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Late Wisconsinan Glacial and Glaciomarine Sedimentary Facies in the Lower Androscoggin Valley, Topsham, Maine

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ABSTRACT

A facies model is proposed for late Wisconsinan glaciomarine deposits in the lower Androscoggin Valley that includes four lithofacies assemblages that are defined by morphology and detailed stratigraphic and sedimentologic analysis. The end moraine facies assemblage includes subglacial and resedimented diamicton, and interbedded and locally deformed sand and gravel beds. The sediments form linear ridges which are former grounding line positions of the tidewater glacier margin. The submarine outwash fan facies assemblage commonly drapes or flanks the end moraine assemblage. In proximal regions of the fan, gravel, bedded sand, and diamicton lithofacies predominate and represent rapid deposition at the mouth of the meltwater tunnel by fluvial and mass flow processes. Distal and lateral to the ice margin, fan sediments consist of graded and cross-laminated sands deposited by underflow currents and slump-generated turbidites interbedded with rhythmically bedded silt attributed to suspension deposition from overflow or interflow plumes. The submarine plain facies assemblage is laterally and distally transitional with the submarine fan assemblage and consists of apparently massive, structureless fine-grained sediments deposited from suspension. The shallow marine facies assemblage consists of well-sorted tidal to subtidal sand lithofacies, poorly sorted gravelly and bouldery lag deposits on moraine crests, and lagoonal muds. Collectively, these lithofacies were deposited as a result of reworking previously deposited sediments during isostatic emergence.

INTRODUCTION

Retreat of the late Wisconsinan Laurentide ice sheet through the coastal zone of Maine is documented by a complex stratigraphic sequence of glacial and glaciomarine sediments. The purpose of this paper is to report the results of detailed stratigraphic logging and sedimentology of such deposits in two adjacent borrow pits in south-coastal Maine. The data include lithofacies distribution, thickness, and texture, and are provided to lead to accurate modeling and detailed paleoenvironmental reconstruction of the sedimentary environments associated with retreat of a tidewater glacier margin.

Study Area

The study area is located in Topsham, Maine, in the northwestern one-ninth of the Brunswick 7.5 minute quadrangle (Bath 15 minute quadrangle). Two gravel pits, the Webber pit and the Bisson pit are located along the west side of Meadow Road approximately one-half mile west of the Cathance River (Fig. 1). The gravel pits are both located on the west side of a bedrock structural and topographic high that reaches a maximum elevation of 198 feet in the Webber Pit.

The larger of the pits, the Webber Pit (Fig. 1), has exposures in a moraine ridge complex. The land surface drops off to the

