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QUATERNARY SECTION AT OTTO, NEW YORK*

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ABSTRACT. At Otto, New York, the South Branch of Cattaraugus Creek exposes several peat zones beneath gravel, till, and thin lacustrine rhythmite beds. These sediments were deposited in a cross-valley cut as a result of stream derangement during pre-Wisconsin glaciation. Near the base of the section, the pollen profile is dominated by *Picea* and *Pinus* with irregular upward increase in the ratio of *Pinus* to *Picea*. Groningen radiocarbon analyses yield a minimum age of 52,000 years for the uppermost organic zone and a finite date of 63,900 ± 1700 years near the base of the section. Accordingly the organic zones are assigned to an early Wisconsin interstadial correlative with the St. Pierre interval of Quebec. It predates the Port Talbot interval of western Ontario but postdates the Sangamon interglacial.

INTRODUCTION

The high bank of South Branch Cattaraugus Creek at the village of Otto exposes one of the most important Quaternary stratigraphic sections in western New York. First reported by MacClintock and Apfel in 1944, the exposure has received the attention of a number of investigators during subsequent years. It is the purpose of this paper to present the writer's geological observations together with data from paleobotanical studies by William S. Benninghoff and Darlene Helmich of the University of Michigan, Clair A. Brown of Louisiana State University, Joakim J. Donner of the University of Helsinki, and Edwin H. Ketchledge of the New York State College of Forestry at Syracuse. These data analyzed in terms of their bearing on pre-Farmdale correlation and chronology in the Erie and Ontario basins indicate a long and complex glacial history during the Wisconsin stage prior to the classical Wisconsin of the upper Mississippi basin.

History of investigations at Otto.—MacClintock and Apfel (1944) first described exposures in the high bank at Otto in connection with their correlation of drifts bordering the Salamanca re-entrant. On the basis of study by Paul B. Sears, peat near the base of the exposure was ascribed to the Sangamon interglacial, and the bluff section was interpreted as displaying Illinoian till, Sangamon peat, Olean outwash, Binghamton till, and proglacial lake sediments.

Peat collected by C. S. Denny in 1949 and analyzed for radiocarbon by the U. S. Geological Survey Laboratory in Washington (Suess, 1954) was dated as more than 35,000 years old. Subsequent repetition of this analysis showed no significant trace of radioactivity above background, suggesting age one or more half-lives of radiocarbon greater than the range of the apparatus employed (Rubin, personal communication).

Visiting the site for the first time in 1957, the present writer was surprised to find not one, but several organic zones within the basal portion of the bluff, interbedded with silt, sandy silt, and gravel. Furthermore, the transition upward from the organic zone into the overlying gravel is gradual and without apparent change in direction of deposition. On the basis of this initial investigation the writer suggested the presently confirmed hypothesis that the Otto interglacial beds represent a post-Sangamon, pre-Farmdale interval of partial

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deglaciation of the Allegheny Plateau in southwestern New York (Muller, 1957a).

During succeeding field seasons the writer has revisited the bluff annually. Bank erosion constantly changes the aspect of the exposure so that new data are gathered on each visit. Peat samples collected in 1958 were submitted to William S. Benninghoff for analysis. Later in the same year the writer accompanied Clair A. Brown on a collecting trip which included the Otto site. Joakim Donner, then at Yale University, sampled the bluff in 1959. Thus three uncoordinated sets of pollen analyses were undertaken almost simultaneously. Material was submitted to Edwin H. Ketchledge by the writer for identification of mosses. Preliminary results were published in the field guide for the 23rd Reunion of the Friends of the Pleistocene (Muller, 1960).

ACKNOWLEDGMENTS

Investigations by the writer were supported by the New York State Museum and Science Service as part of a continuing program of mapping of Quaternary geology in western New York. Charles Ruth, Robert T. Dodd, Jr., G. Gordon Connally, and James S. Street assisted during successive seasons. John G. Broughton, Clair A. Brown, Hessel de Vries, Aleksis Dreimanis, John Droste, Paul MacClintock, John H. Moss, and George W. White discussed relationships with the writer in the field. Stimulating suggestions resulted when the site was visited during the 1960 field conference of the Eastern Friends of the Pleistocene. The manuscript was critically read by William S. Benninghoff, Clair A. Brown, Joakim J. Donner, Aleksis Dreimanis, Richard F. Flint, Richard P. Goldthwait, Morris M. Leighton, Paul B. Sears, Jaan Terasmae, and J. C. Vogel.

Radiocarbon analyses were carried out through the cooperation of Meyer Rubin at the U. S. Geological Survey Laboratory in Washington, D. C., and Hessel de Vries, H. de Waard, and J. C. Vogel at the Groningen Laboratory in The Netherlands. Isotopic enrichment for extended-range dating by the Groningen Laboratory was accomplished by A. Haring at the Laboratory for Mass-Separation in Amsterdam.

Data on depth to bedrock in the basin north of Otto were supplied by the Iroquois Natural Gas Company and by Robert Ehmke, well driller in Silver Creek, New York.

SETTING

The small village of Otto is located in northern Cattaraugus County, 35 miles due south of Buffalo and 14 miles north-northwest of Salamanca (fig. 1). It is near the center of the Cattaraugus 15-minute quadrangle of the U. S. Geological Survey 1:62,500 map series. The Wisconsin terminal moraine at Elkdale is 11 miles south-southeast of Otto. Glacial and interglacial beds are exposed where the South Branch Cattaraugus Creek cuts against the valley side for a distance of several hundred yards downstream from the highway bridge at the south edge of Otto.

