Vol. 7, No. 1

PROCEEDINGS OF THE ROCHESTER ACADEMY OF SCIENCE

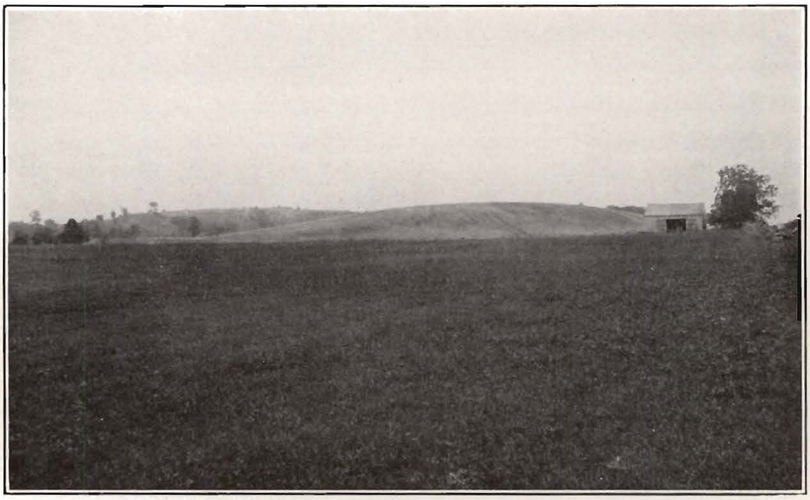
VOL. 7, PP. 1-37, PLATES 1-20

NEW YORK DRUMLINS

BY

HERMAN L. FAIRCHILD

ROCHESTER, N. Y.
PUBLISHED BY THE SOCIETY
OCTOBER, 1929



DRUMLINS

Upper view, one mile south of Lincoln, Wayne county. Looking south of west.
Lower view, three miles north of Walworth. Looking east of north.

PROCEEDINGS OF THE ROCHESTER ACADEMY OF SCIENCE
VOL. 7, PP. 1-37 PLATES 1-20 OCTOBER, 1929

NEW YORK DRUMLINS

BY HERMAN L. FAIRCHILD

CONTENTS.

	PAGES
Foreword	2
General characters; terminology	2
Occurrence in general	4
Display in western-central New York	5
Favoring conditions	5
Distribution; area	5
Numeration	6
Boundaries	6
Erosion features	7
Subdivisions; time relations	9
Attitude; orientation	9
Relation to the land surface	12
Relation to the rock strata	13
Form; dimensions	14
Composition	18
Structure; concentric bedding	20
Relation to moraines	21
Island-like groups	22
Non-drumlin spaces	23
Open channels	24
Rocdrumlins	25
Physical factors in drumlin formation	27
Dynamic factors pertaining to the glacier	27
Factors relating to the drift held in the ice	28
Factors of external control	28
Summary; fact and philosophy	29
Origin of drumlins	29
Thrust movement of the ground-contact ice	29
Dynamics	30
Relative age	31
Form and relations	32
Depth of the drumlin-making ice	33
Drumlins of eastern New York	34
Complexity in the history	37

Foreword

The singular hills of glacial origin which we now call drumlins were noted by James Hall in his report of 1843 on the geology of the Fourth New York District. Sir James Hall of England had referred to the English forms as early as 1815. They came under active study in Europe in 1864, and in America from about 1878.

Previous to 1907 considerable literature on the subject had accumulated, but there had been no comprehensive publication in description and explanation. And owing to considerable variation in the characters and relations of the hills, as seen by geologists in different regions, the question of their origin or manner of construction was yet under debate.

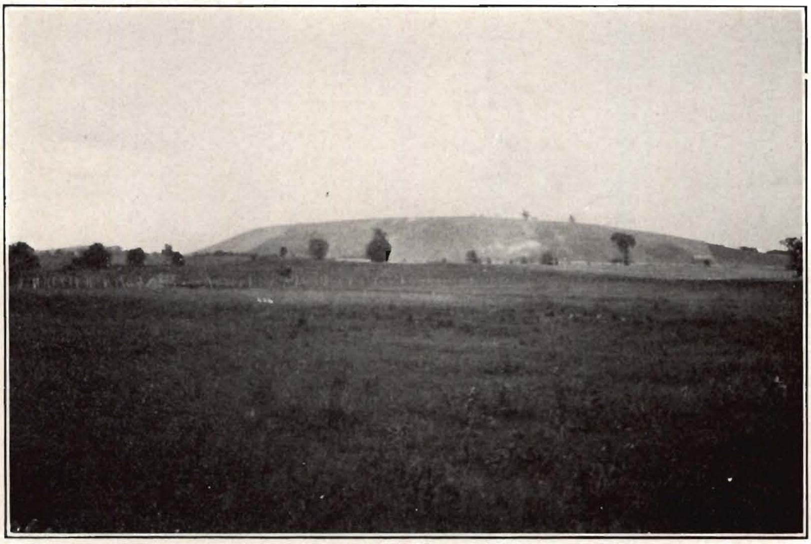
In the year 1907 the writer published a detailed description of the west-central New York drumlins, richly illustrated, as Bulletin 111 of the New York State Museum. Because the State has the finest group of drumlins in the world, exhibiting the greatest range in all of their features, that paper was the most comprehensive and conclusive on the subject. Moreover it was the only writing which proved from observed features the subglacial construction of the hills, and discussed the complex mechanics of their upbuilding.

Unfortunately that Bulletin 111 was in limited edition, and with scanty distribution, and in a short time was "out of print." Because of this condition it appears desirable to publish the present writing, and in the proceedings of a scientific society which has particular interest in the earth features of western and central New York. No apology is made for making large use or even repetition of matter in the former paper, and with regrets that it is not feasible to reproduce the elegant three-color maps.

General Characters; Terminology

Drumlins are the most massive, singular and interesting of all the varied products of glacial agency. In their occurrence, attitude and relation, form and structure they are not only the most remarkable of ice-sheet deposits but in their size, convex surfaces and graceful outlines they are the most striking of the drift-forms; and perhaps the most beautiful of all earth-forms of moderate size.

Previous to the discovery of continental glaciation these hills were the greatest geologic enigma. There composition, like that of moraines and the veneer of till, classed them with the "drift," the mass



DRUMLINS

Upper, between Sennett and Skaneateles Junction. Looking north of east.
Lower, west of Skaneateles Junction. Looking west.

of heterogeneous earth-stuff then supposed to have been drifted down from arctic regions by overwhelming yet mysterious cataclysism of polar waters. And when glacial science arose, much less than a century ago, these mounds and ridges were confidently cited as fatal to the glacial theory. They were inconsistent with the assumed leveling and planing effect of a sliding ice-sheet. And even down to the year 1906 the mechanics of their construction was in doubt.

The glacial genesis of drumlins is evident. They occur only in glaciated territory and their composition, at least in New York, is compact till or "ground-moraine."

The conspicuous superficial characters of drumlins are the smooth surfaces, convex profiles, and their axial direction parallel with the ice-flow direction of the locality. Their topographic expression is so distinctive that they are readily detected on topographic maps having the contours with a vertical interval of 20 feet. (See plates 3, 5–7.)

Their molded forms attest the overriding effect of the ice-sheet, while their internal structure proves that they were built up from the bottom by a plastering-on process. Their relation to moraines, described below, indicates that they were built and shaped under the relatively thin border of the continental glacier, in the peripheral zone where the transporting energy of the ice-sheet had become incompetent to carry any farther its heavy load of rock-rubbish borne in the lower strata of the ice, the "subglacial" drift.

Definition of drumlins must be in rather general terms because of their varying characters. They are smoothed-surface hills of till, built and shaped by the overriding action of an ice-sheet, and elongated in the direction of ice movement. More tersely, they are smooth, convex masses of drift, built and shaped beneath an ice-sheet.

Terminology. Previous to 1884 various names for the drift hills were used by different geologists, suggestive of the form and relations. Some of these names were parallel ridges; lenticular, mammillary and elliptical hills; parallel drift hills; whalebacks and sow-backs.

In 1877 James Geikie used the term "drum," celtic for hill or ridge. The name "drumlin," diminutive for drum, was applied by H. M. Close in 1866 for the units in a large and very interesting group in northern Ireland; and the name was given greater publicity in a paper by Kinahan and Close in 1872. Professor W. M. Davis, who has introduced many very useful names in earth-science, first made use in America, in 1884, of the term drumlin, since which time it has universal usage.

Occurrence in General

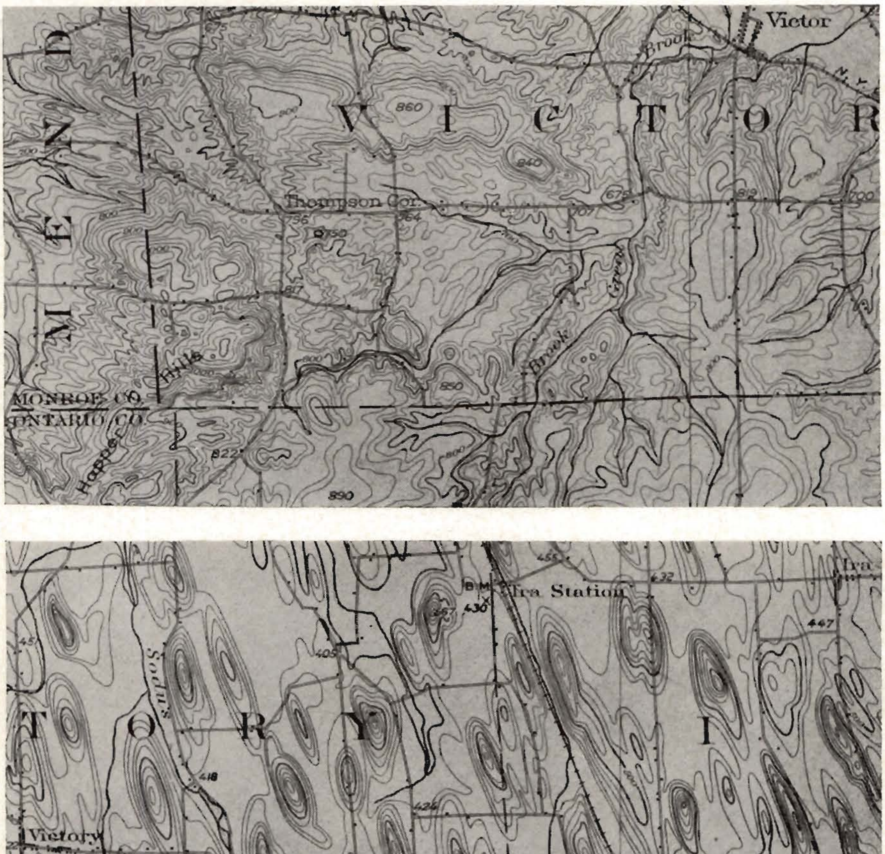
As these masses of drift were accumulated beneath the continental ice-sheets it might naturally be expected that they would be of universal, or at least of very general, occurrence. But such is not the fact. Over vast areas of glaciated territory they are entirely wanting. They are not reported from Ohio, Indiana, Illinois, Minnesota, the Dakotas, southern Michigan and Iowa. They are at least very infrequent in other states.

Some forms interpreted as drumlins have been noted in southern Canada, Nova Scotia and in the western provinces.

The drumlins of Ireland are the type forms, which are similar in all essential features to the New York forms. They occur also in Scotland and England; and a large group in northern Germany.

