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ABSTRACT


Most of the papers in this thematic section present regional perspectives that build on more than 100 years of geologic investigation in Long Island Sound. When viewed collectively, a common theme emerges in these works. The major geologic components of the Long Island Sound basin (bedrock, buried coastal-plain strata, recessional moraines, glacial-lake deposits, and the remains of a large marine delta) interact with the water body to affect the way the modern sedimentary system functions.

Previous work, along with our present knowledge of the geologic framework of the Long Island Sound basin, is comprehensively reviewed with this theme in mind. Aspects of the crystalline bedrock, and the deltaic deposits associated with glacial Lake Connecticut, are examined with respect to their influence on sedimentation along the Connecticut coast and in the northern and western Sound. We also discuss the influence of the glacial drift that mantles the coastal-plain remnant along the north shore of Long Island and in the southern Sound.

A total of approximately 22.7 billion m$^3$ of marine sediment has accumulated in the Long Island Sound basin. A significant portion (44%) of the fine-grained marine section in the central and western basins was redistributed there from the eastern Sound, as tidal scour removed slightly over 5 billion m$^3$ ($5.3 \times 10^{12}$ kg) of fine material from glacial-lake and early-marine deposits east of the Connecticut River. The remainder of the estimated $1.2 \times 10^{13}$ kg of fine-grained marine sediment that now resides in the central and western Sound can be accounted for by riverine input over the past 13.5 ka.

ADDITIONAL INDEX WORDS: Glacial Lake Connecticut, marine delta, glacial history, sedimentation, sediment budget, marine geologic investigations, Long Island Sound.

INTRODUCTION

Most of the papers in this volume share a common thread. The geologic components of the Long Island Sound (LIS) basin interact with the water body to influence the distribution and character of bottom sediments, sedimentary environments, infaunal assemblages, and the patterns of sedimentation, sediment transport and contaminant accumulation. Conceptually, this interaction appears to make simple common sense. However, the iterative process of understanding the components that collectively control the sedimentary system of the Sound has taken more than 100 y to evolve. Development of this understanding has important implications for wise use and management of the Sound.

Building on previous work, an 18-year cooperative between the U.S. Geological Survey and the State of Connecticut has produced an overall characterization of the Quaternary stratigraphy and history of the Sound (LEWIS and STONE, 1991; STONE et al., 1998). Most recently, studies presented in this volume have tied the cumulative evidence together and collectively support a holistic view of sediment-related processes in LIS.

This paper draws from these, and other previous findings, to provide a geologic setting for several of the papers that follow. Selected past contributions to our geologic legacy are highlighted. The relevance of the bedrock, coastal-plain, glacial and postglacial components of the LIS basin to the development of the modern sedimentary system is examined within the context of our inferred chronology of Quaternary events. A discussion of the volume and sources of postglacial sediments is also presented.

PREVIOUS AND RELATED WORK

Pioneering workers in the latter part of the 19th century (DANA, 1875, 1890; HOLLICK, 1893) and early 20th century (VEATCH, 1906; FULLER, 1914; ANTEVS, 1922; REEDS, 1927) set the stage for future endeavors with their interest in the origins of the LIS basin and its possible occupation by a glacial lake. From the late 1940's through the 1970's, remote sensing and physical sampling technologies (developed during and after World War II) provided new opportunities for subbottom and surficial-process studies.

