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Title: *Surficial Geology of the Kennebunk 7.5-minute Quadrangle, York County, Maine*

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Surficial Geology of the Kennebunk 7.5-minute Quadrangle, York County, Maine

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INTRODUCTION

The Kennebunk area (Kennebunk, Wells, Alfred, and North Berwick 7.5-minute quadrangles) is located along and immediately inland of the southwest coast of Maine, approximately 25 miles south of Portland and 30 miles north of Kittery-Portsmouth. The area lies within the Seaboard Lowland physiographic province, where altitudes range from sea-level to 600 feet above sea level. Most of the area is drained by Branch Brook, the Mousam River, and the Kennebunk River, all of which flow to the coast in the vicinity of Kennebunk Beach. The northeast portion of the area is drained by the Saco River and its tributaries.

Kennebunk and adjacent areas of southwestern Maine are underlain by a variety of igneous intrusive rocks and complexly deformed metamorphic rocks that dip steeply and strike in a general northeast-southwest direction. The dominant structural grain is clearly reflected both in the present topography of the upland areas and in the courses of many streams that drain the area. This structural control is also evident in the orientation of the many embayments along the present coastline, particularly north of Kennebunk.

During the last (Wisconsinan) episode of glaciation, ice advanced from the northwest across the area to a terminal position on the continental shelf. Glacial erosion produced a distinct northwest-southeast lineation, superimposed upon the northeast-southwest topographic grain. Streamlined erosional features are common, and several valleys paralleling the direction of ice movement display the effects of erosional deepening and steepening. Glacial deposition resulted in a general reduction of preglacial relief by preferential infilling of valleys. This effect is most pronounced in that portion of the area below the limit of late-glacial marine submergence.

Ice retreat, accompanied by marine submergence, progressed rapidly across the area in a general northwesterly direction. End moraines and composite deltas were produced at or near the ice front during the period of retreat and outline the pattern of ice withdrawal from the coast.

Original mapping of the Kennebunk quadrangle was conducted by Bloom (1960) at a reconnaissance level (1:62,500; 1:250,000). The area was remapped by J. T. Andrews (1975) at a scale of 1:24,000, and subsequently by G. W. Smith (1977) at a scale of 1:62,500 in the early stages of the Maine Geological Survey's inventory mapping program. More detailed mapping of portions of the Kennebunk quadrangle was undertaken in the several stages of the Survey's aquifer mapping program (T. Brewer, *in* Caswell, 1979a,b; Tolman and others, 1983). The surficial geology of the Kennebunk, Wells, Alfred, and North Berwick quadrangles was revised and updated at a scale of 1:24,000 by G.W. Smith during the 1984 and 1985 field seasons (this report; Smith, 1998, 1999).

Information bearing on the stratigraphy and glacial geologic history of this portion of coastal Maine can be found in the following publications: Bloom (1960, 1963); Smith (1981, 1982, 1984, and 1985). Publications by Thompson (1979, 1982), Thompson and Borns (1985), and Stuiver and Borns (1975) provide helpful general references to the glacial geology of the entire coastal zone.

GLACIAL AND POSTGLACIAL DEPOSITS

The general succession of glacial and postglacial deposits in the Kennebunk area is presented in Tables 1 and 2 and Figure 1. All glacial deposits in this area are ascribed to the Late Wisconsinan glacial episode. Deposits exposed above the marine limit record both glacial advance and retreat, while most sediments exposed below the marine limit are related to deglaciation and late-glacial marine submergence.

