Glacial Geology and Stratigraphy of Western New York Nuclear Service Center and Vicinity, Cattaraugus and Erie Counties, New York

U.S. GEOLOGICAL SURVEY
Open-file Report 79-989

Prepared under grant to the

New York State Geological Survey,
New York State Education Department

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1979

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(in pocket)

CONVERSION FACTORS

The following factors may be used to convert the U.S. Customary (inch-pound) units of measurement used in this report to the International System of Units (metric system).

Multiply	By	To Obtain
inch	2.54	centimeter
foot	0.3098	meter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer (km^2)

GLACIAL GEOLOGY AND STRATIGRAPHY OF THE WESTERN

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CATTARAUGUS AND ERIE COUNTIES, NEW YORK

By

Robert G. LaFleur[1]

ABSTRACT

A detailed glacial geologic map at a scale of 1:24,000, embracing a 165 square-mile area in Erie and Cattaraugus Counties, N.Y., shows 27 mapping units, including the till complex in which the West Valley radioactive-waste burial site is located. Stratigraphic relationships at 24 boreholes at the burial site and 6 newly described exposures indicate the age of the till complex to be early late Woodfordian (post-Kent, pre-Lake Escarpment [Valley Heads]), equivalent to the Lavery glacial advance. Correlations of mapping units and measured sections with Woodfordian and older glacial and deglacial episodes are proposed.

The Lavery till is confined to the valleys of Cattaraugus Creek and its major tributaries. At the waste-burial site in Buttermilk Creek Valley, the Lavery is an interfingering complex of clayey-silt till and thinner beds of deformed, poorly stratified lacustrine clay and silt. Ice readvance after the Kent glacial recession and Erie Interstade erosion imponded proglacial lake water in Buttermilk Creek Valley and covered post-Kent kame deltas and Erie channel gravels with as much as 130 feet of till. The Lavery till thins southward to a thickness of 80 feet at the waste-burial site and to less than 16 feet near the hamlet of West Valley.

Water from the Lavery till may flow through subjacent Erie channel gravel and Kent-recessional kame delta sand to the bluffs along Buttermilk Creek, where discharge of water from these exposed pervious deposits appears to cause major slumps.

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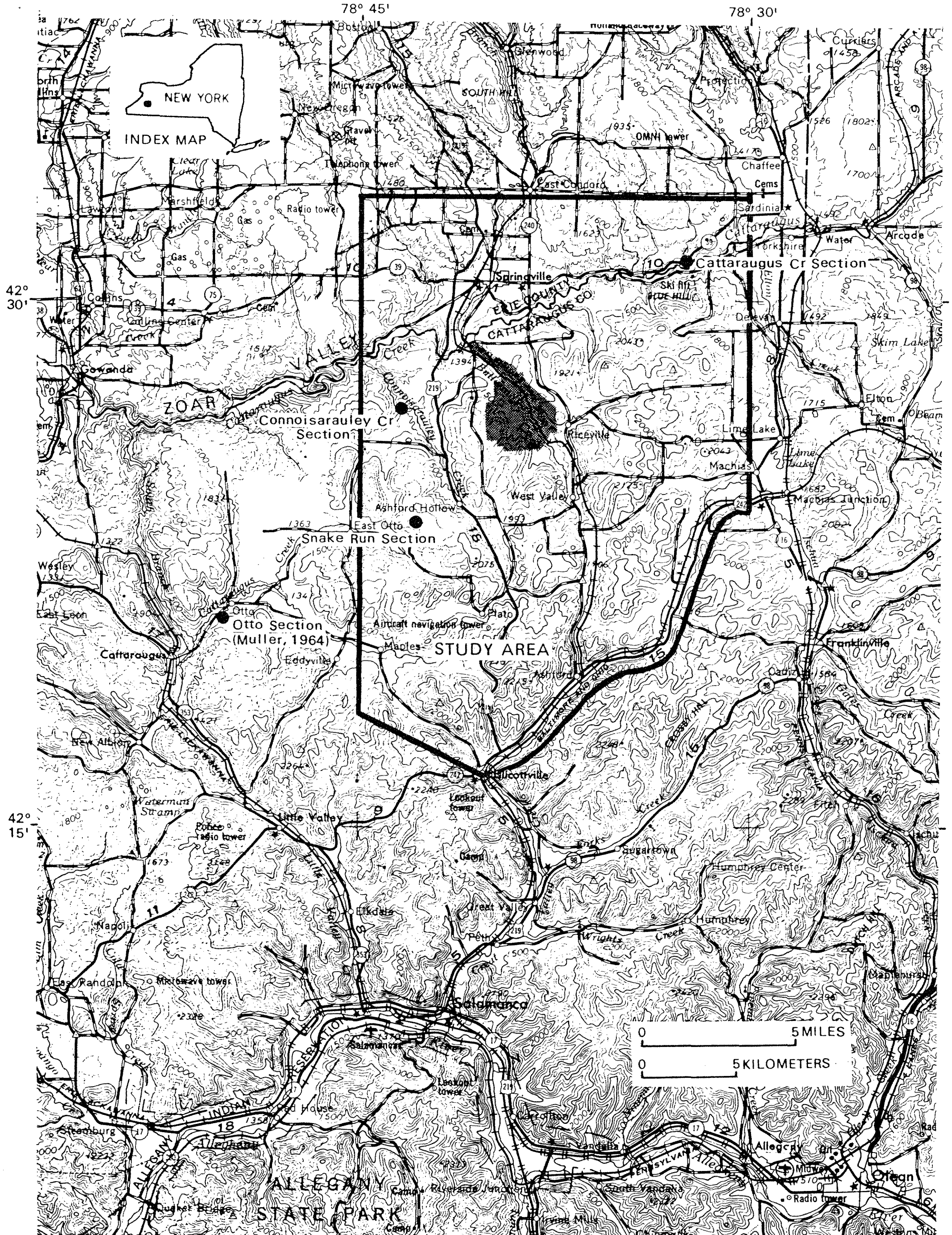

Base from U.S. Geological Survey
Buffalo, 1:250,000, 1962

Figure 1.--Location and major geographic features of study area, Erie and Cattaraugus Counties, N.Y. Shaded area indicates location of western New York Nuclear Service Center.