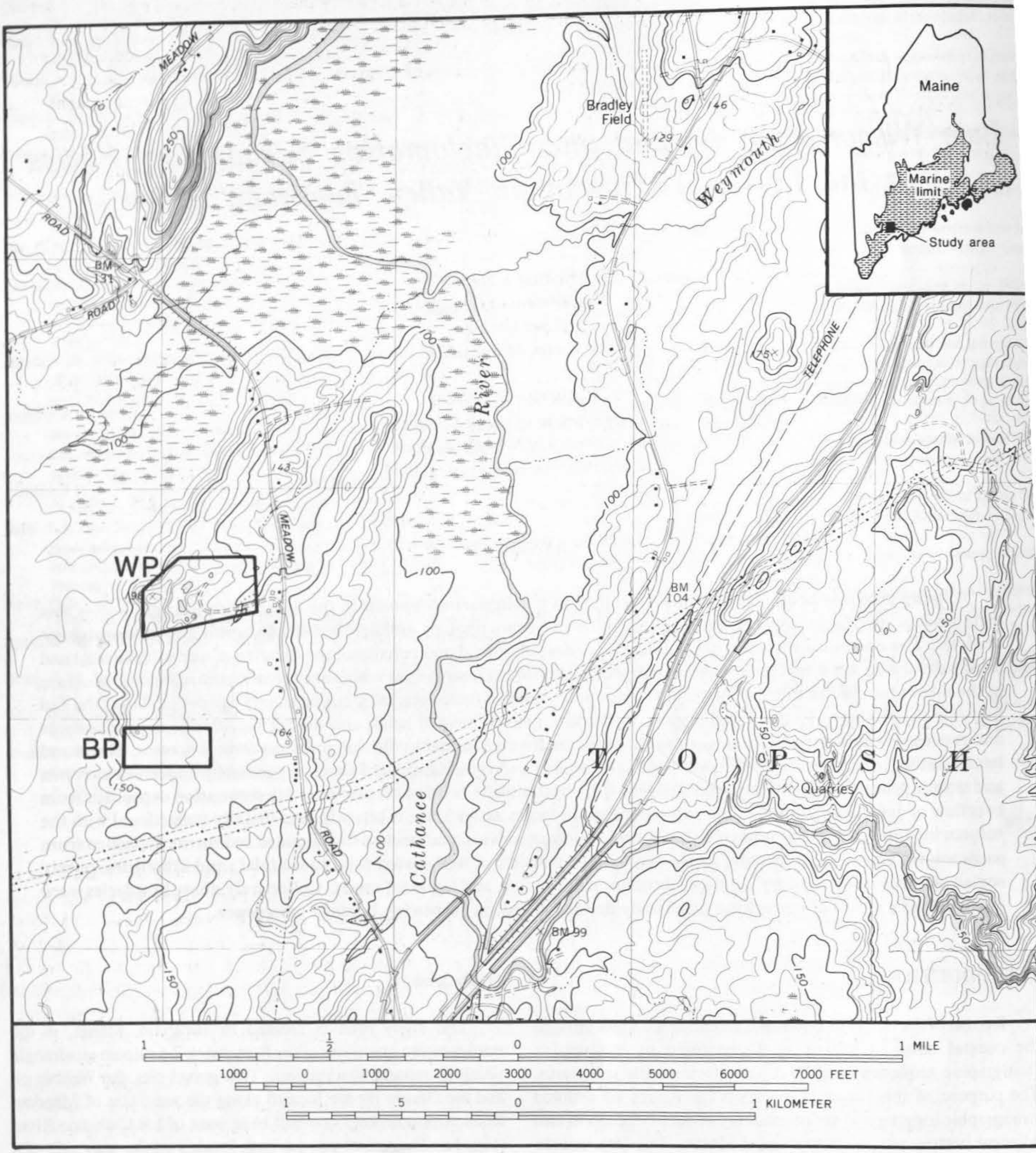


Figure 1. Location map of the study area, Topsham, Maine. Letters refer to Webber pit (WP) and Bisson pit (BP). Shading on inset map refers to area of late Wisconsinan marine submergence.

north behind the moraine complex. Additional exposures are cut into a flat to rolling plain that descends to the Cathance River lowland to the east.

The Bisson pit is located approximately 500 m due south of the Webber pit along the axis of the same bedrock ridge (Fig. 1). Excavation along the northern margin of the pit has exposed the bedrock ridge while southern excavations are approximately 20 feet lower along the plain contiguous with the lower exposures in the Webber pit.

Bedrock Geology

The bedrock within the area is the Richmond Corner Member of the Cushing Formation (Hussey, 1981), consisting of quartz-plagioclase gneiss with rusty weathering schistose compositional layering. The Cushing Formation, part of the Cambro-Ordovician Casco Bay Group, lies in fault contact with the Silurian Vassalboro Formation (Hussey, 1981). The trace of the fault is located along the northeast-trending lowland to the west of the study area (Fig. 1).

Surficial Geology

At its maximum, the late Wisconsinan Laurentide ice sheet extended beyond the present coastline of Maine onto the continental shelf (Schnitker, 1974; Fastook and Hughes, 1982; Belknap, 1987; Belknap et al., 1986, 1989; Oldale, 1989). It is generally believed that recession from that maximum position began around 17,000 to 15,000 yr B.P. (Tucholke and Hollister, 1973). Stuiver and Borns (1975) estimate that the ice margin reached the coast around 13,500 yr B.P. Smith (1985), however, places the retreating margin at the coastline as early as 13,800 yr B.P. in the southwestern corner of the state, and inland of the marine limit by 12,800 to 12,600 yr B.P.

The retreat of the marine-based ice sheet was interrupted by numerous, perhaps annual (cf. Meier, 1984) forward oscillations recorded by many end moraines, both small and large, and submarine outwash fans (Thompson, 1979, 1982; Smith et al., 1982; Smith and Hunter, this volume). The ice-marginal deposits are distally and laterally intercalated with fine-grained, locally fossiliferous glaciomarine sediments. The marine silt and clay, referred to as the Presumpscot Formation (Bloom, 1960, 1963), exhibits a distinctive smooth to gently rolling topography as a veneer on the end moraine and outwash fan deposits. Marine submergence of the coastal zone occurred from the time of deglaciation (ca. 13,000 to 12,600 yr B.P.) until isostatic emergence of the coastal zone was complete by ca. 11,500 yr B.P. (Smith, 1985). Based on data from a marine limit elevations map (Thompson et al., 1983), it is estimated that the water depth over the Topsham area at the time of deglaciation was approximately 30 to 45 meters (90 to 140 feet). Water depths over the site were probably greatest immediately following deglaciation due to isostatic depression. Accelerated uplift after ice retreat produced a shoaling of the coastal zone, reflected in the stratigraphy by intertidal and beach sediment overlying the fine-grained silt and clay.

In this study, we propose a preliminary model for glacial and glaciomarine sedimentation in the lower Androscoggin Valley. The model uses vertical and lateral lithofacies changes and facies associations as primary data. Interpretation relies heavily upon studies conducted on distribution of sediments and related processes in modern glaciomarine environments (e.g. Gilbert, 1982; Powell, 1981, 1983, 1984; Mackiewicz et al., 1984; Dowdeswell, 1987). A model for the deposits associated with deglaciation of coastal Maine is also presented by Smith and Hunter elsewhere in this volume.

Methods

Stratigraphic logging of deposits was accomplished in the field by methods as described by Eyles et al. (1983). Individual lithofacies are identified in the field by texture, sedimentary structures, and stratigraphic relationships (Table 1). Lithofacies logs were constructed to show vertical changes in the sedimentary succession; several cross-sections of pit faces were mapped to show lateral and vertical lithofacies changes. Facies associations (cf. McCabe et al., 1986) used in this report reflect the assemblage of lithofacies within morphostratigraphic units such as moraines or submarine fans.