TABLE 1. DESCRIPTION OF MAP UNITS*

SYMBOL	UNIT	DESCRIPTION
Ha	Stream alluvium	Gray to brown fine sand and silt with some gravel. Comprises floodplains along present streams and rivers. Extent of alluvium approximates areas of potential flooding.
He	Eolian deposits	Sand dunes resulting from wind erosion of coastal sediments.
Hws	Wetland, swamp	Muck, peat, silt, and sand. Poorly drained areas, often with standing water.
Hwfm	Wetland, freshwater marsh	Poorly drained freshwater grassland.
Hwsm	Wetland, saltmarsh	Muck, peat, silt, and sand. Coastal settings subject to tidal fluctuation.
Hms	Marine shoreline deposit, beach	Sand, some gravel and minor silt. Coastal settings of active beach construction.
Pmn	Marine nearshore deposits	Areas of till that have been reworked by the sea during regressive phase of marine submergence. Till has had finer constituents (silt and sand) removed and redeposited as thin veneer over till. Bedrock commonly at shallow depth. Average thickness probably less than 3 m.
Pms	Marine shoreline deposit	Predominantly sand with minor gravel. Beach deposits formed during period of stillstand in regressive phase of marine submergence. Thickness variable from less than 3 m in beach ridges to more than 10 m in aprons around eroded drumlins.
Pmrs	Marine regressive sand deposits	Massive to stratified and cross-stratified, well sorted brown to gray-brown sand. Generally with gradational basal contact to Pp. Thickness between 1 and 5 m. Deposited during regressive phase of marine submergence.
Pp	Presumpscot Formation	Massive to laminated gray and blue-gray (weathering brown) silt and silty clay. Locally may contain boulders, sand, and gravel. Occurs as blanket deposit over bedrock and older glacial sediments. Variable thickness from less than 1 m to more than 50 m. Deposited during period of late glacial marine submergence.
Pm	Marine deposits (undifferentiated)	Pp and/or Pmrs deposits mapped in areas of poor access or poor exposure, or where both units occur as areas too small to be mapped separately. Thickness variable within range described for Pp and Pmrss.
Pgo	Outwash	Sand, gravel, and minor silt deposited by glacial streams in a proglacial (away from ice) setting. Sometimes terraced. Average thickness probably between 5 and 10 m.
Pgi	Ice-contact deposits (undifferentiated)	Coarse gravel and sand in areas not mapped as Pmdi or Pge. Primarily kettled glacial stream deposits in the immediate vicinity of eskers (Pge). Average thickness probably between 10 and 15 m.
Pmd Pmdo Pmdi	Marine delta	Coarse sand and gravel grading to sand and silt. Flat to gently sloping constructional surface formed by glacial streams discharging into late glacial sea. Heads of ice-contact deltas (Pmdi) are commonly kettled and mark ice frontal position. Distal deltaic sediments (Pmdo) commonly grade into glacial marine sediments (Pp, Pmrs). Variable thickness from more than 30 m at delta head to less than 1 m at delta toe.
Pge	Esker	Coarse gravel and sand comprising distinct linear ridge forms, mostly in major valleys. Generally surrounded by Pgi deposits and terminating in ice-contact deltas (Pmdi). May be more than 10 m thick.
Pem	End moraine	Coarse gravel and sand, some till and silt. Generally occur in areas of glacial marine sediments (Pp, Pmrs) and are complexly interstratified with them. Formed at or near the ice front during retreat of marine-based glacier. Sediments commonly display significant deformation. Commonly 5 to 10 m thick.
Pemc	End moraine complex	Coarse gravel, sand, till, and silt; commonly over shallow bedrock. Mapped in areas of closely spaced small (DeGeer) end moraines. Formed at or near ice front during retreat of marine-based glacier. Sediments commonly display significant deformation. Generally less than 5 m in thickness.

* Some of these units are not present in every quadrangle in the Kennebunk area.

TABLE 1. CONTINUED.

Pt	Till	Gray to gray-brown poorly sorted mixture of silt, sand, pebbles, cobbles, and boulders. Forms a blanket deposit over bedrock, and is inferred to underlie younger sediments where not exposed at surface. Thin over topographic highs; thickens in topographic lows. May occur in and over end moraines (Pem, Pemc). Averages 3 to 5 m in thickness.
rk	Bedrock	Rock units not distinguished. Individual outcrops not shown in large areas of poor access. Ruled pattern indicates areas where surficial materials are thin (less than 1 to 2 m) and bedrock exposures are common. Areas of continuous bedrock exposure (solid color) are mapped in part from aerial photographs.

TABLE 2. TIME / SPACE RELATIONSHIPS OF GLACIAL AND POSTGLACIAL MATERIALS

	Glacial	Glacial Fluvial	Glacial Marine	Fluvial	Marine	Wetland	Eolian
HOLOCENE					Hms		He
						Hws	
					Hwsm	Hwfm	
				Ha			
				Qst			
PLEISTOCENE / LATE WISCONSINAN			Pms		Pmn		
			Pmrs				
			Pp	Pgo			
			Pmdo				
		Pgi	Pmdi				
		Pge	Pm				
		Pem					
		Pemc					
	(Pmn)						
	Pt						

Till

Glacial till (Pt, Pmn) occurs throughout the Kennebunk area, both above and below the marine limit. Thickness of the till is variable, as is its composition. Below the marine limit, till occurs in a variety of genetic types. Lodgement till, flow till, and melt-out till comprise the cores of many small moraines and are exposed in coastal cliffs at Great Hill in the Wells quadrangle. Above and below the marine limit, lodgement till forms a blanket deposit over topographic highs and is inferred to underlie younger deposits in topographic lows. This till is typically a bouldery, gray, compact material, with a silt-sand-clay matrix. Locally, thicker accumulations of lodgement till have been streamlined to form drumlins. Elsewhere, till has been substantially reworked during marine submergnce to form a sandier till phase (Pmn).

