The materials from which the limestone is made were probably drawn from the sea water by the invertebrate animals in the making of their hard parts.

This second great limestone-making epoch was followed by a gradual shallowing of the water, during which the Guelph dolomites were formed. Eventually the water became very shallow ; enclosed lagoons, occasionally flooded, were numerous ; in these lagoons the salt and gypsum beds of the Onondaga were formed by the evaporation of the water and the concentration and precipitation of the saline compounds in solution.

The sandstones of the succeeding Devonian period are now many miles distant from the front of the Niagara cuesta. They may at one time have reached out and overlapped it, but if so, what their north-eastern extension may have been is unknown. During the period of their formation the central portion of the Archean area may have been above water, and the denudation which has subsequently removed all the Niagara limestone, with a very few small protected areas excepted, could then have already begun. It is interesting to note that the peneplain represented by BC (figure 1, page 144) may date its beginning from this Devonian degradation.

The area had thus taken part in three great cycles of deposition concomitant with three great continental oscillations, or a long continued single oscillation of varying rate. During two of the cycles great limestone deposits were made within its boundaries. The nearest known areas of Lower Carboniferous are in Michigan, 140 miles away, and their composition is such that it is usually inferred that ever since the close of the Devonian period this area has been above sea level and exposed to denudation and dissection.

POST-CARBONIFEROUS HISTORY.

MESOZOIC, CAINOZOIC AND EARLY PLEISTOCENE EPOCHS.—There is little or no direct evidence of the history of the area during Carboniferous and Mesozoic time. The late Mesozoic was a period of extensive peneplanation throughout most of North America. In Wisconsin and Michigan to the west, and in New York and Pennsylvania to the south, the remnants of the planation surface have been recognized. It seems probable that the same planation processes, working northward from these areas, and southward from the Arctic region, may have, in part, produced the younger of the two plains upon the Archean areas in Canada. It is true, this plain may be of pre-Palæozoic age. Whether it is such, and yet younger than that beneath the sediments cannot be shown until it is proven that the sediments once actually rested upon it, and not upon a surface now eroded away. This latter would be the former northward extension upon which they now rest (figure 1, BF p. 144). The study of the isolated outliers, such as those of the small areas of limestone in the Lake Nipissing region and elsewhere, may show that they are preserved because thrown into their present protected positions by the downthrow of a fault block. If so, the probability of this plain being of Cretaceous age will be strengthened. By way of comparison it may be noted that a series of faults dislocated the early sedimentary rocks of Sweden and Norway. Later planation left only a few small patches at baselevel, upon the downthrown blocks. Subsequent elevation of the whole area, and erosion of these softer remnants produced a series of depressions, in some of which are still found isolated patches of the soft rocks. The lower portions of these depressions frequently form lake basins, the most noted of which are Boren, Roxen, Glan, and Braviken.

The period of Cretaceous planation was followed by an undetermined amount of elevation of portions of the continent, probably including this area. The immediate effect of such an uplift would be the active

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MAP
of the
RIVER SYSTEMS
of
CENTRAL ONTARIO
by
A.W.G.Wilson
Scale
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81°30'
81°
80°30'
80°
79°30'
45°
44°30'
44°
43°30'
GEORGIAN BAY
Nottawasauga
Bay
Owen Sound
Orillia
Severn R.
Collingwood
SIMCOE
Nottawasauga R.
Barrie
Lake
Simcoe
GREY
BRUCE
DUFFERIN
Palgrave
YORK
Humber R.
WELLINGTON
PEEL
TORONTO
HALTON
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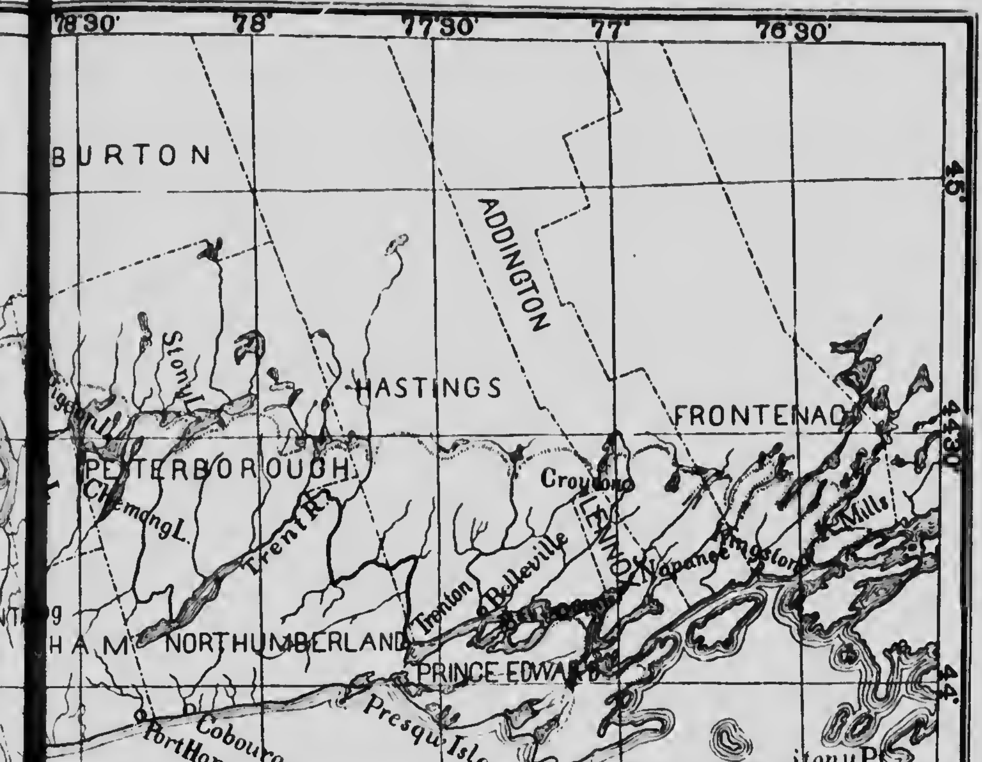
78°30'
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76°30'
BURTON
ADDINGTON
HASTINGS
FRONTENAC
PETERBOROUGH
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Stony L.
Trent R.
Croydon
Belleville
Trenton
Napanee
Mills
NORTHUMBERLAND
PRINCE EDWARD
Presqu Isle
Cobourg
Port Hope
Pt. Peter
O N T A R I O
NEW YORK
45°
44°30'
44°
43°30'
43°

renewal of the process of subaerial degradation, and the development of topographic forms and an adjusted drainage system appropriate to a region underlain by alternate series of strong and weak rocks at low angles of dip. During the extensive Pleistocene glaciation the topographic features, the product of the preceding cycle, may have been largely modified, destroyed, or otherwise obliterated, and new forms produced.

Measure of erosive work.—Our measure of the work performed during these two periods must necessarily be derived from a knowledge of the present features, and of the conditions existing before the operation of the erosive agents. The proportion to be assigned to either period depends upon a knowledge of the relative competence of the processes of degradation, and of the time during which they were operating. The amount of work performed by either process, and by both, will vary with the locality, and with the conditions under which the process is in operation, *e.g.* geographical position, elevation, position with reference to baselevel, character of the rocks, relation to the ice front and to the névé of a glacial lobe. At present the knowledge of the total effects of both processes, and of the method of operation of sheet-glacier ice, seem too limited to warrant the assignment of a definite portion of the work to either, except in local cases.