INTRODUCTION

As part of an investigation of factors controlling the subsurface movement of radioisotopes near low-level radioactive-waste burial grounds, the U.S. Geological Survey, in cooperation with the New York State Geological Survey, mapped the surficial geology of the area surrounding the Western New York Nuclear Service Center.

Ground-water conditions at this burial ground have not been adequately defined. As a first step in understanding the ground-water regime, the New York State Geological Survey designed a mapping program to delineate the areal extent of the till in which the nuclear waste is buried and to describe all exposed stratigraphic sections that could be used to estimate its character beneath the burial trenches. This information was needed for use in related studies to (1) determine the number of monitoring wells needed to characterize the hydrology of the burial ground; (2) understand the geological context of regional water movement as defined by well data; (3) understand the hydrologic system in enough detail to assess the impact of drilling holes into the burial ground; and (4) determine the regional effect of sand lenses and cracks within the till near the trenches.

The study was made in 1975-76 and encompassed a 165-mi^2 area surrounding the burial site.

Geologic Setting

The Western New York Nuclear Service Center (fig. 1) is 30 miles south of the city of Buffalo on the glaciated Appalachian Plateau of western New York, midway between the east end of Lake Erie and the unglaciated reentrant south of Salamanca. The Center includes a nuclear-fuels reprocessing plant, a burial ground licensed by the U.S. Nuclear Regulatory Commission for some products of plant operations, and a commercial burial ground licensed by the State of New York for low-level radioactive waste. All facilities at the Center lie on or in a late Wisconsinan till complex that floors the valley of Buttermilk Creek. Buttermilk Creek joins Cattaraugus Creek 3 miles north-northwest of the reprocessing plant and drains westward through Zoar Valley toward Lake Erie. In the 165-mi^2 study area, the dissected and glacially modified Appalachian Plateau is underlain by shale and sandstone of the Upper Devonian Canadaway and Conneaut Groups (Canadaway and Chadakoin Formations of Tesmer, 1975). Although total relief is about 1,300 feet and summits reach 2,400 feet above sea level, bedrock exposures are restricted to a few steep-walled gorges cut by former glacial melt-water streams and by the modern Cattaraugus Creek and its tributaries. Small discontinuous ledges on major hilltops become more frequent to the south. Repeated glaciations have veneered the plateau with a complex of till, lacustrine sediment, moraine deposits, and outwash. Depths to bedrock exceeding 500 feet are found in deeper valley bottoms (Nuclear Fuels Services, 1962; Muller, 1975; Calkin and others, 1974), but drift is much thinner on hillsides and is 5 feet or less in thickness on summits.

Scope and Purpose of Study

A detailed glacial geologic map of the area surrounding the Western New York Nuclear Service Center was prepared at a scale of 1:24,000. The area mapped includes the Ashford Hollow and West Valley $7\frac{1}{2}$-minute quadrangles and parts of the Ellicottville, Ashford, Springville, and Sardinia $7\frac{1}{2}$-minute quadrangles (pls. 1-6, respectively). Six freshly exposed sections within this 165-mi^2 area were measured and described in detail, and cores from test borings near the low-level burial ground were examined. In addition, a large-scale map of the immediate vicinity of the facilities at the Center was prepared to show the distribution of surficial deposits in detail and the locations of mass movements (plate 7). The immediate goal of this work was to define the distribution, stratigraphic position, lithology, and mode of deposition of the till in which the radioactive-waste burial grounds are located and the relation of this till to other identifiable glacial deposits. Stratigraphic nomenclature in this report was approved by the New York State Geological Survey.

The maps and text were prepared as part of a U.S. Geological Survey investigation of the factors controlling the subsurface movement of radioisotopes near low-level radioactive-waste burial grounds. Funds were provided by the U.S. Geological Survey through a grant to the New York State Geological Survey, which administered and supervised the fieldwork. The New York State Geological Survey, under contract to the U.S. Environmental Protection Agency, also assumed responsibility for a comprehensive investigation of all avenues of radioisotope migration from the low-level burial ground at West Valley. Essential to both studies is an understanding of the character, origin, and distribution of glacial deposits near the West Valley site, particularly for interpretation of the direction of flow of ground water that percolates through or beneath the burial ground, and determination of the amount of test drilling needed to characterize in three dimensions the geology near the burial ground.

Acknowledgments

The author is grateful to A. D. Randall of the U.S. Geological Survey and P. E. Calkin of the State University of New York for critical review of the manuscript and their many suggestions. R. H. Fakundiny of the New York State Geological Survey, New York State Education Department, designed and administered the project, and D. E. Prudic and R. Garber of the U.S. Geological Survey assisted in the field.

Previous Work

Detailed mapping and stratigraphic work 25 to 100 miles west of the study area by Muller (1963) in Chautauqua County, N.Y., and by White and others (1969) in northwestern Pennsylvania, provides a framework for correlation of glacial deposits in the study area. Measured sections at

Otto, N.Y. (Muller, 1964) and at Gowanda State Hospital (Calkin and others, 1975) contain organic material radiocarbon dated at 63,000 B.P. and more than 48,000 years B.P., respectively. The dates help fix parts of those sections, which lie 15 to 20 miles west of the study area, in the regional Wisconsinan chronology of Dreimanis and Goldthwait (1973).