Initial studies of the subbottom in the vicinity of LIS and Block Island Sound (Figure 1) outlined the general relationship of bedrock, coastal-plain, and glacial-drift surfaces. Oth-
IVER and DRAKE (1951) presented the first depth-to-bedrock map of Long Island and Block Island Sounds. Later, TAGG and UCHUPI (1967) further described the bedrock surface as low-relief topography overlain by unconsolidated sediments. Several of the bedrock valleys in and around LIS were discussed by UPSON and SPENCER (1964), McM ASTER and ASHRAF (1973 a, b, c) and HAENI and SANDERS (1974). A total magnetic intensity map was prepared by ZURFLUEH (1962). The aeromagnetic map of HARWOOD and ZIETZ (1977) and the free-air gravity map of DEHLINGER (1978) followed. RODGERS (1985) and HERMES et al. (1994) compiled the bedrock geological maps of Connecticut and Rhode Island. A summary of the geology of New York is contained in ISACKSEN et al. (1991). WINTSCH et al. (1992, 1995) outlined the bedrock terranes of eastern Connecticut and Rhode Island. McM ASTER et al. (1968), McM ASTER and ASHRAF (1973 a, b, c) and NEEDELL and LEWIS (1984) described the regional relationship of a south-dipping bedrock surface, unconformably overlain by a remnant of Cretaceous coastal-plain strata, in Block Island Sound. A similar relationship was mapped by LEWIS and NEEDELL (1987) and NEEDELL et al. (1987) in southeastern and east-central LIS.

The concepts of HOLICK (1893), ANTEVS (1922), REEDS (1927) and LOUGEE (1953), regarding a glacial lake that once occupied the LIS basin, were revived by NEWMAN and FAIR BRIDGE (1960) in their naming of glacial Lake Antevs. Early physical evidence of the occurrence of glacial lake clay in the vicinity of LIS was supplied by FRANKEL and THOMAS (1966) and COCH et al. (1974). BERTONI et al. (1977) identified freshwater-lake deposits in central Block Island Sound on the basis of bottom samples, cores, and seismic profiles. The most recent maps of the extent of glacial-lake deposits in Block Island Sound and LIS were prepared by NEEDELL and LEWIS (1984), LEWIS and STONE (1991), and STONE et al. (1998). STONE et al. (1985) clarified previous ambiguities by defining glacial Lake Connecticut as the lake that once occupied the LIS basin. Several investigators have reported on glacial deposits associated with the study area. Detailed studies of deposits on Fishers Island (Figure 2) and Long Island were completed by FULLER (1905, 1914), and CRANDELL (1962) worked on Plum Island (Figure 2). GOLDSMITH (1960, 1982), SCHAFER (1961), and SIRKIN (1982) studied the moraines of eastern Connecticut, Rhode Island, and Long Island (NY). STONE and BORNS (1986) presented a Pleistocene glacial and interglacial stratigraphy for the area. LEWIS and STONE (1991) also examined the nature and history of ice retreat across the LIS basin and presented findings that were incorporated in the Quaternary Geologic Map of Connecticut and Long Island Sound Basin (STONE et al., 1998). GOSS (1993) used seismic-reflection data from Block Island Sound (NEEDELL and LEWIS, 1984) to compare and integrate his interpretation of the Block Island Sound geology with ice-marginal sedimentation and ice-retreat models proposed for LIS (LEWIS and STONE, 1991) and Narragansett Bay (PECK and McM ASTER, 1991).

The composition and distribution of bottom sediments in and around LIS have been reported on by numerous investigators (e.g., McM ASTER, 1960; BUZAS, 1965; McCrone, 1966; SAVARD, 1966; DIGNES, 1976; WILLIAMS, 1981; FRIEDRICH et al., 1986; KELLY and ALBANESE, 1989). BLOOM (1967) outlined the character of the Connecticut coast. BOKUNIEWICZ et al. (1976) presented a sediment budget for LIS, and
Fenster (1995) studied sand-sheet facies in eastern LIS. Thrumbll (1972) and Schlee (1973) provided some information on the bottom sediments of Fishers Island Sound, but Akpati (1974) conducted the first study specific to the mineralogy and sedimentology of the area. Poppe et al. (1994) outlined the distribution of surficial sediments in Fishers Island Sound.


The inferred geology of LIS has been summarized by Grim et al. (1970), Gordon (1980), Williams (1981), and Lewis and Stone (1991). These studies described the coastal-plain remnant as a highly dissected cuesta, cut in strata of Cretaceous age, that lies on an irregular, southeast-dipping bedrock (Precambrian? and Paleozoic?) surface. Extensive glacial-lake deposits, and a marine delta, associated with the draining of glacial Lake Hitchcock, have been mapped by Stone et al. (1998). Special Issue No. 11 of the Journal of Coastal Research (Gaves et al., 1991) was dedicated to geologic-framework, paleo-environmental, and sea-level studies in and around LIS.