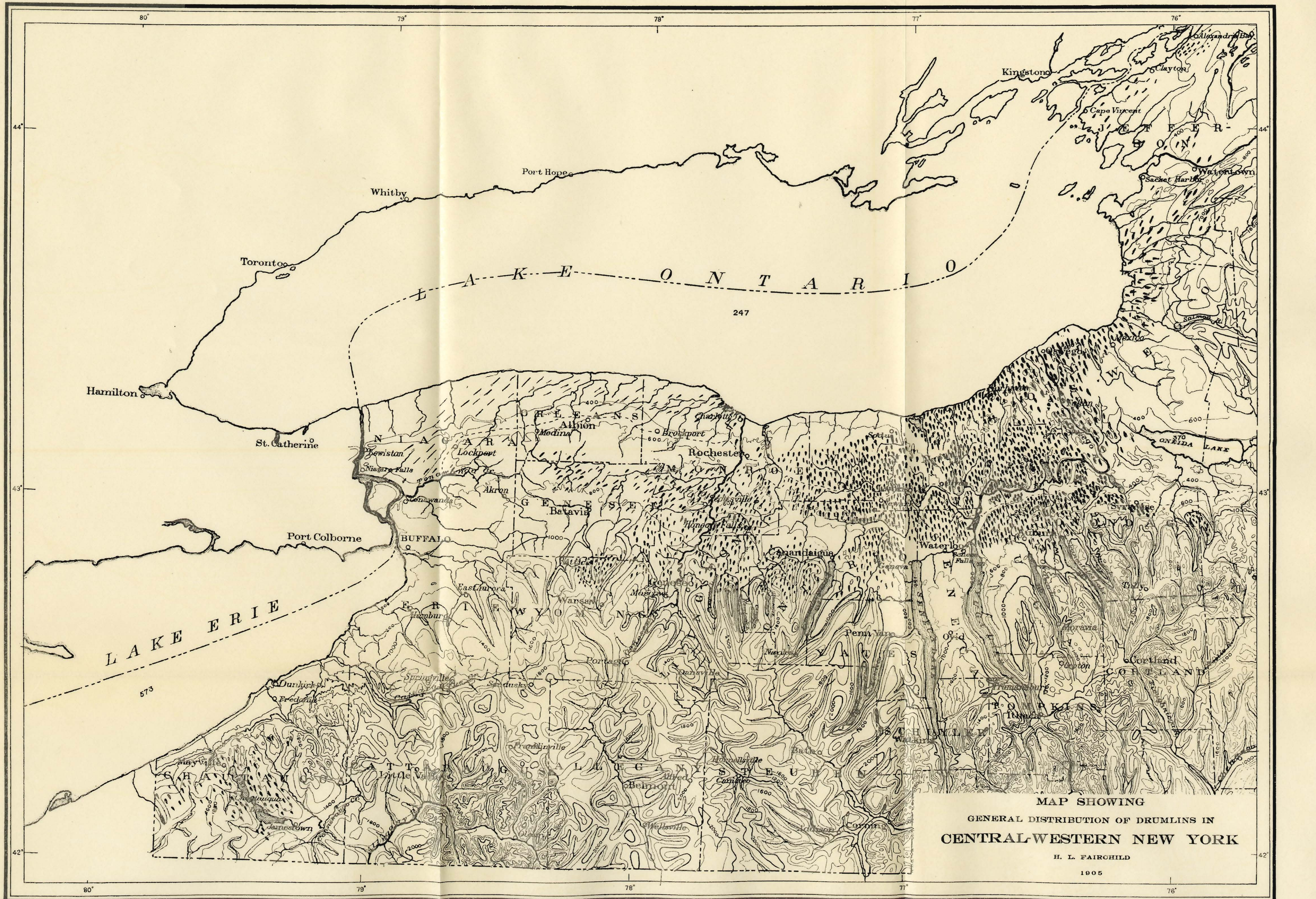
In the United States there are three large districts of drumlin development. The New England area includes southern New Hampshire, with toward 700 examples; Massachusetts, with 1,800; and a southward extension into Connecticut. The Wisconsin-Michigan area was estimated by Chamberlin to hold 5,000 drumlins. The third and largest area is the subject of this writing.

The apparently capricious distribution of drumlins in the glaciated territory of Europe and America was one cause of the uncertainty and debate regarding their origin. However, when it is recognized that the typical or well developed drumlins and drumlin ridges are only the most emphatic of a variety of forms produced by the rubbing effect of the ground-contact ice under horizontal thrust (see page 29); and that on the one hand these forms shade off into indefinite flutings or moldings of the drift, and on the other hand are represented by scoured or rounded rock hills (rocdrumlins) (see page 25) it is probable that this class of glacial phenomena is more widely distributed than has been supposed. But the requisite conditions for production of typical drumlins were not commonly fulfilled, as great areas of glaciated lands seem never to have been subjected to the drumlinizing effect of the ground-contact ice.



GLACIAL TOPOGRAPHY

Upper, moraine. Part of Canandaigua sheet.
Lower, drumlins. Part of Weedsport sheet.



DISTRIBUTION AND ORIENTATION OF THE NEW YORK DRUMLINS

Display in New York

Favoring Conditions. The drumlins of western and central New York form the largest group in the world, and with their varied characters and relations are the most remarkable and instructive.

It is recognized that no single group or area is likely to illustrate all possible features pertaining to these drift forms; but this New York field includes such a great variety in form, attitude and relationship that they fully exemplify this class of glacial phenomena and clearly reveal the manner of their making.

The great development of the New York drumlins was due to the conjunction of favoring conditions, as (1), character of the rock strata in supplying an abundance of pasty till; (2), topography of the Ontario basin and lowland; (3), deployment of the ice body, as controlled by the land surface; and (4), thrust-movement of the ground-contact ice. These factors will be discussed below.

Distribution; Area. The map, plate 4, shows fairly the location of the drumlins and also their relative abundance. The topography of the map is not reliable.

The principal area is the Ontario field, a belt about 35 miles wide bordering the south side of Lake Ontario; with an east-west extent, from Syracuse to the Niagara River, of about 140 miles. At least half of this territory, or about 2,500 square miles, carries many thousands of typical drumlins.

The field of greatest development may be defined as the low ground of the Ontario plain north of the Finger Lakes, and reaching southward on the flank of the north-facing slope of the highland. Between Honeoye and Canandaigua lakes they lie as high as 1,700 feet elevation.

The heart of this drumlin area is shown in plate 5, which includes the Palmyra and Clyde quadrangles of the New York topographic map.

A somewhat distinct group of drumlins borders the Ontario shore, eastward from Sodus Bay. The eastward extension of this field swings around the east end of the lake, as a belt five to ten miles wide, reaching past Watertown into the St. Lawrence valley. These have peculiarities of attitude and form to be described later. They are shown on the Pulaski, Sacketts Harbor and Watertown sheets.

The main drumlin field extends westward in well-defined forms to beyond the meridian of Batavia, the termination being shown on the Batavia and Attica sheets.

Another drumlin field of remarkable character lies west of the Genesee River and bordering the Ontario shore, where the waters of Lake Iroquois were too deep for effective erosion. On the Niagara-Genesee prairie in Orleans and Niagara counties these drift forms become elongated ridges, fading out southwestward, in the direction of the ice flow, as faint and invisible swells of the till veneer. This drumlinized fluting of the land surface has given northeastward direction to the streams of the district, which singularly are flowing oblique to the general slope of the land. This feature is shown in plate 4, and by the topographic sheets bordering Lake Ontario.

In the southwest corner of the State a group of handsome drumlins surrounds Chautauqua lake. These point southeast, having been formed by the deployment in that direction of the lingering ice body in the Erie basin. Their genesis and history are distinct from those of the great Ontario display.

A small group stands about the north end of Cazenovia lake, some 12 miles southeast of Syracuse. See plate 4.

Numeration. This New York area probably includes over 10,000 drumlin crests, of which on a conservative estimate at least 6,000 are indicated on the topographic sheets. Where they are close set from 20 to 35 can be counted in a square of four square miles. Five drumlins to the square mile is common. Three to the mile is not more than the average, counting large and small, and on the 2,500 square miles of strong drumlin topography this would give 7,500 examples. Estimates have been made by counting the distinct drumlin summits or crests indicated by the contour lines in certain districts and using the figures for larger areas, with a result giving about 5,000 crests for the fifteen topographic sheets that cover the best parts of the drumlin area. On the 216 square miles of the Palmyra quadrangle (plate 5) the estimated number of crests was 800, but the actual count gave 955. Great number of minor ridges are beneath the recognition of the 20-feet contours, but are conspicuous to the field observer.

Boundaries. A clear distinction must be drawn between the natural or original limits of drumlinizing work and the induced boundaries produced by erosional effects of river and lake. A glance at plates 4, 5, 6 and 17 will show sharp northern boundaries, and passageways more or less distinct across the larger field. The northern limits have been produced by wave erosion of the glacial Lake Iro-

THE HEART OF THE DRUMLIN AREA

Palmyra and Clyde quadrangles. Shore features of Lake Iroquois in the upper part of the map. Channels and deltas of glacial drainage in lower part of map. Amount of land uplift, in feet, since glacial time is shown by the lines of equal rise (isobases). Other numerals give the present height above ocean.

quois and the existing Lake Ontario. The breaks are partly due to eastward flow of rivers of the copious glacial drainage. (For the latter see Bulletin 127 of the New York State Museum.) The subject of drumlin erosion will be treated later.

The southern limits of the drumlin groups are original or constructive, and of course somewhat indefinite. On higher ground the drumlins disappear as scattered mounds in the bolder relief of the rock hills. On low ground they fade off as smooth flutings in the drift sheet (see page 16), and in one stretch clearly correlate with a frontal moraine (plate 13 and page 21).

Southeastward the main drumlin field terminates in a tongue or point at Syracuse, with the detached Cazenovia group twelve miles further. The maps show no drumlins north and northeast of Syracuse, over the Oneida lake depression, nor on the high ground south of the Syracuse district. This extension of the drumlins as a tongue in an otherwise barren territory becomes yet more striking if the Cazenovia group is included in the work of the Syracuse ice lobe.

East of Syracuse, at Fayetteville, Canastota and Oneida, the soft Salina shales, which compose the irregular ground surface, exhibit no effect of ice-rubbing and carry only just enough drift to prove the former presence of the ice-sheet. The topography is easily mistaken for morainal, but is really due to atmospheric erosion.

Further description of the natural borders of the drumlinized drift surface would be of slight value to the reader. But the study of the topographic sheets with reference to drumlin forms will be found very interesting. And precise mapping in the field would be fine exercise in the discrimination of land forms and the interpretation of geologic processes. Very interesting surface relief is not expressed by the map contours with only 20-feet vertical relief.

Erosion Features. Plates 6–8, 14–16, show that the waves of Lake Ontario are dissecting the heavy drumlins which happen to stand at the water level. Of course the incoherent drift composing the drumlins cannot stand up against storm waves like solid rock.

Similar destructive wave-work was done by the great glacial lakes that preceded Ontario (See *Geologic Story of the Genesee,* Rochester, 1928.) Along the straightened, mature shore of Lake Iroquois, extending from Niagara River to Sodus Bay (plate 5), no drumlin was able to survive the wave erosion; although they survived where immersed in more than 30 or 40 feet of water; and also in the region toward Syracuse where the lake was shallow.

At Sodus village the Iroquois beach, the "Ridge Road," is an erosion cliff in strong drumlins. Eastward the Iroquois shore with less maturity curves southward around Sodus Bay, but yet marks a north limit of close-set drumlins. The villages along this border are South Sodus, Wayne Center, Rose and West Butler; the line passing two miles southeast of Wolcott (plates 4, 5).

South and east from Sodus Bay, over the Montezuma and Oneida lowlands, groups of drumlins stood as islands in the Iroquois waters, and are notched more or less at the ends. To the observant traveller between Rochester and Syracuse the statement that the longitudinal drumlin profile is always convex seems untrue, because decided concave notching may occasionally be seen on both north and south ends. But these are erosional features, due to Iroquois wave action (See plate 9). They are most evident between Clyde and Savannah.

Passing northward in the Sodus embayment, into what had been deeper waters of Lake Iroquois, a group of drumlins appears which is abruptly terminated by the present Ontario beach. It is probable that the Ontario waters hide drumlins in their depths. The series of heavy drumlins that are opposing the waves all the way from Sodus to Oswego suggest that other northern members of the group are submerged. However, these drowned members had been subjected to wave erosion in the lower levels of Lake Ontario, because the lake level has risen from zero to its present elevation of 246 feet over ocean. And previous to Ontario the long-lived Gilbert Gulf, sealevel waters, occupied the basin.

Of the series of glacial lakes which bathed the receding front of the ice-sheet Lake Dana had such elevation and relation to the drumlins as to produce conspicuous erosion features. In the east-west belt between Honeoye Falls and Caledonia the tall drumlins stood as small islands in the Dana waters, and are notched at 700 feet elevation. The Rider Hill, at Industry, is a good example. Similar, and even clearer, examples are the high drumlins on the Albion quadrangle, seven miles north of Batavia in the town of Elba, east and northeast of East Oakfield. These were severely wave-cut and the debris was swept into gravel bars and spits, similar to the Iroquois features between Lyons and Syracuse.

The glacial Lake Warren, predecessor of Dana, left conspicuous wave work, especially south and east of East Avon. An eroded drumlin a mile south of East Avon has heavy gravel bars curving from both north and south ends, at 880 feet above tide.

Some drumlins exhibit vertical grooves, furrows and ridges running up and down their side slopes. These are regarded as erosional, due to atmospheric effects, especially stormwash. The rubbing and shaping effect of the ice in horizontal movement could not produce vertical irregularities.

In some cases the erosion on the side slopes has gnawed into the summit so as to produce a wavy or irregular crest line.

These erosion forms will be mentioned in a later chapter on the forms of the drumlins.

Subdivisions; Time Relation. The great drumlin field (plate 4) comprises some divisions with differences in time of their formation. The hills were built beneath the waning ice-sheet, and the complex dynamic conditions necessary for their production were migrating northward, along with the receding ice border. It is apparent that the extreme southern hills were constructed before the northern.

Considering both position and age the first series appears to be the group which may be named the Attica-Geneva, or the western Finger lakes series. These forms lie on higher ground, between the Tonawanda valley and Seneca lake.

The second, the main group, stretches from Oakfield eastward to the Oswego river. This includes the heart of the drumlin field (plate 5) with the most striking topography of close-set drumlins.