Maps of the gravel pits were produced by both plane table and alidade, and pace and compass methods. Till fabrics were measured according to methods proposed in Andrews and Smithson (1966). Particle size was measured by wet and dry sieving for the coarser than 4.5 phi fraction. The finer than 4.5 phi fraction was analyzed using a Micromeritics Sedigraph 5000 D housed at the University of Massachusetts.

RESULTS

Webber Pit - Description of Sections

Section A. Section A is situated on a transverse cut approximately 50 m long and 7 m high in the northwest corner of the Webber pit (Fig. 2). The stratigraphy consists mainly of alternating bodies of diamicton and gravelly sand and sand layers. At least 3 layers of diamicton are present in the section (Fig. 3a). Diamicton bodies in this section and in the pit in general, range from tabular to wedge shaped. Upper and lower bounding surfaces, when viewed parallel to the moraine axis, are commonly sharply defined and horizontal; however, some lower bounding surfaces of some of the bodies are slightly arcuate to concave upwards. In longitudinal section, some diamicton bodies thicken in wedge shape towards the ice proximal (north) face. Some units display an upturning or flexure towards the south or free face of the moraine ridge.

The uppermost diamicton unit (Dmm1, Fig. 3a) is a tabular block up to 1.6 m thick with a sharp basal contact. The matrix is olive (5Y 4/3, damp) and compact with a well-developed

TABLE 1. A LITHOFACIES SCHEME FOR THE LOWER ANDROSCOGGIN RIVER VALLEY, MAINE (AFTER EYLES ET AL., 1983; MIALL, 1978)

Facies Code	Lithofacies	Sedimentary Structures	Interpretation	Facies Assemblage
Dmm	massive, matrix-supported diamicton	none	lodgement till	End moraine, submarine fan
(s)			sheared	End moraine
(c)			current reworked	End moraine
(r)			resedimented	End moraine
Dms	matrix-sup. diamicton	stratified	debris flow deposits	End moraine, submarine fan
(r)			resedimented	End moraine, submarine fan
(s)			sheared	End moraine
Gm	massive or crudely bedded gravel	horizontal bedding, pebble imbrication	turbidite, lag deposits, tractive flow	Submarine fan, shallow marine, end moraine
Sm	massive sand	none	turbidite, tractive flow	Submarine fan, shallow marine, submarine plain, end moraine
(s)		sheared		End moraine, submarine fan
Sp	planar crossbedded sand, (med. to v. coarse, may be pebbly)	solitary (alpha) or grouped (omikron) planar crossbeds	turbidite, tractive flow	Submarine fan, end moraine
Sr	rippled sand (v. fine to coarse)	ripple marks of all types	ripples (lower flow regime)	Submarine fan, end moraine
Sh	horiz. lam. sand, (v. fine to v. coarse, may be pebbly)	horizontal laminations	planar bed flow (l. and u. flow regime)	Submarine fan, end moraine, shallow marine
Sg	graded sand, (v. fine to v. coarse, may be pebbly)	graded	turbidite	Submarine fan, submarine plain, end moraine
(s)		sheared		Submarine fan, end moraine
(d)	with dropstones			Submarine fan
Fl	clay, silt, sand	laminated	turbidite, overflow plume	Submarine fan, shallow marine, end moraine
(d)	with dropstones			Submarine fan, submarine plain
Fm	massive clay and silt	none	turbidite, overflow	Submarine plain, shallow marine, end moraine
(d)	with dropstones			Submarine plain

horizontal to sub-horizontal fissility. Mean grain size of eight samples of matrix sediment in this block showed a range from 3.2 to 4.2 phi units (very fine sand to coarse silt). Sorting values range from 2.4 to 3.2 (poorly to very poorly sorted). Sand contents in the block range from 25 to 55% (cf. Fig. 3d). In general, no distinct trends in grain size distribution are discernible within the unit.

Clasts in this unit are widely dispersed through the matrix and range from pebbles to boulders 70 cm long. Clast lithologies are dominated by local metapelitic and metavolcanic rocks. Several black gabbro boulders occur in the diamicton. These presumably were transported by ice from the Androscoggin Lake complex 40 km to the north-northwest. Clast fabric (n = 25 stones) is distinctly bimodal with one strong north to north-northwest grouping (340° to 360°) and a strong 280° to 300° trend (Fig. 3b). No clay skins or silt caps were observed around the clasts.

Lower in the section (at approximately 2 m from the base) a one meter-thick slab of diamicton (Dmm2, Fig. 3a and Fig. 4a) has essentially the same color and grain size distribution as the uppermost diamicton, Dmm1. However, the lower unit is more complex structurally. The upper surface of the body lies in sharp contact with the overlying sand unit. Along this surface a cluster of 5 striated "bullet-shaped" boulders lies with long axes trending from N3°E to N16°W. In addition to the thin fissility similar to that of the upper block, the lower diamicton contains thin subhorizontal to curvilinear sandy partings and lenses (up to 10 cm long) and several arcuate concave upward fractures (up to 1.5 m long) that is in places highlighted by a thin bed of medium to coarse sand. The sand lenses are texturally similar to those sand beds overlying and underlying the diamicton.