PRESENT FEATURES.—*General Description.*—The Niagara cuesta is a prominent topographic feature extending along the south shore of Lake Ontario from east of Rochester to Hamilton, thence northward across Ontario to the Manitoulin Islands, thence curving southwestward to the east of Green Bay and across parts of the States of Wisconsin, Illinois and Iowa. Lakes Erie, Huron, and Michigan are situated upon the outer lowland; Lake Ontario, Georgian Bay, and Green Bay lie upon the lowland in front of the cuesta; Lake Superior lies in a position outside of both lowland and cuesta.

The cuesta-front forms one boundary of a great inner lowland. The southwestern loop of this lowland is best developed in the State of Wisconsin, and may thus be appropriately designated the WISCONSIN LOWLAND. The eastern part, the ONTARIO LOWLAND, includes the basins of Lake Ontario and Georgian Bay, as well as the adjacent land areas. The two parts of the inner lowland are connected by a narrow, more or less submerged belt, passing across the Manitoulin Islands. It has been found convenient to refer to the present unsubmerged part of the Ontario lowland, within the Province of Ontario, as the CENTRAL ONTARIO LOWLAND. (Map I.)

The northeastward extension of the Ontario lowland merges gradually with the cuesta formed by the Black River strata. The escarpment-front of the Black River cuesta extends from the vicinity of Kingston northwestward to Georgian Bay, and thence across the bay, beneath whose waters it seems to be still traceable, to the Manitoulin Islands. The unsubmerged portion of the escarpment averages about ninety feet in height, and locally is occasionally much higher In the region west of Lake Simcoe, and in northern parts of Hastings and Addington counties, it is partly obscured by drift deposits.

The fronts of both cuestas present many irregularities appropriate to development under subaerial processes. The principal physical features of "Old" Ontario are those characteristic of an ancient coastal plain which has passed through a period of planation followed by one of uplift, dissection, and the development of an adjusted drainage system. Similar topographic forms have been developed, also with varying strength and expression, in Middle England, in the Paris Basin and elsewhere near oldland areas.

The drift deposits in Central Ontario form a prominent ridge, or series of ridges, the Oak Ridges, of varying breadth, lying at an average distance of about ten miles north of Lake Ontario, and extending eastward to the vicinity of Trenton. At the western end, near Palgrave, the thickness of the deposits is sufficient to almost obliterate the escarpment of the Niagara cuesta. A number of spurs extend southward and northward from the main ridge.

This morainic ridge divides Central Ontario into two drainage slopes, a northern and a southern. The Trent river, the largest stream within the area, conveys a large percentage of the drainage from the northern slope, and from the southern slopes of the crystalline area to the north, across the ridge to the Bay of Quinte in the vicinity of Trenton. The remaining portion of the drainage of this northern slope reaches Georgian Bay, chiefly by the Severn river from Lake Simcoe basin, and by the Nottawasaga river. The waters from the southern drainage slope reach Lake Ontario by a number of small streams. East of Trenton the drainage, which is across the area from within the Black River cuesta, is controlled almost wholly by the rock topography.

The present features of Central Ontario, as a product of the operation of the two processes, Pliocene and early Pleistocene subaerial erosion, and Pleistocene erosion by sheet-glacier ice, are of special interest, not only in themselves, but because of their relation to the

PLATE I.

FIGURE 1.—Pleistocene deposits at Taylor's Brick Mills, Toronto. The lowest beds are Lorraine shales; these are overlain by a thin sheet of till, and this in turn by the beds of the first Interglacial epoch. (Photo. taken 1895).

FIGURE 2.—Pleistocene Deposits at Taylor's Brick Mills, Toronto. Beds of the second Interglacial epoch. (Photo. taken 1895).

question of the origin of the basin of Lake Ontario. Although over large areas the topography of the rock floor beneath the Pleistocene deposits cannot be ascertained, there are also large areas in which there is no difficulty in determining its essential features, often even to minute details. Since the interpretation of the features of this rock topography depends upon its relation to the overlying Pleistocene debris, it has been thought best to first describe in outline, these latest deposits.

Pleistocene Deposits.—Hinde ('77), Coleman (**'94, '95, '97, '98, '99, 1900**), and others, have described Pleistocene deposits occurring in the vicinity of Toronto, notably at Scarboro' Heights, describing three sheets of glacial till. The two upper sheets overlie thick deposits of stratified and finely laminated clays and stratified fossiliferous sands and gravels. (Plate I.) One hundred miles east of Toronto, just north of Trenton, occur series of deposits in which is cut a sea-cliff attributed to Lake Iroquois. The crest of the Iroquois sea-cliff is 718 feet (bar.), and the rock surface just east of this, along the Trent River is about seventy-eight feet above Lake Ontario.* The total thickness is thus 640 feet. These deposits show three till sheets alternating with two series of stratified beds, chiefly sands and gravels. The precise thickness of each of the five series of beds has not been ascertained as yet, but the till beds certainly, and the stratified beds probably, are much thicker than the similar beds at Toronto.

Between this locality and Toronto, in each of four other transverse sections northward from Lake Ontario, the three till sheets have been encountered by the writer. In a trip, on foot, along the lake shore from Presqu' Isle to Burlington beach, the two lower of these three till sheets have been traced for a long distance. East of Port Hope, between Bowmanville and Whitby, and west of Toronto, a till sheet rests in many places directly upon the rock surface. Sometimes only the upper portion of this sheet is visible, and occasionally it passes wholly below the lake level. Provisionally this lowest sheet may be considered as the equivalent of the lowest till sheet at Toronto and at Trenton.

From Port Hope westward a second till sheet, with varying thickness, resting upon stratified deposits, both sands and laminated clays, and once (near Oshawa) upon the lower till sheet, can be followed along the lake shore almost continuously to Scarboro'. At Scarboro' there is a nearly continuous section about nine miles in length. Between Port Hope and Trenton the edge of this sheet lies from one to four miles

*There is a continuous exposure of rock surface along the Trent, transverse to the ridge, and in a number of localities to the eastward the general topography of the rock surface can be well established.

back from the lake shore. Provisionally this bed, from its position, not from any identification of underlying beds, may be correlated with the middle till sheet, the lower of the two sheets exposed at Scarboro'.

Except in the Scarboro' section, the edge of the third till sheet is found at a varying distance back from the lake shore. At Trenton it is about three miles from the Bay of Quinte; in Northumberland county it is about six miles north of the lake. Its extent northwest of Toronto has not been traced. The upper till in these localities is thus provisionally correlated with the upper till in the Scarboro' section and in the vicinity of Toronto. In no place, so far as the writer is aware, is it known to rest upon the middle till sheet, but always upon stratified sands, gravels, or clays. In Northumberland and Durham, and elsewhere, the upper till sheet is overlain by a series of stratified sands and gravels.

In the districts around Lake Scugog and around Lake Simcoe, and for some distance on either side of these areas, till sheets, overlying sands and gravels also occur. From their relative position and other relations, there is reason to think that the upper one of these is the equivalent of the third till sheet on the Lake Ontario side of the ridge.

The middle till sheet rests unconformably upon the beds of the first interglacial epoch; the amount of erosion which preceded its deposition cannot at present be determined because the necessary data are not all collected. Obviously the amount of erosion to be attributed to the ice sheet is also, at present, indeterminate. A maximum limit of less than five miles may be assigned in one case for part of the underlying deposits, because of the fragments of Utica shale in the middle till. It may be possible to define the upward limit later when the precise relations of the stratified beds are worked out.