Ice-Contact Stratified Drift

Ice-contact stratified drift (Pgi, Pmdi, Pge, Pem, Pemc) has been mapped in a broad zone over the central, western and northwestern portions of the map area. These deposits occur primarily as a variety of moraines (Pem, Pemc) and ice frontal (or marginal) deltas (Pmdi) that can be traced northwestward into the foothills of the White Mountains where they give way to eskers (Pge) and kettled valley trains (Pgi). Of particular importance among this group of deposits are Merriland Ridge, Bragdon Road delta, and Perkins Town (L Pond) delta. These features are a succession of partial to complete deltas constructed to a constant sea level (approximately 220 feet above present sea-level) probably during the period of maximum marine submergence. In their distal portions, the ice-contact deposits commonly intertongue with sand and silt of the marine Presumpscot Formation.

Stratified deposits of sand and gravel that both underlie and intertongue with the Presumpscot Formation are considered to be subaqueous outwash sediments (Smith, 1982, 1985; Thompson, 1982). These materials are generally not exposed as surface materials, but do form an extensive blanket of deposits beneath the younger marine sediments. In many exposures, these materials display a variety of distinctly fluvial primary structures. Elsewhere, they have the appearance of subaqueous debris flow deposits. In many cases, the sediments have been severely deformed by thrusting and ice shove, and are complexly interstratified with till and marine silt, sand, and clay.

Presumpscot Formation and Related Marine Deposits

Glacial marine sediments of the Presumpscot Formation (Pp) occur as a discontinuous cover of sediment up to 50 m thick throughout the area of late glacial marine submergence. The general distribution of the marine sediments was originally mapped by Goldthwait (1949), and the sediments were described in detail and given formational status by Bloom (1960). The marine clay and silt (Pp) is the type Presumpscot Formation described by Bloom. It underlies in gradational contact the

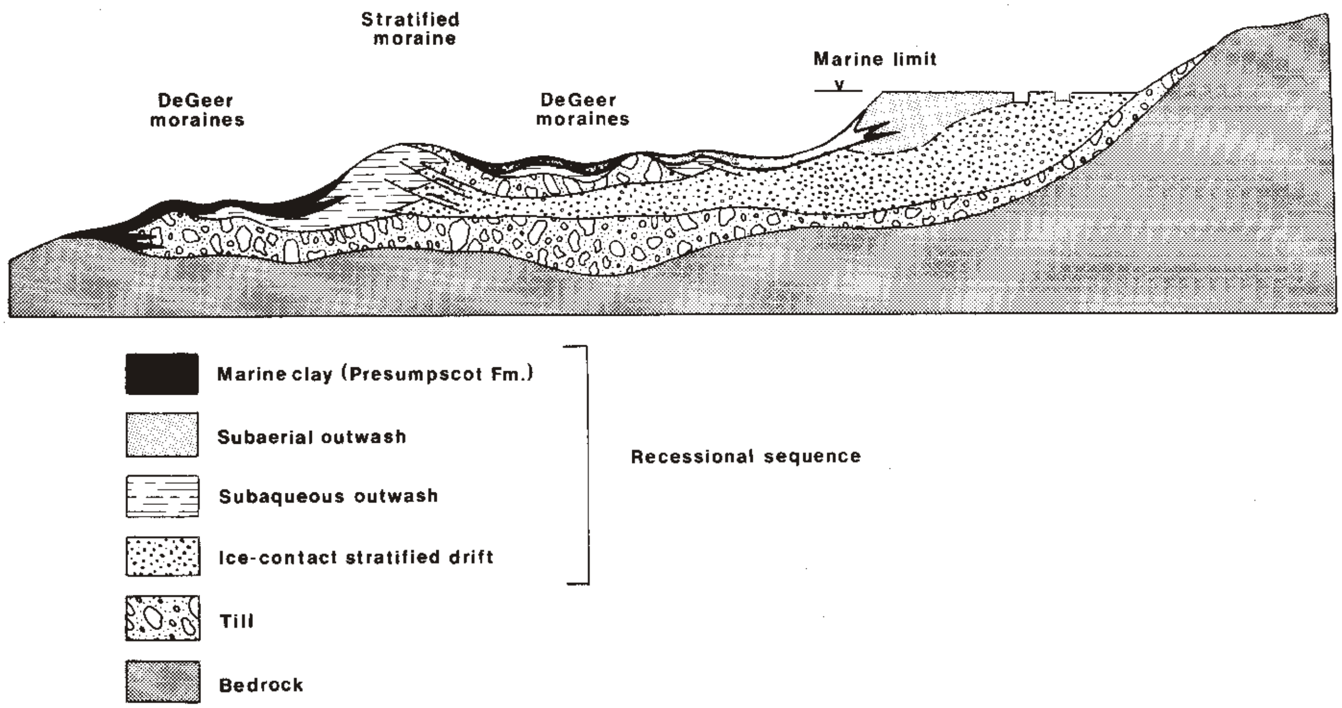

Figure 1. Generalized glacial stratigraphy for the southern Maine coastal zone (from Smith, 1985).

sandy facies (Pmrs) of the marine sediments, which is considered to be a regressive deposit that was graded to falling sea level.