Approximately 4 m from the base of section A (Fig. 3a), a second type of diamicton Dmm(r) is exposed. This unit is variable in texture and structure. The unit ranges from a com-

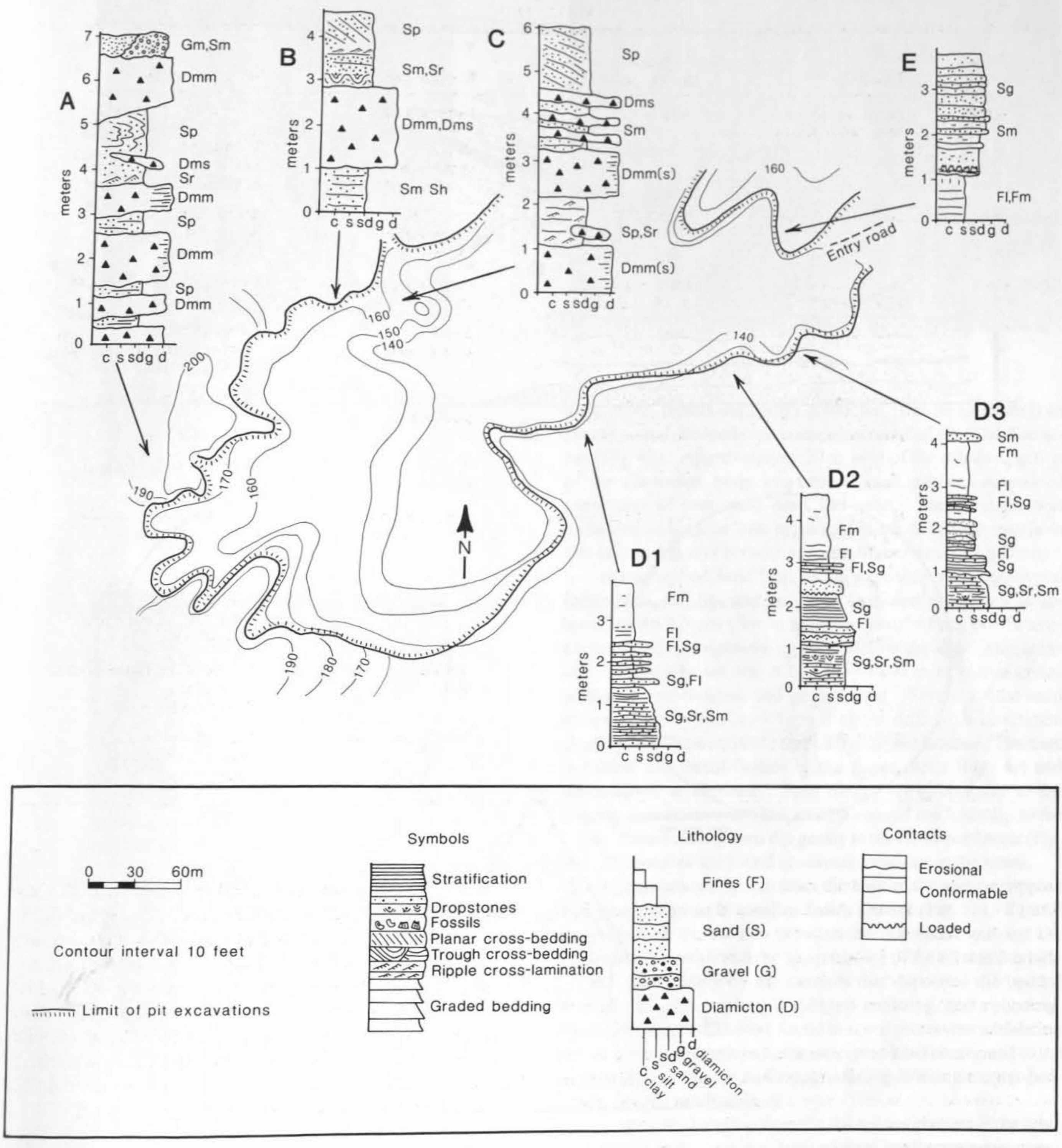


Figure 2. Map of the Webber pit with lithofacies logs and locations of sections described in text. Stratigraphic symbols after Eyles et al. (1983) and Miall (1978) (see Table 1).