White and others (1969) recognized a middle Wisconsinan Titusville glaciation and, in the late Wisconsinan (Woodfordian), four glacial advances (Kent, Lavery, Hiram, and Ashtabula) that were separated by northward recessions of the Erie lobe. In Cattaraugus County, which includes most of the study area, Muller (1975) identified four Wisconsinan glaciations--Olean, Kent, Defiance, and Valley Heads. Olean drift described by MacClintock and Apfel (1944) in Cattaraugus County, south of the study area, was correlated by Muller (1977) with the Titusville (middle Wisconsinan) glaciation.

Muller (1977) traced moraines and drift borders eastward from northwestern Pennsylvania and projected the Kent moraine northeastward through the study area along an irregular border sharply controlled by topography. He equated the moraine with the Woodfordian glacial limit. The Kent moraine lies 6 miles south of the Nuclear Service Center.

Some of the till and recessional deposits associated with the Kent glacier contain high percentages (20-40 percent) of exotic rocks derived from the Niagaran escarpment and the Canadian shield. The expression "bright" refers to drift of this character. The bright drift is calcareous, leached to a depth of 1 to 3 feet, and oxidized to a depth of 8 to 10 feet. Morainal topography developed on Kent deposits is fresh and not noticeably colluviated. In contrast, "drab" Olean drift contains only a small percentage of exotics, is much less calcareous, and is more deeply oxidized. Throughout the Olean landscape, valley walls are commonly colluviated, and morainal deposits are topographically subdued. North of the Kent moraine, Muller (1963) recognized in Chautauqua County (in order of decreasing age) the Clymer, Findley Lake, Defiance, and Lake Escarpment (Valley Heads) moraines. The Clymer and Findley Lake moraines project toward the study area and may be represented here by recessional moraine loops just inside the Kent moraine, but tight crowding of these loops precludes accurate correlation. The locations of these features are depicted in figure 2. Dissected segments of ice-contact outwash equated with the Defiance moraine by Muller (1975) are well exposed along the south wall of Cattaraugus Creek valley. The Lake Escarpment outwash complex (White, 1960) is a massive valley fill at the northern border of the study area.

Geologic studies were undertaken in the early 1960's to evaluate the suitability of the Western New York Nuclear Service Center for radioactive-waste burial and other proposed facilities. A report was prepared (Nuclear Fuels Service, 1962), and logs of test borings remain in the files of the U.S. and N.Y. State Geological Surveys.

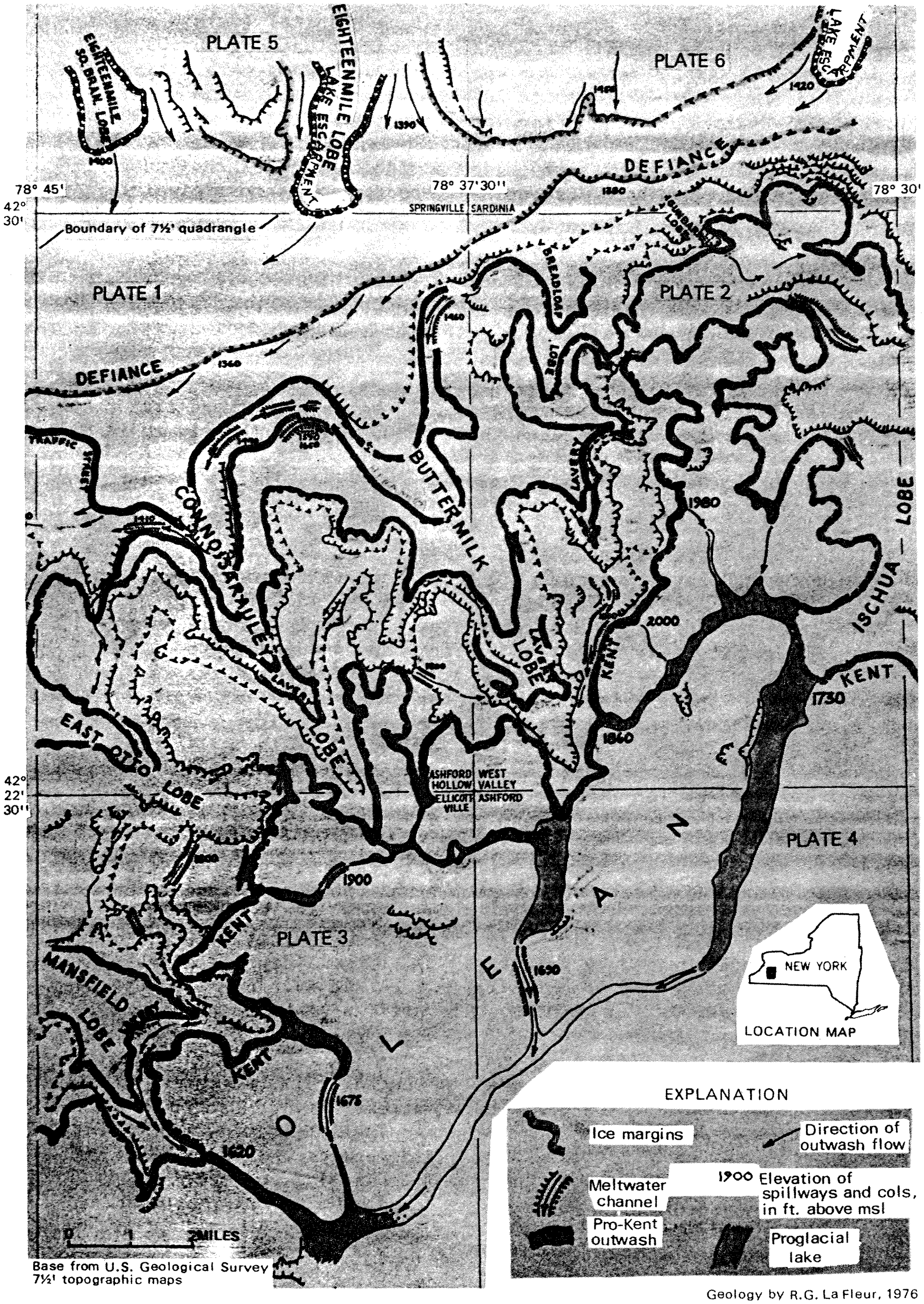

Figure 2.--Major glacial ice-border positions and related features within study area.

