Erosion and infill of New York Finger Lakes: Implications for Laurentide ice sheet deglaciation

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ABSTRACT

A comprehensive seismic reflection profile investigation of the New York Finger Lakes has revealed the extent of bedrock erosion and nature of sediment fill beneath the lakes. Bedrock deepens to the south, where gorgelike profiles have been eroded to as much as 304 m *below* sea level and infilled with up to 275 m of late Quaternary age (<14 ka) sediment. We propose a working hypothesis that invokes ice streaming and pressurized subglacial meltwater and sediment to account for regional geomorphology. This working hypothesis is consistent with recent concepts of the collapse of continental ice sheets via ice streaming and the marine isotopic record for a meltwater spike at 13–14 ka. The Finger Lakes may provide a critical testing ground for deglaciation models of the southern Laurentide ice sheet because they contain a thick, well-preserved, and now seismically defined record of the deglaciation process.

INTRODUCTION

The Finger Lakes of central New York State (Fig. 1) have been considered one of the world's great testimonies to continental glaciation ever since Louis Agassiz's 1868 address at Cornell University on the "glacial heritage" of the region (Coates, 1968). Yet today the origin of the Finger Lakes remains unresolved, in large part due to the paucity of subsurface geophysical data from the lakes (Bloom, 1984). In this paper we present the first-order results of a comprehensive seismic reflection profile investigation of the Finger Lakes.

SETTING AND PREVIOUS IDEAS

The Finger Lakes (Fig. 1) occur along the northern margin of the glaciated Appalachian Plateau and are cut principally into undeformed, but well-jointed, Devonian sedimentary rocks (largely shale) that dip gently to the southwest. The seven eastern Finger Lakes (80 km across) form a radiating pattern that projects northward to eastern Lake Ontario, whereas the four smaller western lakes (17 km across) project to a point near Rochester (Fig. 1). The lakes vary considerably in size, ranging in length from 5 to 61 km; in lake-level elevation from 116 to 334 m; and in maximum water depth from 9 to 198 m (Coates, 1968).

Figure 1. Satellite photograph of Finger Lakes region of central New York State. 1—Conesus; 2—Hemlock; 3—Canadice; 4—Honeoye; 5—Canandaigua; 6—Keuka; 7—Seneca; 8—Cayuga; 9—Owasco; 10—Skaneateles; 11—Otisco. Arrow points to city of Syracuse at southeast end of Onondaga Lake; large lake northeast of Syracuse is Oneida.

North of the Finger Lakes is an extensive drumlin field and a system of north-south meltwater channels (Muller and Cadwell, 1986). To the south of the lakes, and confined to the valleys, is the Valley Heads moraine, which consists of large volumes of water-laid drift. Radiocarbon dates from the Valley Heads indicate an age of 12.95–14.1 ka (Fullerton, 1986), which correlates well with the marine isotopic record for large-scale melting of the Laurentide ice sheet 13–14 ka (Ruddiman, 1987).

Early ideas (pre-1900) on the origin of the lakes were that they are simply preglacial river valleys that were modified by glacial activity. Contemporary views, though, are that there has been large-scale glacial erosion in the Finger Lakes region aided by large volumes of glacial meltwater (reviews by Coates, 1968; H. T. Mullins et al., in prep.).

METHODS

Approximately 1300 km of single channel seismic reflection profiles have been collected from the Finger Lakes using an EG&G Uniboom fired at up to 1000 J. Both east-west–oriented (transverse) profiles with a spacing of 1 km or less and a north-south (longitudinal) profile were collected from each lake. Profiles have been correlated with lakeshore outcrops and available drill-core data on land, as well as 26 piston cores (up to 5 m long) recovered from seismically defined outcrops in Seneca and Cayuga lakes. In addition, wide-angle reflection measurements were made in five lakes to determine velocity structure of the sediment fill.