The Presumpscot Formation bears a complex stratigraphic relationship to other glacial sediments below the marine limit. It generally overlies till with sharp contact. Subaqueous outwash underlies and intertongues with the Presumpscot Formation, while subaerial outwash (Pgo) overlies and intertongues with the marine deposits. Local beach deposits (Pms) overlie gradationally the Presumpscot Formation and record successive stages of the falling late-glacial sea.

Outwash

Glacial outwash (Pgo) and outwash deltas (Pmdo) consist of sand and gravel deposits that occur as valley fills adjacent to major stream valleys and as extensive sand plains in the Sanford - Kennebunk area. These sediments were deposited by glacial meltwater streams in a proglacial setting as ice retreated and sea level fell. Technically speaking, the distal portions of ice-contact deltas (Pmdi) can be considered to be outwash deposits. However, for the sake of clarity in the presentation of map units, the deltas were considered to be simple depositional entities formed in contact with the ice margin.

Holocene Deposits

Deposits of wetlands, modern streams, and coastal settings (Ha, Hws, Hwsm, Hms, He) have been mapped throughout the Kennebunk area. They are most significant in the vicinity of the present coastline where they occur as saltmarsh (Hwsm), modern beach (Hms) sediments, and sand dunes (He). Inland, this group of deposits includes swamps (Hws) and local occurrences of floodplain alluvium (Ha).

GLACIAL AND POSTGLACIAL HISTORY

All glacial deposits found in the Kennebunk area have been ascribed to the last (Late Wisconsinan) glacial episode to affect coastal Maine. The oldest deposits thus far recognized in this area are those exposed in coastal cliffs at and near Great Hill in the Wells quadrangle. Brown and gray-brown, compact lodgement till that overlies glacially striated bedrock at this locality is thought to record advance of the Late Wisconsinan ice sheet to its terminal position on the continental shelf east of the present coastline. While other occurrences of lodgement till likely record this same event, the evidence elsewhere is not as clear.

The orientations of drumlins and other streamlined forms, as well as of glacial striations, indicate that the last ice to cover the area advanced from the northwest. Local divergence from this general trend resulted from topographic control on the pattern of ice flow.

Withdrawal of Late Wisconsinan ice from its terminal position was underway between 17,000 and 15,000 years ago, and the ice had retreated across the Gulf of Maine to a position roughly parallel to, but some distance offshore of, the present coastline by 14,000 years ago (Smith, 1985). Dates on shells collected from Great Hill and the Kennebunk landfill site sug-

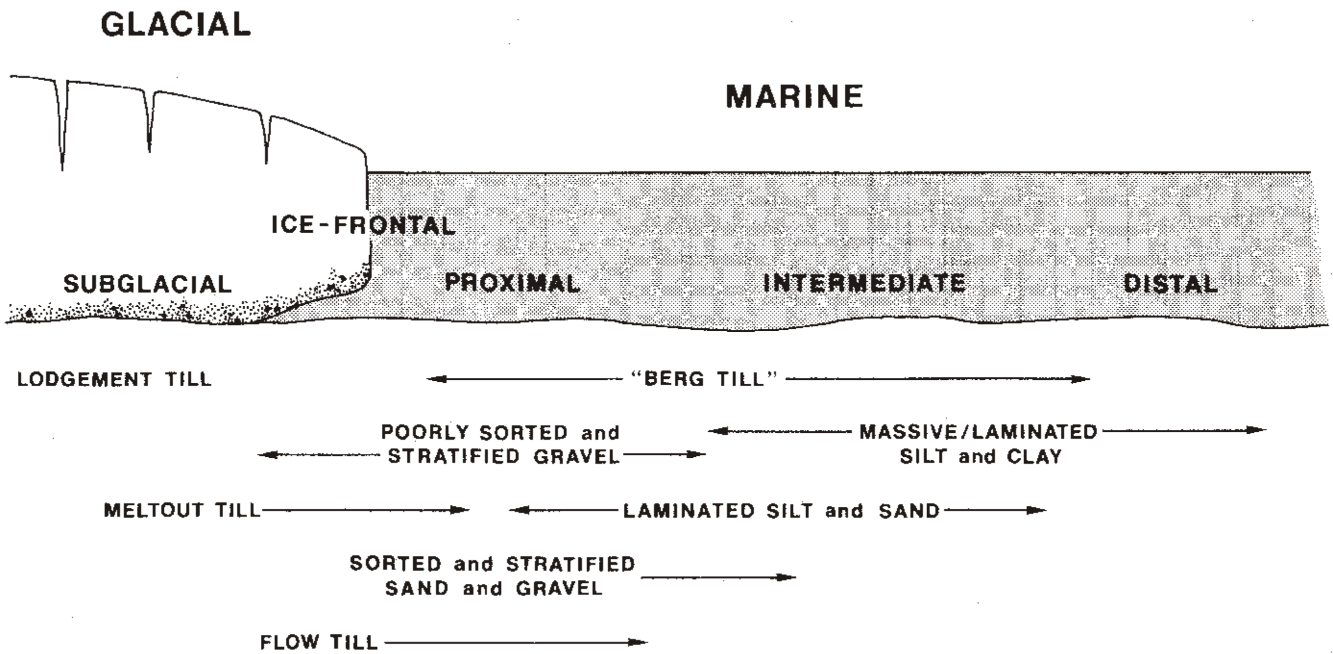

Figure 2. Glacial marine facies associations for the Maine coastal zone (from Smith, 1984).

gest that ice may have remained in the vicinity of Kennebunk until 13,200 years ago. It should be noted, however, that some workers feel that ice had retreated from the Kennebunk area much earlier.