**GEOLOGIC SETTING**

Long Island Sound is an elongate east-west estuary, which is rather unique in that its long axis runs parallel to the coast (Figure 1). It has communication with the Atlantic Ocean at its eastern and western ends, and it receives drainage from...

Crystalline bedrock has a strong influence on the depth and configuration of westernmost LIS, and it controls the shape of most of the Connecticut shoreline. Owing to its southeast dip (GRIM et al., 1970), crystalline bedrock is generally too deep to directly influence the shape of the north shore of Long Island, which is composed primarily of glacial material and yields little surface runoff to the Sound.

The northeast trend of the Roanoke Point-Orient Point-Fishers Island-Charlestown moraine (Figure 2) presently controls the eastward constrictio of the LIS basin. West of New Haven (Figure 2), the basin is confined by near-surface bedrock and, along the south shore, by a series of north-northwest trending reefs that reflect the shape of the underlying coastal-plain deposits. The shape and composition of the LIS basin influence how physical processes affect the sedimentary system of the Sound (see KNEBEL and POPPE, this volume; SIGNELL et al., this volume).

Bedrock

The bedrock that lies under LIS is believed to consist of metamorphic and igneous (?) rocks of pre-Mesozoic age. Pre-cambrian (?) and Paleozoic gneisses and granites of the Avalonian Terrane (RODGERS, 1985) crop out along the Connecticut coast east of New Haven (Figure 2, Eastern Uplands).

North of Fishers Island, the Avalonian Anticlinorium is locally intruded by the Westerly Granite (Permian?), now noted by HERMES et al. (1994) as the fine-grained component of the Narragansett Pier Plutonic Suite (RODGERS, 1985). Drill holes have encountered light-gray granite (presumably the Westerly Granite) at about ~86 m under Fishers Island (FULLER, 1905). Gneiss/granitic gneiss and schist have been reported under eastern Long Island at depths ranging from ~153 m at Orient Point (Figure 2) to ~488 m at Brookhaven (SUTER et al., 1949; DE LAGUNA, 1963; PIERCE and TAYLOR, 1975).

In the New Haven area, sedimentary and igneous rift basin rocks of the Early Jurassic-to-Late Triassic Newark terrane underlie the Hartford Basin (Figure 2). Offshore, HAENI and SANDERS (1974) reported a deep bedrock valley south of New Haven, and LEWIS and STONE (1991) defined an area of anomalously deep bedrock, trending southwestward from New Haven (Figure 2). The deep valley mapped by HAENI and SANDERS (1974) is partially filled with deposits that are older than glacial Lake Connecticut, but as yet unidentified. As of this writing, there is no direct evidence for the existence of Newark terrane rocks under LIS.

Westward of New Haven, schists, gneisses and phyllites of the Connecticut Valley Synclinorium (Middle-to-Early Paleozoic Iapetos terrane) crop out along the north shore of LIS (RODGERS, 1985; ISACHSEN et al., 1991), (Figure 2, Western Uplands). VEATCH (1906) reported outcrops of gneiss and dolomite in northwesternmost Long Island. The bedrock gets deeper toward the east, and well data indicate that the crystalline bedrock surface under western Long Island dips southeast at about 25-50 m/km (NEWMAN, 1977).

The Iapetos and Avalonian terranes of central New England, southeastern New York and Connecticut are characterized by north-south trending bedrock ridges and south-draining bedrock valleys. The Hartford Basin is also oriented north-south (Figure 2). This north-south "grain" developed as the area was compressed during the closing of the Iapetos Ocean, and rifted during the opening of the Atlantic Ocean. Subsequent fluvial and glacial erosion exploited north-south weakness zones, and several south-draining fluvial systems, which feed into LIS, developed on the bedrock.