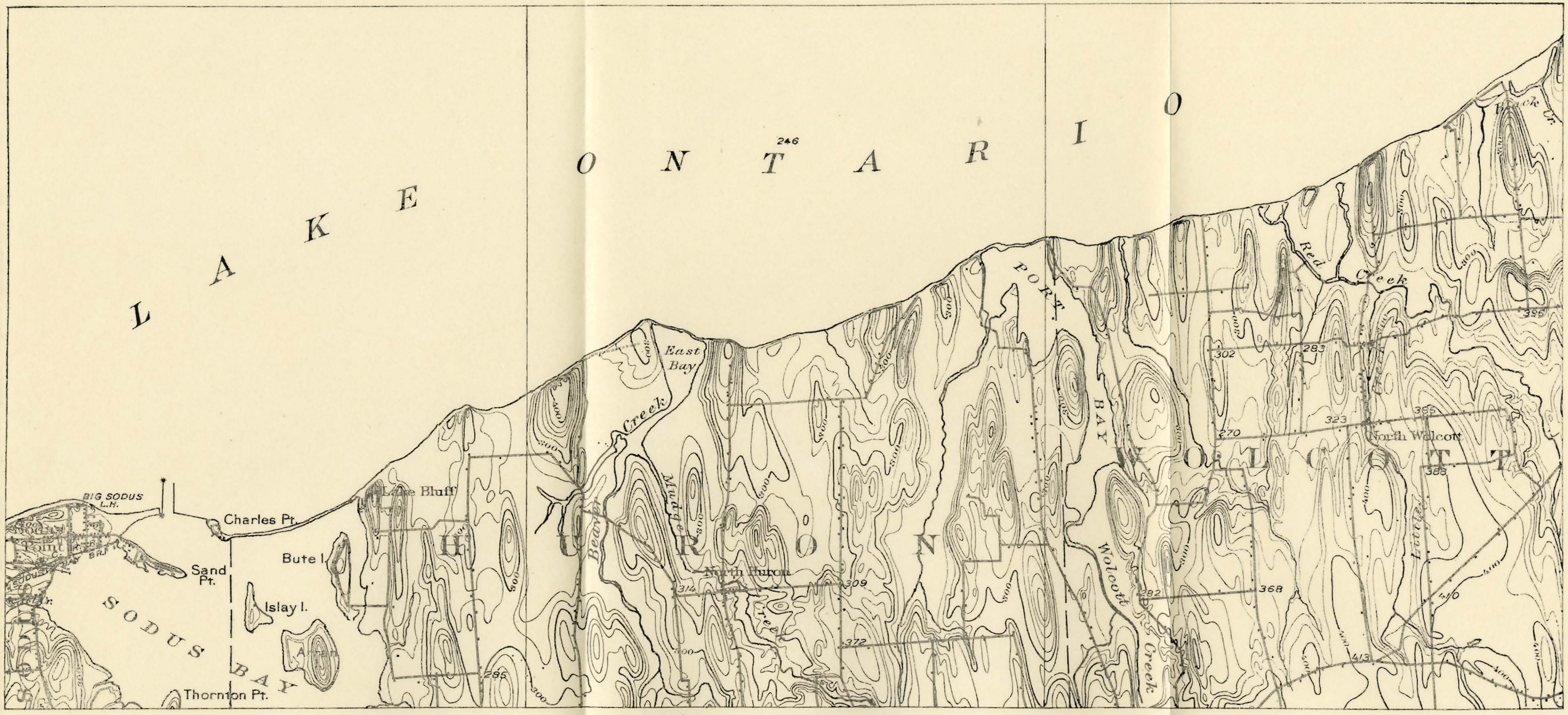
A third and late series includes the hills which border Lake Ontario eastward from Sodus. This we may call the Ontario series.

In the Genesee valley the first series blends with the second, the main group. And it is possible that the outlying drumlins at Syracuse and Cazenovia were formed contemporary with the first series.

The drumlinizing of the Niagara-Genesee prairie, in Orleans and Niagara counties, was perhaps contemporary with the second or main series.

The Chautauqua group, constructed by the Erian ice body, certainly antedates all the forms in western and central New York.

Attitude; Orientation. In its maximum development the Quebec ice cap had over central and western New York a flow direction west of south, or about southwest. At that time it was not influenced by the land relief. But in the thinning of the ice-sheet there came a phase when, as a plastic solid, its movement was affected by the



DRUMLINS ALONG THE SHORE OF LAKE ONTARIO
Sodus Bay sheet. Scale: one inch equals one mile.

larger relief or the gross topography of the overridden land. With the waning of the border and thinner ice its flow was more and more directed by the inequalities of the land surface.

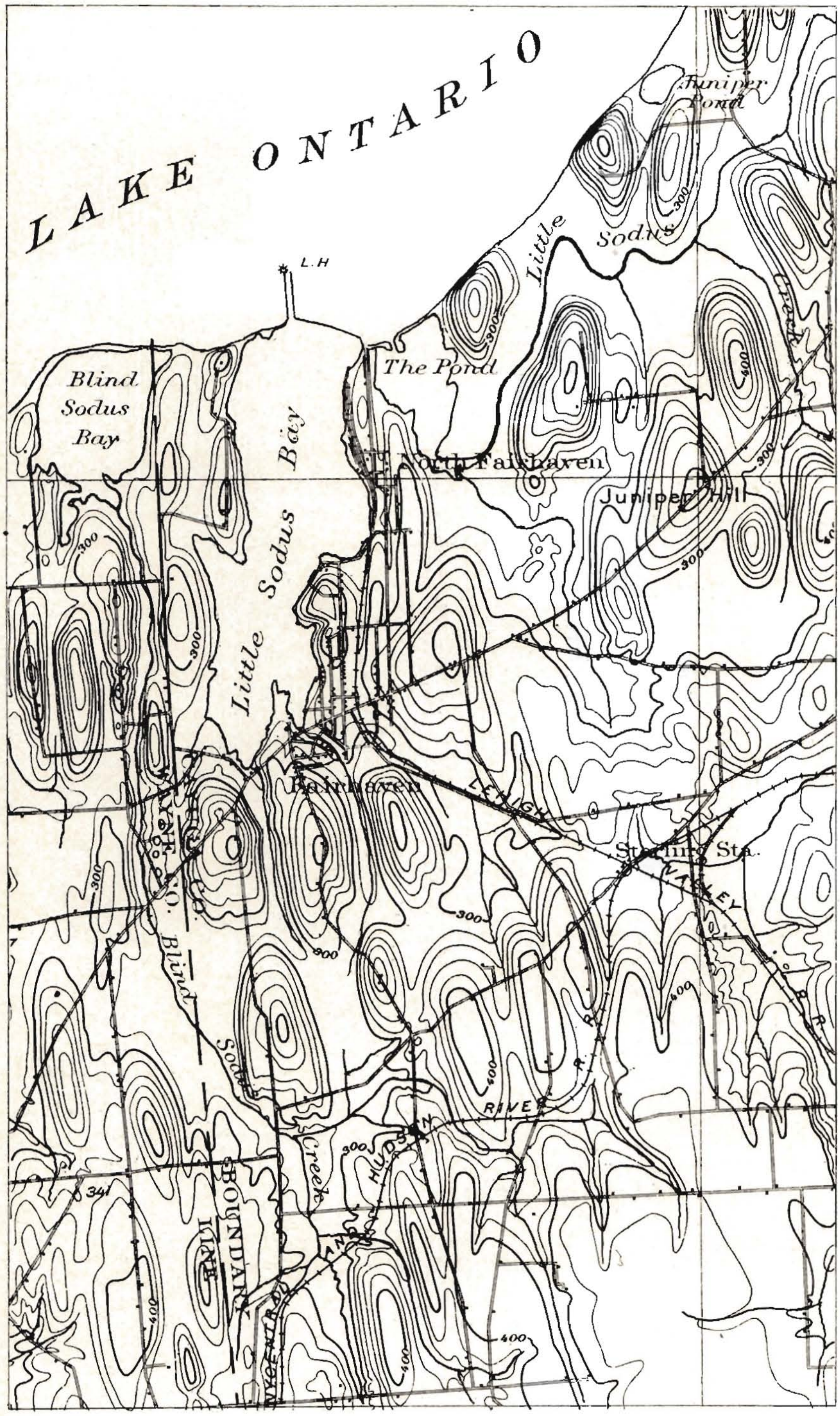
The drumlins are the best criteria for the later ice-flow direction. The long axes of the drumlins indicate the direction of the latest vigorous movement of the ice-sheet in their locality. The variant directions of the drumlins throughout the whole field prove a radial or spreading flow of the ice body that filled the Ontario basin during the stage of its waning that is represented by the drumlin formation.

The attitude of the drumlins with reference to compass direction varies according to their position in the area. The angular directions of their longer axes cover nearly a half circle. In the district east of Lake Ontario they point east, that is they were shaped by a movement of the ice from the west. As we pass westward around the south side of Ontario we find the direction gradually shifting to southeast, then to south, and finally in the western part of the field to southwest. And on the Niagara-Genesee prairie, in the northwest corner of the state, the direction is even more westerly. This radial attitude is well shown by the map, plate 4.

The consonance of the drumlin attitude to the latest ice flow is strikingly confirmed by study of the drumlins in the outlying districts. The Chautauqua hills point southeast, with the spreading flow of the Erian lobe of the melting ice-sheet. On the other hand, the drumlins of the Watertown district point southwest, conforming to the latest flow of the thinning ice in the St. Lawrence valley.

Another interesting fact in this connection is that the axial direction is not always uniform along the same meridian. If the topographic control over ice movement changed with the varying latitude of the ice front, as the latter was receding, the drumlins record that fact. For example, twenty miles south of Rochester the ice margin was guided by the deep Conesus, Hemlock and Honeoye valleys, and the drumlins lie north and south. But on the same meridian, six to twelve miles south of the city the drumlins point to the southwest. The ice flow was then controlled by the broad Genesee valley and the thrust was from the northeast. This also indicates the relation in age.

The radial or spreading flow of the ice-sheet at any single stage must be found by comparison of the drumlin directions within a single series of forms, that is, drumlins which were built simultane-



MASSIVE DRUMLINS

About Fairhaven (Little Sodus) Bay. Part of Oswego sheet.
Scale: one inch equals one mile.

ously. This is so evident on the map that specific description is unnecessary.

The genetic relation between ice-flow direction and the attitudes of the drumlins finds singular confirmation in the district east of Lake Ontario, already noted. Passing eastward around the corner of the lake (Mexico Bay) we find that the drumlin axes veer from southeast to east. Passing on north some 10 miles, to Ellisburg and Belleville, we see the drumlins pointing southwest, nearly opposed in direction to the forms at Oswego and Mexico.

These opposing directions represent ice-flow movements during different stages of the same body of ice. The ice-sheet did not entirely disappear and then return in different direction. While the Ontarian lobe yet covered the Mexico Bay district the radial flow produced the forms pointing southeast at Oswego and east at Sandy Creek. But during a final stage of the glacier in the same region a thrust of the ice lobe from the St. Lawrence valley produced the southwest-pointing forms between Ellisburg and Watertown.

Recognizing that if the southeast-pointing forms were made by an earlier flow of the same waning ice body that produced the later southwest-directed forms, then somewhere between the two opposing forms the drumlinized drift should indicate a turning, swinging or pivotal motion of the ice; and such is found. Seen in the field the drumlins of the Pulaski district show peculiarities of form which the map contours do not suggest and which appeared inconsistent and puzzling. From whatever direction we may view some of these hills the convex drumlin form appears. In some cases one detects a faint but distinct molding of the hill in direction highly inclined to the main mass. Sometimes an irregular surface which has been regarded as morainal becomes equivocal, or even clearly ice-molded, with a change in the point of view.

An important fact which has a bearing on the origin of drumlins and the mechanics of their construction must be noted. The secondary or contrawise forms just noted do not seem to have been made by cutting or carving of the primary forms, but to have been produced by the addition or plastering-on of material during the later molding. The work was constructional not erosional.

A singular form of drumlin is found in the district south and southwest of Rochester. This suggests one drumlin superposed on another; a sort of two-story drumlin. The feature is related to the present topic of orientation. Examples are seen in the Hosmer hill, four miles northwest of Scottsville (Plate 10); Cushman hill, two and one-half miles northwest of Scottsville; and Martin hill, one mile east of West Rush.

Some of the concave slopes on these "double-deckers" may coincide with the Lake Dana level, and it is possible that they have been accentuated by wave erosion. But the molding is found at other levels, and the surfaces have the characters of ice-molding. The lines are out of horizontality and erosional phenomena are wanting. The explanation is found, it is thought, in a slight change in the direction of the ice movement during the construction process. Such change in the ice-flow direction was apparently due to the directive influence of the wide Genesee valley on the thinning ice-sheet. The later flow was changed from west of south to south and east of south.

A suggestion that the superposed drumlins might be the product of a second ice invasion, or of a large readvance of the ice front, appears to be ruled out by the fact that the peculiar feature is found only in the northern portion of the Genesee valley, where it widens out into the Ontario plain.

Relation to the Land Surface. A glance at the map, plate 4, shows that the general drumlin area covers ground of all altitudes from the level of Lake Ontario (and perhaps in the depths of Ontario) up to about 1,700 feet, west of Canandaigua Lake. West of the Seneca valley they reach up to high ground, 1,100 to 1,500 feet. In the low north and south depression of the Seneca and Cayuga valleys, where we might expect them to be well developed, they are weak or absent above 500 or 600 feet.

While scattering drumlins in poor form may occur between the eastern members of the Finger lakes it appears that the area of close-set and well developed forms does not reach south on the high ground east of Seneca Lake; but that extensions of the field do reach up on the high ground west of Seneca Lake, and as far west as the Tonawanda valley.

The greatest development of the drumlins is on the low ground north of the Finger Lakes, and chiefly under 500 feet altitude. This great development on the low Ontario plain, and their comparative absence on the higher ground which faced the ice-sheet, is most striking in the central and eastern part of the drumlin belt.

This distribution of the drumlins indicates that altitude and gross-

DISSECTION OF DRUMLIN

Undercutting by storm waves of Lake Ontario. Chimney Bluff, four miles east of Sodus Point. Looking southeast.

er topography were not the only controlling factors in the drumlin formation. The direction of ice-flow was another important factor.