In the Scarboro' section this till sheet fills an old erosion valley in the underlying stratified deposits. Hinde ('77, 402), who first described the depression, regarded it as a result of glacial erosion, but recent investigators, because of its form, location transverse to the direction of the ice movement, and the absence of any evidence of violent erosion, consider it an old river valley. Similar but smaller depressions, some of which even Hinde regarded as stream channels, are found elsewhere in the Scarboro' section, and more rarely in sections to the east. At the eastern end of the Scarboro' section, where the ice *ascended across the beds*, the stratified beds, which underlie the till sheet, are very much contorted and plicated. Westward from this there is little or no

PLATE II.

FIGURE 1.—Plications in stratified sands of the first Interglacial epoch, Scarboro' Heights.

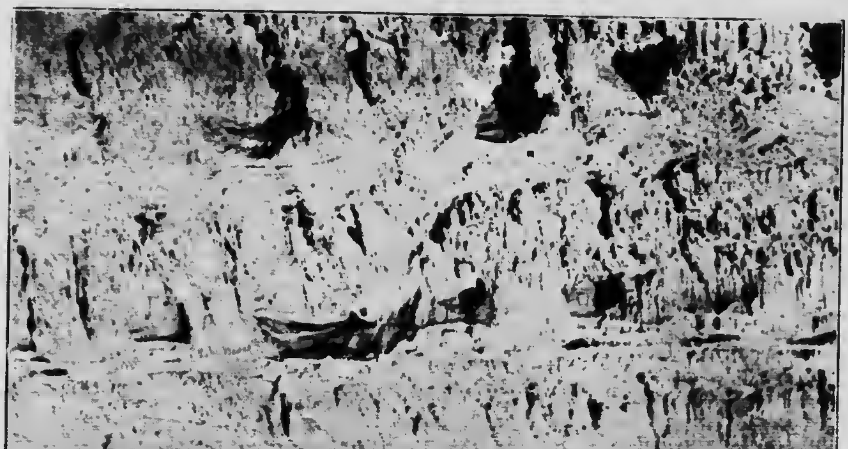


FIGURE 2.—Laminated clays and sands slightly folded by the overriding ice sheet, near Newtonville.

plication, not even at the crossing of the old depressions, and the till sheet descends at the opposite side of the section. Some twelve miles further west it again ascends over plicated beds. In some sections east of Scarboro' the till sheet is seen in clear cut cross section ascending across the beds with almost no plication of the underlying deposits (Plate II).

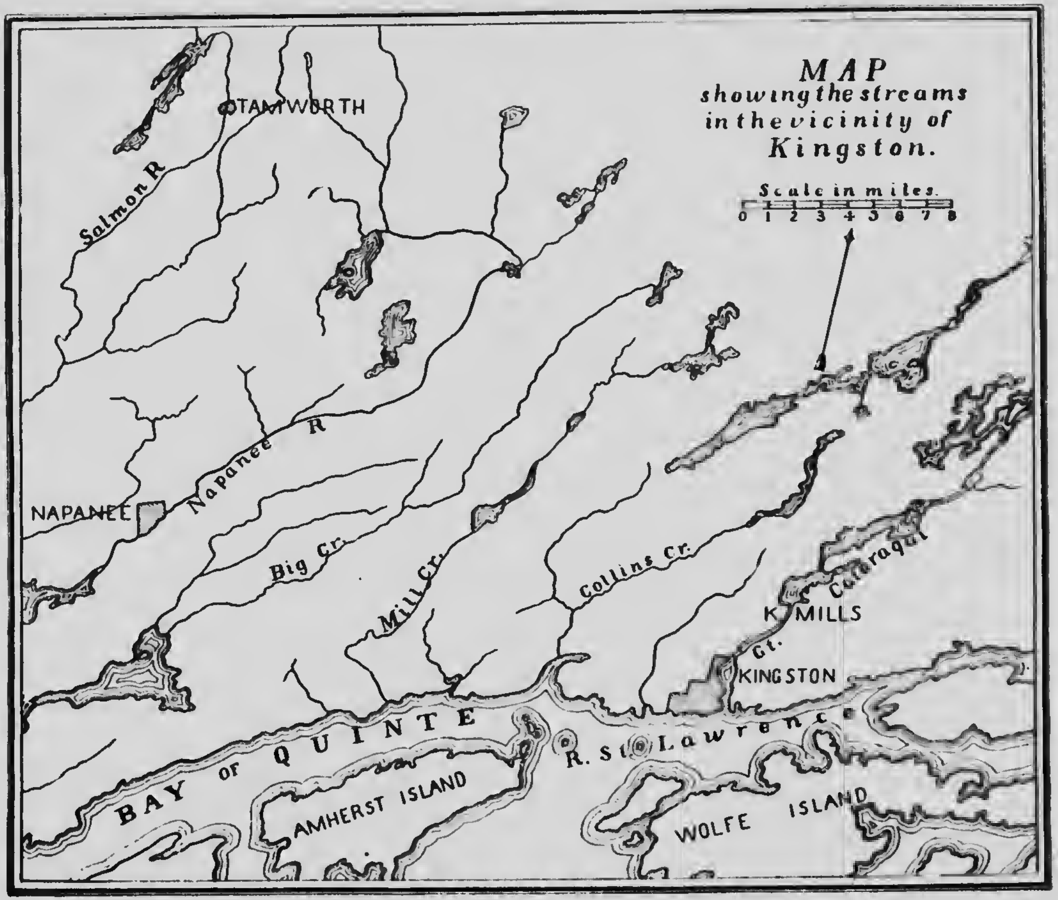
Whether the three periods of glacial transgression and retreat, marked by the three till sheets and the intermediate deposits in Central Ontario, are to be correlated with similar periods as determined to the south of the lake, or represent local variations in the later positions of one ice sheet, it is at present impossible to say. The correlation of the deposits in the two localities, for lack of sufficient knowledge of intervening areas, is not yet definitely determined. Professor Chamberlin has provisionally classified the fossiliferous beds beneath the middle till sheet as contemporaneous with the interval preceding the Wisconsin formation, regarding the middle till sheet of the Toronto sections as equivalent to the Wisconsin till ('**95**b, 273). He suggests that the Toronto beds might lie in a position at least one hundred miles back from the front of the ice sheet whose till deposits overlie them ('**95**a, 768; see also, Coleman, **1900**).

A feature of particular interest is the fact that here are two sheets of glacial till, overlying still soft sands and gravels, over which the ice that deposited the till sheets must have transgressed. In its transgression the ice sheet has passed over large areas without leaving any mark of disturbance in the underlying beds. In some cases, not in all, where it ascended, the beds on the side from which the ice came are very much disturbed, but the disturbance is confined to the place of ascent. Many instances of modern glaciers over-riding soft deposits have been cited as evidence of the inability of the ice to do significant erosive work. To this the principal objection has been that this inability is shown only at the edge of the sheet. In Central Ontario, whatever the distance between these beds and the edge of the ice sheet which overlay them may have been, it is extremely improbable that at its maximum extension they were just at the margin. There were two periods when the ice overran obviously very incoherent deposits, and there is no known evidence of great erosion by these ice sheets *alone*, over a distance of more than one hundred miles in length, and of a width undetermined, but more than six miles for the middle till sheet, and over an area very much larger for the upper, and perhaps for both. Whatever may have been the amount of material eroded by the ice during these two advances, there is an enormous amount still in place, lying between the rock floor and the youngest till sheet. The inability of the sheet-glaciers, under certain unknown conditions, to remove this material during the two last periods of transgression, raises the question as to whether these conditions may not have existed also during the period of operation of the first ice sheet, when it was overriding bed rock instead of soft sands and clays. This question can in part be answered by a study of the bed rock features.