South-draining bedrock valleys, and bracketing south-trending crystalline rock promontories, can be traced under northern LIS (Figure 2). The large embayment in the New Haven area is bounded to the north by the rift basin rocks of the Newark terrane (Figure 2, Hartford Basin). East and west of New Haven, crystalline bedrock promontories often extend, as south-trending bathymetric highs, quite far offshore. This is particularly true for the westernmost Sound, and for the area east of New London (Figure 2).

Bedrock valleys form numerous small embayments and coves along the north shore. These coves and embayments usually contain fluviodeltaic deposits (STONE et al., 1998) associated with glacial Lake Connecticut. Some of the sediment-related patterns noted by other workers in this volume (e.g. KNEBEL and POPPE, this volume; POPPE et al., this volume) are influenced by the north-south "grain" of the shallow, near-shore crystalline bedrock that underlies the northern Sound.

Coastal Plain

FULLER (1905) reported 21 ft (6 m) of Cretaceous blue clay, resting on granite, on Fishers Island, but no Cretaceous deposits are known to exist in northernmost LIS (Figure 2) or along the Connecticut coast. Coastal-plain sediments of Cretaceous age (consisting of unconsolidated to semi-consolidated gravels, sands, silts, and clays) have been reported along the north shore of Long Island (FULLER, 1914; SUTER et al., 1949; DE LAGUNA, 1963). The coastal-plain material that crops out along the immediate north shore of Long Island is not in place; it has been incorporated in glacial deposits, of varying thickness, that mantle the coast (LES SIKIRIN, personal communication, 1999).

The overall shape of the coastal-plain remnant depicted in Figure 2 is consistent with earlier interpretations for Block Island Sound (McMASTER et al., 1968; NEEDELL and LEWIS, 1984), where north-draining valleys incise and segment the cuesta front. Inferred north-draining, coastal-plain valleys are associated with the north-shore bays of western Long Island, and with the submerged coastal-plain promontories of central and eastern Long Island (Figure 2).

Seismic data from Block Island Sound show gently south-dipping reflectors that have been interpreted as internal contacts between coastal-plain strata (NEEDELL and LEWIS, 1984). These reflectors are a useful indicator of the presence of coastal-plain strata because they are distinctive, and they are commonly truncated along the inferred, north-dipping scarp of the coastal-plain cuesta. Internal coastal-plain reflectors have not been identified on any of the LIS seismic
data reported on by LEWIS and STONE (1991). This complicates the identification of the north-facing cuesta front and opens the possibility that the glacial deposits of southernmost LIS are thicker than LEWIS and STONE (1991) have indicated.

The configuration of the LIS basin is most obviously influenced by the shape and position of the coastal-plain remnant south and west of the Housatonic River (Figure 2). Shallow bedrock limits the depth of this portion of the basin so that the overlying coastal-plain deposits are more prominent. The net result is a confined basin where north-trending promontories (underlain by the coastal-plain remnant) nearly meet the south-trending promontories of crystalline bedrock (Figure 2). The "Norwalk shoal complex" of KNEBEL and POPPE (this volume) is an example of this. The southern half of the "Stratford shoal complex" (KNEBEL and POPPE, this volume) is also associated with a coastal-plain promontory or outlier. The presence of these shoal complexes has an influence on the modern physical processes and habitats of the western Sound (e.g. KNEBEL and POPPE, this volume; POPPE et al., this volume; SIGNELL et al., this volume; ZAJAC et al., this volume).

East of New Haven, the bedrock is deeper, and the central Sound has more fetch. The present northern Long Island shoreline curves gently northeastward. It is formed by the Roanoke Point-Orient Point moraine, which rests on coastal-plain strata, and lies well south of the inferred position of the buried cuesta front (Figure 2). Other than its role in forming the buried southern flank of the LIS basin, the coastal-plain remnant is inferred to be too deep to have a great influence on modern processes in this area.