The dominant topographic feature was, and yet is, the wide and deep Ontario basin. Previous to the epoch of drumlin formation this feature had little influence on the glacier movement. The ice over New York was then subject to a push or thrust-movement from the northeast by the central mass of the Quebec ice-cap. However, during the drumlin phase the push from the northeast had ceased, and the Ontario lobe of the glacier had been left as a semi-stagnant body of ice, which as a plastic solid spread by its own weight and deployed over the Ontario lowland and its borders. The effects have been described in the preceding chapter.

The valleys of the Finger Lakes were carved in Preglacial, Tertiary, time by a remarkable series of parallel rivers which flowed northward to join a great master river, the Ontarian, in the bottom of the west-leading Ontario valley. As shown in plate 11 the northern sections of all these ancient valleys are now filled with drift and entirely obliterated. The basins produced by the northern blockade now hold the series of parallel Finger lakes.

The belt of "open valleys," plate 11, with small amount of drift on the slopes, suggests that the deeper ice in the valleys had been comparatively stagnant, and served as a bridge over which the upper ice rafted its load of drift and piled it into the "valley-heads" moraine. Later the ice-sheet thinned and its front backed away, northward, without leaving conspicuous drift masses either as moraine or drumlin. But the abundant drift held in the deeper ice was used to fill the northern portions of the ancient valleys, and then to heap the drumlins on the plain.

As stated above the land surface east of Syracuse did not feel the rubbing effect of the ice-sheet. The Syracuse district was subjected to the thrust of a tongue of ice which pushed southeastward from the spreading Ontarian mass. The southward and southeastward flow did not affect the land surface in the Oneida lake region, nor over the high ground east of the Seneca valley.

Relation to the Rock Strata. The glacial stuff built into the drumlins was mostly derived from the exposed or outcropping strata adjacent on the north. Exceptions will be noted below.

The central area of the drumlin field is the low ground north of the belt of limestones, known as Helderberg and Onondaga. Beneath these limestones, and extending northward down under Lake

Ontario, the very thick strata are chiefly shales, with some Niagaran limestone and Medina sandstone. It is estimated that of the total thickness of some 3,700 feet over 3,100 feet are shale. Through millions of years of exposure in Preglacial time with atmospheric weathering the old land surface had acquired a mantle of residual clay. This became the first grist of the glacial mill. All of the thick rock strata have a southward downslope, or dip, which gave the outcrops a northward projection, opposing the impact of the ice movement. The abrasion of the bed rock, after the removal of the decay product, produced a second grist of clayey material.

It is probable that the bulk of the rock-rubbish in the drumlin area was not carried far away from its source by the bottom ice, but on the contrary was plastered into the drumlin hills. The thick shale and limestone rocks supplied a load of unusually clayey and adhesive drift. It is quite certain that the plastic and adhesive character of the subglacial drift was an important factor in the upbuilding of the massive, close-set drumlins.

The occasional occurrence of numbers of far-traveled bowlders in some of the drumlins, crystalline rocks from the western Adirondacks and from Canada, qualifies the conditions stated above and emphasizes the complexity of the glacial history. A fine example of the occurrence of foreign bowlders was found in the Ely drumlin, on the eastern edge of the city of Rochester. In 1928 the cutting for a street, Hurstbourne Road, across the crest of the handsome drumlin exposed large numbers of huge bowlders of crystalline rocks of various kinds derived from far northeast. Their well rounded forms and smoothed surfaces attest severe abrasion during their long journey, and this implies grinding pressure under great depth of ice. But these far-journeyed bowlders occur chiefly at or near the surface of the drumlins. Some of the coarse subglacial material of the northeast highlands had been rafted into the district and incorporated with the bottom drift of the thinning ice-sheet.

Form; Dimensions. The characteristic form of the New York drumlins is that of an elongated oval, with the length three to five times the breadth. This shape prevails in the crowded areas (plate 5), and also in the detached and scattered hills. Apparently this dolphin-back form is typical and normal for all drumlins wherever found, when the mechanical factors involved in their construction were normally balanced.

WAVE-ERODED DRUMLIN

Two miles west of Savannah; looking east. The south end is deeply cut by the wave-work of Lake Ontario. The farm residence and orchard are on the shelf, north of the road.

All the outlines or profiles of typical drumlins are convex. The lengthwise profile is an elegant, convex curve, characteristically more abrupt or steeper at the north end. The south ends, except of the steeper ovals and domes, normally taper off into the mantle of till, unless eroded by waves or other agency.

The crest line of the longer ridges is commonly a straight line, which may appear as true as if cut to a straightedge. In cross-section the variation in profile for single and typical drumlins is more limited than in longitudinal section. The summits naturally have a symmetric curve. But in close-set or crowded areas the drumlins have a common habit of coalescing or uniting by growth, and a cross-section may show two or three or perhaps more ridges. Not infrequently this welding of ridges produces quite irregular masses (plate 6). The Mormon Hill, four miles south of Palmyra is such example.

The blending of drumlin ridges is generally from a position of overlapping, as they usually lie in eschelon. Sometimes they build side by side in even ranks.

The junction of the convex drumlin with the horizontal ground surface naturally gives a concave slope at the drumlin base. Above this basal concavity all drumlin surfaces are normally convex, and departures from convexity are due to some interference or to some subsequent effect. As noted above two or more drumlins may overlap or coalesce so as to produce irregular or unusual forms. Morainal drift is frequently banked against the sides or bases of the drumlins so as to rarely change the true drumlin form. Erosion by the waters of glacial outflow may have cut the slopes and even the crests, but decided crest cutting by glacial flow is rare in New York. Vertical ridging or ribbing of the slopes is thought to be positively erosional, either by glacial waters or by postglacial storm wash and weathering. On the other hand, longitudinal fluting or molding is regarded as a constructional effect of the drumlin-making process.

With few exceptions the drumlins are cleared of timber and their surfaces are under cultivation, as they afford excellent soils. Some minor irregularities of surface may be subdued by farm cultivation, but when the atmospheric elements contributing to their erosion are considered it is surprising that they are so well preserved. In the great majority of cases the original form is preserved with little change.

The type of drumlin form least displayed in New York is the dome shaped or mammillary. Judging from the topographic sheets the group which most nearly approaches the dome lies about Fairhaven bay, partly shown in plate 7.

The most common variation in New York from the normal type is in the way of elongation. Long ovals and even-crested ridges are characteristic. They are well shown on the Clyde (plate 5), Auburn, Oswego and Brockport sheets. Quite extreme examples are shown in plate 12.

The most extreme forms in elongation are the slender, attenuated flutings which are too small to be represented on the maps. Plate 13 is the best mapping. This form will be described below.

It is an important fact that the several variations from the normal drumlin form are not intermingled, but are grouped distinct. Certain areas display only a particular form. For example, the type form with moderate elongation is seen in plates 5, 6; rounded masses in plate 7; very long ridges in plate 12; and attenuated ridges in plate 13. It is evident that some definite unbalancing of the several mechanical factors results in the production of a particular form.

The very extreme form of elongated ridges is so unlike the typical drumlin that it deserves a different name. It is a fluting or ribbing of the drift surface, a "wash-board" structure. Existing apart from true drumlins this drift form would not be recognized as of the same genesis. The term "drumlinized" has been given by the writer to this product of the sliding ice-sheet. On first thought it might appear that this fluting of a broad till surface was the more natural effect than the heaping of the drift into oval hills. And it is probable that this structure may be found in wide areas where typical drumlins do not occur.

We can discriminate three varieties of the drumlinized surfaces. The larger form includes the broad, low rolls which may not be recognized by the map contouring. They have been partially described on page 6. These low, broad moldings of the till mantle are the common and only form produced by the rubbing of the ice-sheet over most of the surface of the Niagara-Genesee prairie. Passing westward by railroad or highway the change can be seen from quite typical long drumlins near the Genesee river to the long swells of low relief. When not indicated by the topographic maps they may be recognized by the transverse, shallow cuts for the railroad grade. Westward these rolls gradually fade into gentle undulations of the

SUPERPOSED DRUMLIN

Hosmer Hill, three and one-half miles northwest of Scottsville. Looking southeast. The superior or superposed ridge is wholly in the maple grove.

surface, quite imperceptible except by the up and down grades of the railroad. Large areas appear quite flat to the eye.

This northeast by southwest fluting of the land has directed the postglacial stream flow in a wide belt south of Lake Ontario, as noted above. The fluting is well developed southwest of Alden and west and southwest of Buffalo over the lower and smoother plain. The contouring on the Erie county sheets, Attica, Depew, Buffalo and other quadrangles to the south, fail to indicate the drumlinizing of the land surface.

Of the smaller drumlinized form there are two varieties. One of these has been described, page 16, and is suggested on plate 13. The other form is a subordinate, secondary or parasitic fluting. This structure is displayed in the Lyons, Clyde, Savannah district, where the primary drumlins carry on their slopes, and in the intervening hollows, a secondary or minor order of ridges. These are very straight, parallel, close-set, and often not larger than a small railway embankment. They are difficult subjects for photography and no picture is here included. But they are conspicuous from any highway in the district.

These intermediate, and attenuated ridges clearly prove the molding effect of the moving ice and its drumlin-forming tendency, even in the hollows between the primary structures. The major and minor ridges taken together suggest comparison with a piece of wood molding struck by the planer. And the comparison is closer if we take the long drumlins which carry longitudinal ribbing along their sides and bases. It is perfectly evident that this longitudinal molding of the drift structures was constructive, and a part of the general process of drumlin building.

The size and dimensions of the drumlins are variable, within limits, according to the quantity and quality of the drift carried in the lower ice and the depth and movement of the ice-sheet.

There appears to be a limit to the height of individual drumlins. In New York this limit is about 200 feet. Using the map contours for determining the altitudes of the bases and summits (an inexact method, with maximum error of 40 feet) only one drumlin has been found with height over 200 feet. At some elevation the upbuilding process is antagonized by the eroding and leveling effect, and a balance is struck between the two opposing factors which limits extreme height, and results, apparently, in the production of multiple ridges of moderate size instead of one huge ridge. This principle appears to be illustrated in the shape of the peculiar island groups in the Syracuse region, described later.

The most conspicuous drumlins, striking because of their isolation, like those rising out of the Montezuma marshes, are not the highest.

Using the map contours, as noted above, for approximate data, along with precise figures given by the map for some higher drumlins, following are figures for a few of the highest hills. A longer list is given in Bulletin 111, N. Y. State Museum.

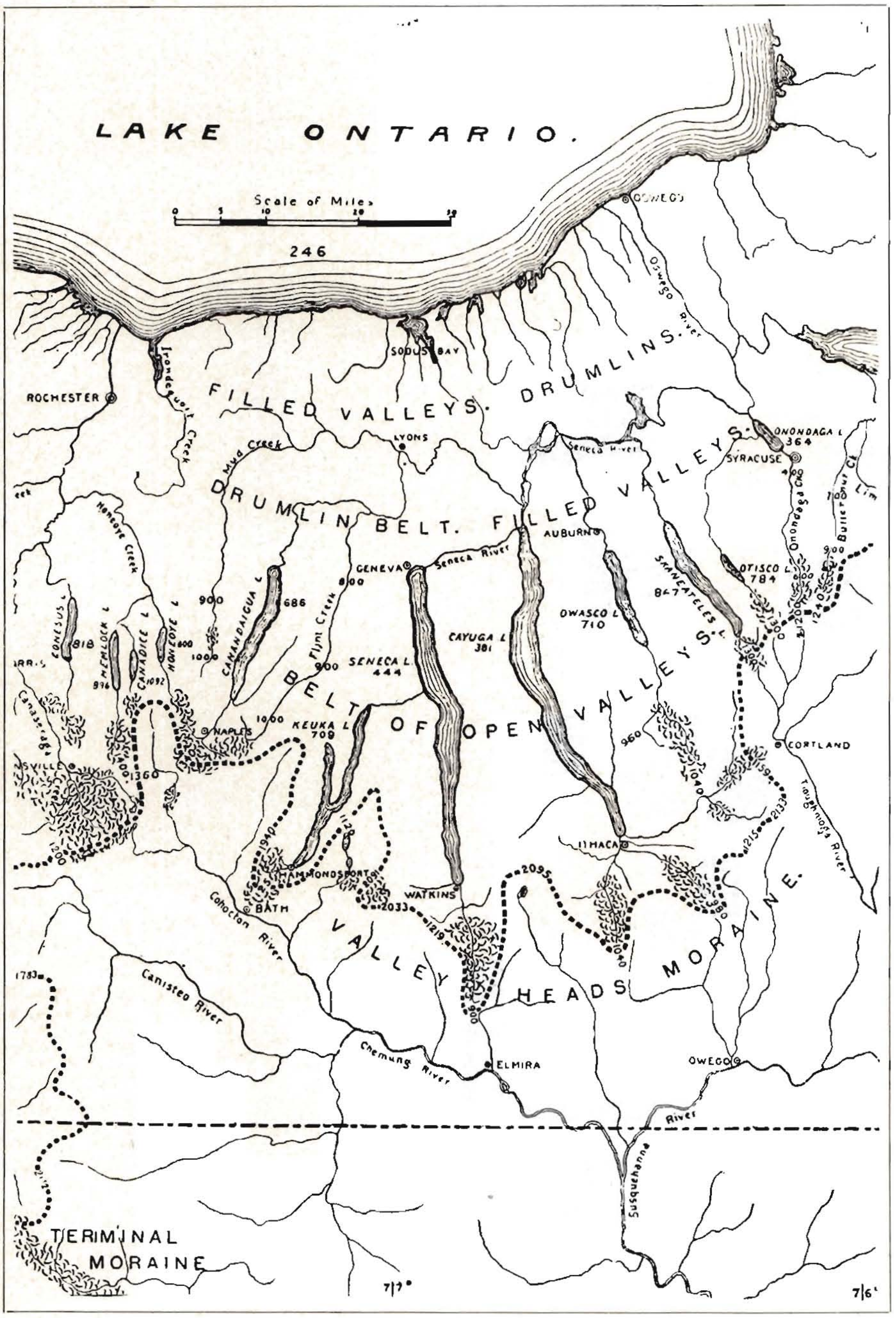
	FEET
On the Rochester meridian.	
Rider hill, at Industry	180
Palmyra meridian.	
Pigeon hill, 2½ miles northwest of Marion	185
Sodus meridian.	
Zurich hill, 5 miles south of Sodus	200
Baker hill, 6 miles south of Sodus	220
Clyde meridian.	
Chimney hill, 1 mile northwest of Rose	180
Triangulation station, hill 2½ miles south of Clyde	180
Fairhaven meridian.	
Hill 4 miles southeast of Montezuma	180
Oswego-Auburn meridian.	
Three hills, each	180

An interesting fact is that the prevailing maximum height of 180 feet is the same as of the type drumlins in north Ireland.