Eastern Rock-Valleys.—The eastern boundary of the moraines is approximately a line running northeast from Trenton to a point just south of Croyden in the northern part of the township of Camden, Addington county. East of this line in the southern part of the county of Hastings, in Prince Edward, in Lennox and Addington, and in Frontenac, the topography of the underlying rock surface is but little concealed, large areas of almost bare limestone are quite common. This is also essentially true of the rock topography along the margin of the Black River cuesta between Mud Turtle lake and Kingston, with the exception of a narrow belt in part of Huntingdon and Hungerford townships.

In the eastern counties the drift cover is very thin, and rock valleys, now occupied by streams, can be followed readily from their outlet on Lake Ontario or the Bay of Quinte, more or less completely across the limestones towards the Archean. In these counties there are six at least which can be followed all the way across, each to a long narrow lake whose limestone scarped basin is floored with crystalline rocks. There are many more which reach nearly across (Map II). From a map study of Jefferson county, New York state, it seems probable that at least some of the streams in that state belong to this category. The whole series of valleys, some twenty-five and more, is remarkable for its parallelism, the general direction being southwest, and for the regular spacing of the streams. The valley depressions of some are readily traceable under the lake waters, with some complications, to a line running between Stony Point and Point Peter, and in some cases beyond. Where these valleys are unsubmerged, their sides, at the lower ends, are generally steeper on the southeast, towards which the rocks dip, and less steep, sometimes broadly open, on the northwest. Towards the upper end, especially in the case of those which reach the Archean highlands, the valleys are sometimes still broad, but both sides are of about equal altitude and steepness. The average depth is about one hundred feet, locally often much more, and rarely less, except in the smaller valleys. Towards the lower end the width varies to about five miles, while at the upper ends they are usually much narrower.

MAP II.



MAP
showing the streams
in the vicinity of
Kingston.
Scale in miles.
0 1 2 3 4 5 6 7 8
TAMWORTH
Salmon R
NAPANEE
Napanee R
Big Cr.
Mill Cr.
Collins Cr.
Cataraqui
K MILLS
Ct.
KINGSTON
BAY OF QUINTE
R. St Lawrence
AMHERST ISLAND
WOLFE ISLAND

Near the edge of the cuesta, the breadth is sometimes over a mile, and some of the valleys are remarkably flat-bottomed, occasionally with gneiss outcropping in the floor, the sides being limestone. Very frequently the bounding walls in the upper reaches are so steep that they are in places unscalable.

The intervalley spaces are flat topped, inclined gently southward at a less angle than the dip, and have a thin, more or less discontinuous covering of drift, rarely enough to significantly change the flat upland topography. Some few of the intervalley areas, though flat topped, are very narrow in parts, even to one hundred yards in width.

The drift blocked equivalents of these valleys are found all the way to the vicinity of Lake Simcoe and perhaps beyond. The upper reaches along the Black River cuesta, are generally occupied by streams or lakes. The Trent river, through part of its course, occupies portions of several of these. The Bay of Quinte, itself a complex, may be a member of the series.

The lower courses of all lie below the level of the first interglacial deposits, and in some cases the lowest till sheet, overlaid by some of the interglacial beds, is found within the valleys. They are thus either of glacial or of preglacial origin.

The axial direction of the drumlins in Hastings county, corroborated by the direction of striæ upon the inter-valley upland surfaces, indicates that the direction of ice flow sometimes made an angle of about fifteen degrees with the direction of these valleys. Sometimes, just at the edge of the escarpment, striations are found on a curved rock surface bending down obliquely into the valley. The best example is on Mill creek, about two miles west of Sydenham. Occasionally in the valley bottom striæ are found which are not accordant in direction with those upon the adjacent upland, but which nearly accord with the direction of the valley sides, suggesting in some cases, local oblique motion beneath the general ice stream. In other cases the direction of ice motion and that of the valley coincide. As a rule the escarpments and valley-sides, where the rock is exposed, are little, and generally not at all, scoured. On the other hand, where there is a change in the direction, and the valley is bounded by a steep rock wall, that cliff face is sometimes polished smooth on the thrust side, but not elsewhere, in one case, near Napanee, for over one hundred feet below the crest. The postglacial retreat of the escarpments has been very small in some cases, and in others nothing at all, there being no talus in some places, in others striæ rounding over the edge, or, again, the cliff presents a polished face. In one

PLATE III.

FIGURE 1.—Long Reach, on the Bay of Quinte—a drowned rock-valley.

FIGURE 2.—Benches on the lower Trent, north of Trenton.

case a broad open valley (Great Cataraqui) suddenly turns slightly and narrows to a gorge cut in granite, through which the ice has passed. In another case (Consecon creek, Prince Edward county) the present creek heads on the upland and runs southwesterly, the valley gradually broadening and deepening. About a mile to the east of its head the Bay of Quinte valley, (Plate III., fig. 1) whose depth below the upland at this place is 185 feet, cuts across at an angle of about fifty-five degrees.

These valleys are all, with the single exception of the gorge at Kingston Mills, carved out of homogeneous limestones, lying in a nearly horizontal position. Before the carving of the valleys the country must have been one of almost no relief. The adjacent region, from which the ice came, is also one of low relief. There are thus no topographic features which would cause the action of the sheet-glacier to be concentrated along certain lines which are oblique to its own general direction of motion, and there is no reason why these lines should sometimes unite into one trunk valley. The expectation is that a sheet of ice would under such circumstances tend rather to reduce than to accentuate topographic features. This was true in this area in the case of the second ice sheet, and has been shown to be true elsewhere, and therefore is not an assumption as to a method of *sheet-glacier* action. It is known that an *ice stream*, which invades a valley of subaerial erosion tends to destroy the systematic arrangement of spurs and re-entrants. That a sheet-glacier in a less confined area would tend to erode systematic valley-systems more or less athwart its course seems highly improbable.*

On the contrary, their form and adjustments are appropriate to stream erosion. Loose debris in the bottoms of the valleys near their heads, pinnacles, and isolated outliers along the valley sides, are, however, almost completely wanting. Occasionally the present stream is held back, forming a small pond, by the accumulation of a little drift debris across a portion of the valley, or by a rock obstruction. Where the tributary valleys join a main valley there is no discordance, or as Playfair puts it, there is "such a nice adjustment of their declivities, that none of them join the principal valley, either on too high or too low a level; a circumstance which would be infinitely improbable, if each of these valleys were not the work of the (predecessor of the) stream that flows in it." (**'02**, 102).

The fact that these valleys are broadly open towards the southwest,

*Compare with the valley of the Rhue, Davis, **1900**, p. 275.

and are narrow and steep-walled towards the northeast, indicates that the streams which carved them flowed towards the southwest. These streams may have been initially consequent on a plain inclined towards the southwest, but whose inclination has since been altered by secular uplift or depression, so that the present St. Lawrence flows over the lowest portion of the sag. The direction of the streams has undoubtedly also been controlled by the direction of the master joints of the limestone, and the valleys may have been developed by headward growth of streams guided by these joints. To the writer this latter alternative seems the more probable, though additional field work is necessary before a definite opinion can be expressed. The outlet to the present St. Lawrence seems to be a complex of several of these valleys in which the water is now flowing in a reversed direction owing to secular changes in elevation.