Two indirect effects of glaciation had a very strong bearing on the character of ice retreat and the deposition of the glacial sediments in this portion of the coastal zone. First, the great weight of ice depressed the crust beneath the glacier significantly below its present level throughout the region. Secondly, as the glacier expanded, water was trapped on land as ice, and sea level, as a result, was lowered by several hundred feet. As ice began to melt and retreat, water was returned to the ocean and sea level rose immediately. At the same time, the crust began slowly to rebound to its original level. The interaction of these two effects resulted in submergence of the entire Maine coastal zone for a period of several hundred years following retreat of ice. Furthermore, during its retreat, the glacier was grounded in the sea so that a complex assemblage of glacial-marine sediments was deposited over the area below the marine limit.

As ice began to retreat in a general northwesterly direction across the Kennebunk area, coarse clastic sediments (till, ice-contact stratified drift, and subaqueous outwash) accumulated in a narrow zone adjacent to the ice front, while fine sediment (silt and clay of the Presumpscot Formation) was deposited further away from the ice (Fig. 2). Continued ice retreat resulted in the overlap of distal (fine) sediments on proximal (coarse) sediments.

During the period of retreat, at least while ice was marine-based, it remained active and continued to advance periodically over short distances. These advances resulted in deformation of previously deposited sediments and construction of minor (De-Geer) moraine ridges. During periods of extended stillstand, sediments accumulated at the ice front (or grounding line) to form larger stratified end moraines and partial or complete deltas.

This sequence of events is clearly illustrated in a transect from the vicinity of Wells to Perkins Town and L Pond (Fig. 3). Along this transect, an assemblage of deltas and end moraines mark successive ice-frontal positions during ice retreat. The first, and most prominent, of the ice-frontal features is Merriland Ridge. Merriland Ridge is a well defined sinuous ridge of sand and gravel that can be traced between bedrock hills for a distance of approximately 7 km in a southwesterly direction along State Route 9. The ridge stands 7-8 m (20-25 ft) above the surrounding lowland and is 200-450 m (600-1300 ft) wide at its base. The crest of the ridge, at an elevation of roughly 67 m (200 ft) a.s.l., is between 100 m and 200 m (300-600 ft) wide.

Coarse ice-contact gravel and sand is exposed at both ends and in the central portion of Merriland Ridge, while well-sorted sand comprises the intervening, narrower segments of the ridge. Well-defined bedding dips 20-35 degrees away from the ridge crest, to the northwest on the proximal (NW) slope and to the southeast on the distal slope. These beds are commonly truncated by 2-3 m (6-10 ft) of gravel with dips parallel to the present surface slopes. Collapse structures occur within the gravel comprising the proximal slope of the ridge.

Bragdon Road delta is a small kettled delta approximately 1.5 km northwest of Merriland Ridge. The delta is 3 km long, 7-8 m (20-25 ft) high, and roughly 1 km from front to back. The top of the delta is marked by numerous kettles and several linear