BEDROCK EROSION

Although it has been known that the lake floors of Seneca and Cayuga extend below sea level, the full extent of bedrock erosion beneath the lake valleys has been a major unknown. East-west–oriented reflection profiles (Fig. 2) indicate that bedrock at the north ends of the

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lakes forms broad, shallow profiles (Fig. 3). However, bedrock becomes more deeply incised to the south, where it takes on gorgelike profiles.

Longitudinal bedrock profiles (Fig. 4) show that the Finger Lakes occupy true rock basins. Bedrock deepens to the south, reaching maximum depths about two-thirds of the way to the south before ascending beneath the southern ends of the lakes (Fig. 4). Depth to bedrock has been confirmed by drilling at the north end of Seneca Lake, where bedrock was reached at about 74 m below lake level, and at the south end of Cayuga Lake, where bedrock is found at depths of about 133 m below lake level (Coates, 1968).

Erosion was most intense beneath Seneca and Cayuga lakes, where maximum depths to bedrock are 304 m and 249 m *below* sea level, respectively. Canandaigua Lake also has a bedrock floor that extends as much as 46 m *below* sea level, and Skaneateles Lake has been eroded at a maximum to within 3 m of sea level.

SEDIMENT INFILL

In addition to deep bedrock scour, the Finger Lake valleys have been infilled with large volumes of sediment. Sediment thickness generally follows bedrock morphology, typically being thin in the north and thickening to the south, with a maximum of 275 m of sediment beneath Seneca Lake. Seismic sequence analysis has defined six first-order depositional sequences beneath the Finger Lakes (Fig. 2). The oldest sequence (I) is characterized by a chaotic seismic facies with a hummocky upper surface that is onlapped by younger units; it occurs only in the southern half of the lake basins where it projects to on-land outcrops of the water-laid Valley Heads moraine. Sequence II typically occurs in the southern two-thirds of the lake basins and is characterized by strong lateral changes in seismic facies from hummocky, high-amplitude reflectors in the north to a smooth, low-amplitude facies to the south, suggesting a proximal to distal transition of coarse- to fine-grained sediment. Where present, sequence III typically occupies much of the lake basin and is characterized by a reflection-free seismic facies that is locally diapiric, suggesting rapid deposition of fine-grained sediment. Sequence IV occurs throughout the lake basins and consists of continuous, high-frequency, high-amplitude reflectors, suggesting temporally variable but spatially widespread deposition; piston cores indicate fine-grained varvelike rhythmites with dropstones and thin sandy turbidites. Sequences V and VI thicken to the south and are characterized by low-amplitude, continuous reflectors that onlap sequence IV to the north, indicating a southerly sediment source.

Our seismic reflection data have also detected two glacial geologic features of particular significance. Collapse, or ice melt-out, structures occur only at the north ends of the lakes, which suggests that grounded ice occurred there, where it was pinned. The second feature is eskerlike

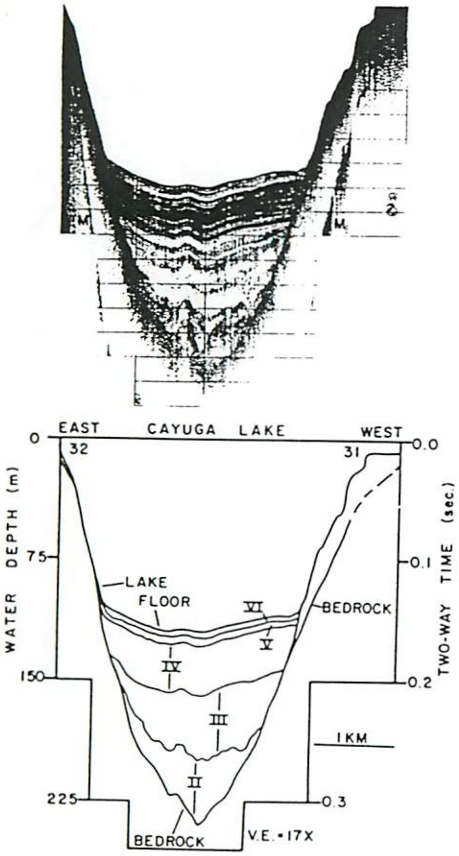


Figure 2. Transverse seismic reflection profile (top) and line drawing interpretation (bottom) from central Cayuga Lake illustrating bedrock profile and sediment fill. Roman numerals refer to seismic stratigraphic units discussed in text; M = multiple reflection; V.E. = vertical exaggeration.