Northern Cattaraugus County is part of the Southern New York section of the Appalachian Plateaus, an area of moderate relief reflecting glacial modification of maturely dissected plateau developed on nearly flat-lying Upper

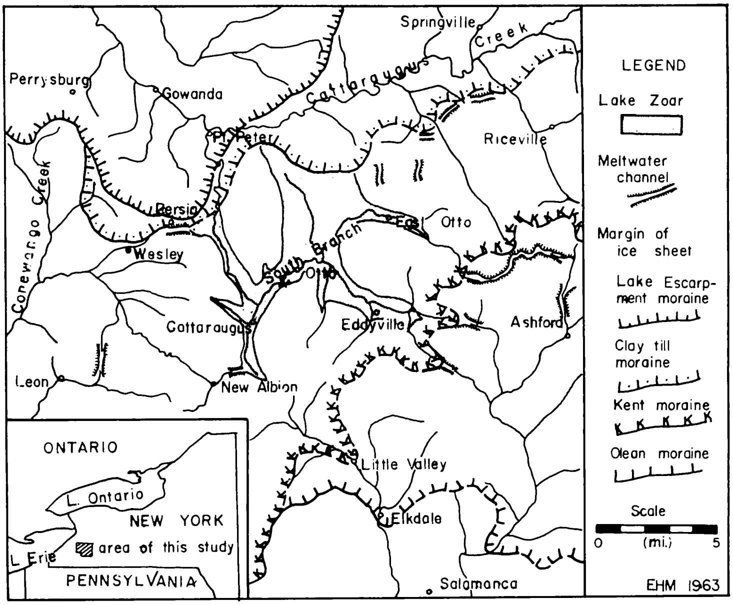

Fig. 1. Index map showing physiographic relationships in the vicinity of Otto, New York.

Devonian strata. Multiple glaciation of this portion of the plateau has been previously demonstrated on the basis of features bordering the Salamanca re-entrant as well as the stratigraphy of beds exposed at Otto and Gowanda (MacClintock and Apfel, 1944; Bryant, ms; Muller, 1957a, 1960).

The northern part of Cattaraugus County is in the drainage basin of Cattaraugus Creek, one of the few streams in New York that flow northward across the Lake Escarpment-Valley Heads moraine system (Leverett, 1902; Fairchild, 1932). The course of the creek is generally west-southwest to within a few miles of Gowanda where it crosses the moraine belt. From its headwaters to the moraine, the creek flows through three broad open reaches cut into glacial drift and separated by intervening bedrock gorges (Cuthbert, ms) before it enters the broad drift-filled valley of the Ancestral Allegheny River (Carll, 1880; Leverett, 1902) near Gowanda. This headward part of the basin is apparently composed of several preglacial northward-opening valleys which were joined by glacial derangement.

One such beheaded preglacial drainage basin extends as a horn-shaped plain for about 10 miles from Eddyville northwest past Otto, thence broadening northward to Cattaraugus Creek. Limited available data suggest that the bedrock of this valley slopes northward from about 1100 feet near Eddyville to less than 900 feet northeast of Otto and less than 800 feet one and a half miles north of Cattaraugus Creek. Valley-fill in the axis of the basin northeast of Otto is more than 400 feet thick. Exposed sediments are primarily clay till and laminated lake silts and clays. A low ridge of clay till crossing the plain about 2 miles south of Cattaraugus Creek and concave northward prevents present drainage of this part of the basin from reaching Cattaraugus Creek. Instead, South Branch Cattaraugus Creek is diverted southwestward past Otto toward Cattaraugus through a confined valley and thence northward through Skinner Hollow to its juncture with Cattaraugus Creek at Point Peter, 1.5 miles southeast of Gowanda.

Recognizing the nearly level surface of the Otto plain as evidence of a proglacial lake, Fairchild (1928) postulated a hypothetical history of drainage changes and resulting lake levels during glacial recession. As the waning ice tongue thinned in the valley south of Cattaraugus, Lake Zoar came into existence. Its level was controlled initially by a steep narrow gorge across the upland southwest toward New Albion which notched the divide to about 1430 feet above sealevel. This gorge was abandoned in favor of the lower outlet exposed when withdrawal of the ice margin from the north end of Skinner Hollow permitted drainage west past Persia and Wesley into the present Conewango Valley at about 1350 feet above sealevel. This postulated history of Lake Zoar ended with outflow northward past Gowanda, thence westward between the waning ice border and the plateau margin.

Fortuitous circumstances prepared the valley southwest of Otto for preservation of deposits during subsequent glaciation. Stream diversion at a low point in the divide during an early glaciation joined the valley north of Otto to Skinner Hollow at an angle oblique to the principal directions of subsequent glacier flow. A northwestward projecting bedrock spur at Otto protected the area of the high bluff from subsequent scour which bared higher slopes to the south.

Circumstances responsible for the present excellent exposure of the Otto section are as fortuitous as those that prepared the site for preservation of the deposits during glaciation. The channel of the creek is pinned where Cattaraugus County Route 12 bridges it at the south edge of the village. With the meander system locally unable to migrate down-valley in normal manner, the channel has been shifted increasingly sharply against the base of the bluff downstream from the bridge. During recent years the abandoned but still barren floodplain at the tip of the meander spur has broadened to as much as 50 feet, and the current has seemed to impinge against the cliff progressively closer to the bridge. The circumstances that favor present exposure of this important stratigraphic section simultaneously reduce the life expectancy of the record it contains.

STRATIGRAPHY

Only in the reach of South Branch Cattaraugus Creek extending about 200 yards downstream from the highway bridge is the following complex stratigraphic section exposed. Sharply cut banks upstream from the bridge and a few tenths of a mile downstream from the bridge expose only the latest till and postglacial deposits, in some places lying directly on bedrock.