The length of drumlins is as variable as their height. It cannot be closely determined from the map contours, as a relief of less than 20 feet may carry a distinct ridge for a long distance. Scores of drumlins can be found on the maps with a contoured length of a mile or more. A length of one and one-half miles is not rare, but two miles is extreme for a typical drumlin. The close welding of overlapping ridges may give great length. Perhaps the longest well contoured forms are in the Oswego district, plate 12.

The drumlinized flutings in the northwest part of the state, described above, may have unit length of several miles, but have not been measured.

Composition. The drumlins are composed of very compact till and represent the subglacial or "ground-moraine" drift. The material is decidedly harder and more compact, especially the deeper layers, than the ordinary till mantle. The included stones of all



PHYSIOGRAPHIC BELTS IN CENTRAL NEW YORK

sizes are very commonly abraded or glaciated. All the characters of the drumlin till indicate movement under pressure. The material is emphatically the grist of the glacial mill.

The occurrence of water-laid drift, sand or silt, within the drumlin body is very rare. In extended examination of the internal structure only two cases were found of sand layers in the interior of drumlins, exposed by erosion on the shore of Lake Ontario. Some cuttings made by the electric railway between Rochester and Syracuse showed sand and sandy till as occasional upper beds.

As the drumlins were built under the thinner border of the ice-sheet it would seem very probable that streams on the surface of the glacier might sometimes carry sand down through crevices; and the sand become buried in the subsequent growth of the drumlin. The chances of such inclusion would increase as the thickness of the ice diminished.

The rarity of included water-borne material in the New York drumlins is conclusive evidence against the old supposition that they had been produced by overriding and reshaping of older moraine drift masses. In New York the moraines are largely water-laid materials, while the drumlins are hard till. It may be possible that in some other region of drumlin occurrence they might be produced by overriding of moraine drift during considerable readvance of an ice front. The relation of the New York drumlins to moraines will be noted later.

Water-laid materials on the surfaces of drumlins is to be expected, as the deposit of glacial stream work and of the subsequent glacial lakes. Most of the New York drumlin area was buried in standing water after the ice was removed.

As the ice melted away over the drumlins it sometimes left marginal or morainal drift on and among the drumlins. Rarely this might be so abundant as to partially bury or obscure the smaller drumlin forms. Such a case is found in the Junius kame-moraine, midway between Geneva and Lyons. However, such superficial morainal drift must not be mistaken for nor confused with the drumlin material. It is not only emphatically distinct in its genesis from the subglacial drumlin substance but subsequent in its deposition.

The proportion of far-brought and crystalline rocks is theoretically less in drumlins than in terminal moraine deposits. In any belt it probably will be found that the proportion of drift derived from the subjacent strata, or from the rocks immediately northward, is larger in drumlins than in the moraines; for the reason that the drumlins are built beneath the ice-sheet, of the subglacial or ground-moraine rock-rubbish.

However, the far-traveled bowlders sometimes occur in large numbers in the capping layers of drumlins (see page 14).

In some districts in central New York the base of the drumlins and perhaps large portion of the mass is soft shale rock. This is discussed below under the topic of Rocdrumlins.

Structure; Concentric Bedding. If the drumlins are constructional, or built up by a plastering-on process, then it must be expected that on a cross-section they would reveal some bedding or onion-peel structure, with the upper layers parallel to the drumlin surface. Theoretically such stratification would not be conspicuous, as variation in the building process would not be great as compared with the work of water, in either kind and quality of material or in the rate of deposition. The comparative steadiness in the action of the glacier taken in connection with the heterogeneous character of the material would seem unfavorable to the production of any very conspicuous bedding.

Artificial cuttings in drumlins do not expose large sectional areas, and these can usually be seen only at close range, which is not favorable for inspection of indefinite and large-scale structures.

Fortunately for this study Nature has assisted. We have a splendid exposure of the interior structure of drumlins along the south shore of Lake Ontario, specially between Sodus Bay and Oswego. In this stretch of about 28 miles not less than a score of drumlins, many of large size, are dissected to the core, sliced from top to bottom, by the wave erosion. The constant undercutting by storm waves yields continually fresh sections, and fortunately in different directions. Some of the drumlins are cut in direct cross-section; some in oblique section; and some quite longitudinally.

The erosion cliffs vary in height from 20 feet up to 140 feet. The growth of vegetation rarely is enough to obscure the structure, but in some cases is a proof of bedding in the till, as it lies in zones. The higher cliffs are bare. (See plates 14–16.)

A majority of the cliffs show undoubted concentric bedding, and in several it is surprisingly distinct. Unfortunately, some lines of bedding which appear to the eye are not recorded in the photographs. At distances which minimize the irregularities of the cliff faces, in salients, reentrants, amphitheaters and monuments, the

ELONGATED DRUMLINS

Part of the Fulton sheet. On the north the drumlins are overlapped by moraine deposit. Scale: one inch equals one mile.

fact of bedding parallel with the drumlin surface is strikingly evident, and is shown by different features. Even at close range a difference in the texture of the beds is evident. Distinct lines or zones of bowlders are frequent. Some difference in shade of color is common, and such color difference due to varying capacity for moisture is pronounced. The latter is also shown by patches of vegetation clinging along certain lines.

A striking proof of stratification is the differences in weathering, indicated, as in plate 16, by uniformity in elevation on the cliff face of irregular weathering and conical buttresses.

In cross-section view the concentric bedding decreases in convexity passing downward toward the base of the drumlin. Near the base the bedding is nearly horizontal, and the arching increases toward the top. A good test and confirmation of the concentric structure is found in the oblique and the nearly longitudinal sections. The stratification exposed in these different sections has directions that pertain to concentric structure. The application of these facts of drumlin structure to the problem of drumlin origin will be considered in a later chapter.

To aid the study of the subject by any one who wishes to examine the drumlins personally the following notes are given. West of Sodus Bay (Pultneyville sheet) the cliffs are partly morainal and only two good drumlin sections occur, one of them shown in plate 16.

East of Sodus Bay the lake shore and the dissected drumlins are mapped in plates 6 and 7. The dissections which displayed the bedded structure in the clearest manner at the time when plates 15–17 were made, in 1905, are in order eastward, using local names; Lake bluff, by Sodus Bay; Cline's bluff, one mile east; Blind Bay bluff, one mile west of Port bay (plate 16); two cliffs either side of Juniper pond, three miles east of Fairhaven (Little Sodus) bay.

It should be understood that the distinctness of the structures in the drumlin till will vary with the degree of moisture in the surface, and with the illumination. Probably the appearance of the cliff sections may change with deeper cutting, and so vary as time passes.

Relation to Moraines. If the drumlins represent vigorous movement of the ground-contact ice during episodes of either advance of the ice front or halts in its rescession then each drumlin belt should correlate with a line of frontal moraine. Such relationship appears definite for the main drumlin field, north of the Finger lakes. Where the drumlins fade out to attenuated ridges, from

Geneva westward to Auburn, a distinct belt of moraine drift lies two or three miles in front, on the south. This, the Waterloo moraine, is well shown in plate 13.

Morainic belts, like the weak Waterloo moraine, represent only the superglacial and higher englacial drift, carried to and passively dropped at the extreme margin, while at the same time the drumlins were forming beneath the ice-sheet in the rear of the moraine, from the subglacial and the lower englacial drift.

Theoretically the moraines should be weak in front of heavy drumlins, and in central New York the facts are in accord. But there is another reason. During the drumlin-making epoch the ice-sheet in central New York was faced by deep lakes. These were held up by the ice itself acting as a dam on the north. The drift in the terminus of the ice-sheet was dispersed by flotation of the ice and by the waves and currents of the lakes.

While definite lines of moraine are lacking a few kame-areas are s'rong. At the termination of the rivers which drained the melting ice-sheet very heavy deposits of water-laid drift was piled into kame-moraine hills, as the Mendon, Victor and Junius.

During rescession episodes of the ice front, by increased melting or diminished thrustal movement, the drift in the ice was quietly lowered on the drumlin territory. Not infrequently we may find a patch of irregular surface among the drumlins which can readily be discriminated and mapped as moraine. Rarely this may obscure the half buried drumlins.

Sometimes the volume of morainal drift increases northward so as to give decided moraine topography, as in the Walworth district in Wayne county. Plate 12 shows how a subsequent land-laid moraine laps on the north limit of the latest drumlins.

Island-like Groups. These remarkable masses are partly illustrated in plates 17, 18. They occur in the main drumlin area, in the belt from Lyons eastward to Syracuse. They are partly bounded by river channels cut in soft Salina shales by the latest glacial drainage. North of Warners, plate 17, is an example of such drumlin massing not wholly surrounded by channels or open spaces.

One peculiar feature of most of these masses is an increase of height toward the center, which gives them an individuality or unity. If these drumlin masses have a core of rock reaching above the Salina shale, which forms their base or pediment up to about 500 feet in the more easterly groups (plate 17), it has not been found. But

ATTENUATED DRUMLINS

South edge of the drumlin belt, with the correlating moraine. Parts of the Clyde and Geneva sheets. Extensive fluting of the drift is not shown by the 20-feet contours. Scale: one inch equals one mile.

such rock core is not improbable for the more northerly groups.

Plate 18 shows the largest of several groups of drumlins which rise out of the marshes north of Cayuga lake. These are not so conical or cumulative as those eastward (plate 17), but are isolated groups of irregular form and size, even down to individual drumlins. In the Montezuma district these rise out of the broad marshes as if half drowned.

However, it does not seem probable that the absence of drumlins over wide tracts could be due to entire burial of the hills under lake and vegetal accumulations. More likely the low marsh areas are destitute of drumlins for the same obscure reason as others at higher levels. This leads to the next topic.

Non-Drumlin Spaces. An important fact, not previously noted in this writing, is that the drumlin area of central New York was from 270 to 290 feet lower during the period of glacial occupation and drumlin construction than it is now. The lines of equal postglacial uplift (isobases) are drawn on plate 5. This depressed condition of the land continued during the earlier phase of Lake Iroquois.

Another element in the very complex history relates to the north and south depression from Sodus bay to Seneca lake. It is believed that in preglacial time the Susquehanna river turned north at Waverly-Elmira and occupied the Seneca-Sodus valley. It was the largest of the north-flowing rivers described on page 13. The ancient valley of the Susqueseneca river is indicated faintly in the low north and south tract west of Clyde (plate 5).

Another element in the history is the fact that all of the area from Lyons east to Syracuse was under the water of Lake Iroquois.

The lack of drumlins in the bare spaces shown in plates 4, 5 and 18 appears to be involved in the geologic conditions just stated. Wave erosion by Lake Iroquois was not responsible, although such erosion did remove the drumlins north of the Iroquois shore, shown in plate 5.

Apparently the lack of drumlins north and northwest of Clyde is due partly to non-construction and perhaps in some degree to burial under Iroquois deposits. The weak drumlins two to three miles northwest of Clyde suggest the tops of half-buried hills.

The open spaces of the lower ground, illustrated in plate 18, lie in the region of deep drift-filling of ancient valleys, the northward continuation of those now holding the Finger lakes, chiefly in the north and south depression of the Sodus embayment and the Seneca and Cayuga valleys.

Many suggestions in explanation of the drumlin-bare spaces are ruled out. We have to recognize the probable equality in both the drumlin and the non-drumlin tracts of the depth and pressure ot the ice; of its impact and rate of movement; and of its burden of drift. The inequality in the drumlin construction probably relates to unequal conditions in the land surfaces.

In the areas of deep valley-filling perhaps some depressions were yet below the average level, and consequently beneath the plane of vigorous thrust movement. In such case a plane of shearing might have been established over the depressions. With shearing action the initiation of drumlins would be discouraged, as they imply some obstruction or some degree of local drag in the bottom ice. The occurrence of drumlins within or along the open spaces might be due to casual obstructions, while the shearing process prevented creation of new obstructions.