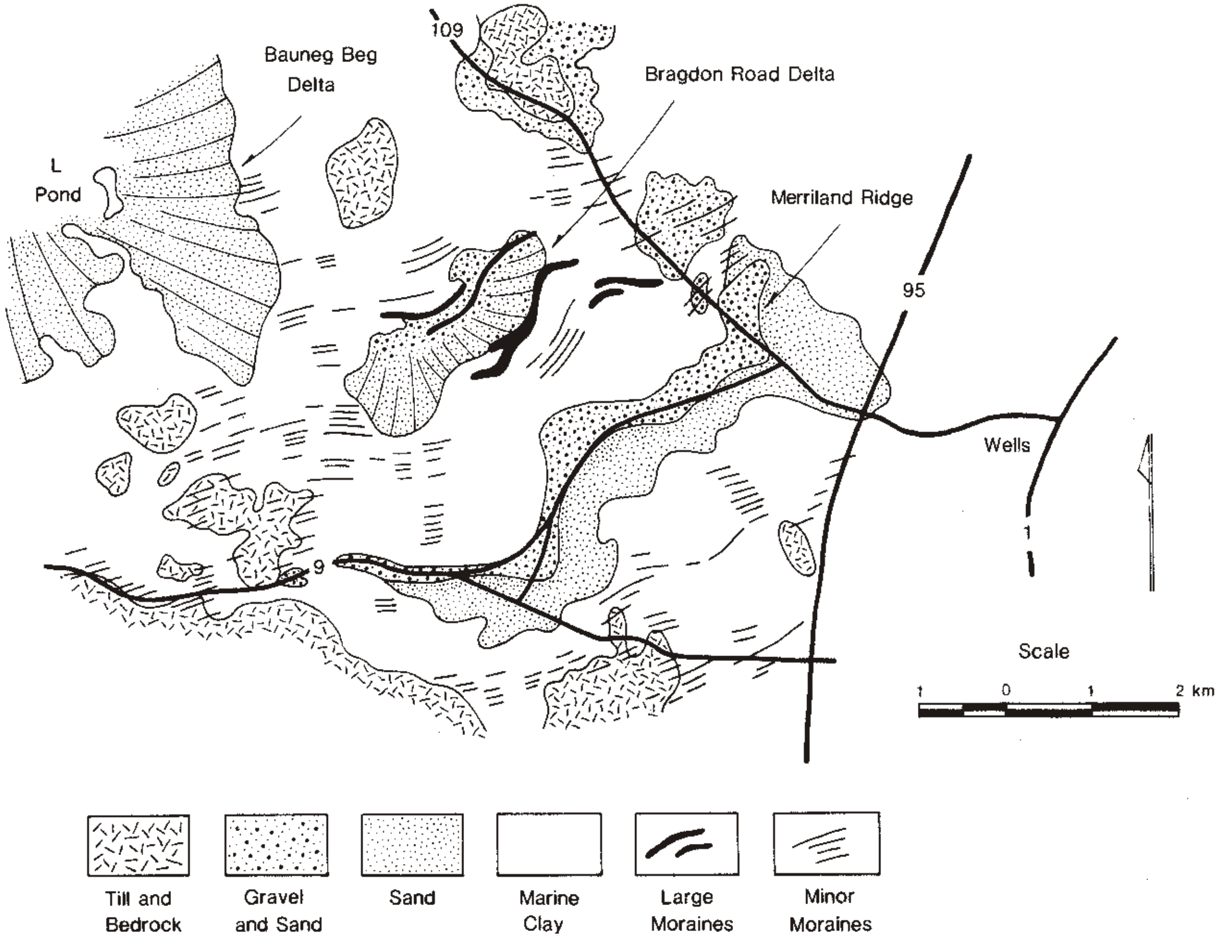

Figure 3. End moraines and glaciofluvial deposits in the vicinity of Wells, Maine (from Smith, 1982).

moraine ridges paralleling the ice-contact slope. A large moraine segment is partially covered by deltaic sediments along the delta front. Several minor moraines occur north of the delta and in the area between the delta and Merriland Ridge.

The proximal portion of the Bragdon Road delta consists of moderately well sorted sand and gravel that displays ice-contact deformation. Grain size decreases and degree of sorting increases toward the delta front, where fine-sand foreset beds are interbedded with thin layers of silt and clay (Presumpscot Formation). Sand and fine gravel foresets are overlain by 2-3 m (6-10 ft) of gravel topsets. Current flow during construction of the delta was toward the south and southeast.

Still further to the northwest, the distal portion of a large ice-contact delta (Bauneg Beg delta) marks the inland limit of marine submergence at an elevation of about 67 m (220 ft) a.s.l. The delta can be traced northwestward through areas of kettled and collapsed ice-contact deposits, to its source in a group of eskers in the vicinity of Bauneg Beg Pond.

Merriland Ridge and the Bragdon Road delta are considered to record sediment deposition at the ice front. Deposition was controlled by the contemporary sea level during the period of maximum marine submergence. The Bauneg Beg delta was constructed as ice withdrew northwestward above the marine limit and discharged sediment into the sea while sea level remained at its maximum stand. This delta succession indicates that sea level rose quickly to its maximum position during ice retreat and remained at that level for much of the time that it took for ice to withdraw across this portion of the coastal zone. Furthermore, the shallow depth to bedrock within the deltas (Merriland Ridge) indicates that water depth during delta construction was less than 10 m (30 ft).

North and west of the delta succession just described, and particularly west of Estes Lake between the Sanford municipal airport and the town of Alfred, a series of kettled ice-contact deposits of sand and gravel occur as remnants of deltas constructed to the same position of sea level (present elevations average about 220 feet). These deltas head in narrow topographic gaps at Sanford and just north of Alfred. Extensive deposits of ice-contact sediments (Pgi, Pge) can be traced from this point northwestward into the foothills of the White Mountains.

As ice continued to retreat northwestward across the coastal zone, isostatic rebound began to elevate the land, and sea level began to fall. Meltwater streams continued to carry sediment to the ocean as sea level fell. The broad sand surface extending from Sanford to Kennebunk records construction of an outwash plain (fan/delta) into the receding ocean (Pgo, Pmdo). Much, if not most, of this outwash plain was deposited subaerially, although the distal portion was graded to sea level.