The upper part of the Otto high bank is partly overgrown and severely slumped, but the basal 50 to 60 feet are freshly exposed and swept clean by stream erosion. Seeps and active crescentic slump scarps about 160 feet above the river and as much as 300 feet south of the water's edge show the extent of slope movement in the upper part of the section. Plastic red lake clay a short distance below the middle of the exposed section is the lubricating layer which facilitates this movement as evidenced by overhanging slump masses with slickensided undersurfaces. Accordingly, some uncertainty exists regarding lateral tracing and correlation of units in the slumped upper part of the section.

In the lower part of the column the problem is one of constantly changing aspect due to progressive cutting away of the cliff where the organic zones and associated strata are best exposed. Thus, whereas MacClintock and Apfel had described basal till and a single overlying peat in 1944, by 1957 the pocket of till had ceased to exist and the peat could be differentiated into multiple zones. A boulder lens exposed in 1957 has been virtually removed in succeeding years. In the following composite section and discussion, an attempt is made to integrate units observed at different times.

Figure 2 illustrates schematically the lower part of the composite section described below. Units 6 through 10 were measured near the southwest end of the bluff; units 2 through 5 were measured near the northwest end.

Unit (Top of section)	Description	Approximate thickness
10	Stratified sand, silt, and clay	3 feet
9b	Till, calcareous gray-brown, silty clay, sparsely pebbly with "bright" lithology; silt streaks; unleached but oxidized	20 feet
9a	Till, as above, but unoxidized	10 feet
8	Stratified sand, silt, and clay; sparsely pebbly	3 feet
7	Till, calcareous, gray, sandy silt, sparsely to moderately pebbly; includes pockets and streaks of washed drift	40 feet
6	Pebble gravel, calcareous, decreasingly coarse at base	5 feet
5	Rhythmically laminated silt and clay, calcareous, contorted	5 feet
4	Gravel, coarse with angular to subrounded pebbles and cobbles of sandstone and siltstone; essentially non-calcareous. Contains fine sand 0.5 feet thick about 8 feet below top. This marker grades toward northeast into organic silt, dated at more than 52,000 years (GRO-2565)	20 feet
3	Sand, silt, pebbly silt, muck, and peat, interbedded. Includes boulder gravel lens near north end of exposure. Contains several organic zones. Top of main zone is dated at 63,900 ± 1700 years (GRN-3213)	7 feet
2	Gravel, cobble with lag concentration of boulders 20 inches across just above contact with underlying bedrock. May thicken toward northwest where base is concealed	3.5 feet
1	"Till, blue-gray, weathered, rich in igneous stones" (MacClintock and Apfel, 1944). This unit is no longer exposed	3.5 feet
0	Bedrock; blue-gray siltstone; Machias formation	

INTERPRETATION

Cutting of the cross valley southwest of Otto.—The geologic record at Otto begins before deposition of the exposed section. The bedrock topography indicates preglacial drainage northward. An early ice sheet imponded lakes which drained across the former divides. Such was the presumed origin of the narrow

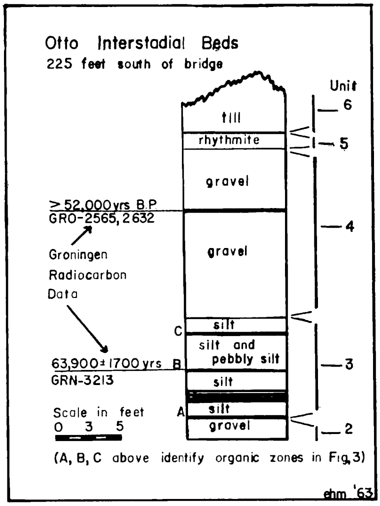

Fig. 2. Otto interstadial beds, as exposed 225 ft south of bridge, showing stratigraphic units, chief organic zones, and pertinent radiocarbon data.

valley southwest of Otto, connecting the preglacial basin now occupied by upper reaches of South Branch Cattaraugus Creek with Skinner Hollow on the west. The cutting of the cross valley necessarily predates deposition of the oldest strata contained therein. The configuration of the valley is such as to further suggest that it was cut during an early glaciation and thereafter occupied during successive oscillations of the ice margin.

Petrology of the older drift.—MacClintock and Apfel (1944) observed "weathered, blue-gray till, rich in igneous stones" as the lowest unit exposed at the north end of the high bank. This till has not been exposed in the cliff face since 1957.

In 1961, exposure of a previously covered portion of the bank about 160 feet from the bridge revealed cobble gravel with a suggestion of imbrication by water flowing from the south. As described by MacClintock and Apfel, similar gravel (unit 2) crops out beneath peat in the southwestern part of the exposure. At the base of this unit is a discontinuous lag concentration of boulders with an abundance of crystalline rock types. Aleksis Dreimanis (1960) pointed out striae trending N 20° E on the underlying bedrock surface. A coating of plastic gray clay in voids between some of the basal boulders may be a remnant of till from unit 1. Dreimanis reports that garnets comprise 32 percent of the heavy mineral content, and purple garnets exceed red garnets by a ratio of 1.2 to 1 in this material. These properties are similar to those of till above (unit 7) and suggest glacier flow from the northeast.

A boulder gravel lens dominantly of local rock types but containing a few crystalline boulders cropped out just above stream level in unit 3 at the north end of the exposure in 1957. Faint striae, though uncommon, were observed. The interstitial gravel and coarse sand were oxidized and essentially noncalcareous. Oxidation was most pronounced at the upper contact beneath less permeable materials where it appeared to be a product of ground water action rather than of pedogenic processes.