GEOLOGY OF BUTTERMILK CREEK VALLEY AND WASTE-BURIAL SITE

Stratigraphy and Origin of Glacial Deposits

Plates 1-6 show the areal distribution of 27 mapping units, including the till at the waste-burial site. Figure 2 is a plot of drift borders and ice margin-positions based on this detailed mapping.

After emplacement of the Kent moraine, ice withdrew into the Erie basin. Pauses in the recession of the Kent ice margin through a proglacial lake in Buttermilk Creek Valley permitted accumulation of a series of kame deltas in which topset pebble gravel and clinoform turbidite sand and silt prograded southward over bottomset rhythmic clays. At least three kame-delta sequences formed north of Riceville Station at intervals of half a mile or less; each is well exposed in bluffs along Buttermilk Creek.

As deglaciation proceeded, the glacial lake in Buttermilk Valley drained and exposed the kame deltas and lacustrine floor to subaerial erosion during the succeeding Erie Interstade. The upper part of a section near the former stream gage on Buttermilk Creek (fig. 4) includes an erosion surface overlain by locally derived gravel beds, then by proglacial lacustrine clay and clayey silt till; these deposits record the advance of the ice after subareal Erie Interstade erosion. One or more earlier glacial-deglacial episodes, the latest of which is of probable Kent age, are also recorded in this section. Similar relationships are shown in exposures along Connoisarauley Creek, which drains the next valley to the west. The clayey silt till is more likely to be of Lavery age than Defiance (Hiram) age because:

(1) It extends south in Buttermilk and Connoisarauley Valleys to West Valley and Ashford Hollow, 6 miles beyond the position of the Defiance moraine as proposed by Muller (1975), and only 2 miles short of the Kent drift border (pl. 1 and fig. 2).

(2) It overlies a freely drained surface that suggests a regionally significant withdrawal from the Kent drift border, and is rich in clay, silt, and fragments of lacustrine material. According to Dreimanis and Goldthwait (1973), ice retreated north of the Erie basin during the Erie Interstade, then in Lavery time readvanced across the basin to override and reconstitute clay-rich lacustrine sediment laid there during the Erie Interstade.

One of several Lavery lobes refilled Eighteenmile Creek Valley, which is aligned with Buttermilk Creek Valley to the north (fig. 2), then advanced into Buttermilk Creek Valley through imponded lake waters and terminated at a valley-plugging moraine at West Valley. In Buttermilk Creek Valley, the pro-Lavery glacial lake was controlled by the summit of the Kent moraine, which is 1,710 feet in altitude. The top of the Lavery till now lies at an altitude of about 1,380 feet at the latitude of the waste-burial site, so the Lavery glacier must have been buoyed up by a hydrostatic head approaching 400 feet as it overrode a saturated muddy substrate. It emplaced a stony, clayey, silt till with minor interbedded silty clay. The Lavery till is concentrated along the valley floor and extends only slightly onto the valley wall; it forms the host formation at the waste-burial site. During advance, the glacier sole seems to have periodically floated free from the substrate and allowed space for rapid accumulation of poorly bedded pebbly silt and clay. Regrounding of the ice on the lake floor and renewed movement could be responsible for the till deposition as well as the structural deformation observed throughout both till and lacustrine subunits.

The overridden Kent kame deltas experienced only minor alteration from the partly bouyant Lavery ice and retained much of their original sedimentary structure and landform beneath the Lavery till. Disjointed lenses of badly deformed sand and fine gravel, exposed in trenches on the waste-burial site, are overlain by the uppermost 9 feet of Lavery till and might indicate a major ice withdrawal and readvance equivalent to the Defiance glaciation. However, there is no lithologic, textural, or weathering evidence to warrant separation of the uppermost till from the Lavery beneath. Withdrawal of Lavery ice from Buttermilk Creek Valley seems to have been rapid and accompanied by erosion by upland streams, which deposited as much as 10 feet of channery gravel over small lingering ice masses and on exposed Lavery till in Buttermilk Creek Valley. Flow direction indicated by the imbrication of these capping gravels is downstream to the northwest. Ponded water dissipated westward, first through outlet channels cut into till and rock on the north-facing Dutch Hill spur. Lacustrine sediments were found between the fluvial gravel blanket and the top of the Lavery till at only one locality, along Buttermilk Creek 0.4 mile north of the highway culvert near West Valley.

As the ice margin receded northward from the Dutch Hill spur to a position coincident with the present south wall of Cattaraugus Valley, a sandy pebble-gravel blanket 15 to 30 feet thick was emplaced directly on Lavery till by melt waters that drained freely to the west. This outwash (Wdo in pl. 1), kamelike along its north edge, is slightly younger than the fluvial gravel of Buttermilk Creek Valley. It has been proposed to be equivalent to the Defiance moraine (Muller, 1975). which marks the Defiance glacial limit (E. H. Muller, written commun., 1978), but may be Lavery recessional.

Postglacial alluvial-fan deposition completed the sedimentary history of Buttermilk Creek Valley. The fuel-reprocessing plant is built on 2 to 5 feet of fan gravel that overlies the Lavery till and laps onto the fluvial gravel blanket toward the valley axis (pl. 7). The upland stream that supplied the fan gravel has incised 60 feet into the fan and shale beneath, which suggests that fan deposition may have occurred for only a short time after deglaciation.