Glacial Deposits

In Connecticut, and on the north shore of Long Island, the bedrock and/or coastal-plain strata are unconformably overlain by two drift sheets. The older till is commonly attributed to pre-late-Wisconsinan events, whereas the younger deposits are a product of the late Wisconsinan ice advance (DONNER, 1964; SIRKIN, 1971, 1976, 1982; MILLS and WELLS, 1974; RAMPINO and SANDERS, 1981). Two late Wisconsinan end-moraine lines cross Long Island (SCHAFTER and HARTSHORN, 1965; SIRKIN, 1982; STONE and BORNES, 1986). The Ronkonkoma-Amagansett-Shinnecock moraine line, which marks the maximum extent of the late Wisconsinan glaciation, lies across central and southeastern Long Island (Figure 3) and extends eastward across the shelf in the direction of Block Island. To the north, a second moraine (Harbor Hill-Roanoke Point-Orient Point-Fishers Island-Charlestown, Figure 3) caps northern Long Island, Plum Island, and Fishers Island and extends eastward across southern Rhode Island (CRANDELL, 1962; SCHAFTER and HARTSHORN, 1965). Less prominent recessional moraines (SIRKIN, 1982) lie between the two major moraine belts on eastern Long Island. Several moraine segments have been mapped in southeastern Connecticut, and offshore (GOLDSMITH, 1982; STONE et al., 1998). Portions of the Charlestown Moraine and most of the southeastern Connecticut recessional moraines (Figure 3) have been mapped and described as double linear belts (SCHAFTER 1965; STONE et al., 1998). An extensive ice-marginal lacustrine fan seaward of Lordship (Figure 3) is thought to be associated with an ice position involving the Norwalk Island moraine, to the west, and the Old Saybrook moraine, to the east. The tills that are exposed along the margins of the LIS basin continuously yield sediment to the estuary. This is evident in the mapping of POPPE et al. (this volume).

Deltaic and lake-bottom deposits of glacial Lake Connecticut are found along the Connecticut coast and throughout the LIS basin (Figure 4). At its height, Lake Connecticut was part of a series of glacial lakes that stretched eastward, occupying Block Island and Rhode Island Sounds, and Narragansett and Buzzards Bays (Figure 1). Varved lake-bottom deposits of glacial Lake Connecticut (Figure 4) are commonly 80 m thick and locally more than 150 m thick (LEWIS and STONE, 1991), west of the Connecticut River. These deposits were once similarly abundant to the east. Lake Connecticut was dammed by the Roanoke Point-Orient Point-Fishers Island-Charlestown moraine (Figure 3), and its spillway was at the Race (LEWIS and STONE, 1991; STONE et al., 1998).

Deltas, fed by meltwater streams and rivers that re-occupied south draining bedrock valleys, prograded into the northern margin of glacial Lake Connecticut as the Wisconsinan glacier retreated (STONE et al., 1998). Coalescing Lake Connecticut deltas extended well into what is now northern LIS between the Norwalk Islands and New Haven, and between Guilford and the mouth of the Connecticut River (Figure 4). A large delta also was built southward from the Thames River valley.

The extensive, coalesced, glacial deltas south and east of Lordship, form the northern part of the "Stratford shoal complex" of KNEBEL and POPPE (this volume), and glacial deltas comprise the northernmost part of the "Norwalk shoal complex" (KNEBEL and POPPE, this volume) in the vicinity of the Norwalk Islands (Figure 4). The presence of these and other glacial deltas (e.g. Connecticut River mouth) (Figure 4) of the northern Sound, influence the sediment and habitat distributions reported on by several of the other authors in this volume (e.g. KNEBEL and POPPE, this volume; POPPE et al., this volume; ZAJAC et al., this volume).

Fluvial and fluviodeltaic deposits that fed the Lake Connecticut deltas (STONE et al., 1998) occupy south draining bedrock valleys all along the Connecticut coast (Figure 4). The overall distribution and magnitude of Connecticut's beaches and marshes is tied to these deposits. In smaller valleys, deltaic and/or feeder deposits are typically associated with pocket beaches and small marshes that are bracketed by rocky headlands. Postglacial erosion of the Lake Connecticut delta has provided a source of sediment to the northern Sound throughout Holocene time.