A recheck in the field following preparation of the initial draft of this manuscript confirmed that this boulder-gravel lens, though now poorly exposed and nearly removed, lies within the series of organic horizons of unit 3. Well-developed sets of parallel striae were observed on upper surfaces of two large boulders which though let down by stream erosion may not have undergone rotation. The striae closely parallel the north-northeasterly orientation of bedrock striae observed by Dreimanis. This might be expected in lodgment till. Nevertheless, because the boulder gravel lacks typical till matrix and because the organic horizons reveal no other environmental or stratigraphic evidence of glaciation within unit 3, the boulder gravel is interpreted as a lag from stream erosion of a till bank (Muller, 1960, p. 26).

Otto organic zone (*unit 3*).—Stratigraphic relationships in the lower part of the Otto exposure are illustrated in figure 3. In the foreground unit 3 lies between two gravelly units. Downstream it fingers out into the associated gravel (fig. 4). It dips upstream and becomes richer in organic material, concentrated in several peat layers. The compact peat forms shelves visible in the photograph whereas the interbedded sandier units are readily recessed by slopewash. The organic zone and the enclosing beds are apparently completely conformable.

Comparison of figure 4 with the aspect of the bluff 20 years earlier (MacClintock and Apfel, 1944, fig. 1) reveals an increase in bedrock exposure and rise in elevation of the top of the organic zone above river level. It is inferred that the stream is cutting against a rising bedrock slope on which the gravel and organic horizons were deposited. It is probable that the organic zones finger out up slope, just as they do downstream along the face of the bluff.

Fig. 3. Otto organic beds as exposed near north end of Otto High Bluff in 1961. Photo by Clair A. Brown.

Fig. 4. Panoramic view north, upstream, toward mid-portion of Otto High Bluff, showing relationships of partly concealed bedrock, gravel, Otto interstadial beds, and overlying drab cobble gravel.

On the basis of study of peat samples submitted from the Otto site by MacClintock and Apfel (1944, p. 1152), Paul B. Sears commented:

> All specimens contained a great predominance of coniferous pollen with only suggestions of any deciduous material. With the exception of two specimens which seem to contain only fir and pine, the rest contained fir, spruce and pine. There were some interesting variations in the nature of the peat, some being mainly silt, some wood, some moss and some mainly sphagnum. In the absence of any information as to stratigraphy of these samples, however, there would be no point in drawing conclusions from this or from certain fluctuations in the proportions of pollen. The indication is clear that the interglacial represented agrees in character with the early postglacial conditions throughout the North Central States when the climate had not warmed sufficiently to permit the dominance of conifers by deciduous forms.

The organic zone comprises several distinct peaty layers intercalated with muck, silt, and fine sand (fig. 3), and ranging through about 6 feet. In all samples the organic matter is moderately to strongly humified. Generally the samples do not approach the richness in numbers of pollen and spores per unit volume commonly found in bog peat of cool temperate forest regions. The intercalated silt and fine sand units, particularly in the upper half of the organic zone, contain abundant organic debris but are too deficient in pollen for statistically reliable pollen counts. In view of the quantity of fungus mycelia, Brown suggests that destruction by oxidation or by microorganisms accounts for the low pollen content, but points out that rapid deposition or deposition during seasons when pollen is not shed might achieve the same result.

The pollen profile as prepared by Donner for that part of the organic zone with adequate pollen is presented as figure 5. *Pinus* and *Picea* are dominant among arboreal pollen throughout the section. A progressive, but somewhat irregular, increase in *Pinus*:*Picea* ratio upward through the section is noted. In the lower 40 centimeters *Pinus* and *Picea* generally vary inversely. The deep trough just below the 50 centimeter level marks the sudden rise of the *Cyperaceae* to rival arboreal pollen in abundance in the upper part of the section.

Brown observes that the Picea pollen include a quantity of small grains suggesting the presence of both *Picea glauca* (white spruce) and *Picea mariana* (black spruce). Similarly, size differentiation among *Pinus* pollen may be interpreted as indicating the presence of both *Pinus banksiana* (jack pine) and *Pinus strobus* (white pine). Overlap in size range makes calculation of percentages by species meaningless. Nevertheless, the simultaneous occurrence of these several species suggests proximity of both wet and well-drained sites.

Abies (fir) and *Larix* (larch) are not represented in significant quantity in listings by Benninghoff and Helmich, Brown, or Donner, though *Abies* was prominently mentioned by Sears (MacClintock and Apfel, 1944). The complete absence of *Tsuga* (hemlock) is noteworthy, for it is a normal component of most postglacial successions in this region. In some cases *Tsuga* has been interpreted as a moisture indicator (Cox, 1959) but if variety in *Picea* and Pinus representation be accepted, sites with a range of moisture conditions were available.

Among non-coniferous arboreal pollen represented, *Betula* is an expectable component with *Picea* and *Pinus*. On the other hand the erratic occurrence of