Holocene erosion by Buttermilk Creek and its tributaries has subsequently dissected Kent and Lavery glacial deposits and bedrock to a maximum depth of about 130 feet. The position of the profile of Buttermilk Creek with respect to the glacial deposits in Buttermilk Valley is plotted to scale in the longitudinal section depicted in figure 3; proposed stratigraphic relationships in the valleys of Buttermilk and Cattaraugus Creeks are summarized in the correlation chart in plate 8.

Lavery Till

Although the Lavery till has wide areal extent (pls. 1-6), exposures showing more than a few feet of section are uncommon. Because of its clayey, fine-silty texture, its thickness of over 100 feet, and its deep postglacial dissection, the till is highly susceptible to slumps and shallow-seated rotational slides. Periodically during mass wasting, sections several feet thick are exposed in slide scars but are lost by failure within a few weeks. The basal 10 to 15 feet of Lavery till in contact with Kent recessional beds is well exposed in a left bank bluff of Connoisarauley Creek, 0.6 mile northwest of Connoisarauley Road (fig. 1), and in a high bluff of Buttermilk Creek 0.85 mile upstream from its confluence with Cattaraugus Creek (fig. 4). Deformed pro-Lavery lacustrine sediments overlying Kent recessional gravel are well exposed in a bluff on Cattaraugus Creek 2.2 miles southwest of Sardinia (fig. 1). The upper 12 feet of Lavery till was exposed in 1976 in the sides of a new lagoon on the waste-burial site. Additionally, 24 boreholes produced core samples to depths of 50 feet. A composite type section for the Lavery till can be based on these data, although the entire unit is nowhere completely exposed. The thickest Lavery section measured was at the north end of Buttermilk Creek Valley, where 130 feet of till is overlain by 6 feet of Defiance outwash gravel. Lavery till averages 80 feet in thickness near the waste-burial site, thins to 16 feet at Riceville Station (fig. 4), and pinches out near West Valley. North of Cattaraugus Creek, the Lavery till is covered by Lake Escarpment outwash (pl. 5, Springville quadrangle).

Wherever the Lavery is exposed or clearly shown in test borings (fig. 4), it is an interfingering complex of three subfacies. The most abundant subfacies, which forms about 70 percent of the formation thickness, is a pebble and cobble till, moderately bright, with a clayey silt matrix. Stones constitute 10 to 20 percent of the unit in field exposures, although cobbles larger than 2.5 inches could not be recovered in the core barrel during drilling. Textural and mineralogical analyses by Whitney (1977) on three till matrix samples from the waste-burial site show nearly uniform percentages of clay (40 percent), silt (48 percent), and sand (12 percent), with the silt and clay fractions dominated by quartz, mica (illite), and chlorite. Textural analyses of two core samples by the U.S. Geological Survey (unpublished) showed 55 percent clay, 25 percent silt, and 20 percent sand and gravel.

The second subfacies is texturally similar to the first, except that stone content is less than 5 percent and the matrix contains thin, torn wisps of light-gray (N8)[1] quartz silt. Rarely, the till includes or

[1] Colors designated according to Munsell Soil Color Charts, 1954, Baltimore, Md., Munsell Color Company.

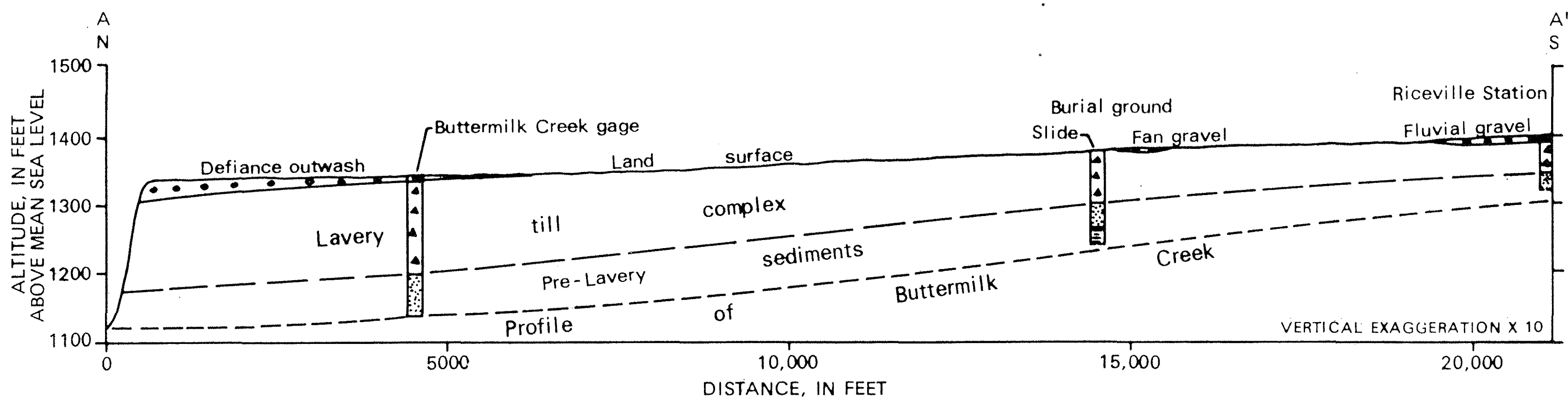

Figure 3.--Generalized stratigraphic section showing relationships of glacial deposits exposed in the bluff along Buttermilk Creek and penetrated by nearby boreholes. Line of section is given in figure 4. For simplicity, the section omits thin Holocene deposits on the valley floor and bedrock exposed locally near Buttermilk Creek gage (pl. 1); pre-Lavery deposits generally extend more than 100 feet below profile of Buttermilk Creek.