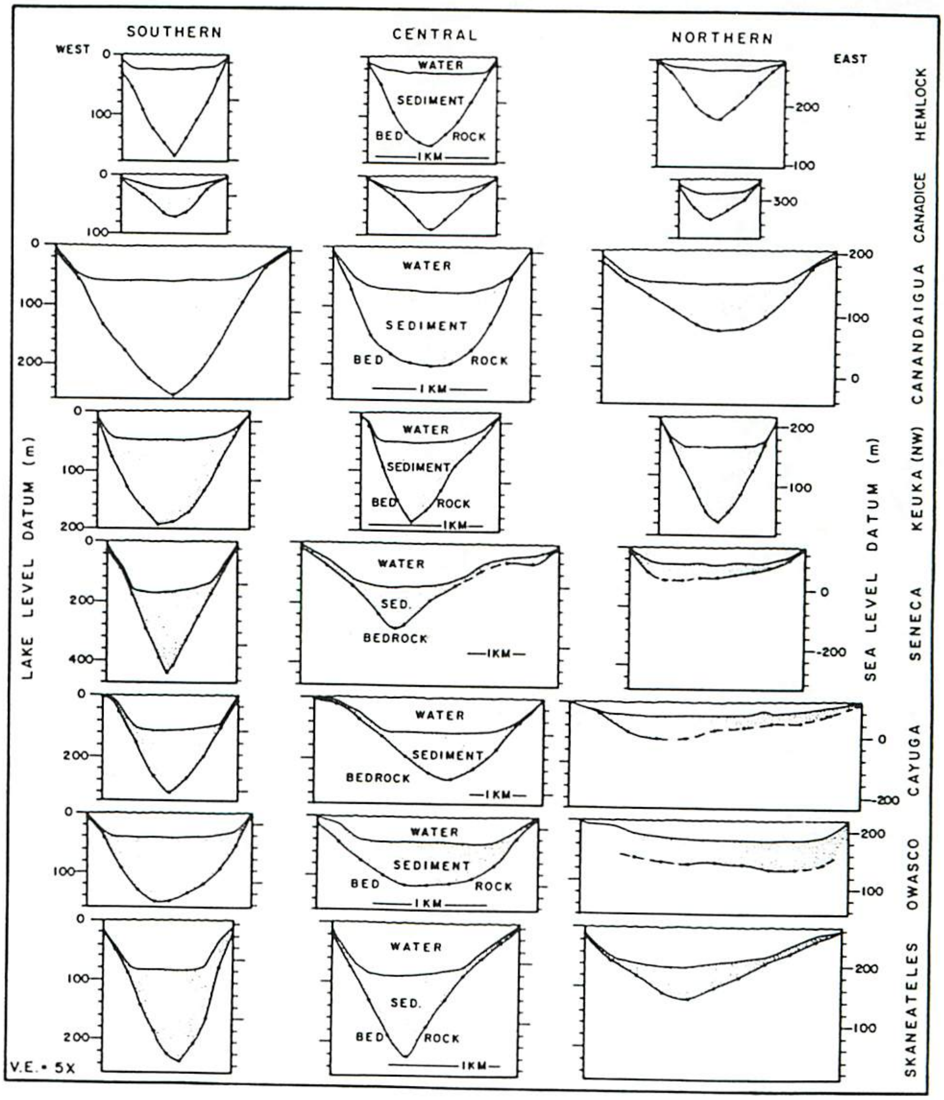


Figure 3. Selected transverse bedrock profiles and sediment fills for southern (left), central (middle), and northern (right) parts of eight Finger Lakes (right-hand column) relative to both individual lake levels and sea level. Profiles digitized from velocity corrected reflection profiles; dots represent data points. Note that scales are same for all lakes except Seneca and Cayuga; vertical exaggeration (V.E.) is constant.