The lowest of the open spaces have been partly filled with postglacial lake silts, stream detritus and vegetal accumulation. And the very lowest are yet partly under water.

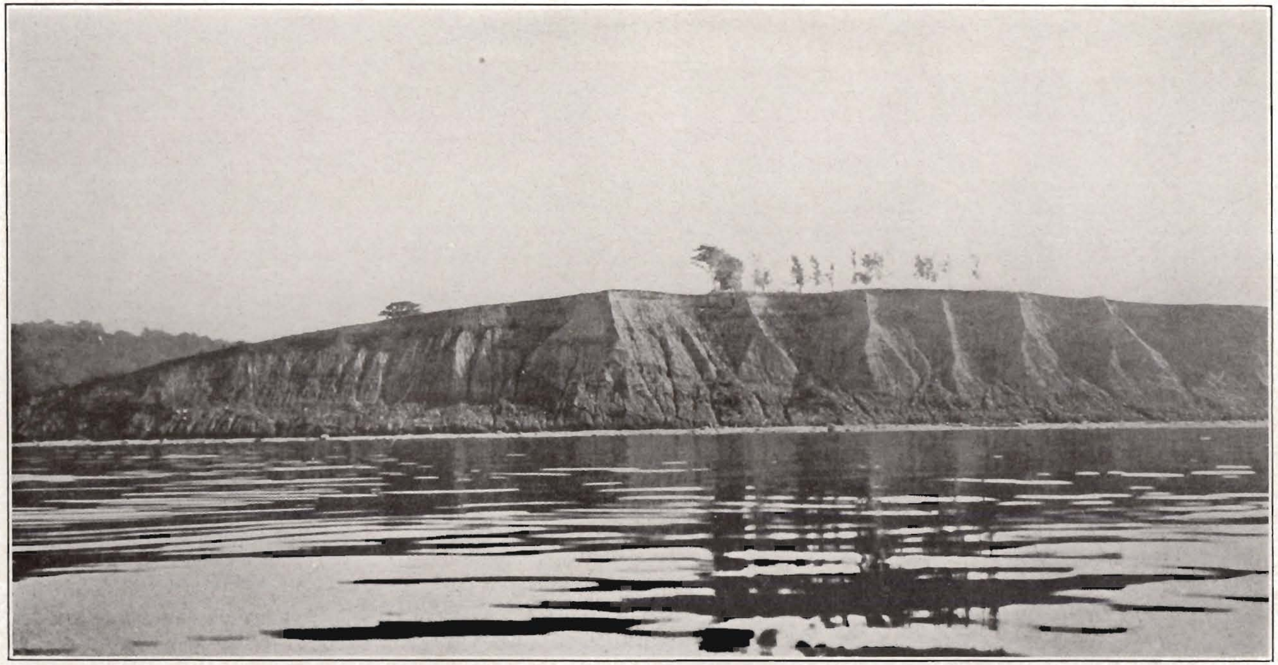
Open Channels. The channels or water courses with more or less direct eastward direction, like those from Fairport to Lyons, shown in plate 5, and between Montezuma and Syracuse, were occupied if not wholly produced by the copious ice-border drainage, escaping eastward to the Mohawk-Hudson. These channels are all cut in erodible Salina shale, and were effective when the land stood nearly 300 feet below the present level.

The uncertain and puzzling channels are those with windings and wayward indirection, and these may be related in their origin to some of the nondrumlin spaces. Seneca river is an example, with its northward turn east of Savannah, and from Cross lake (an open tract) around to Baldwinsville, and then south to near Onondaga lake. This is partly shown in plates 4 and 19. The Clyde river (plate 18) and Dead creek (plate 19) are other examples.

When the ice-sheet finally melted off from central New York it was succeeded by Lake Iroquois. The vagrant and erratic drainage lines must have been initiated, around and among the drumlins, as the lake waters were drained away. The land was then much lower than it is at present, and with more slope to northward. The sluggish stream-flow through many thousands of years has probably

BEDDED DRUMLIN STRUCTURE

Lake Bluff, two miles east of Sodus Point. Looking southeast.



BEDDED DRUMLIN STRUCTURE

Blind Bay Bluff; five miles northeast of Sodus Bay. Looking south.

been influenced and perhaps diverted by organic growths and peat fillings.

Rocdrumlins. It is found that the molding effect of the overriding ice-sheet was not restricted to the drift masses, the drumlins, which were deposited during the rubbing process by the ice itself, but was felt by the hills of soft rock that were exposed to the ice erosion (plate 19).

The term drumlin cannot appropriately be applied to ice-shaped rock hills, even though the genetic relationship may be evident. The term "drumloid" is appropriate, but the word has long been used for hills of glacial stuff having an accidental resemblance in form to drumlins. A distinctive term with obvious meaning is needed, and such a term is *rocdrumlins*, using as a prefix the Celtic word for rock.

It must be very clear that rocdrumlins are an effect of a moderate amount of erosion, or removal of material, while drumlins are the product of upbuilding and shaping at the same time. The genetic distinction is important and fundamental.

Between Palmyra and Syracuse the foundation of the drumlins is Salina shale, mostly the soft red and green beds known as Vernon. All of the deeper valleys of the district are cut in this shale, which may be seen on the slopes as bare patches of bright colors, light green and red. In the area of Jordan and Memphis these shales, forming the walls and bottom of the broad valley, are eroded into forms simulating morainal topography. As far east as Oneida the rock forms might, as seen from a distance, be mistaken for moraine.

In the Jordan-Memphis district the Vernon shales reach up to over 500 feet elevation, while the lake and stream fillings in the valleys are about 400 feet altitude. The Vernon shale, therefore, extends upward about 100 feet above the lowlands and are overlain by the gypsum-bearing Camillus shales. East of Jordan they form the common platform from which the drumlins rise (plates 17, 19).

It appears that in the belt from Lyons to Weedsport the Salina shales belong in the same horizontal plane, or topographic horizon, as the drumlins, and the interesting question arises if the drumlin masses may not be partly shale beneath a veneer of till. One and one-half miles northeast of Port Byron, and three miles west of Weedsport, the red Vernon shale appears clearly on the slopes and on the summit of a drumlin-shaped hill with a summit contour of 460 feet. Here is certainly a drumlin form in rock, a rocdrumlin.

It is very likely that other of the lower drumlin forms may be chiefly shale with only a varnish of drift; and it is more than likely that some of the larger drumlins have a base or a core of rock.

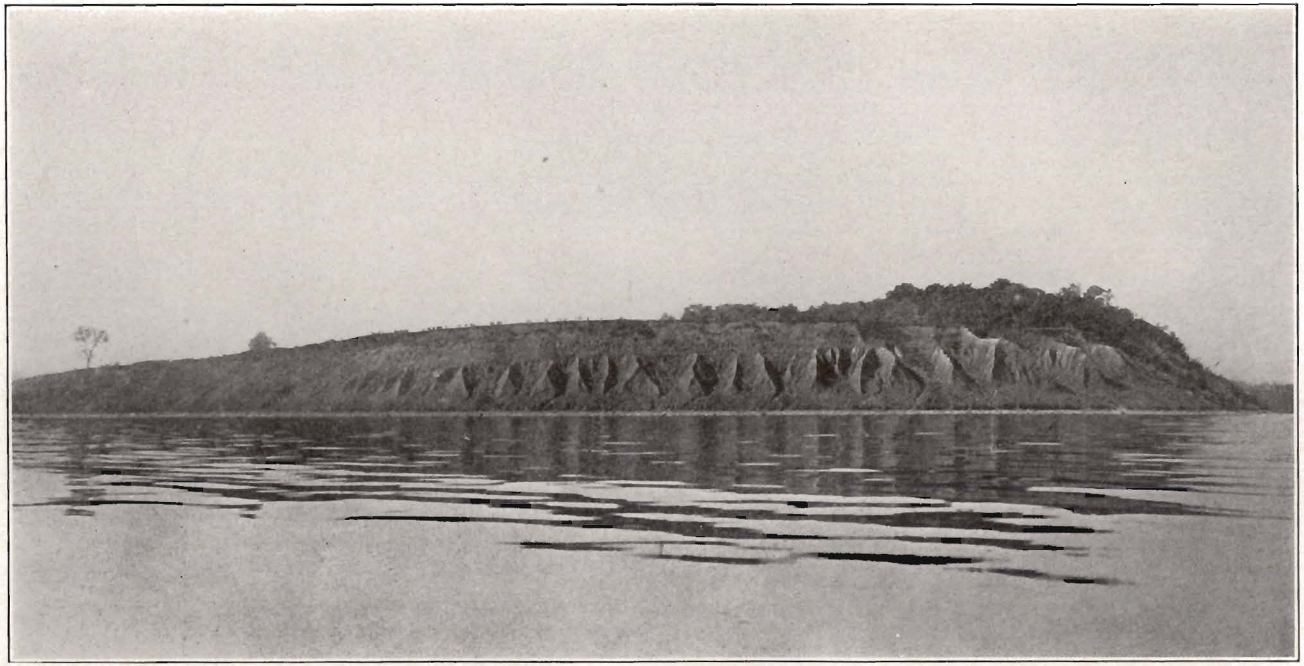
All the western-central New York rocks have a decidedly southward dip. It appears, therefore, that north of the Lyons-Syracuse parallel the rock strata must lie at increasingly higher elevations. And the vertical or stratigraphic range of the Vernon shale, several hundred feet in thickness, would include the whole height of the drumlin forms in a considerable belt of the northern territory. An examination was made of the hills west of Baldwinsville, with result not unexpected. It was found that all the drumlin forms are clearly composed of red shale, with only an apology of till coating. All of the hills in the upper half of the map, plate 19, and lying between the two north and south valleys, are not drumlins but rocdrumlins.

On first sight these hills would be regarded without question as true drumlins. But there are decided though refined differences which appear on close study. The rocdrumlins are not so symmetrical as the till forms. The slopes are less regular, and the struck ends are liable to be abrupt and irregular, and not so symmetrical as true drumlins. Even the 20-feet contours of the map reveal the differences. Looking at plate 19 it may be noted that the bases of the hills are indefinite, and that the hills do not have the clear-cut individuality of drumlins, as shown in plates 3, 5, 6, 7. The differences in form between the rocdrumlins and drumlins are clearly recognized in the field, and are fundamental.

Vernon shale is only hardened clay, without structure and easily decomposed. It yields readily to weathering and to erosion, and the product of the ice-rubbing was a plastic paste and lubricant, essentially like clayey till in its mechanical properties. In consequence the hills of Vernon shale which stood within the zone of drumlin formation were, in conflict with the moving ice, easily shaped into the drumlin form. And when given that shape they resisted the ice-impact. They were, like drumlins, both compliant and resistant. They became drumlin in form, in clever masquerade.

The Salina shales as a whole, many hundreds of feet in thickness in the drumlin territory, must have supplied a large amount of plastic and adhesive material for the drumlin-making process. Probably this was an important factor in the New York area.

Recognizing that glacial rubbing shaped the Salina shale hills, the rocdrumlins, it would appear likely that hill summits in other



BEDDED DRUMLIN STRUCTURE

Dissected drumlin four miles west of Sodus Point. Looking southwest.

districts beyond the drumlin area might, under exceptional conditions receive a drumloid expression. It is quite possible that such forms do occur. Some uplands, especially the intervalley areas in the Finger lakes region, exhibit some horizontal grooving. The smooth and graceful walls of the deep north and south valleys indicate a moderate amount of general sandpapering.

Some effect of ice abrasion and the shaping of land surfaces, where exposed to movement of the ground-contact ice, is probably more widespread than has been recognized. However, this does not at all imply that glacial erosion can excavate valleys or produce lake basins.

Physical Factors in Drumlin Formation

It is apparent that the drumlin-building process involves many factors, and most of them indeterminate and elusive. The problem is complicated, including not only the difficult subject of the behavior of plastic solids but the action of the ice under a complexity of geologic conditions.

In considering the mechanics of drumlin construction three sets of factors are recognized: those pertaining to the ice itself; those relating to the drumlin-forming drift; and the external influences of topography and atmosphere. These will be briefly considered in order.

Dynamic Factors Pertaining to the Glacier.

1. Vertical pressure. This is directly proportionate to the vertical thickness of the ice-sheet.

2. Horizontal pressure. At the periphery of the continental ice-sheet the horizontal pressure required to produce flow, on either level ground or on an upslope (as in the New York area), was mainly an effect of the vertical pressure in the rearward and deeper part of the ice-body. The depth of the ice along the drumlin-making zone was probably insufficient to greatly aid the forward movement. However, with plasticity effective the vertical pressure or weight might have had some local effect in modifying the movement or in producing differential flow.

3. Vigor and velocity of flow. This is due primarily to the thrust from the direction of the deeper ice. The horizontal displacement or mass movement of the ice border would be influenced by the larger features of the land surface, and by the local temperature and rainfall.

4. Differential flow. Plasticity of the ice would theoretically allow unequal flow, or a tendency to flow in prisms or currents analogous to currents in water streams; and the drumlins are evidence of such local variations in the ice flow.

5. Plasticity. This property of the glacier ice would be increased by pressure, heat, and water as a lubricant. In the marginal, drumlin-forming zone plasticity due to vertical pressure would be reduced; that due to horizontal pressure would be fairly constant; while that due to heat and water, from rainfall or melting, would be increased.