Jointed and Fissured Uplands.—Another feature of the rock surface of the limestone uplands, found upon the intervalley ridges, along the Black River escarpment, and upon the many outliers in front of the escarpment, is the joint structure, which has split the surface layers into rhomboidal blocks of various sizes. Subsequent weathering of the upper blocks especially, has widened the fractures and rounded the edges of the blocks more or less. In some cases we find till and pieces of gneiss in these widened fractures, and in others the glacial striæ bend obliquely downwards in crossing the curved surfaces near the open fissures. Again, over wide areas of almost bare rock, the joints occur, but the blocks are close together and there is no weathering or rounding of the edges, and the striæ cross the joints without deflection. These features occur sometimes within short distances of each other on limestones that are identical in texture, and so far as known, identical in composition. They are found both at the edges of the upland and some distance back from them; unfissured areas are sometimes found close to the edge of the escarpments.

The jointing which produced the rhomboidal blocks preceded the earliest ice advance. The relation of the ice-scoured surface to the open fissures shows the existence of these fissures before the advent of the ice which planed that surface. The low temperature of the subglacial water, and the absence of organic matter in solution, except the small amount derived from the preglacial soils, render it improbable (but not impossible) that the subglacial waters could have materially widened them. During interglacial times, at least portions of the area were below the level of standing water, and were possibly covered with ice, so that it seems very probable that much of the weathering pro-

PLATE IV.

FIGURE 1.—Blocks on the Black River cuesta, about one-third of a mile from its edge, near Stoco Lake.

FIGURE 2.—The front of the Black River cuesta, Deer Bay. Talus nearly to the crest.

cesses which opened the fissures must have operated during preglacial time. In any event ice which was capable of scouring passed over the area after the fissures were opened, removed some of the blocks from small areas, but left still larger areas with the blocks still in position, even on narrow ridges.

The topography of these uplands is in many places similar to that peculiar to a limestone region undergoing the process of subaerial degradation. A comparison with ridges in like situations in the unglaciated area of Wisconsin shows that the similarity is very striking. In central Ontario, however, there are no pinnacles nor small prominences in front of the escarpments. Many of the larger outliers still remain as such, generally each with a steep cliff and talus slope in the direction from which the thrust of the ice-sheet came. On the lee side there is a long trail of rhomboidal blocks from the rear slopes of the outlier. (Plate IV, fig. 1.)

Along the escarpments where the old cliff faced the ice thrust there is always a well defined talus slope, sometimes right up to the crest. (Plate IV., fig. 2.) When the direction of the cliff approaches parallelism with the direction of ice motion, the talus is frequently much smaller and occasionally nearly wanting. Where the valley sides are graded to the edge of the upland, loose blocks usually seem to be altogether wanting in the valleys. Whether any of the original soil cover is still in situ it is at present impossible to say. Certainly much of the present soil is imported.

Gorges and Valleys of the Niagara Cuesta.—Along the Niagara cuesta from east of the Dundas valley, described by Spencer (**'81**), to Cabot's Head on Georgian Bay, are a number of incisions transverse to the escarpment, varying from deep and narrow gorges to deep but broadly open valleys, sometimes as much as ten miles across the mouth, whose bottoms are occupied by obsequent streams flowing to the inner lowland. There seem to be three types of these valleys; first, narrow short and deep gorges, which in some cases might almost be described as hanging gorges, since they are not yet cut down to grade with respect to the rock floor in front of the escarpment. Second, narrow steep-walled gorges, which so far as known appear to be graded with reference to the frontal rock floor. Third, deep broadly open valleys, whose upper reaches may become gorges. They are graded with respect to the rock floor of the inner lowland some distance, sometimes a number of miles, away from the immediate vicinity of the escarpment.

The gorges of the first type seem to be free from drift debris, and their immature form would indicate that they are largely of postglacial origin. The second and third types are usually more or less drift filled, especially in the upper reaches of the third type. The valleys of the second type are relatively narrow and steep walled. The level to which their mouths are graded is not known. The valleys of the third type are broadly open at the point of exit from the cuesta, and some of them penetrate ten to eighteen miles back from its front. Occasionally they are indicated by topographic depressions beyond the point where the bounding rock scarps can actually be followed, though the amount of drift material upon the cuesta has usually obliterated all rock-surface features beyond the limits already mentioned. The rock-walls of each valley (except the Dundas valley as far as can be traced at present) tend to converge, but convergence to a point of union has only been demonstrated for the walls of some of them. Some have also tributary lateral gorges. Spencer has described several entering the Dundas valley. In these tributaries the walls usually unite and the present stream falls over a cliff. The tributary gorges may belong to any one of the three types.

Owen Sound, sometimes wrongly designated a fiord, Colpoy's bay, and other bays upon the Georgian Bay coast, may serve as illustrations of the type (Map III). There are, however, between Owen Sound and Burlington, a number of valleys, not submerged, and equally typical. The north shore of Manitoulin Island seems also to possess many comparable with these, but developed on Trenton and older strata.

As in the case of the rock-sided valleys at the eastern end of the area, we lack an accurate knowledge of the precise form of valley which a sheet-glacier, acting on homogeneous rocks in a region of very low relief, might possibly be capable of eroding, and of the form of escarpment-front, which it might, acting alone, produce. It is necessary then to make the partial assumption, that if the sheet-glacier were capable of producing such topographic features, the products would bear a definite relation to the direction of ice advance, and would, in homogeneous rock, assume forms less tortuous than those carved by the more mobile erosive agent, running water charged with sediment.

The direction of the valleys as a whole is entirely independent of the general direction of the ice movement, whether it be determined from the evidences out upon the lowland or from those upon the crest of the cuesta at the edges of the valleys. They lie in all positions through an angle of about 180°; all but one (that at Dundas) in such a position

PLATE V.—VALLEYS IN THE NIAGARA CUESTA.

FIGURE 1.—View across the unsubmerged valley of the Bighead river. Cape Rich in the right background. Looking west.

FIGURE 2.—View across a portion of the unsubmerged valley of the Beaver river. Blue Mountains in the distance. Looking east.

FIGURE 3.—Fisher's Gully, a tributary of the Dundas valley, showing systematic arrangement of spurs and reentrants.

that any water which formerly flowed through them must have reached the lowland in front of the cuesta. In many of them the rock scarps which form their sides show no evidences of glacial action. Had the ice advanced up or down them we would expect to find ascending or descending glacial striæ. In places there is a systematic arrangement of alternate spurs and re-entrants, producing a tortuous channel, eminently characteristic of stream erosion, but, if we may judge from existing examples elsewhere, such as no ice stream could have passed through. (Compare with the valley of the Rhue, Davis, **1900,** 275.)

The Owen Sound valley, and several others along the Georgian Bay shore, both northwest and southeast of this, in their lower reaches, flare broadly open towards the direction of the ice advance. Striæ show that in part they controlled the direction of the ice motion, diverting it, in the Owen Sound case, about fifteen degrees to the east of its general direction. This broadly open portion of the valley was certainly modified by the ice. Along the eastern side of Owen Sound, and similarly in some of the other embayments in the escarpment, there are spurs which have not been removed, while upon the western sides, which received the thrust of the ice, the escarpment presents a much more even face.

North of Owen Sound in Colpoy's bay, and between Lion's Head and Cape Croker, there are a complicated series of channels, irregular bays, and islands in front of the escarpment. The different channels bear no definite relation to the direction of the ice movement in adjacent regions, some being even transverse to it. There is no evidence of discordance where the smaller side channels join the principal channel.

Between Owen Sound and Collingwood there are two unsubmerged sinuses extending far inland. Through one of these the Bighead river enters Georgian Bay at Meaford. The other, which reaches back for more than fifteen miles, over eight miles in breadth at the mouth, and about 1,000 feet in depth, is now the valley of the Beaver river, which enters the bay at Thornbury (Plate V, figs. 1 and 2). Between Collingwood and Hamilton there are a number of similar valleys. The most important of these are those now occupied by the Noisy, Mad, Nottawa, Nottawasaga and Credit rivers, Sixteen-Mile creek and Twelve-Mile creek. A branch of this latter heads on the outlier west of Milton, and through its upper course passes between it and the main escarpment. The largest of all the valleys is that at Dundas, described by Spencer (**'81**). (Plate V, fig. 3.)