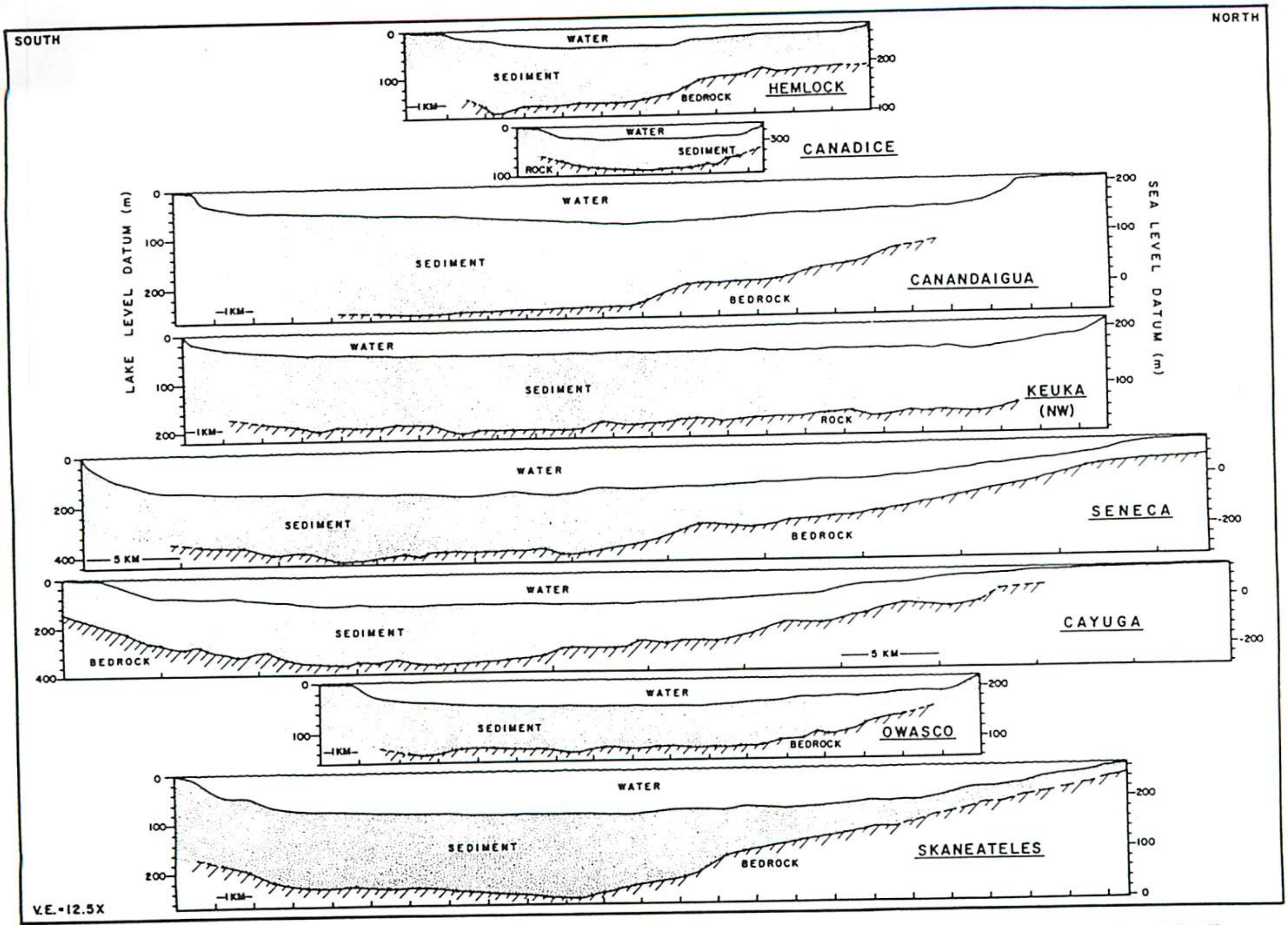


Figure 4. Longitudinal bedrock profiles and sediment fills for eight Finger Lakes relative to individual lake levels and sea level. Profiles were constructed by measuring maximum depths to bedrock from velocity-corrected transverse reflection profiles; dots indicate data points. Note that scales are same for all lakes except Seneca and Cayuga; vertical exaggeration (V.E.) is constant.

ridges at the northern ends of Owasco and Seneca lakes from which we infer the presence of large subglacial channels.