Factors Relating to the Drift Held in the Ice.

1. Volume of the drift. It has long been recognized that the plastic flow of glacier ice diminishes with increase of rock debris. But the movement of the ice by rearward thrust would not be greatly affected by the contained drift. The influence of the load of drift toward producing rigidity might aid in producing differential flow in prisms or bolts. Whatever was the effects on the flow of the ice by variation in the load of drift, its abundance in the lower portion of the ice-sheet was a direct help in drumlin construction.

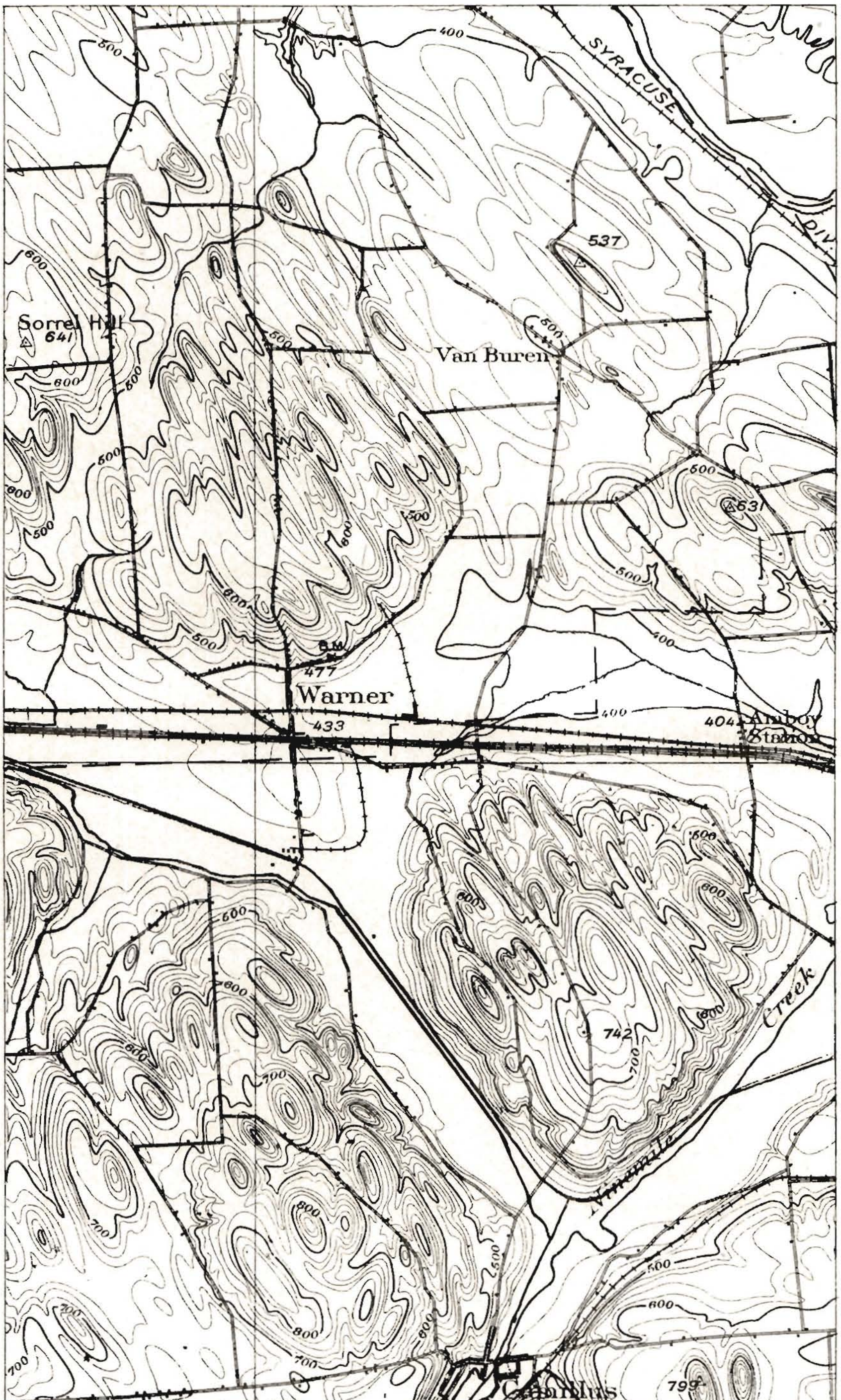
2. Position of the drift. The vertical location of the rock-rubbish in the ice is an important factor. Debris superficial to the ice-sheet could produce only frontal moraine. Drumlins were built from the debris carried in the lower layers of the ice.

3. Quality of the drift. It would appear that a clayey, adhesive character of the drift would facilitate the plastering-on process, by which the New York drumlins certainly were made. No drumlins are found composed largely of bowlders and friable material.

Factors of External Control.

1. General slope of the land. A down slope would favor movement of the ice both by thrust and by plastic flow, and perhaps by shearing of the upper over the lower layers. An upslope would retard or prohibit any motion at the bottom except by thrust. The drumlin area of New York has, in general, an upslope, though the central district of massive display is nearly level.

2. Minor topography. This element is indefinite because variable in many ways. It would appear that great irregularity of the overridden land surface would be unfavorable to movement of the lower ice; and in which case the drumlin-making process would lie more in the plane of the hilltops. This may have a bearing on the con-



DRUMLINS IN ISLAND MASSES

Part of the Baldwinsville sheet. The valleys are cut in Salina shale, which also forms the bases of the groups.
Scale: one inch equals one mile.

struction of the island masses, page 22. Small prominences or obstructions in the floor of the ice-sheet might be favorable, as nuclei, for the initiation of drumlins.

3. Temperature and water supply. Plasticity of the ice was favored by heat and water. Cold and dryness favored rigidity. The margin of the ice-sheet must have had, especially in summer, nearly its highest possible temperature, and large supply of lubricating water from the ice melting and the rainfall.

Summary; Fact and Philosophy

Origin of Drumlins. It is certain that the New York drumlins were built up by a plastering-on process. The ice-sheet did not drop its drift burden in the depressions or low places, but plastered it on the obstructions. The plastic and adhesive character of the shale-derived drift of central New York was probably an important factor accounting for the great number, height and shape of the hills.

The rocdrumlins, or shale hills with the peculiar drumlin form, were shaped by a moderate amount of erosion or rubbing off of the soft rock.

The upbuilding of the drumlins by the plastering process was coincident with a rubbing-off and shaping effect. As masses or hills the drumlins were built by accretion of drift, but their singular form is due to the erosional factor. The whole process may be compared to the work of the sculptor on a clay model, a plastering on and rubbing off. The accretion was because of the greater friction between clay and clay than between clay and ice.

The hills of accretionary drift resisted the ice impact and its rasping effect just as did the hills of shale. The form possessed by both classes of hills is that which opposed successful resistance to the ice erosion, and the least resistance to the overriding movement.

Thrust Movement of the Ground-Contact Ice. Drumlins were shaped by the sliding movement of the bottom ice, that in contact with the land surface. This implies that the whole thickness of the ice-sheet participated in the movement. Such motion was not due to gravitational stress on the ice over the drumlin area, because the general slope was uphill, but it was produced by an effective thrust on the marginal ice by the pressure of the thicker rearward mass. As the ice-sheet became thinner by ablation there came a time when the drift-loaded ice in contact with the ground felt less vertical pressure but was subjected to greater horizontal push by the thick ice in the rear, and was pushed forward bodily. In this behavior of the ice-sheet lies the key to drumlin formation.

It does not follow that drumlins must always be formed where the bottom ice had a sliding motion, as other associated conditions are requisite. Such thrustal movement would be effective only where a border of the ice-sheet was backed by a thick and spreading rearward mass.

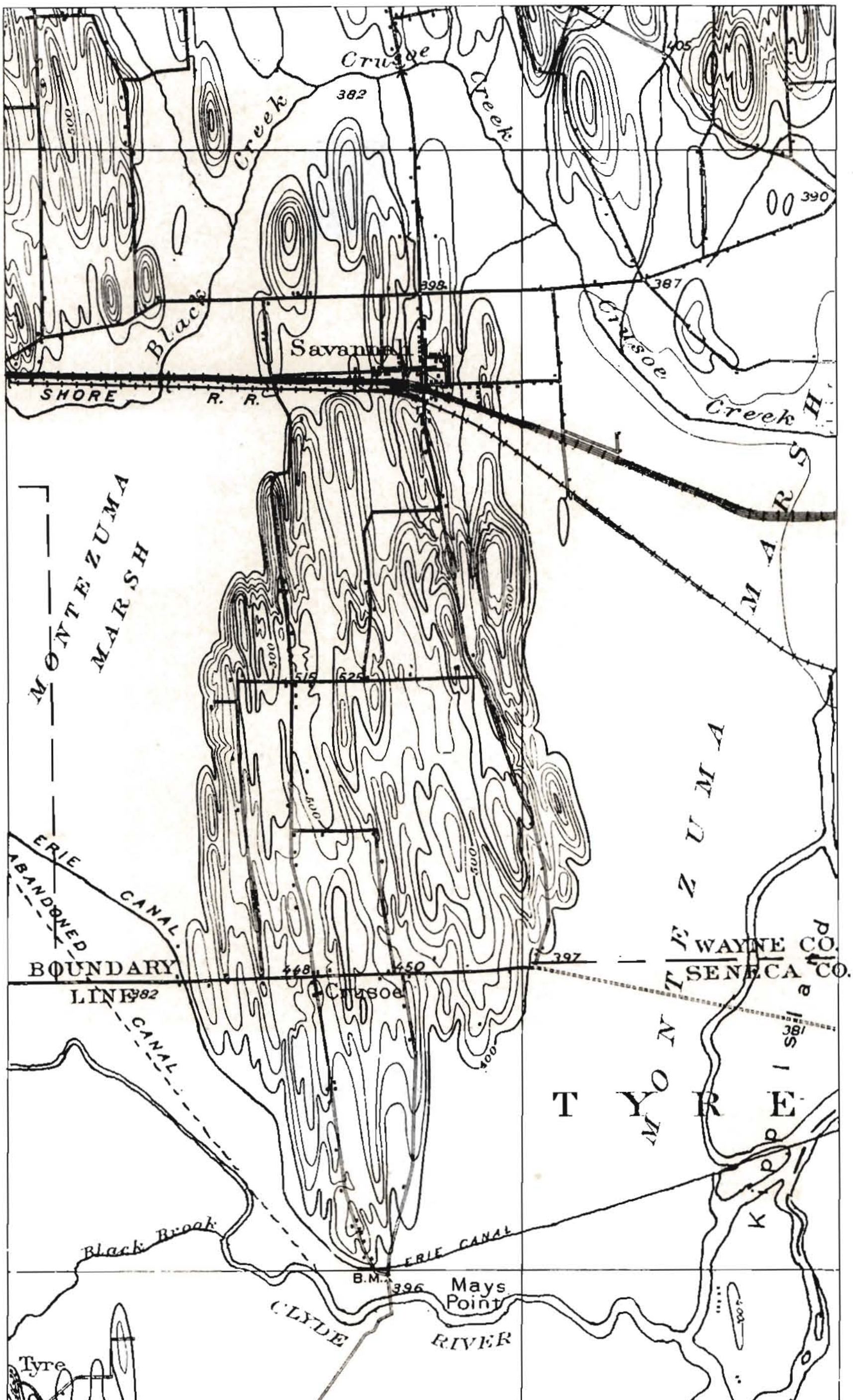
The combination of conditions requisite for effective thrust movement over a belt of country and for the considerable time necessary to create drumlins was not common. However, it may be assumed that wherever the ground-contact ice had vigorous movement of some duration it might be indicated by some molding of the ground surface, especially where that surface was comparatively smooth and composed of drift. The degree and form of the ice molding would vary with the strength and balancing of several factors. Some evidence of this ice work may perhaps be found where drumlins do not exist.

Dynamics. It appears that in the typical drumlin area the ice did not move as a solid mass, or even in wide sections, for such motion would have produced a planing or levelling effect. The typical drumlins are proof of a plastic and variable flow, while the long, straight ridges imply that the ice was pushed in comparatively rigid bolts or prisms that wavered and shifted.

In the balancing and adjustment of the several dynamic factors in the drift-burdened ice the two opposing forces of rigidity and plasticity seem to be the more fundamental. The amassing of the drift into drumlin form, or at least the nonremoval of the hills, implies that the depth of ice and the vertical pressure were so moderate as to allow the plastic ice to override and adapt itself to the obstructions, while at the same time the whole sheet of ice was sufficiently rigid to move under horizontal thrust.

Judging from the facts and the theoretical mechanics it would appear that the typical drumlins represent short lines of temporarily diminished pressure and of lagging flow. The lines of variable pressure and motion, though close set in the dominant drumlin area, must have been discontinuous, short and constantly shifting.

The drumlins could not have been determined, at least as regards location, by external influences, as atmospheric agencies above or topographic and geologic features beneath, but must have been pro-



DRUMLIN MASS IN MONTEZUMA MARSH
Parts of Clyde, Weedsport, Geneva and Auburn sheets.
Scale: one inch equals one mile.

ROCDRUMLINS

Part of the Baldwinsville sheet. The drumlin-like hills in the upper part of the map are composed of Salina (Vernon) shale.
Scale: one inch equals one mile.

duced by the interaction of the mechanical factors resident within the ice itself, the latter behaving as a plastic solid. The germ of each drumlin must have been some obstruction beneath the ice or a fortuitous massing of drift, or perhaps the lodgment and anchorage of a big bowlder.