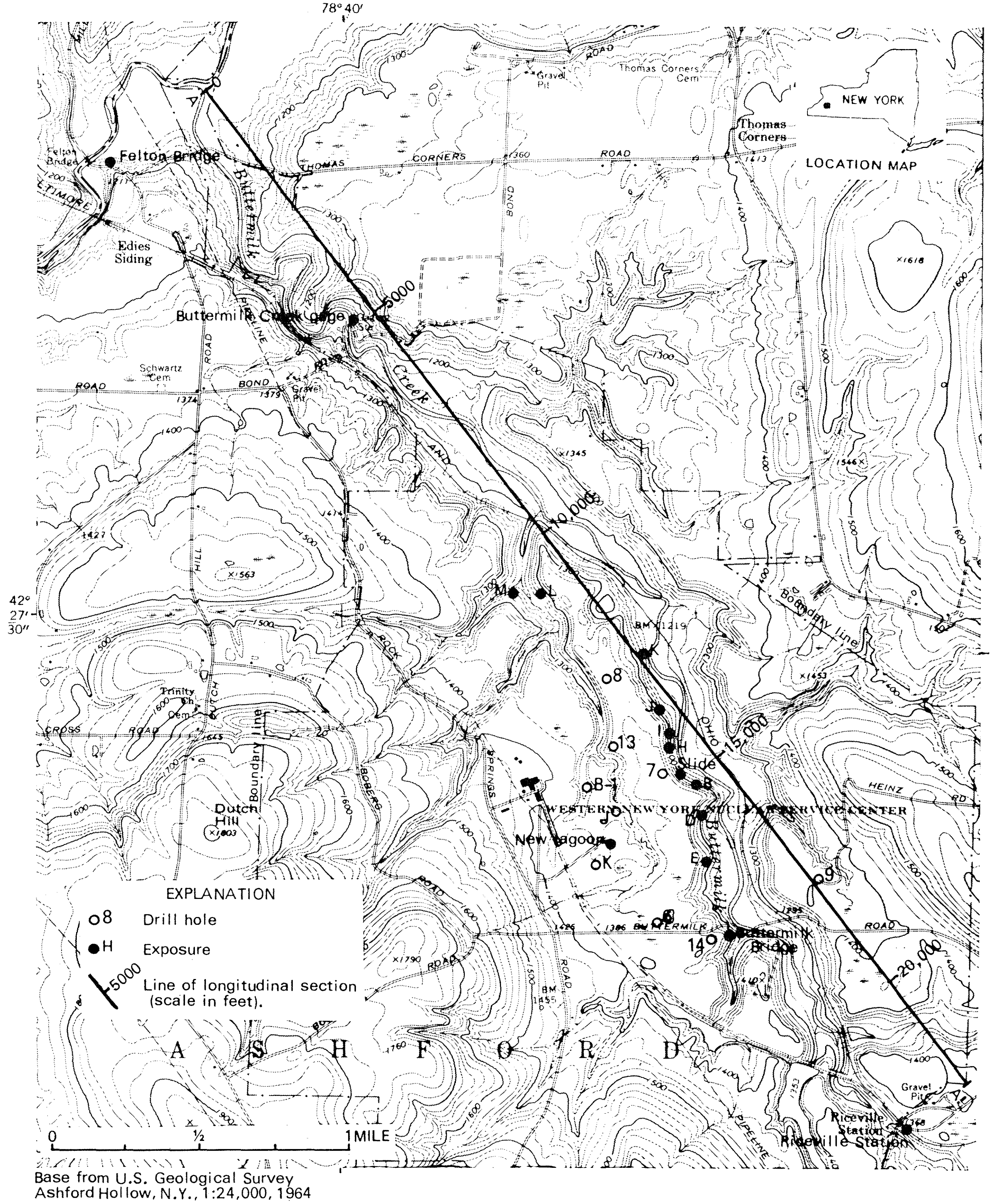

Figure 4.--Locations of exposures and boreholes depicted on plate 8, and position of longitudinal section depicted in figure 3.

grades into layered silt and clay; otherwise, there is no indication of varved or other rhythmic bedding in either of these subfacies. Both subfacies interfinger, and, although they have a general stratiform relationship, each is internally deformed. Any particular lens of each subfacies is of small areal extent. Unoxidized matrix color is a consistent medium olive gray (N5-5Y5/1). Oxidation extends to a depth of about 8 feet. Altered matrix colors above this depth are olive gray (5Y6/1) or pale yellowish brown (10YR6/2). The matrix is highly calcareous and leached to a depth of less than 1 foot. X-ray analyses showed quartz and illite to constitute well over half the material in each of seven samples of the till (table 1).

The third subfacies, exposed only in excavations on the burial site at depths of 7 to 12 feet, consists of stratified sand and gravel with included torn masses of till (subfacies 1) and rhythmic clay. Lenticular and discontinuous, this subfacies represents ice-frontal deposits overridden by late surges of Lavery ice or perhaps by the slightly later

Table 1.--Mineral composition of selected core samples from Western New York Nuclear Service Center[1/]

[All values are in weight percent; locations of test holes are shown in Prudic and Randall, 1977, fig. 1]