Just north of the Race, tidal scour has completely removed the lake deposits and re-exposed bedrock and till. The glacial lake-bottom deposits of adjacent Block Island Sound also have been extensively scoured in the vicinity of the Race (NEDELL and LEWIS, 1984). Some of this fine material, and most of the fines stripped from the lake deposits of eastern LIS, are inferred to have been incorporated into the marine deposits of the central and western Sound.
Postglacial Deposits

Glacial Lake Connecticut drained to the lowered sea, subaerially exposing its lakebed, by about 15.5 ka (Stone et al., 1998). The paleo-channel system that carried drainage across the lakebed and out of the LIS basin (through the notch in the moraine at the Race) is depicted in Figure 5. Fluvial sediments in the paleo-channels are overlain by estuarine sediments that were deposited after eustatic sea-level began to rise between 16 ka and 15 ka (Stone et al., 1998).

As the stable phase of glacial Lake Hitchcock ended around 13.5 ka, its lakebed (which extended over much of the Connecticut River valley) was also subaerially exposed. It is estimated that about 12 billion m$^3$ of lake-bottom sediments were removed and carried down the Connecticut River as the lakebed was incised (Stone et al., 1998). Most of this sediment (11.5 billion m$^3$) is inferred to have built the marine delta depicted in Figure 5 (Lewis and Stone, 1991; Stone et al., 1998).

The present irregular sea-floor topography in eastern Long Island Sound (Knebel and Poppe, this volume, Figure 2) is primarily the result of extensive tidal scour that removed the fine components of the eastern flank of the marine delta, and most of the lake-bottom deposits of the eastern Sound. Fenster (1995) estimated that 2.1 billion m$^3$ of fine material has been removed from the lake-bottom deposits, and 2.0 billion m$^3$ of coarser material is missing from the eastern side of the marine delta. Knebel and Poppe (this volume) estimate that an area of 195 km$^2$ was stripped of about 15 m of deltaic material (2.925 billion m$^3$) since tidal scour began.

Lag deposits, up to 17m thick, are now exposed at the sea floor throughout most of eastern LIS (Lewis and Stone, 1991; Fenster, 1995, Knebel and Poppe, this volume). The distribution of these lag deposits corresponds with the coarse deposits shown on the map of Poppe et al. (this volume). The transition of sedimentary environments westward, from the deeper area of erosion or nondeposition, through environ-
ments of coarse-grained bedload transport, and up across the zone of sediment sorting and reworking, to the shallower environments of fine-grained deposition (Knebel and Poppe, this volume, Figure 13) takes place across the “Mattituck Sill” of Bokuniewicz et al. (1976). This “sill” is not structurally controlled but rather it developed as a result of postglacial tidal scour, and did not exist prior to the marine incursion. It is formed by remnants of the marine delta resting unconformably on relatively intact lake-bottom deposits to the west, and an eastward-thinning remnant of marine-deltaic and lake-bottom deposits to the east.

The distribution and thickness of postglacial sediments in LIS is depicted in Figure 6. West of the Connecticut River, the postglacial section (including the marine delta) primarily rests unconformably on the ravinement that developed across the surface of the lakebed, as the sea invaded LIS. To the east, tidal scour has cut below the ravinement, and the postglacial section rests unconformably on a scoured, composite surface that locally includes sub-crops of bedrock, till, and glacial-lake deposits.

Given that LIS is an effective sediment trap (Bokuniewicz et al., 1976), Figure 6 is inferred to be a good approximation of the total amount of marine sedimentation that has occurred in the Sound. After digitizing hand-drawn isopachs, we used GIS technology to estimate that the total volume of sediment represented on Figure 6 is approximately 22.7 billion m$^3$.

Chronology

The Long Island Sound basin was an existing interior lowland, that had been fluvially eroded and modified by at least one glacier (Illinoian?), before the last ice advance. By about 26 ka, the late Wisconsinan glacier was advancing into Connecticut (Stone et al., 1998). As it advanced, it scoured the south-dipping bedrock surface, further modified the interior lowland, and reached its terminal position, on the coastal-plain remnant, by about 21 ka.