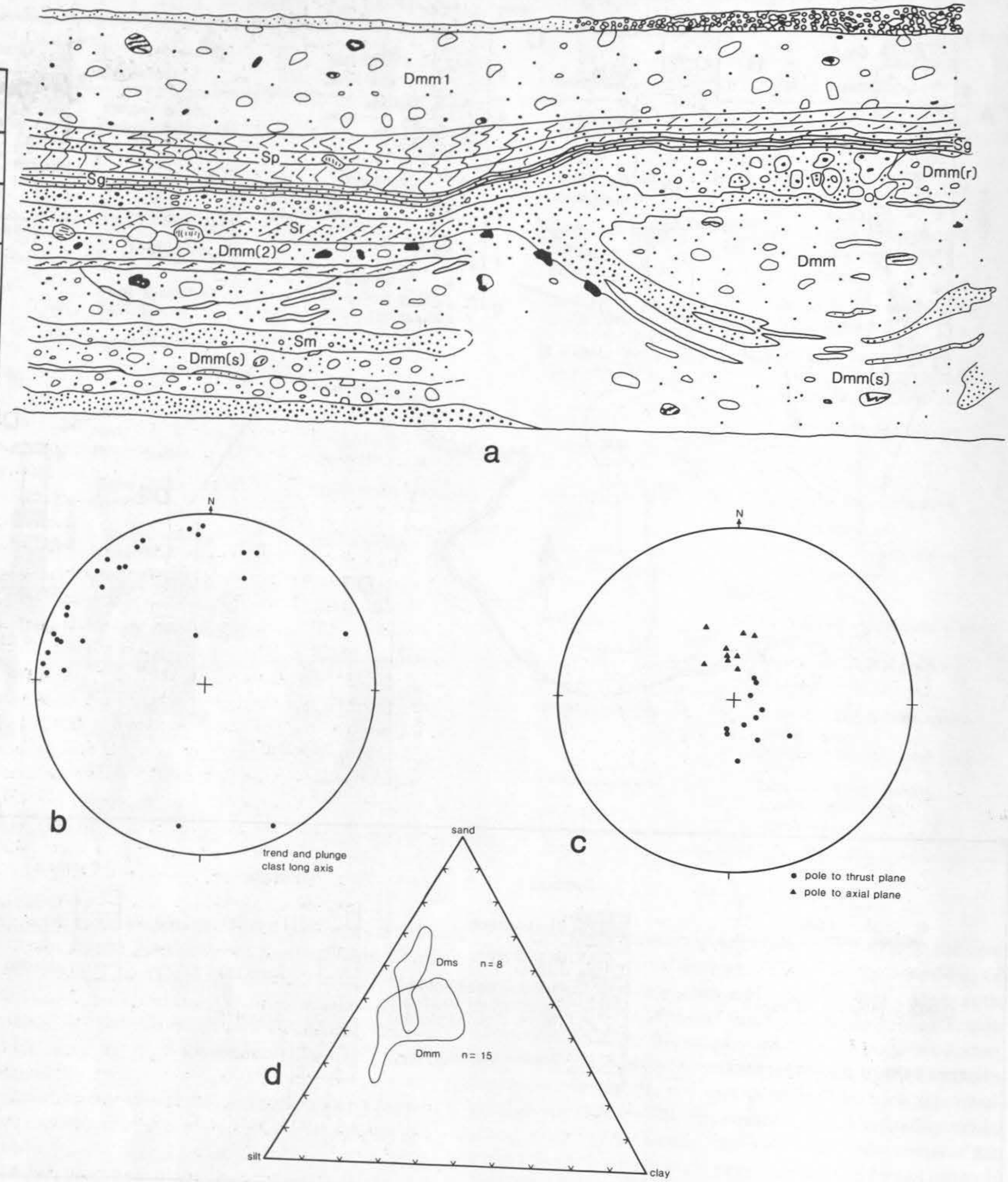
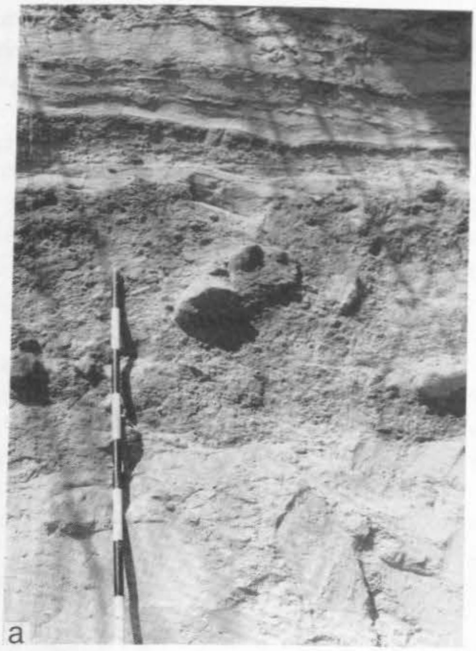
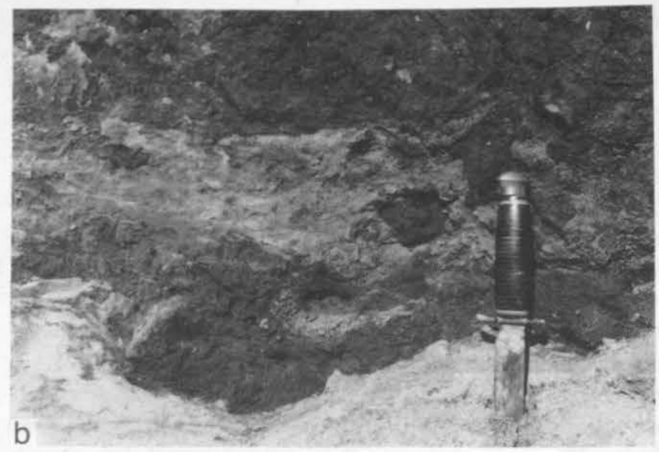


Figure 3. (a) Lithofacies diagram of section A in Webber pit. Stratigraphic symbols after Eyles et al. (1983) and Miall (1978; see Table 1). (b) Till fabric of unit Dmm1 plotted on 3-D stereoprojection. (c) Stereonet projection of structural features in deformed sand unit (Sr, Sp, Sg) beneath Dmm1. (d) Sand-silt-clay ternary plot of diamictons in Webber Pit.