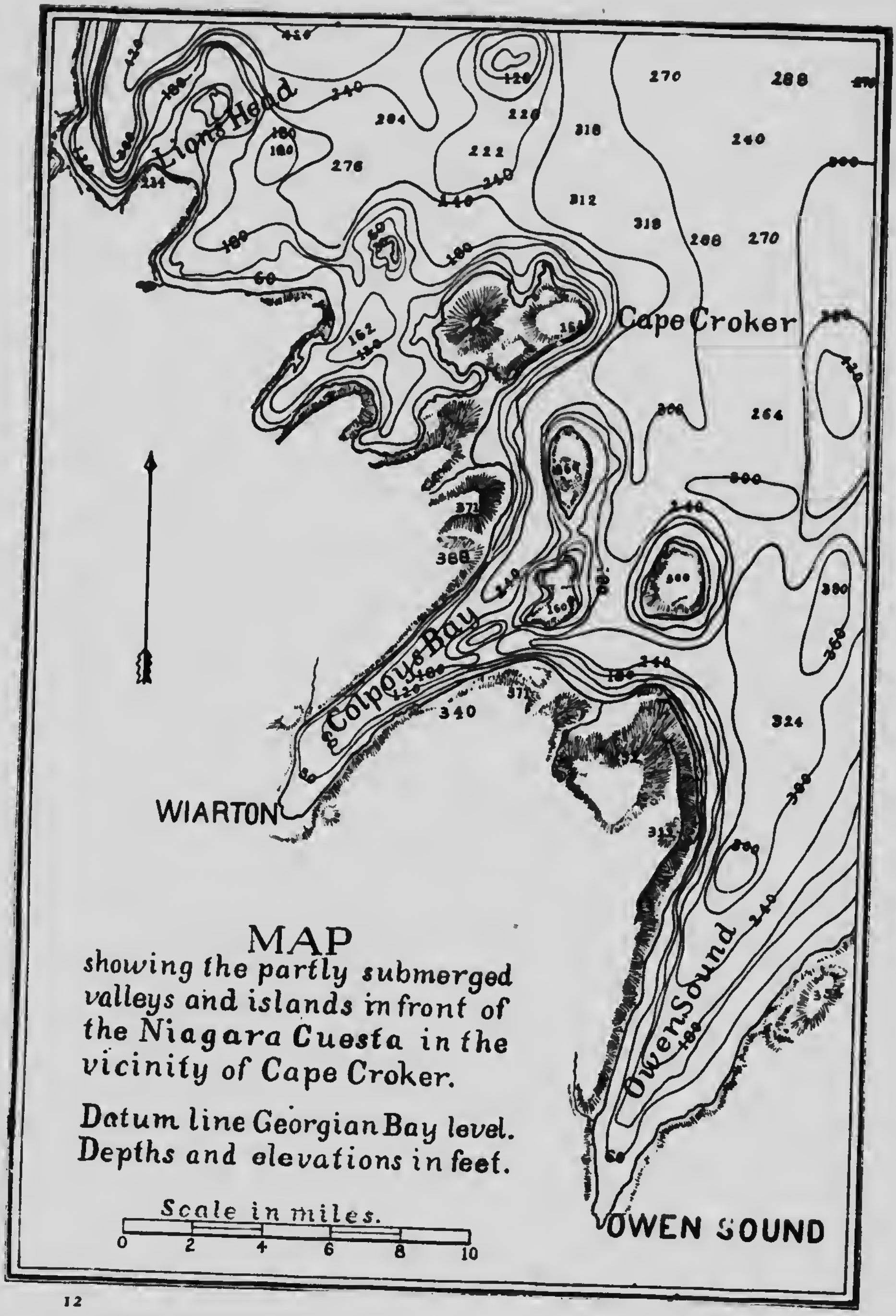
In most of these the mouth of the valley is more or less drift-encumbered, but it can be shown in several cases at least that they are graded with respect to some level lower than that of the Medina sediments immediately in front of the escarpment. This is definitely proven for those which lie northwest of Collingwood, for the Dundas valley, and for some others north of Burlington.

Hence, the systematic form of each, their direction independent of the ice movement, and other features cited, render it very improbable that they are due to glacial erosion. On the contrary, they may all except the Dundas valley, be regarded as due to the development of obsequent drainage, tributary to some master stream or streams running along the inner lowland. Some of them are, in their lower courses, occupied by till, which in some cases is, and in others probably is, that of the lowest till sheet; many of them are graded to a level on the rock floor, which must have been deeply submerged at the time of the deposition of the lowest interglacial beds. In the Dundas valley some stratified deposits are found overlying the till. The similiarity of form and development of the valleys whose relations to the lowest till sheet and to the interglacial beds has been proven, to those in which the relations are unknown, because not worked out, renders it probable that none of them are of interglacial origin. It is possible, though very doubtful, that the upper reaches of some of them may have developed during interglacial time.

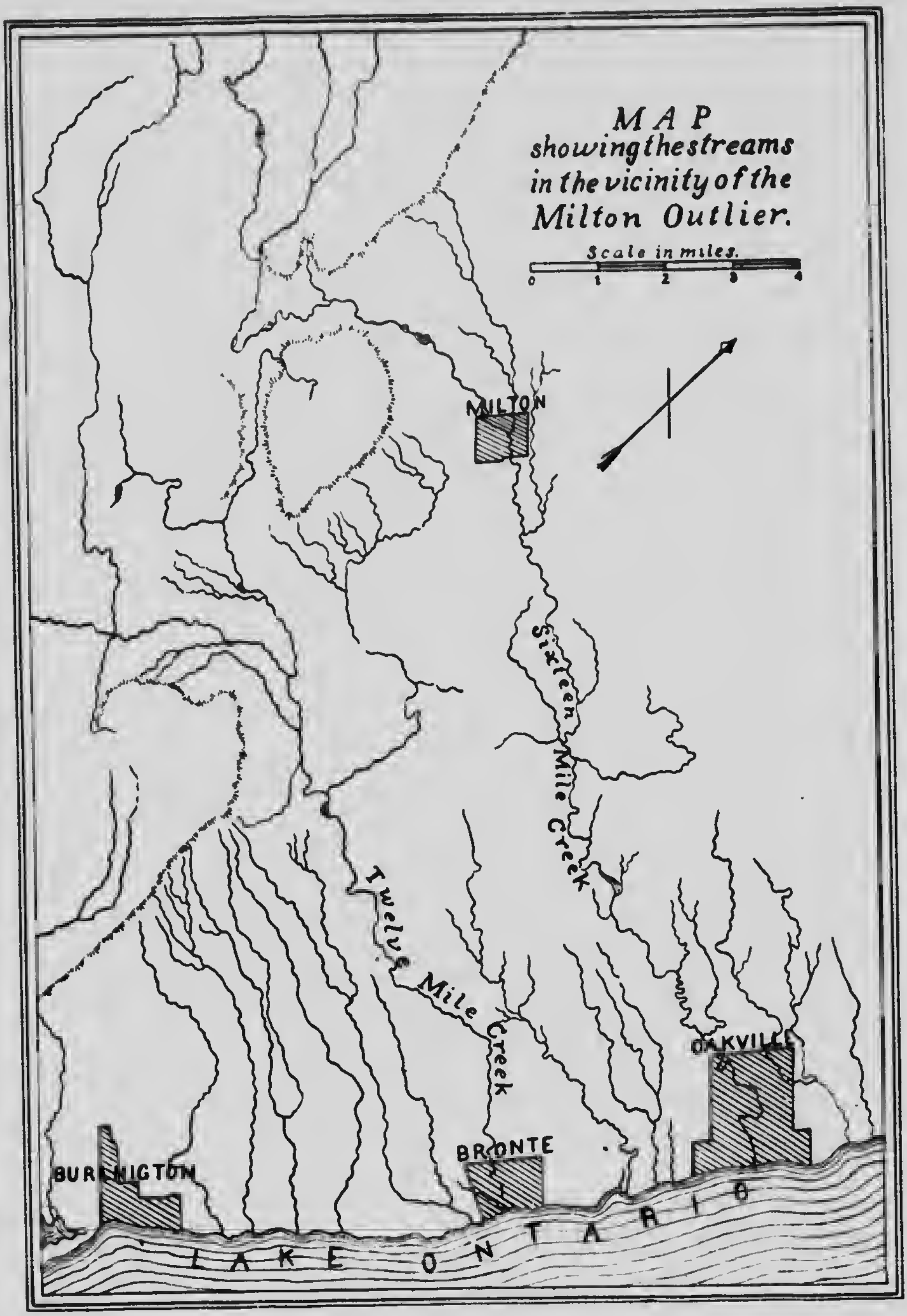
Islands and Outliers.—In Lake Ontario towards the eastern end, and extending as far west as Presqu' Isle, are a great many large and small limestone islands and shoals, all lying north of the line between Stony Point and Point Peter. Gull Island, four miles west of Cobourg, is also a limestone island. In the northern part of Lake Huron, between Cape Hurd and Grand Manitoulin Island, are a number of small rock islands. Some of these are of rock fragments at water level, the bed rock not being visible, but the large majority are composed of bed rock in situ. The Manitoulin Islands are rock islands. In Georgian Bay many of the islands are of limestone rock—attention will be specially called to those along the Bruce peninsula (Map III). In Lake Simcoe, along the east side, there are a few islands with limestone bases. Many of these islands are unsubmerged portions of the higher irregularities of the series of escarpments. Some of them lie in front of the main escarpments, as indicated by soundings around them.