	Test-hole identification symbol; depth interval;[2/] and material									
Minerals	F 22.4-22.9 Till	I3 7.5-7.9 Oxidized till	J 52.7-53.2 Till	N 24.5-24.9 Till	C2 9.5-10.0 Oxidized till	C2 42.5-43.0 Till	D 14.0-14.5 Till	D 29.8-30.3 Lake beds	G 36.2-36.7 Lake beds	L 15.3-15.8 Lake beds
quartz	24	24	24	22	26	22	27	32	23	33
potassium feldspar	1	<1	<1	1	2	1	1	3	0	3
plagioclase feldspar	7	7	5	4	7	5	5	9	6	10
calcite	11	7	7	8	9	7	9	11	7	9
dolomite	5	3	5	5	7	5	5	9	5	11
chlorite	3	0	4	4	1	12	5	4	6	4
kaolinite	9	9	10	9	7	0	9	6	8	5
illite	24	27	27	21	28	26	30	16	19	15
montmorillonite	0	<1	0	0	0	0	0	0	0	0
mixed-layer clay minerals	4	9	4	6	4	1	<1	4	7	5
Totals	88	86	86	80	91	79	91	94	81	95

1/ Mineral composition determined by B. J. Anderson, U.S. Geological Survey, by X-ray diffraction according to method of Schultz (1964). Totals between 90 and 105 percent are considered normal for this semiquantitative method. Low totals in some samples probably indicate a higher iron content; the fluorescent radiation produced by iron causes loss of peak intensity and therefore generally lower percentages (B. J. Anderson, written commun., 1978).

2/ Depths are in feet below land surface.

Defiance glacier. One torn mass of 32 varves embedded in disjointed laminated fine sand 1 to 3 feet thick was exposed in 1975 at the bottom of a new lagoon. The strong deformation, variable podlike thickness, and small areal extent of this subfacies preclude its serving as a water-transmitting body for more than a few yards in any direction. Figure 5 shows idealized stratigraphic relationships among the various deposits exposed and drilled in the vicinity of the waste-burial site.

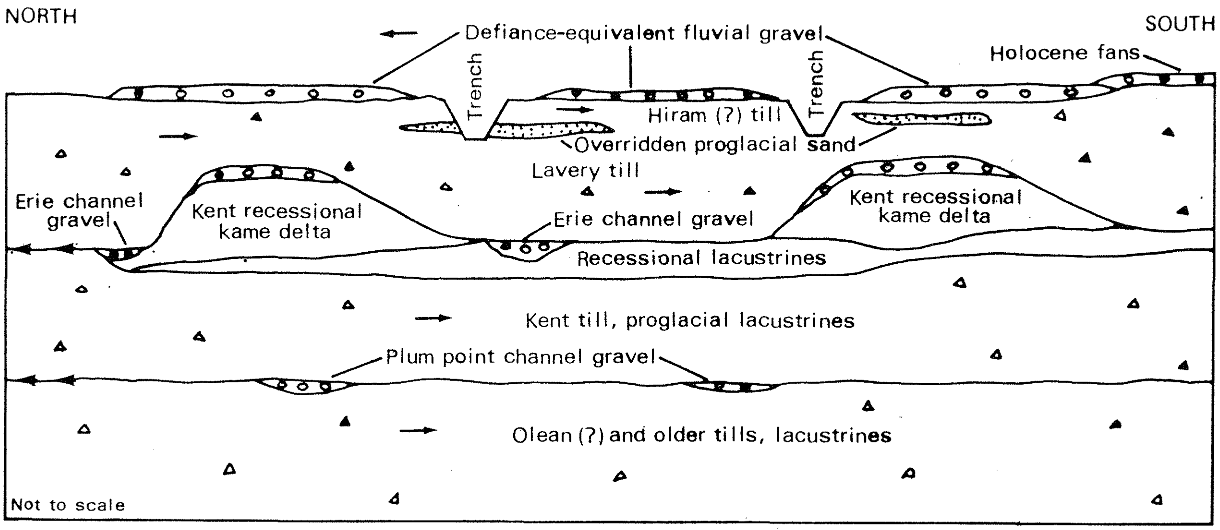

Figure 5.--Idealized stratigraphic relationships of Lavery till and adjacent deposits near waste-burial site. Arrows indicate direction of ice flow or streamflow during deposition or erosion.

Hydrologic Relationships of Lavery Till and Subjacent Strata

The Lavery till as a whole is a homogeneous mass whose very low permeability would seem to be little improved by the discontinuous, severely deformed sand stringers and pods (subfacies 3, described above). However, where the Lavery overlies kame deltas of Kent-recessional age or fluvial gravel of the Erie Interstade, these relatively permeable deposits may serve to conduct water to areas along the bluff bordering Buttermilk Creek, which has cut through these deposits. The upper part of the Kent-recessional delta-lacustrine deposits east of the burial ground is unsaturated, but water seeps from a small spring in the bluff along Buttermilk Creek (Prudic and Randall, 1977, fig. 5). Saturated basal delta sand near the point of seepage has triggered mass movement in the underlying clay beds. The water level in permeable deposits at wells J and V (Prudic and Randall, 1977, fig. 5) seems to be lower than at the spring. This could be explained if a sinuous gravel channel, developed during the Erie Interstade, were the principal avenue of water escaping from the till-kame delta system. All along its present course, Buttermilk Creek has dissected the Lavery, Erie, and Kent deposits to a depth at least 30 feet below any probable course and profile of an Erie Interstade channel (pl. 8). Therefore, it is not anticipated that water discharged from these deposits nourishes Buttermilk Creek through its bed; instead, the water probably escapes on the bluff overlooking Buttermilk Creek as seeps where kame deltas or possible Erie channel gravel intersect the bluff. However, no substantial springs or indentations in the bluff that might be ascribed to spring sapping have been detected near the Western New York Nuclear Service Center.