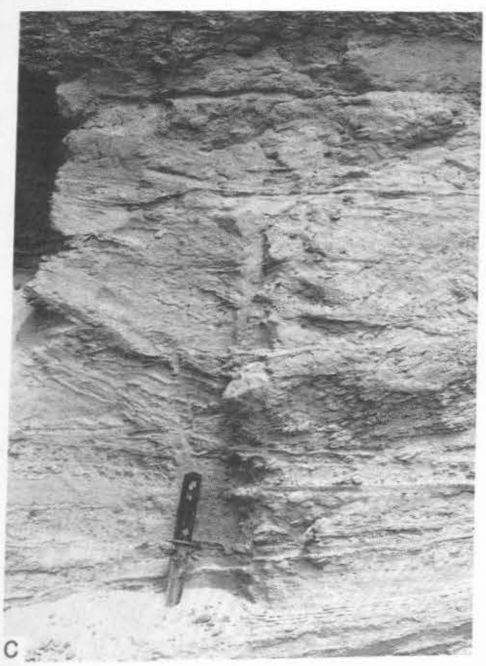


Figure 4. Photographs of section A, Webber pit. (a) Facies Dmm beneath a bedded sand unit. (b) Facies Dmm(r). Clast of diamicton is surrounded by poorly sorted coarse sand which is in turn incorporated in 0.5 m thick layer of diamicton. (c) Facies Sp, Sh deformed by folds and thrust faults beneath facies Dmm1.

pact, olive, matrix-supported diamicton (similar to Dmm1) to poorly sorted, bedded sand containing rounded clasts of diamicton (Fig. 4b). Approximately 20 m west of the massive portion of the diamicton body, the bedded sand contains suspended intraclasts of laminated mud and sand. Sand content was measured as high as 70% by weight in the diamicton matrix in this unit and gravel content was also higher than facies Dmm.

Interstratified sand beds in the exposure make up several facies (Sm, Sh, Sp, and Sr, Table 1). Mean grain size is approximately 2.5 phi (fine to medium sand); sorting coefficients average 0.85 (moderately sorted). Below the upper diamicton unit (Dmm1) in section A lies 1.0 to 1.6 m of planar cross-bedded, plane-bedded, and graded sand. Several of the sand beds contain Type A and Type B ripple-drift cross-lamination (Jopling and Walker, 1968) draped by fine silt laminae. The sand is folded and thrust-faulted in the upper meter (Fig. 4c) and undeformed at the base. Fold hinges are subparallel to the outcrop face (east-west) and axial planes of the folds dip to the south. Thrust fault planes dip gently to the north-northwest (Fig. 3c). Dropstones are found at several locations in the sands.

At approximately 3 m from the base of the section, rippled fine to medium sand overlies facies Dmm2 (Fig. 3a). Careful excavation of the contact between the diamicton unit and the rippled sand reveals that the upper surface of the till was fluvially eroded, presumably by the currents that deposited the bedded sand. The till surface displayed molding and rounding. Rounded clasts of till were found in scour pits on the undulating till surface. Laminations in the overlying sand conformed to the topography on the till surface, producing low angle cross-bedding from the sand infilling.

Section B. A series of cuts in the central portion of the ridge (Fig. 2) exposes various longitudinal and transverse views through deformed diamicton facies (Dmm(s) and Dms(s)), and massive sand (Sm(s)), which are overlain by structureless mud and thin horizontal-bedded sand and silt (Fig. 5).

Several diamicton layers are exposed in this section. The thickest layer is a massive unit that forms a wedge that thickens

Figure 7. Photographs of section D within the Webber pit. (a) Gravel channel deposits overlain by massive and horizontal bedded sands at the base of the section. (b) Rippled and ripple-drift cross-laminated sand. (c) Rhythmically bedded sand and mud lithofacies draping a truncated fan lobe. (d) Laminated sand and mud containing a lens of ice rafted diamicton with accompanying soft sediment deformation. (e) Vertical burrow (?mollusc) cutting through laminated sand and mud.

planar cross-bedded sand. Above the channeled sand and gravel, the section contains interbedded graded sand and gravel beds with erosional scour contacts and gravel lag deposits. Sets of graded and planar-bedded sand range in thickness from 10 cm to 1 m. The interbedded sand and gravel is, in turn, overlain by rippled and ripple-drift cross-laminated sand (Fig. 7b) with sandy silt interbeds. Sand and silt beds range in thickness from 5 to 60 cm.

A distinct unconformity separates sand and gravel-dominated lithofacies near the base of the section from the overlying rhythmically bedded sand and mud lithofacies (Figs. 6, 7c). At approximately the 2 m level of the section (Fig. 6) the sand layer thickness is approximately equal to silt layer thickness. The sand is moderately- to moderately-well sorted while the silt laminae are very poorly to extremely poorly sorted. Sand and silt layers are laterally continuous for tens of meters. The proportion of mud increases upward within individual sand beds and, in general, up-section. Individual laminae thicken as they fill channels incised through underlying coarser facies (Fig. 7c) and thin as they drape over topographic highs. Soft sediment deformation is common especially where the laminated sand and silt drape over steep sloping channel sides. Isolated pebbles and diamicton lenses are common (Fig. 7d) in both sand and silt layers. Vertical burrows (Fig. 7e), probably formed by bivalves, are found in several horizons. The laminated sand and mud grades transitionally into structureless blocky marine mud (Fm) above the 3 m level (Fig. 6).