DISCUSSION

On the basis of our seismic reflection results, integrated with a surficial geologic map of the region (Muller and Cadwell, 1986), we propose a working hypothesis that builds on previous concepts of large volumes of glacial meltwater in the Finger Lakes region. A premise of the hypothesis is that there is a genetic link between the drumlin field and meltwater channels north of the lakes, erosion and infill of the lake valleys, and deposition of the Valley Heads moraine to the south (Fig. 5). We suggest that the region was subjected to strong ice-stream flow facilitated by large volumes of pressurized subglacial meltwater and sediment as the Laurentide ice sheet began to collapse after the last glacial maximum (Hughes, 1987). The overall physiography of the Finger Lakes region (Fig. 1) argues for a larger ice-stream system in the eastern lakes region and a smaller one to the west. Ice streaming may have been facilitated in part by impounded waters in the Lake Ontario basin (White,1985) which were similar to marine ice streams (Hughes, 1987).

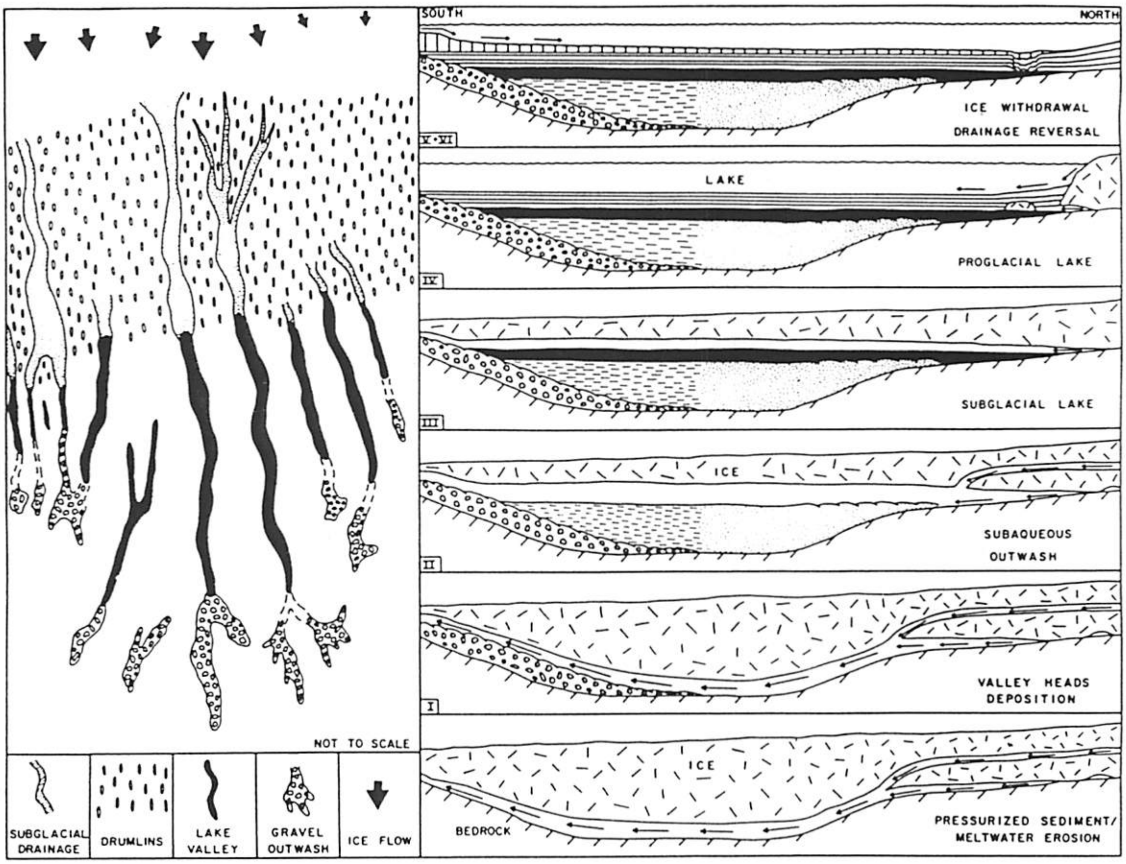
Boulton and Hindmarsh (1987) have argued, on theoretical grounds, that as large temperate ice sheets flow over deformable beds (commonly drumlinized) near a glacier margin, subglacial drainage systems and ultimately tunnel valleys must form to accommodate overpressurized subglacial meltwater and sediment. Although their model was developed for unconsolidated sediment, in the Finger Lakes region there is a similar relation among shallow channels in the drumlin belt north of the lakes that feed into the larger lake (tunnel?) valleys, which terminate in gravel outwash (Fig. 5).