On the Central Ontario lowland in Halton county, just west of Milton, is an outlier, capped by Niagara limestone, severed completely

MAP III.


Lions Head
Cape Croker
Colpoys Bay
WIARTON
Owen Sound
OWEN SOUND
MAP
showing the partly submerged valleys and islands in front of the Niagara Cuesta in the vicinity of Cape Croker.
Datum line Georgian Bay level.
Depths and elevations in feet.
Scale in miles.
0 2 4 6 8 10

MAP IV.


MAP
showing the streams
in the vicinity of the
Milton Outlier.
Scale in miles.
0 1 2 3 4
MILTON
Sixteen Mile Creek
Twelve Mile Creek
OAKVILLE
BRONTE
BURLINGTON
LAKE ONTARIO

from the main escarpment, having a surface area of about four square miles (Map IV). Were the land under water this would form a large island, comparable to some of the islands already noted along the Bruce peninsula. Similar outliers may occur elsewhere along the line of the escarpment. In some other localities in front of the cuesta, outliers, capped with Medina sediments and surrounded by drift-filled valleys, were noted, suggesting a similarity to the Milton outlier, but being further out on the lowland, they had perhaps undergone greater degradation.

In front of the Black River escarpment, notably in Hastings county, are a number of outliers of limestone, with much jointed and fissured upper beds. Some few of the outliers are of sandstone. If the region were partly submerged these also would form islands in front of the escarpment. As already noted, many of these outliers present a steep face, with a talus slope at the base, towards the direction of the ice advance, and a long trail of loose blocks on the lee side.

Some of the islands and outliers were certainly in areas protected from ice erosion. The case of the Manitoulin Islands cannot be considered, as the writer has not sufficient personal knowledge of the facts. In the great majority of cases, however, they do not occupy such protected places, and there is direct evidence that the ice transgressed them. Their relation to the escarpments, and the effects which have been produced by the ice, seem clearly to indicate that they had an existence prior to the advance of the ice sheet. The more salient features were smoothed off, but the essential features are still preserved.

Depth of Excavation.—Another interesting fact is the remarkable uniformity in the depth of excavation of the lowland below the crest of the Niagara cuesta. At Cabot's Head the depth is about 800 feet, at Collingwood 1,100, near Dundas 1,000.* The unsubmerged portion of the Ontario lowland is located on rocks ranging from the Trenton to the Medina; the submerged portion is on Trenton in both cases. The lowland has thus been excavated on rocks of four different horizons, and of very diverse texture.

Lowland Rock-Surface.—An almost continuous transverse section of the rock surface of the lowland is shown along the north shore of Lake Ontario, parallel to the Dundas valley, from Hamilton to Lorne Park (twenty-five miles). Between here and the river Rouge (thirty miles)

*743 measured, 1,000 calculated, Spencer, '81, 323.

there are many exposures in the valleys of creeks and rivers, and in a few places along the shore. It is thus known that there is no extensive discordant deepening for forty miles east of Burlington Heights. The lowest part of this section, with reference to the present lake level, is situated on Lorraine shales and sandstones. The surface is lightly rolling, but the average elevation toward the escarpment is about one foot per mile. At right angles to the lake shore it varies to about fifteen feet per mile.

Between the Rouge and Whitby (thirteen miles), there is no known rock exposure. At Whitby and near Bowmanville the Utica shales come to the surface; between these two points there is possibly a valley twelve miles in breadth, but probably of no great depth. For twenty miles east of Bowmanville, to Gull Island (three miles east of Port Hope) the rock, Trenton limestone, is again concealed. From Gull Island to Presqu' Isle (twenty miles), there are a number of exposures of Trenton limestone. East of Presqu' Isle the rock is continuous to below Kingston.

Between the Rouge and Presqu' Isle the upper edge of the lowest till sheet seldom sinks below the water line. Were there any very deep or cañon-like depression of the rock surface the till might reasonably be expected to give some indication of the existence of such depression, for in every case within the area, where such depressions are known to occur, the till sheets above would give ample evidence by their accordant depressions.

Along the Georgian Bay unsubmerged portions of the old valleys are in some cases over 1,000 feet below the escarpment, and are graded with reference to a level still lower. So far as is at present known there is no evidence of discordant deepening due to the movement of the ice along the front of the escarpment in a direction different from that of the general movement; if such deepening has taken place it is not located on the soft Medina strata, but on the Lorraine, which are known to form escarpments, or upon the Trenton. In no case, so far as the writer is aware, has drift from a higher geological horizon been found overlying a lower horizon, well out on the lowland, a result which must obtain if there has been significant lateral motion of the ice from the Georgian Bay region.

Summary.—The work of the ice sheet in Central Ontario seems to have been that of smoothing off pinnacles, small spurs, and other outlying features of the limestone areas. Only the larger of these topographic forms were able to resist the ice, and these, more or less modified, have remained to form islands or outliers in front of the different escarpments, or the spurs of the intervalley ridges along the valley sides. The essential features of the topography are not destroyed, though they are more or less completely obscured and obstructed by drift.

The relation of the area to the fronts of the ice sheets which crossed it is not yet determined. The results of the writer's studies at present suggest that the great moraine of Central Ontario is largely an interlobate moraine between an ice lobe coming from the east of north, and a lobe coming from the east; and that the lateral spurs, on the north and on the south sides of the great moraine, represent the positions successively occupied by the retreating ice front.* The area seems to have been almost always one receiving deposits rather than one from which the soil and rock was being removed.