Section E. Approximately 2.7 m of sandy and muddy sediment overlies massive mud in section E in the northeastern area of the Webber pit (Fig. 2). The underlying mud (Fm) is massive blue gray plastic silty clay with horizons stained with black sulfide. The silty sand beds are intercalated with the clay near the top of the massive mud unit. Within the interbedded silt and clay, a rich *in situ* assemblage of invertebrate fossils is found. Paired valves of *Mytilus edulis* with *Balanus* attached on the upper valve lie on a pavement of articulated and broken shells including *Macoma calcarea* and *Hiatella arctica*. A sample of *Mytilus* and *Balanus* from this horizon at 47 m (152 ft) asl yielded a date of 12,820±120 yr B.P. (SI-7017; Retelle and Konecki, 1986a). The fossiliferous horizon is overlain by a 3 cm thick silty medium to coarse sand followed by 70 cm of massive to laminated brown sandy silt with lenses and laminae of medium sand. The upper 1.35 m of the section consists of beds of massive, moderately sorted sand with 0.5 to 1.0 cm laminae of silt. The deposit thins against the slope of the topography to the north.

Bisson Pit - Description of Sections

Section X. This exposure is located in the northwestern corner of the Bisson pit (Fig. 8) along a south facing hillslope. Bedrock crops out at the northern margin of the pit. Large boulders are common in the drift and on the surface in this area. At least 1 m of cross-bedded to planar bedded sand (Sp, Sh) occurs at the base of this section. This unit is overlain by approximately 1.5 m of faintly fissile, compact, olive (5Y 5/3) diamicton (Dms, Fig. 8). This diamicton matrix contains from 41 to 59% sand, 36 to 42% silt, and 5 to 17% clay. The range of mean grain size (3.9 to 5.5 phi) and sorting (2.1 to 3.7 phi) values are slightly finer-grained than other diamictons analyzed from the Webber pit, although there are abundant lenticular inclusions of well-sorted medium to coarse sand throughout the unit. A clast fabric on 25 stones shows a strong east-west orientation, perpendicular to regional ice flow direction. Clasts in the deposit, in general, lack silt caps and clay skins. The section is capped by approximately 2.5 m of well-sorted trough cross-bedded and planar-bedded sand. The dip of the bedding in the pit fans out from southwest to southeast, generally parallel with the topographic expression of the landform.

Sections Y and Z. These sections are lower in elevation and approximately 50 and 100 m to the southeast of section X, respectively, on relatively flat topography south of the bedrock ridge (Fig. 8). Section Y consists of approximately 4.5 m of vertical exposure in bedded and structureless sand and mud. Section Z, approximately 50 m to the east, exposes approximately the same stratigraphy as the upper 3 m of Y (Fig. 9). The bottom unit of the exposed stratigraphy is bedded medium to coarse sand with thin interlaminated silt. Sand layers are up to 20 cm thick in this part of the section and consist of massive, graded, and multiple graded beds (Fig. 10a). Most beds extend laterally for several tens of meters, however some beds pinch out or thin against bedrock or drift highs. Single sandy and muddy beds and sets of beds and laminae can be correlated between sections Y and Z. Dropstones are present, but not in great abundance. No *in situ* invertebrate fossils were found, however vertical burrows are present in some sand beds. Silt layers separating the sand beds are from 1 to 3 cm thick and are predominantly light olive-gray (5Y 6/2, damp) and structureless, although some contain 1-2 mm thick sand interlaminae. Other fine silt layers which occur in the section are dark olive-gray (5Y 4/2) and finer grained.

In general, sand thickness decreases up-section while mud thickness increases. Sand laminae up to 0.5 cm thick, separated by fine-grained silty clay layers 1 to 2 cm thick, are found up to approximately 3 m from the base of section Y (Fig. 9). Additionally, several continuous sand layers, each several grains thick, occur in the middle of the silty laminations (Fig. 9b). Some of the silty layers demonstrate a fining-upward trend (90-92 cm, Fig. 9b); others do not. This facies is transitional to the mud-dominated facies above and is designated Sm/Fm on the lithofacies log.

Above the 3 m level in section Y (and the 1.5 m level in section Z), the stratigraphy is dominated by fine grained laminated and structureless mud (Fig. 10b). Sand laminae thin up-section. Several 0.3 to 0.5 cm continuous sand laminae are found in the laminated mud facies (Fl) before disappearing completely (Fig. 10c). The mud laminae consist of alternating light olive-gray (5Y 6/2, damp) and olive-gray (5Y 4/2) couplets.