By 19 ka (Stone and Borns, 1986), the Wisconsinan glacier had already formed the Ronkonkoma-Amagansett-Shin-
Figure 6. Map showing the thickness (in meters) of the marine deposits in Long Island Sound (including the marine delta in the eastern Sound). This map was constructed from 3,500-line km of high-resolution, seismic-reflection data reported on by Lewis and Stone (1991).
necock moraine (Figure 3) along its terminal position, and it was about to retreat from its more northerly recessional position along the Harbor Hill-Roanoke Point-Orient Point-Fishers Island-Charlestown moraine (Figure 3). As the ice sheet retreated northward, meltwater was dammed behind the Roanoke Point-Orient Point-Fishers Island-Charlestown moraine segment (Figure 3), and glacial Lake Connecticut was formed. The spillway for Lake Connecticut was established at the low point in the morainal dam at the Race (Figure 4). At this time, sea level was about 100 m lower than today. Water from Lake Connecticut joined with its neighboring lake in Block Island Sound, to spill across the exposed continental shelf to the Atlantic Ocean.

It took the ice sheet about 1.5 ka to retreat from the position of the Roanoke Point-Orient Point-Fishers Island-Charlestown moraine to the position of the Norwalk Island-Lordship-Old Saybrook moraine (Figure 3). Lake Connecticut continued to grow larger as ice retreat proceeded. It ultimately covered an area roughly equivalent to the area of today's LIS.

Delta building commenced along the Connecticut coast as soon as the receding ice sheet lost contact with the lake, and meltwater streams re-occupied emerging bedrock valleys. Southeastern Connecticut was deglaciated first, and a progression of younger deltas built westward toward New Haven (Stone et al., 1998). A lobe of ice, associated with the Hartford Basin, lingered in the vicinity of New Haven until just before 16.5 ka, when coastal delta building ended (Stone et al., 1998). The thick lake-bottom deposits of LIS (Figure 4) are inferred to be contemporaneous with the coastal deltas. The spillway at the Race was being eroded, and lake levels steadily lowered during (and after) coastal delta building (Stone et al., 1998).

The bed of glacial Lake Connecticut was completely exposed by 15.5 ka. About 500 y later, the fluvial system draining the lakebed was well established (Figure 5), and the rising sea had started to invade the LIS basin through the eroded spillway at the Race (Stone et al., 1998). The marine incursion proceeded westward up the fluvial channels first, and eventually spread north and south over the exposed lakebed.
Wave action planed the lakebed surface, and the sea over­topped outcrops of more resistant bedrock, coastal plain and drift, forming a ravinement surface.

The sea was well into the LIS basin by 13.5 ka. The estuary is inferred to have developed sufficiently for continuous sedimentation to have commenced, and glacial Lake Hitchcock was beginning to drain down the Connecticut River valley. The Connecticut River is inferred to have delivered about 11.5 billion m$^3$ of Hitchcock lake-bottom sediment to the Sound between about 13 ka and about 9.5 ka (STONE et al., 1998). This sediment buried the ravinement and built the marine delta (Figure 5). Eventually, the sea transgressed the nearshore deltas of glacial Lake Connecticut, and beaches and marshes formed along the irregular Connecticut coast. The marine transgression continues today.

As tidal currents developed, scouring and redistribution of glacial and younger sediments became common in constricted portions of LIS, particularly in the eastern part of the basin (see KNEBEL and POPPE, this volume; POPPE et al., this volume; and SIGNELL et al., this volume). Slightly over 5 billion m$^3$ of the lake-bottom (FENSTER, 1995) and fine-grained, marine-delta deposits (KNEBEL and POPPE, this volume) of eastern LIS are inferred to have been eroded and redistributed westward over the past 13.5 ka. The 11.5 billion m$^3$ of Hitchcock lake-bottom sediment that built the marine delta, accounted for slightly over half of the 22.7 billion m$^3$ of marine sediment that has been deposited in LIS.