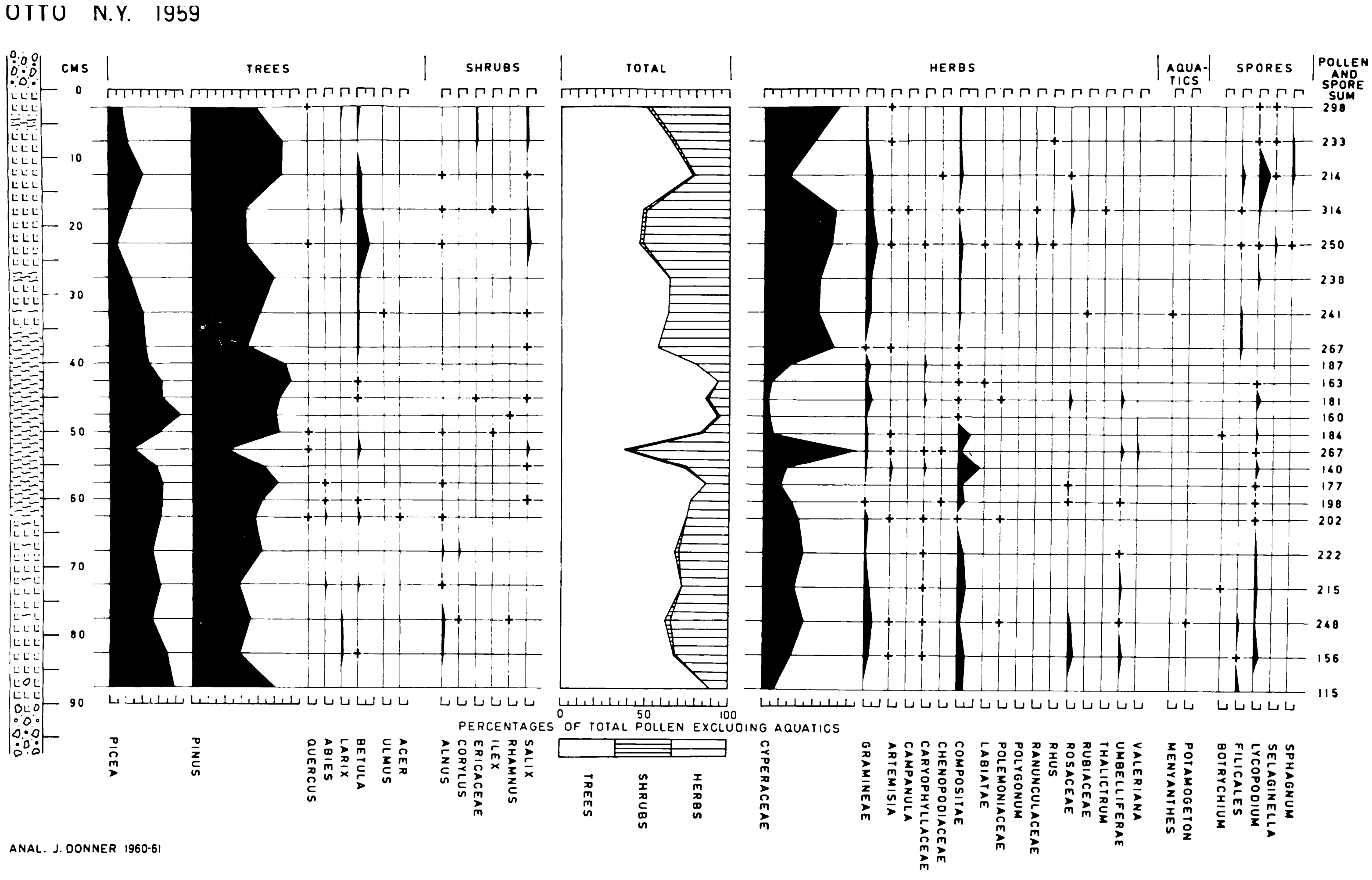

Fig. 5. Pollen profile in Otto interstadial beds about 350 ft southeast of bridge, as determined by Joakim J. Donner, 1959. Percentages computed on basis of total pollen excluding aquatics = 100%.

a few grains of *Quercus* (oak), *Ulmus* (elm), and *Acer* (maple), as also of *Juglans* (walnut) in material studied by Brown, and of *Carya* (hickory) and *Tilia* (linden) in material studied by Benninghoff and Helmich is inconsistent with the strong dominance of a spruce-pine assemblage. These grains may be (a) windblown from a distant source, (b) redeposited from older sediments, or (c) derived from an erratic plant. Although occurring randomly through the section, these species are too sparse to represent principal components of the nearby forest assemblages.

Among the non-arboreal species represented in the pollen spectrum, the *Cyperaceae* are dominant with *Gramineae* and *Compositae* much less abundant. These three families imply muskeg and meadow assemblages within the spruce-pine forest, but also they include species normal to such a wide range of assemblages that their presence adds little to an interpretation of the environment represented. Although aquatics are insignificant in Donner's study, one sample in the upper part of the section studied by Benninghoff and Helmich contains a strong component of aquatics, particularly *Sagittaria* (arrowleaf) and bryophyte spores. Others of the non-arboreal species are typical forest understory types, and some represent drier or more upland sites.

Two zones separated by about 3½ feet are composed largely of moss peat. The lower of these moss zones, studied by Ketchledge, was found to consist of the following:

Tomenthypnum nitens, about 95 percent
Drepanocladus, cf *D. Aduncus*, about 5 percent
Paludella squarrosa, distinctive but quantitatively subordinate.

TABLE 1

Identification and location of pollen sample sites listed by W. S. Benninghoff and D. Helmich, and by Clair A. Brown

Column (table 2)	Sample Number	Analyzed by	Material	Location
1	58-7	WSB & DH	Peat and muck	350 ft southeast of bridge; 35″ to 40″ above river; contains moss layer.
2	58-8	WSB & DH	Muck and peat	350 ft southeast of bridge; 30″ to 35″ above river.
3	58-9	WSB & DH	Peat	350 ft southeast of bridge; 25″ to 30″ above river.
4	58-10	WSB & DH	Muck, pebbly	350 ft southeast of bridge; 20″ to 25″ above river.
5	58-3	WSB & DH	Silt	425 ft south of bridge; 6″ above surface of bedrock.
6	2A3	CAB	Peat	200 ft southeast of bridge; zone B in figure 2.
7	2A6	CAB	Peat	200 ft southeast of bridge; zone A in figure 2.
8	2B1	CAB	Peat	275 ft southeast of bridge; at base of bluff.
9	2C1	CAB	Peat	125 ft east-southeast of bridge; at base of bluff.
10	2D1	CAB	Peat	125 ft east-southeast of bridge; at base of bluff.
11	2E1	CAB	Peat	350 ft southeast of bridge; corresponds approximately to 58-8 above.