Pre-Lavery Lithologies and Stratigraphic Relationships

Kent till and recessional drift can generally be distinguished from Lavery on the basis of color, brightness, and texture. Lavery till, as previously described, is moderately bright (10 to 15 percent of the stones are of exotic lithologies), highly calcareous, and medium olive gray (N5-5Y5/1) and, in the study area, is confined to the valley floors. Kent drift is exposed chiefly in the uplands and along the valley sides, where it is generally drab (less than 5 percent exotics), weakly calcareous, and greenish gray (5GY5/1) oxidized to grayish orange (10YR7/4); however, some of the Kent till and gravel is highly calcareous, generally pale red (5R6/4), and has a stone content that is 20 to 40 percent exotic (including red and white sandstones, carbonates, and crystalline Canadian Shield lithologies). In the few places where till assigned to the Kent glaciation is exposed on the valley floors beneath the Lavery, it is tougher, less clayey, and darker olive-gray (5Y4/1) than Lavery till. The Lavery commonly contains small inclusions of Kent till and clay, particularly the pale red. For example, a slide scar on the west side of Rock Springs Road 1,500 feet north of the waste-burial site (pl. 1, Ashford Hollow Quadrangle) shows Kent red clay and greenish-brown silt 50 yards west and uphill from a Lavery till exposure, which contains torn inclusions and stringers of the same Kent lacustrine sediments. The Lavery-recessional lacustrine deposits cited earlier, north of West Valley, also contain Kent red clay inclusions.

Two major exposures suggest the degree of dissection of the Buttermilk-Cattaraugus Valley after the Kent recession. At Felton Bridge, 2,200 feet southwest of the confluence of Buttermilk and Cattaraugus Creeks, a narrow, steep-walled channel cut in rock is filled with 30 feet of very bright boulder gravel (30-40 percent exotics) that grades upward to pebble gravel and underlies Lavery till. The base of the boulder fill is not exposed and lies below the present low-flow level of Cattaraugus Creek. A northwestward projection of the channel across the modern stream is required to bypass an unbroken shale cliff 130 feet high cut by the postglacial Cattaraugus.

At a north-bank exposure on the Cattaraugus, 2.2 miles southwest of Sardinia and 7.5 miles upstream from Felton Bridge (fig. 1), bright ice-contact clinoform gravel beds, dipping westward, are overlain by pro-Lavery deformed rhythmite clay beds that are in turn overlain by Lavery till.

The melt-water stream that transported the bright Kent gravel westward from an eastward-receding ice margin followed a profile topographically only slightly above that of the present Cattaraugus. Also at this location, deformation in the pro-Lavery lacustrine beds indicates southeastward ice flow from the Erie lobe after the Erie Interstade, whereas the Ontario lobe seems to have been more dominant during the Kent glaciation.

Exposures along Snake Run Road 2 miles north of the Kent moraine (fig. 1) show, in descending order: drab upland moraine gravel, interfingering drab and bright tills, red clay and black gravel, and drab greenish-gray to light olive-gray till and gravel (probably all Woodfordian) over an older well-oxidized and noncalcareous drab gravel and till. The Connoisarauley and East Otto lobes (fig. 2), which deposited the upper Kent part of the Snake Run section, seem to have competed for space along the interfluve separating their valleys. Each lobe contributed a till substrate of very different lithologic composition, determined only by the location in the ice of bright and drab components. An areal facies relationship between drab and bright Kent drift is clearly required by the interfingering till sequence in the upper Snake Run section. Perhaps this facies relationship also includes the drab greenish-gray tills that extend 42 feet below the base of the interfingering bright and drab units. Should further study prove this 42-foot-thick sequence to be Olean, which it strongly resembles, the lithologic similarity of these units to others higher in the Snake Run section may suggest an early Woodfordian age for Olean till. The basal 66 feet of the section contains oxidized, noncalcareous yellowish-gray clean gravel and faulted sand overlying oxidized and leached till that contains abundant slabs of local bedrock. These units, different from any in the section above, may date from the middle-Wisconsinan or earlier. Not all drab till is Olean within the study area nor is all Kent till or gravel bright. The Woodfordian mapping units on plates 1-6 are not separated into bright and drab facies, nor is it certain how much, if any, of the landscape outside the Kent moraine might be covered by drab Woodfordian till.

In spite of the lithologic similarities between Kent and Olean (?) suggested at Snake Run, note that the outwash that emanated from the ice at the time of emplacement of the Kent moraine seems to have been laid down in completely deglaciated valleys (pls. 1-6 and fig. 2). If some or all of the deposits cited as Olean on plates 1-6 should prove to date from the early Woodfordian, a yet unidentified early Woodfordian interstadial interval of some duration prior to formation of the Kent moraine would be indicated. Such an interval may have been important in the colluviation and oxidation of the Olean drift. Although these relationships are speculative at present, they are suggested in some of the correlations shown on plate 8.

SUMMARY

The waste-burial site is in a clayey silt till complex containing minor deformed lacustrine clay and silt. The till complex lies stratigraphically beneath outwash from the Defiance and Lake Escarpment moraines and above a sequence of kame deltas and rhythmic lacustrine beds that record retreat of ice from the Kent moraine. A Lavery (early late Woodfordian) age for the till complex is inferred. Free drainage northward during the Erie Interstade before emplacement of the Lavery till is indicated by channel gravel inset into or covering the Kent recessional deposits. These channel gravel beds and the Kent kame deltas provide the stratigraphically lowest avenue for release of water from the Lavery till, where they are exposed in the bluffs along Buttermilk Creek.

Lavery subfacies include a predominant stony, clayey silt till, minor deformed massive lacustrine clay and silt, and, in the uppermost Lavery only, fragments of overridden sandy pebble gravel and clay beds. All of these subunits are lenticular, and even where permeability is improved by coarse grain size, there is no consistent water-transmitting body within the Lavery. A lodgement mode of deposition beneath a periodically bouyant ice lobe advancing through a proglacial lake is proposed for the Lavery till.

Shallow rotational slumps are common in the Lavery till on gully walls where relief exceeds 6 feet. Larger slumps occur where high bluffs along Buttermilk Creek expose the Kent kame delta sand beneath the Lavery.

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