The breadth of the main drumlin area, supposedly a unit in time of formation, is about 30 miles. If the northern and broader drumlins (plate 7) were built contemporaneously with the southern attenuated forms (plate 13), which appears certain, the physical conditions responsible for the different forms may be assigned. The broader and more widely separated forms, those about Fairhaven (plate 7) were under greater vertical pressure because of the greater depth of the ice. This might have given greater potential plasticity, but the effective plasticity and differential flow should have been less than in the central part of the belt. On the other hand the attenuated drumlins near the extreme border and under the thinner ice were subject to less vertical pressure. Here the ice had freer movement; it was less burdened with drift, having already built the drumlins in the rear; and probably it had less effective plasticity and less differential movement. In other words, the attenuated, border forms were molded beneath ice moving with greater freedom, greater relative rigidity, and with more uniformity and continuity.

The culmination of the drumlin-making process appears to have been in the middle of the belt, where the several dynamic factors were well balanced and working together at the maximum of efficiency. There the drift was abundant and plastic; the rigidity and the plasticity of the ice were active and balanced; and the differential flow was at its maximum, that is to say, the ice was not moving in long rigid bolts nor in wide masses but in short and wavering prisms.

The very long and flat ridges of the Niagara-Genesee prairie (plate 4) were the product of steady and long continued movement of more rigid ice than that which built the shorter, steeper and crowded drumlins in the middle of the area. The ice had less burden of drift, less differential flow and less effective plasticity. The effect was similar to the production of the attenuated flutings in the Waterloo-Seneca Falls district (plate 13), but the work was on a much larger scale. The direction of the drift molding in the western district is that of the prevailing direction of the continental glacier over the state.

Relative Age. The attitude and form of the drumlins in the Pulaski district, due to the change in the direction of the ice flow, prove that they were shaped during the latest phase of the ice work in that locality. The same conclusion is reached by theoretic considerations and is enforced by all facts of observation.

The peculiar distribution of these New York drumlins and their orientation prove that they were built under the spreading flow of the semistagnant ice body reposing in the Ontario basin. The correlation of moraine with the ultimate flutings of the drift shows that the drumlins were built under the thinning border of the ice-sheet. This relation has been noted in other drumlin regions, as Wisconsin, Massachusetts, Ireland and Germany. The drumlins of north Ireland, the type forms, lie in curving lines of ice flowage; and in all essential characters are strikingly similar to our New York forms.

Form and Relations. The interaction of the mechanical and geologic factors has produced a great variety of drift forms which may be covered under the class of ice-molded or drumlinized drift. Following are the typical forms:

1. Domes, or mammillary hills and low broad mounds (plate 7).
2. Broad oval drumlins (plate 6).
3. Oval drumlins with definite outline and high relief (plates 3, 4).
4. Long oval drumlins; the dolphin-back hills (plate 5).
5. Short ridge drumlins (plate 5).
6. Long and low swells of drumlinized drift, having the southwestward direction of the principal movement of the glacier.
7. Minor drift moldings on the flanks of and between the typical, close-set drumlins.
8. Slender ridges at the attenuated edge of the drumlin belt, with correlating moraine (plate 13).

The more striking relations in the distribution and association of the New York drumlins are as follows:

1. The drumlin area is practically on the north-facing or ice-opposing slope of the land (plate 4).
2. The region of greatest development is on the low Ontario plain (plate 5).
3. The greatest development of typical, close-set drumlins is in the region of the greatest thickness of the Salina shales, which supplied clayey and adhesive drift.
4. The predominant drumlin area is where the ice flow was south

and east of south, or at a high angle with the preceding, southwestward movement.

5. The drumlins are not placed in any orderly sequence or regular disposition, but are spaced in irregular manner.

6. The several varieties in form are not intermingled, but similar forms are grouped together.

7. Within the same belt, or what is regarded as a formational unit, the south forms, or those nearer the ice front, are the more attenuated; while the north forms, those beneath the deeper ice, are broader (plates 13, 7).

8. A belt of moraine lies in front of the attenuated border of the central drumlin area (plate 13).

9. The greater height of the drumlins, steepness of slope and regularity of form occur in the middle of the drumlin area, and characterize the maximum and most effective work of the constructive process.

10. The development of the broad, low swells in the northwest part of the great drumlin area is where the ice flow had only one direction, and where it had less volume of very clayey drift.

Depth of the Drumlin-Making Ice. No conclusive or definite data are available on this matter. The following calculation is merely suggestive.

The Waterloo-Seneca Falls moraine (plate 13) was laid under the water of a glacial lake which bathed the glacier front, with its control or outlet on the east. It is believed that the highest elevation of that water was about 700 feet, the height of Lake Dana.

The moraine lies at about 500 feet elevation, which implies 200 feet depth of water. As the moraine is weak, because the drift load had been incorporated into the drumlins in the rear, it may be assumed that the ice was not heavily anchored in the lake water by a load of rock-rubbish. In order to retain its position against the buoyancy of the water the ice should have been at least 25 feet over the lake, or with a thickness of 225 feet. Taking this as the minimum depth of ice at the glacier margin, and assuming a surface slope of 30 feet to the mile, the elevation of the surface of the glacier over Clyde, 12 miles north of the moraine, would be ($725 + 30 \times 12$) 1085 feet. As the floor of the Clyde drumlins is about 400 feet elevation the depth of ice in the center of the drumlin belt was 685 feet. And as the tallest hills there are 180 feet the depth of ice over their summits was about 500 feet.

Northward to the parallel of the massive hills (plate 7) is about 15 miles. Allowing for a reduced slope of the glacier surface, say to 20 feet per mile, the ice surface over the Fairhaven district would be 1,385 feet. And the depth over the hill summits over 1,200 feet.

Drumlins in Eastern New York

While the drumlin display in west-central New York, as described above, is by far the largest and richest it is not the only field in the state. Very interesting areas of drumlins and molded land surfaces are found in the eastern and northern parts of the state. The occurrences are widespread, with singular forms and relations, and a fair description of the features would make an extended paper. During over thirty years in the study of the Pleistocene geology of the state the writer has seen nearly all of the drumlin areas, and fain would describe them in detail, but only a brief outline is fitting here, which may however serve as a guide.

For the geographic references the quadrangles of the New York topographic map, or the corresponding sheets, will be named. The reader should have available a full set of the topographic sheets.

In the eastern half of the state there are three principal regions of ice-shaping phenomena. These are the great valleys which during the waning phase of the Quebec glacier held tongues or lobes of the ice sheet. During favorable stages these lobations had the dynamic conditions requisite for the molding of the land surfaces.

The regions possessing drumlins will be noted as follows: (1) the St. Lawrence valley, with southwestward direction; (2) the great Champlain-Hudson valley, with southward direction; (3) two diversions along the west side of the lower Hudson; and (4) the Mohawk valley, which held a westward lobation of the Hudson ice body.

The stronger flow of ice through the St. Lawrence valley fed the Ontario ice body (page 13) and in a later stage the weaker flow aided in producing some peculiar features described on page 11.

The best drumlin features in the St. Lawrence valley proper are found on the Alexandria Bay, Hammond, Clayton, Cape Vincent, Watertown and Carthage quadrangles. The northeast by southwest alignment of the land relief is quite clearly shown by the map contours. The ice streamed through the valley with force for ages, during both the advance and recession of the Quebec ice cap. Even the crystalline rocks show the rasping process, and some granitic bosses may perhaps be regarded as rocdrumlins.

DRUMLINIZED SURFACE

Southern part of the Amsterdam sheet.

Scale: one inch equals nearly two miles.

On the Carthage sheet a large number of small but typical drumlins with north and south directions are seen some miles west of Lowville, in the town of Harrisburg. Others with similar direction lie in the southeast corner of the Watertown quadrangle. A few forms occur about the village of Redwood.

An extension of the large but irregular St. Lawrence field is found on the Antwerp and Lake Bonaparte quadrangles, especially north and west of the lake, in Diana and Antwerp towns.

On the Canadian side of the St. Lawrence valley no examination has been made in drumlin study, but a good development of drumlin forms may be confidently expected.

Throughout the long stretch of the great Champlain-Hudson valley some detached or sporadic drumlins may be found outside of the well drumlinized fields. They have not been recorded by the writer in the Champlain valley. And apparently the dynamic conditions requisite for the shaping of land surfaces did not effectively occur north of Glens Falls. But in the main and lower Hudson valley drumlin features are handsomely developed.

The Saratoga, Schuylerville and Cambridge quadrangles supply many good examples. A group of drumlins lies east and southeast of Saratoga lake. Others are seen about the village of Argyle, in the northeast corner of the Cambridge sheet. This irregular field in the upper main valley blends on the south with that of the Mohawk valley, described later.

Southward, beyond the Mohawk embayment, the valley carries splendid display of ice-shaping, especially on the west side. On the east side some north and south shaping of the land surfaces, with some east of south, appears on the Kinderhook and Copake sheets, but stronger on the Rhinebeck, Clove, Carmel and West Point quadrangles. The northern part of the Carmel sheet depicts heavy north and south forms, and others are seen on the southeast corner of the West Point sheet. East of Poughkeepsie some suggestive forms due to possible ice-shaping require examination.

The ground west of the Hudson river has superior display of ice-shaped topography. The parallel alienation of the contour lines is as much, or more, in evidence on the topographic sheets than are the oval drumlins. (See plate 20.) The physical conditions or dynamic factors in the broad ice stream appears to have often favored the fluting or drumlinizing of the land surface rather than the local piling of the perhaps scanty drift into typical drumlins.

The long Hudson ice tongue was limited along the west side of the valley and crowded against the Catskill, Shawangunk and Ramapo highlands. This probably intensified the southward thrust, which also intensified the rubbing-down as against the upbuilding process.

The land surface of the Coxsackie, Catskill, Kaaterskill and Newburgh quadrangles is clearly drumlinized in southerly direction. The receding terminus of the ice tongue had some spreading flow, which along the borders of the valley caused diversion from the prevailing southward movement. As the highland wall receded the ice deployed westward so that on the Ellenville, Goshen and Port Jervis quadrangles the excellent drumlin development east of the mountains has southwestward direction. Yet farther south the Ramapo quadrangle carries heavy north and south drumlins along the east face of the Ramapo mountain.

A definite diversion of the ice to the southwest took place in the Kingston district. An ice lobe moved up the three adjacent valleys of the Rondout and Wallkill rivers and Esopus creek. The Rosendale sheet depicts the handsome features. East of the Wallkill river the alignment of the topography is north and south.

The most pronounced diversion or offset from the main Hudson ice lobe flowed westward up the Mohawk valley. On the Albany and Berne quadrangles the flow was southwestward. Beginning some five miles southwest of South Schenectady the ground up the Normans Kill valley is strongly molded in southwestward direction to Delanson and Quaker Street, and on toward Gallupville. This is shown on the north part of the Berne sheet and the south part of the Amsterdam sheet, plate 20. The south part of the Fonda sheet depicts some drumlins with similar direction.

This Mohawk lobe pushed far west, up the valley to beyond Richfield Springs, seventy miles from the Hudson river. Surprisingly, this wayward ice tongue built a group of excellent drumlins north and northwest of Richfield Springs village, all pointing west. These well-spaced drumlins appear on the Richfield Springs and Winfield sheets. They are also depicted, in color, on plate 5 of the New York State Museum Bulletin No. 160, year 1912.

The explanation of these drumlins, in such singular location, requires the narration of a bit of Pleistocene history. In some middle stage of the waning of the Quebec ice-sheet a heavy belt of ice was left in the Mohawk valley. This strait of ice, connecting the

Hudson and Ontario ice bodies, and lying between the Allegany highland on the south and the foothills of the Adirondacks on the north, has interesting relation to the glacial history and especially to the glacial drainage.

At some undetermined stage in the shrinking of the Mohawk ice strait the westward push, from the Hudson, prevailed as far as to the meridian of Utica. Under such conditions, with a vigorous push on the ice from the east, were the Richfield-Winfield drumlins constructed.

The guidance of thinner ice by the larger topography is well shown on the plate 5. A few ultimate drumlins, northwest of West Winfield, point to the southwest. The point of the ice lobe was guided by the gross topography and was pushed southwest between the hills into the head of the Unadilla valley.

Under the theory of multiple glaciation of New York, or at least of very great recession and readvance of the ice sheet margin, it might be held that these drumlins were built during a later and final episode of Mohawk glaciation.

Plate 6 of Bulletin 160 shows why there are no drumlins in the Albany-Schenectady district. The weight of the ice cap had depressed the continent, and on removal of the ice the Albany district was about 350 feet lower than it is today. Whatever drumlins were formed there are deeply buried in the delta of the great glacial Mohawk (the Glaciomohawk river) built in the wide Hudson estuary.

Complexity in the History

It is possible that there are undiscovered and unsuspected elements in the Pleistocene history of New York, and that it is more complicated than now recognized. It is possible that the oscillations of the ice front, recessions and readvances, have covered distances sufficient to amount to multiple glaciation, with important changes in physical conditions and geologic processes. While we must take the phenomena as we find them, and study them as they are, we may not deny the possibility that our New York drumlins and other glacial features are final products of geologic changes not now realized. However, it would be unscientific to minimize the truth before us and magnify the unknown and purely hypothetical.