TABLE 2

Pollen and spore percentages from Otto interstadial beds as determined by W. S. Benninghoff and D. Helmich, and by Clair A. Brown. Percentages computed on basis of arboreal pollen as 100%. For locations see table 1.

	1	2	3	4	5	6	7	8	9	10	11
Total AP count	16	58	111	253	97	169	169	162	161	170	185
Arboreal											
Picea	12.5	36.2	48.6	54.9	58.8	20.7	33.7	22.2	26.3	41.7	23.1
Pinus	62.5	60.3	51.4	43.5	35.1	78.8	63.3	72.2	63.8	52.9	74.5
Abies	18.7	—	—	1.6	4.1	0.5	2.0	3.7	2.4	3.5	1.0
Larix	—	1.7	—	—	—	—	—	—	—	—	—
Betula	—	1.7	—	—	—	T	—	2.5	—	1.0	1.6
Carya	—	—	—	—	1.0	—	—	—	—	—	—
Acer	6.2	—	—	—	—	—	—	—	—	—	—
Tilia	—	—	—	—	1.0	—	—	—	—	—	—
Alnus	—	—	—	—	—	—	—	—	—	T	—
Quercus	—	—	—	—	—	T	—	1.2	—	—	—
Juglans	—	—	—	—	—	—	—	T	—	—	—
Non-arboreal											
Cyperaceae	—	—	—	3.5	2.1	—	—	1.2	—	—	0.6
Gramineae	—	—	—	0.8	1.0	—	—	1.2	—	—	1.8
Typha	6.2	—	—	—	—	—	—	—	—	—	—
Sagittaria	218.7	—	—	—	—	—	—	—	—	—	—
Potamogeton	12.5	—	—	—	—	—	—	—	—	—	—
Compositae	—	—	0.9	0.4	1.0	—	—	1.8	—	T	1.8
Polypodium	—	1.7	—	—	1.0	—	—	—	—	—	—
Dryopteris?	—	—	—	0.4	4.1	—	—	—	—	—	—
Lycopodium	—	—	0.9	—	2.0	—	T	—	—	—	—
Misc.	12.4	—	1.8	—	—	1.0	—	—	—	—	—

Of these species, *Paludella squarrosa* is essentially lacking in the active flora of New York, and *Tomenthypnum* is not now encountered in New York in the rather pure concentration suggested by this assemblage. These species suggest a wet environment, whether fen or streambank or seep, with waters of relatively high pH and climate slightly colder than that of the present. Benninghoff and Helmich point out the absence of the rather distinctive spores of *Sphagnum* throughout most of the section. The pH range of *Sphagnum* substrates is lower than that of *Tomenthypnum*. Furthermore, Benninghoff and Helmich point out that *Sphagnum* is absent today from active floodplains and other sites of silt deposition, and that *Sphagnum* is absent from late-glacial phases of most eastern North American postglacial pollen diagrams.

In summary of the botanical evidence, Brown concludes that:

> The low fir, moderate spruce and predominant pine ratios indicate a boreal forest between the middle and northern limit. The absence of hemlock and hardwoods supports this concept. However, there are certain ecological anomalies. This could be a forest near the southern limit, a successional stage prior to the invasion of hemlock and hardwood, and thus not an indicator of climatic conditions. Certain normal associates of these plants are absent, probably because of differential preservation. The presence of both black spruce and white spruce, jack pine and white pine, would predicate both wet and dry sites . . . The moss species are indicators of cool to cold climates, wet swamp, fen or bog conditions.

The plant assemblage and pollen rain indicated by study of the Otto organic zone are such as are found today some 50 miles north of North Bay, Canada, under climatic conditions that suppress hardwood species (Jaan Terasmae, personal communication). Although the upward increase of ***Pinus*: *Picea*** ratio suggests slight climatic amelioration, no marked change in environment is indicated during deposition of these sediments.

Although the Otto organic zone is beyond the range of routine radiocarbon dating, extended range techniques employed by the Groningen laboratory indicate a finite date for the principal peat zone, at about 40 centimeters in Donner's pollen profile. After isotopic enrichment and counting under several atmospheres of pressure, material from this zone collected by Hessel de Vries yielded an age of 63,900 ± 1700 years (GRN 3213,[1] J. C. Vogel, personal communication). Vogel writes:

> We measured the sample after having enriched it by a factor of more than 10 . . . The sample was decalcified and carefully extracted with dilute sodium hydroxide solution to remove all the soluble organic material which might contain recent humic acids . . .
> This sample contained only 0.035 percent of its original C-14. Thus less than 2/100ths of a percent of recent organic material present in the peat would cause the sample to appear 6000 years too young. Fortunately the possibility of serious contamination can virtually be ruled out in this special case. The 'humus' fraction of the overlying organic silt (GRO 2565) has an apparent age of more than 52,000 years. If we now assume the apparent age of the alkali soluble fraction of the peat layer (Otto 2) to be only 52,000 yrs. corresponding to 0.15 percent of the C-14 content of recent organic material and further assume that this too-young material was not completely extracted from the peat, we can calculate how large an error one could expect. For this sample to appear 6000 years too young one must require that more than 12 percent of the insoluble fraction be 'humic substance'. On the basis of my experience I feel that so

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[1] Groningen Laboratory dates are identified by GRN where ages have been corrected for the Suess effect; earlier analyses are identified by the letters GRO.

> much humic substance could not have been retained in the sample after the pretreatment, and I am confident that the true age of the layer lies within the limits of the statistical error given.

In view of the abundance of mineral matter through all levels of the organic zone, accumulation was presumably rapid. Fragments of spruce wood in the peat are so flattened that in cross section their maximum diameters are several times as long as their minimum diameters. In spite of this compaction factor the 7 feet of organic material in unit 3 probably represents an interval measured in centuries or at most a few millennia.