The streams which produced the pre-glacial valleys throughout the Central Ontario lowland, and the obsequent streams of the Niagara cuesta must have been tributary to some trunk stream, or perhaps to two such master subsequents. The location of these trunk streams would normally be along the lines of deepest cutting. Their direction of flow cannot be determined at present, though that of the tributaries is known from the forms of the valleys. Those on the Black River cuesta flowed southwest, those from the Niagara cuesta northeast, east, and southeast. Obviously the trunk stream, though flowing parallel to the escarpment, must have had some outlet from the region. Determining the location of this valley has been one of the chief difficulties to be met by the river-erosion hypothesis for the origin of the basin of Lake Ontario. The attitude with respect to the present St. Lawrence valley, and certain other features of the rock valleys in the vicinity of Kingston, and the immature character of the present St. Lawrence channel render it extremely improbable that the waste from the lowland was ever carried out through this channel. If the drainage of the Ontario lowland was that of a normally developed river lowland there is but one known outlet which is at all suitable, that by the Dundas valley.† The course of the valley from the vicinity of Copetown westward is highly problematic. Spencer considers that it was towards the south, while Grabau (**1901**) has recently advocated an extension towards the west, in continuation of an initial consequent direction. The direction of flow of the streams that occupied this valley has not

*See Chamberlin, '**95**a, p. 768.

†This suggestion had occurred to the writer before he was aware of Dr. Grabau's opinions, referred to below.

been definitely determined. A river flowing westerly through this outlet would be a normal consequent stream, and tributary streams from both sides would occupy the position of normally developed subsequents. The attitude of the broadly open valleys along the Georgian Bay suggest that there may have been a second master stream with an outlet southwestward from the bay. At present our knowledge is so imperfect that the direction of flow of these master streams, and their relations to these different valleys, which may be members of a normally developed system, have not been determined.

The probability that there were streams on the Central Ontario lowland, to which the streams in the preglacial valleys, already described, were tributary, makes it equally probable that similar features were developed to the southeast along the basin of the present lake. At present we know neither the depth to the rock floor of the basin, nor the amount of drift filling. The relation of the basin to the ice lobes is also unknown. Hence differential deepening, which has not operated on the unsubmerged lowland, may perhaps have been in effective operation in the portion of the basin east of the Niagara river, and west of Stony Point.

PLEISTOCENE HISTORY—*A Summary.*—The Pleistocene deposits of Central Ontario present a complex which has not yet been studied in sufficient detail to warrant more than a brief reference to certain salient features. The best known locality is that in the vicinity of Toronto, where the order of succession of the deposits has been established. The probable relations of these deposits to similar beds elsewhere in the area have already been noted. Mention has also been made of certain sands and gravels which overlie the third till sheet in some parts of the area. The fossils of the lowest group of interglacial beds at Toronto indicate that the climate of that part of the region was, for a time, warm and temperate, perhaps like that of Ohio. During this period the lake was connected with the Mississippi drainage, a connection which may have been an inheritance from the cycle preceding the first ice advance. Whether the ice sheet at this time had withdrawn wholly from the region, or only part way, must at present be a matter of conjecture. The fossils of the upper beds of the first interglacial deposits indicate climatic conditions approaching those of the lower Gulf of St. Lawrence and the Labrador coast at the present day. The close of the interglacial period was followed by an interval during which there was a considerable amount of erosion, just how extensive is not determined. The interglacial beds of the latter epochs have, as yet, been little investigated.

PLATE VI.—PLEISTOCENE L[illegible] BENCHES.

FIGURE 1.—Transverse section of the Iroquois bench and sea-cliff, Scarboro' Bluffs.

FIGURE 2.—Iroquois bench and sea-cliff, and light morainic topography of the third till sheet, Scarboro' Bluffs.

PLATE VII.—PLEISTOCENE LAKE BENCHES.

FIGURE 1. —Iroquois bench and sea-cliff, Scarboro' Bluffs.

FIGURE 2.—Boulder pavement in front of a sea-cliff, near Lake Simcoe and south of Orillia.

PLATE VIII.—The young channel of the Trent river below Fenelon Falls.

—Photo. by J. H. Stanton, Fenelon Falls.

While the ice sheet was retreating across Ontario, a series of lakes were formed between its front and the highlands to the south and west. In the latter stages of the ice retreat, portions of the present land area of Central Ontario were beneath the waters of these lakes. The land was being gradually elevated at the northeastern end, so that at present the old shores are not parallel with the surfaces of the existing lakes. The deposits of the different periods of ice transgression and retreat have been so little studied, and so little differentiation seems to have been made between the deposits of sands and gravels of these periods, and those formed by their re-arrangement during the periods of the great Pleistocene lakes, that at present there is much confusion with regard to the history of the area during the Great Lakes epoch. (Plates VI and VII.)

RECENT HISTORY—*A Summary.*—Since the withdrawal of the Pleistocene lakes the amount of erosion has been small. The courses of the present streams are in part determined by the valleys of the preglacial rivers, in part by the position assumed by the drift deposits with respect to the retreating ice sheets, and in part to the controls exercised by the Pleistocene-lake beach-deposits. There is at least one lake (Scugog) whose drainage seems to have been affected by the differential uplift indicated by the present attitude of the old lake beaches.*

Some of the streams have cut through the glacial deposits into the bed rock. Streams entering Lake Ontario west of Toronto, or flowing into the Georgian Bay, have cut deep steep-sided ravines and valleys through drift and shale. Some few, in the vicinity of Oakville, have cut deep straight-sided, flat-bottomed valleys through about forty feet of drift and eighty-five feet of shale.† The present streams meander in courses largely independent of their valley sides, here truncating an old spur, there widening the former meander belt. Sometimes there are two or three back meanders between adjacent spurs of the old valley. In the upper courses, where the stream is still working upon glacial debris, these misfit meanders are especially common. In the great majority of cases there seems to be but one terrace below the general level of the area adjacent to the valley.

North and east of Toronto, the Trent, the Moira, and a few smaller streams, have in part cut new channels in Trenton limestones. The channels, which average perhaps twenty-five feet in depth, are straight-

*This may be true of Pigeon and Chemong lakes also.

†In one case 400 yards in width.

sided and flat-bottomed. In almost all of these the river breaks into rapids, and occasionally plunges over a low fall (Plate VIII). In parts of the lower course of the Trent there are two rock terraces, one a small rock-cut bench, the other due to the removal of the drift debris from the old rock surface. There is reason to think that in parts of the course there are remnants of yet higher terraces upon the drift, but they are not conspicuous topographic features (Plate III, fig. 2, p. 171).

The relations of all of these terraces to the Pleistocene lake levels and to the former water supply are interesting problems which have not been considered. The present valleys are inappropriate in size and form to the present streams in flood.

Parts of the present valleys of these streams and their tributaries, and the valleys of all streams east of the Moira, are rock-valleys, not of recent origin, and have already been described under the caption "Eastern Rock-Valleys."

Along Lake Ontario the waves have cut benches and sea cliffs in the drift deposits. The longshore action is distributing the material, thus derived, east and west from the vicinity of Whitby, forming bars, spits and hooks. Towards the west the most important of these are Toronto Island and Burlington Beach. Towards the east, from Presqu' Isle neck to Point Peter, there are a great many bars blocking the ends of partly submerged rock valleys, and forming large and small lakes. Back from some of these bars, small sand-dune belts have formed.

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