Many buried structural elements of the western basin still have enough bathymetric expression to influence the physical processes and sediment system of LIS (KNEBEL and POPPE, this volume). In the eastern Sound, the configuration of the basin, and the erodability of the lake-bottom deposits, has promoted so much marine erosion that the irregular, armored seafloor is, itself, a major factor in how the modern sediment system functions.

**POSTGLACIAL SEDIMENTATION**

The fine-grained sediments of Long Island Sound influence the distribution of habitats and contaminants throughout the basin (see related papers, this volume). This makes them of interest to many workers, particularly resource managers. BOKUNIEWICZ et al. (1976) estimated the volume of fine-grained sediment in LIS to be 5.3 billion m$^3$. Using a particle density of $2.65 \times 10^6$ g/m$^3$ and a porosity of 60% for silty sediments (HAMILTON, 1974) this would equate to $5.6 \times 10^{12}$ kg of marine mud. Assuming continuous deposition since 13.5 ka, and nearly 100% trapping efficiency (BOKUNIEWICZ et al., 1976; GORDON, 1980), this amount is about 88% of the accumulation ($6.34 \times 10^{12}$ kg) that would be predicted from the long-term contribution by major rivers emptying into the Sound ($4.7 \times 10^6$ kg/y) (BOKUNIEWICZ and GORDON, 1980; GORDON, 1980).

The 3,500 line km of high-resolution, seismic-reflection data available to us (LEWIS and STONE, 1991), indicate that BOKUNIEWICZ et al. (1976) underestimated the amount of fine-grained marine sediment in LIS by about one half. The total amount of postglacial sediment represented on Figure 6 is 22.7 billion m$^3$. This includes the remaining material in the marine delta, and the lag deposits of the eastern Sound. Of the estimated 11.5 billion m$^3$ of sediment originally in the marine delta (STONE et al., 1998), KNEBEL and POPPE (this volume) calculate that approximately 2.9 billion m$^3$ of the eastern flank of the delta has been redistributed, and the fine-grained component has been transported westward. The coarse fraction from the eastern flank of the delta was incorporated into the lag deposits of the eastern Sound, which FENSTER (1995) estimated to represent about 2.5 billion m$^3$. Subtracting the missing eastern segment of the marine delta (2.9 billion m$^3$) from its original volume (11.5 billion m$^3$) and adding the volume of the eastern lag deposits (2.5 billion m$^3$) will approximate the volume of the marine sediments that were not redistributed westward (about 11.1 billion m$^3$). Assuming that 11.1 billion m$^3$, of the 22.7 billion m$^3$ of postglacial sediment represented on Figure 6, is the eastern lag deposit and the remaining marine delta, we estimate that 11.6 billion m$^3$ of fine-grained sediments lie west of the Connecticut River. Using the foregoing parameters for particle density and porosity, this would equate to $1.2 \times 10^{13}$ kg of relatively fine-grained marine sediment.

Potential sources of this sediment are as follows: (1) KNEBEL and POPPE (this volume) report $2.5 \times 10^{12}$ kg of fine material winnowed from the eastern flank of the marine delta and transported westward; (2) FENSTER (1995) reported the equivalent of $2.8 \times 10^{12}$ kg of lake-bottom deposits stripped from the eastern Sound; and (3) the total 13.5 ka contribution of sediment to the Sound from major rivers is $6.34 \times 10^{12}$ kg (see previous calculation). As presented, these sources account for a total of about $1.2 \times 10^{13}$ kg, an amount equal to the $1.2 \times 10^{13}$ kg of marine sediment derived using Figure 6.

Having arrived at the same number based on both volume and input estimates, we feel that $1.2 \times 10^{13}$ kg is a realistic approximation of the total mass of fine-grained marine sediment in the central and western Sound. It is significant to note that this accumulation of marine sediment can be accounted for without invoking offshore (open ocean) sources. Redistributed glacial and early postglacial sediments from within the LIS basin, and riverine contributions over the past 13.5 ka, are sufficient to balance the estimated mass of fine-grained, marine sediment that has accumulated in Long Island Sound.

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**LITERATURE CITED**


NEEDELL, S.W.; LEWIS, R.S., and COLMAN, S.M., 1987. Maps show-