Cobble gravel (unit 4).—Overlying the organic zone is a cobble gravel which MacClintock and Apfel identified as Olean gravel, associating it with the surface drift in the area east of the Salamanca re-entrant in southern New York because of its drab, slabby appearance.

This gravel is composed of about 98 percent locally occurring siltstone and sandstone, of which perhaps one-third is well-rounded on several sides at least, as much as one-half is sub-rounded, and the remainder angular to subangular. Somewhat rounded tabular and discoid cobbles comprise about 60 percent of the total. Spheroidal cobbles are rare. Neither striae nor soling, other than that due to joint or bedding plane fracture, were observed. The matrix is coarse sand, and the material is essentially non-calcareous throughout, whether because of initial lack of carbonates or because of progressive leaching during deposition as on present day floodplains.

The gravel layer is conformable with the underlying organic zone, interfingering with it in the southwest end of the exposure. At a height ranging from 8 to 15 feet above the base of the unit, there is a thin but persistent finer textured layer. Like the underlying organic zone it is lower toward the northeast where it is a humic silt. Attempts at pollen counts in this unit by Brown and by Benninghoff and Helmich were frustrated by the highly corroded conditions of the few existing pollen grains. Nevertheless, the organic content sufficed for radiocarbon analyses with both humic fraction (GRO 2565) and insoluble fraction (GRO 2632) yielding ages greater than 52,000 years (J. C. Vogel, personal communication).

Although imbrication is not pronounced in the cobble gravel unit, a significant proportion of the tabular cobbles and flaggy bits dips toward the south and southwest, indicating deposition by a current from that direction. Such flow might be controlled by slope of the bedrock valley floor, but it is not the direction from which outwash deposition might be expected to have taken place.

The range of stratified deposits represented in units 2, 3, and 4 may be accounted for best, perhaps, by floodplain deposition. The stream channel may have cut against till bluffs during deposition of the lowermost beds, but shifted against bedrock upward in the section, thus accounting for deposition of drab, non-calcareous cobble gravels. Corrosion of pollen grains and oxidation of some of the peat prior to burial are suggested near the base of the organic section, but at least part of this deposition occurred in a reducing environment of high water table conditions. Oxidation of the boulder layer is almost surely attributable to later ground-water seep, rather than to pedologic processes during deposition. For intervals measured in terms of a few millennia, flood plain conditions may have persisted, in time to be altered by glacial advance beyond the middle course of the northward opening drainage basins.

Zoar lake beds.—Overlying the drab cobble gravel is a lacustrine rhythmite series, in part varved, consisting of an alternation of thin red-brown clay and light gray silt laminae (unit 5). This unit serves as the basal lubricating layer, by which the massive slump complex at the top of the high bank is gradually settling. For this reason, the thickness of the unit is not accurately determinable. Although MacClintock and Apfel refer to 12 to 15 feet of lake sediment, this thickness is not observable under present exposure conditions.

Whereas varves in one exposed part of this section are less than one-quarter inch thick, it is unwarranted to assume this as an average thickness. Rather, the varves may be expected to thicken to a few inches in close proximity to the impounding ice sheet. Nevertheless, it is probable that unit 5 records deposition during a few centuries immediately prior to glaciation of the Otto site. These beds comprise the earliest preserved deposits of Lake Zoar, for no clearly lacustrine beds have been observed in the lower part of the section.

In the thick glacial section that overlies unit 5, at least one interval of lacustrine deposition (unit 8) attests to interrupted glaciation during which the ice margin receded north of Otto without withdrawing from the plateau. The till sheets contain incorporated, though incompletely assimilated, lake sediments, suggesting erosion of proglacial lake deposits.

Final deglaciation accounts for the thin stratified sand, silt, and clay (unit 10) of the latest episodes in the history of Lake Zoar controlled by overflow through the New Albion and Persia outlets while the ice margin lay a few miles to the north.

Later glaciations.—Two tills (units 7 and 9) comprise most of the upper 80 feet of the Otto section. Of these, the lower is light gray to olive gray, with sandy loam matrix. It is strongly calcareous and moderately pebbly, with a significant proportion of exotic pebbles. The polished, rounded character of these pebbles tend to give a "bright" appearance to the till which MacClintock and Apfel associated with Binghamton drift, but which in other parts of New York has proven of questionable reliability as a basis of correlation (Merritt and Muller, 1959; Moss and Ritter, 1962). Aleksis Dreimanis (personal communication) reports that garnets comprise 35 percent of the heavy mineral fraction of a sample of this till and that the ratio of purple garnet to red garnet is 2.5 to 1. The suggestion, as for the basal till (unit 1), is of derivation in the Adirondack area, indicating flow toward the southwest.

The uppermost till (unit 9) differs from unit 7 in possessing finer textured matrix and lower pebble content. The matrix is silty clay, and pebbles are sparse but with significant exotic content, as in the underlying till. In this slope position the till is unleached throughout, beneath 3 feet of lacustrine sediment. Oxidation has penetrated 20 feet.

Waning of the ice sheet following lodgement of the upper till resulted in deposition of kame gravel which is poorly represented in the Otto bluff, but is topographically distinct about 1 mile north across the valley.

Correlation.—Otto is regarded as one of a number of sites that demonstrate evidence of post-Sangamon, pre-Farmdale glaciation in the eastern portion of the Great Lakes region (Flint, 1956; Muller, 1957a; Dreimanis, 1960). It is pertinent, therefore, to review this hypothesis in terms of data presently at hand.