With progressive lowering of sea level, materials deposited during earlier stages of glaciation and deglaciation passed through the wave zone, were eroded, and shed sandy sediment (Pmrs) over the silt and clay deposited at higher positions of sea level (Pp). Short-term pauses in the lowering of sea level allowed for incision of streams into older sediments, producing erosional scarps and thin accumulations of beach sediments. Record of several of these events can be documented between the position of maximum marine submergence and the position of present sea level. Particularly prominent stands of sea level are recorded at 220-, 200+, 190+, 140+, 100+, 80+, 60+, 40-, and 20+ ft a.s.l.

Following withdrawal of ice from the coastal zone and the completion of isostatic rebound, sea level became established at its present position. Streams were graded to this level, and began to construct floodplains. In the beach zone, marine processes began to construct sand beaches and to accumulate saltmarsh de-

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APPENDIX A: RECORDS OF SELECTED WELLS AND TEST BORINGS (from Prescott and Drake, 1962)

posits within the zone of tidal fluctuation. All of these processes continue to the present day.

RECORDS OF SELECTED WELLS

Well No.	Location	Altitude	Depth of Well	Aquifer Material
19	Lyman	140	50 ft.	Gravel/till
38	Arundel	110	240	Bedrock
39	Arundel	90	137	Gravel/till
40	Arundel	200	230	Bedrock
41	Lyman	215	14	Sand
75	Biddeford	100	209	Bedrock
134	Kennebunk	185	2	Sand
209	Kennebunk	200	80	Bedrock
210	Lyman	185	17	Sand
212	Kennebunk	140	42	Sand
220	Arundel	110	25	Bedrock
232	Kennebunk	140	12	Sand
244	Arundel	180	130	Bedrock
245	Kennebunk	20	201	Bedrock
272	Kennebunk	110	157	Bedrock
279	Kennebunk	120	120	Bedrock
280	Kennebunk	135	54	Bedrock
281	Kennebunk	110	10	Sand
282	Kennebunk	140	156	Bedrock
283	Arundel	110	9	Clay
284	Arundel	120	18	Till
285	Arundel	90	9	Sand
286	Arundel	120	22	Sand
287	Arundel	40	26	Clay
288	Arundel	80	16	Sand
289	Arundel	70	206	Bedrock
307	Kennebunk	170	11	Sand
308	Kennebunk	170	16	Till
309	Kennebunk	190	9	Till
310	Kennebunk	165	14	Gravel/sand
312	Arundel	120	14	Gravel/sand
313	Kennebunk	145	12	Sand
317	Kennebunk	145	150	Sand/clay
318	Kennebunk	160	220	Bedrock
319	Kennebunk	180	15	Sand
328	Arundel	85	8	Gravel/sand
564	Arundel	100	90	Sand/clay
565	Arundel	140	14	Till
566	Arundel	170	20	Till
567	Biddeford	140	10	Till
568	Biddeford	110	17	Till
573	Arundel	85	16	Sand
574	Arundel	140	12	Till
575	Arundel	160	200	Bedrock
603	Arundel	160	23	Sand
604	Kennebunk	120	15	Sand

RECORDS OF SELECTED TEST BORINGS

Test Boring	Location	Altitude	Description
664	Kennebunk	80	11.0 ft medium sand 1.0 ft broken rock 5.0 ft fine sand and clay 13.0 ft very fine sand and clay 10.0 ft clay and small amount of medium sand 10.0 ft clay and very fine sand, very soft 10.0 ft soft clay 10.0 ft soft clay forcing water up jet 18.0 ft very soft clay 3.0 ft clay and fine sand 2.0 ft hardpan (till)
665	Kennebunk	119	7.0 ft coarse sand 8.0 ft dense packed sand and clay 1.0 6t hardpan (till) 1.0 ft refusa1
666	Kennebunk	77	6.0 ft fine sand 1.0 ft yellow clay and silt 8.0 ft blue clay 12.0 ft clay and fine sand 7.0 ft soft clay (rock at 34.0 ft)
667	Kennebunk	50	8.0 ft silty clay 3.0 ft gravel and clay 2.0 ft silty clay 21.0 ft clay 17.0 ft Sandy clay 10.7 ft gravel and clay (till) (rock at 61.7 ft)
668	Arundel	57	2.0 ft clay and gravel 1.0 ft silt, sand and brown clay 9.0 ft blue marine clay 70.0 ft soft blue clay 18.0 ft sand and clay (rock at 100.0 ft)
669	Arundel	107	45.1 ft sand 28.5 ft gravel and clay (till?)
670	Arundel	126	3.0 ft clay and gravel 3.0 ft clay 4.0 ft clay and gravel 1.0 ft sandy gravel (refusa1 at 11.0 ft)
671	Biddeford	91	2.0 ft gravel and clay (fill) 67.0 ft clay 7.7 ft sand (rock at 76.7 ft)