Wright (1973) has previously reported shallow tunnel valleys from the drumlin plain southwest of Lake Superior, and Boyd et al. (1988) have recently presented evidence for large tunnel valleys offshore Nova Scotia that extend as much as 450 m below sea level. In both these examples, catastrophic release of subglacial meltwaters has been called upon for erosion, similar to Shaw and Kvill's (1983) suggestion for the Finger Lakes. However, we favor a longer term subglacial drainage system for the Finger Lakes similar to the more uniformitarian view advocated by Boulton and Hindmarsh (1987).

Timing of the erosion for the Finger Lake valleys remains uncertain. Our seismic data indicate that the present sediment fill onlaps the Valley Heads moraine, which has been radiocarbon dated at 13–14 ka. It may be that the Finger Lake valleys were eroded and infilled in the late Pleistocene. However, we cannot rule out a multiplicity of glacial episodes as advocated by Coates (1968) for erosion of the Finger Lake valleys.

In our working hypothesis (Fig. 5), the water-laid Valley Heads moraine (seismic sequence I) was deposited as a pressurized subglacial meltwater and sediment mix. With deceleration of

Figure 5. Schematic, idealized working hypothesis for erosion and infill of New York Finger Lakes. Left side of figure illustrates map view relations of major geomorphic features based on, and simplified from, Muller and Cadwell (1986). Right side illustrates (in longitudinal cross section) progressive stages of erosion and infill. Roman numerals refer to seismic stratigraphic units; see text for further discussion. Not to scale.



subglacial flow, the lake valleys began to fill with coarse- to fine-grained subaqueous outwash (sequence II). This was followed by the rapid deposition of fine-grained sediment (sequence III) in subglacial lakes. Seismic sequence IV consists of classical glaciolacustrine deposits, suggesting that the ice front had retreated to the north ends of proglacial lakes. With continued ice withdrawal, lake levels dropped and a drainage reversal occurred as sediment began to enter the lakes from the south and sides (sequences V and VI). This also may have been when the well-known glens of the region were cut as local base level lowered.

CONCLUDING REMARKS

Our working hypothesis for the Finger Lakes is a departure from the classical concept of simple glacial ice modification of preexisting stream valleys. It is also consistent with recent concepts on the collapse of ice sheets via ice streaming as well as the marine isotopic record for rapid melting of the Laurentide ice sheet 13–14 ka. We emphasize, though, that our model is just that—a working hypothesis. The ideas presented here will need to be tested. However, this can be done by drilling the thick sediment record beneath the lakes, as well as by detailed stratigraphic studies of the drumlin field and meltwater channels north of the lakes and of the Valley Heads moraine to the south. We view this as essential because much of our current knowledge and understanding of Laurentide ice sheet deglaciation has come from proxy data bases, whereas it must ultimately be sought from critical areas such as the Finger Lakes that have thick, well-preserved, and now seismically defined sediment records of the deglaciation process.

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