As indicated in the preceding discussion, the Otto site reveals evidence of three successive environments. The first is glacial, represented by unit 1. The second is boreal, represented by units 2 through 4. The third involves a prolonged and complex history of glaciation.

Correlation of unit 1 involves the greatest uncertainties. To relate unit 1 to pre-Sangamon glaciation would require evidence of subsequent pronounced erosion, strong soil development, climate as mild as or milder than the present, or simply a lapse of a long interval of time. None of these is indicated at the Otto site. Although negative evidence does not clinch an argument, it is considered probable that the lower till postdates Sangamon weathering, soil formation, and erosion.

Radiocarbon dating and paleobotanic data afford basis for relating units 2, 3, and 4 to a time of cooler climates than the present. On the Laurentian uplands the climate was presumably glacial at the time of deposition of these units.

Terasmae (1958) in a palynological study of non-glacial beds in the St. Lawrence lowland describes an analogous though not homologous pollen spectrum at St. Pierre, Quebec. The peat at St. Pierre is characterized by dominance of *Picea* over *Pinus*, but otherwise is similar in the complete absence of *Tsuga* and the presence of only erratic grains of hardwood species. On the basis of the boreal climate and relatively short duration of the interval represented, Terasmae ruled out correlation with the Sangamon interglacial. Instead he named the interval represented by these beds, the St. Pierre interstadial. In subsequent reports he relates the upper part of the Scarborough beds of the classical section at Toronto (1960) and perhaps also the Missinaibi beds in the James Bay lowlands (Terasmae and Hughes, 1960) to the St. Pierre interstadial. A radiocarbon date on the Missinaibi beds indicates an age of more than 53,000 years (GRO 1435). Radiocarbon dates on peat and wood from the St. Pierre beds (GRN 1799, 65,300 ± 1400 years) and at Pierreville, Quebec (GRO 1711, 67,000 ± 1000 years) are of the same range as indicated at Otto (J. C. Vogel, personal communication).

In the Plum Point and Port Talbot sections exposed along the shores of Lake Erie in western Ontario, Dreimanis (1958) established the existence of three Wisconsin interstadials. The oldest of these, the Port Talbot interstadial, is now dated at 44,000 to 47,000 years (de Vries and Dreimanis, 1960).

In Ohio, R. P. Goldthwait and Jane Forsyth have recognized a widely occurring till-gravel-till sandwich of post-Sangamon age. Wood from the drift has been repeatedly assayed at more than 35,000 years, yet on pedologic and paleontologic basis the drift was considered to be of post-Sangamon age (Forsyth and LaRocque, 1956). Recently a finite date of 46,000 ± 2000 years (GRN 3219) has been established for wood in the drift at Rocky Fork near Gahanna, Ohio (R. P. Goldthwait, personal communication).

Accordingly on the basis of radiocarbon dating and pollen data, the Otto organic zone (unit 3) is correlated with the beds at St. Pierre. It is tempting but perhaps misleading to relate the underlying and overlying gravels (units 2 and 4) to intervals of accelerated erosion during more rigorous climate immediately preceding and following glaciation, respectively. Tentatively, at least, the Otto organic beds are also correlated with organic zones exposed at Clear Creek near the New York State Hospital at Gowanda, New York (Muller, 1960). The organic content of the Otto interstadial shows no relationship to the Sangamon flora of the Don beds in the classic Toronto section (Coleman, 1933; Terasmae, 1960). In view of the greater than 52,000 years age for unit 4, the Otto interstadial beds must predate both the Port Talbot interstadial of Ontario and the gravel of the till-gravel-till sandwich in south central Ohio.

Units 5 through 10 represent glacial and near glacial conditions. All dated peat samples from beneath till in western New York (Muller, 1957b) have so far proven to be more than 35,000 years old. Accordingly, units 7 and 9 represent "classical Wisconsin" glaciation. There is no present basis for relating the near-glacial conditions represented by ponding in unit 8 to any specific dated interstadial represented in the Plum Point-Port Talbot sections.

Kame gravels and subsequent Zoar lake beds of unit 10 are features of the Cary recession. On the basis of lateral tracing (Shepps and others, 1959) the Wisconsin terminal moraine on the west side of the Salamanca re-entrant is equivalent to the Kent moraine of northwestern Pennsylvania, dated at Corry, Pennsylvania, as being older than 14,000 years (Droste and others, 1960). Late Cary moraines which imponded Lake Zoar for the last time were deposited more than 12,000 years before the present on the basis of spruce wood on the outwash plain in southeastern Erie County, New York (Merritt and Muller, 1959).

CONCLUSIONS

Study of the unconsolidated drift section exposed by the South Branch of Cattaraugus Creek at Otto, New York, substantiates and contributes to the developing concept of complex glacial and climatic fluctuations in northeastern North America prior to the waning hemicycle of the Wisconsin glaciation.

The drift is preserved in a cross-valley initiated by stream derangement during a pre-Wisconsin glaciation. Till at the base of the section represents glaciation of probable post-Sangamon age.

Organic content of the interstadial beds shows dominance of *Picea* and *Pinus*, with irregular upward increase in the ratio of *Pinus* to *Picea*. Hemlock is absent, and hardwoods are very sparsely represented. This assemblage is completely unlike that of the warmer climate Don beds in classic sections near Toronto. Rather it has its present homolog in forests in the vicinity of North Bay, Ontario. Radiocarbon dating and palynological data confirm correlation of the Otto interstadial beds with the St. Pierre deposits in Quebec and show them to predate the Port Talbot zone of western Ontario and Ohio.

Laminated lake sediments indicative of proglacial ponding mark the glacial advance presumed to represent the beginning of the "classic Wisconsin" of the Mississippi basin. At least one recession of the ice sheet interrupted continuity of glaciation that ended with northward waning during the Cary substage.

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