APPENDIX B: RECORDS OF SELECTED TEST HOLES.
(from Tolman et al., 1983)

Test Hole	Description	Thickness (feet)
T-19	Brown medium to fine sand	9
	Brown to tan medium sand	33
	Gray clay	2
T-31	Medium sand	6
	Sandy silt with pebbles	4
	Gray silty gravelly sand	5
	Wet sandy gray clay and silt	1
	Gray sandy clay and silt	2
	Gray wet compact silt (till)	3
T-32	Medium sand	9
	Coarse sand	12
	Coarse sand, some gravel	10
	Coarse gravel	10
	Gravel and cobbles	10
	Refusal (bedrock?)	

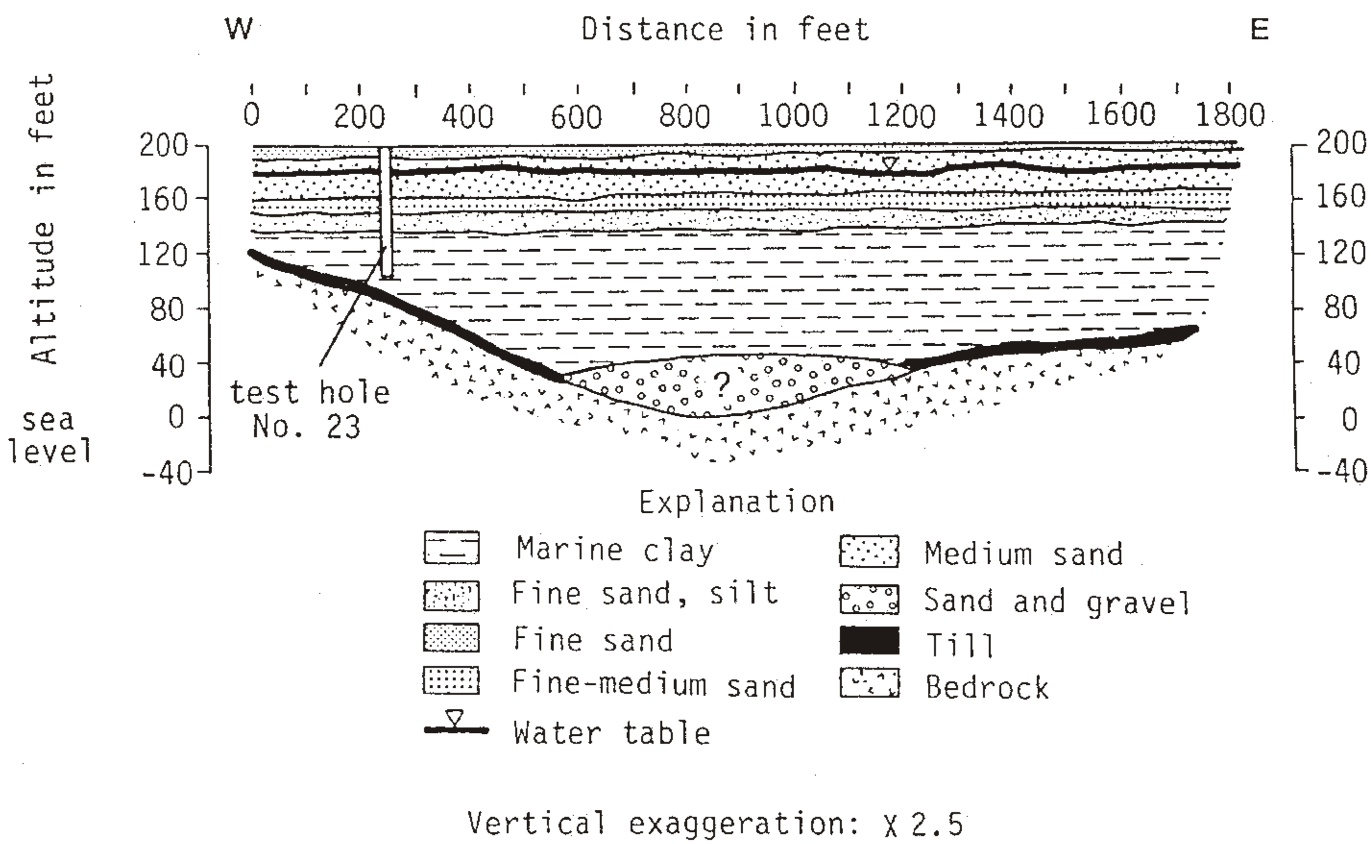

Figure 4. Idealized geologic section across The Plains area, north of Rte. 99, Kennebunk, Maine. Section traverse shown on the materials maps for the Kennebunk and Alfred quadrangles (from Tolman et al., 1983).