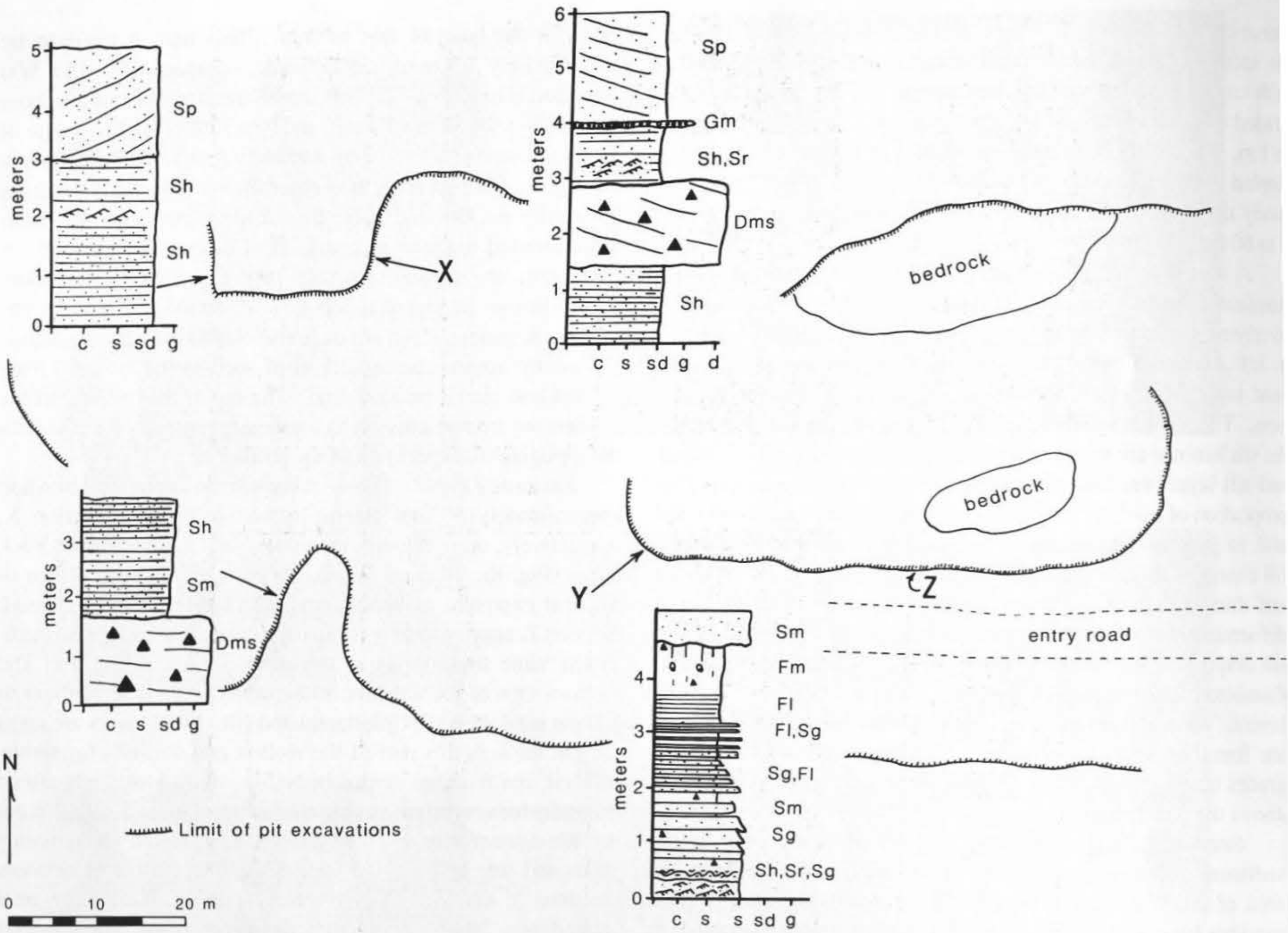


Figure 8. Map of the Bisson pit with lithofacies logs and locations of sections described in text.

Approximately 25 gray-olive couplets are represented in the sections. The lighter gray portion of the couplet in general thins up-section from 4 cm at the base of facies Fl, to several mm thick at the top. The light portion of the couplet commonly grades up to the dark portion of the couplet or is faintly draped by the darker. The contact between the dark olive-gray portion of the couplet and the overlying light layer is generally sharp. Some minor changes in grain size were measured through the light and dark olive-gray couplets (Fig. 9b). Sand content is slightly higher in the light layer; clay content is up to 10% higher in the dark layers. The light layers in the 175 to 190 cm level of the section (Fig. 9b) show fining-upward trends, while particle size within the dark layer remains relatively constant and slightly finer grained.

The laminated mud is overlain by a massive, generally structureless fine-grained mud (Fm). In general, the contact between lithofacies Fl and Fm is gradational. Texturally, lithofacies Fm is similar to the dark olive member of the laminated mud couplets, with low sand contents (1 to 5% sand,

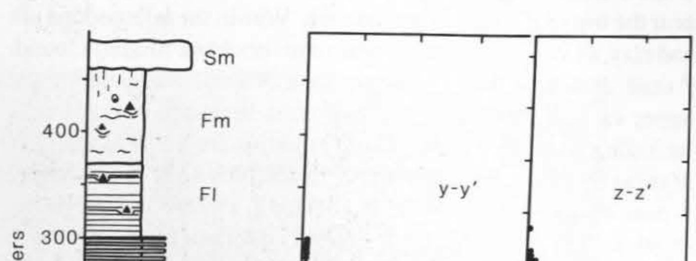


Figure 9. (a) Lithofacies log of section Y with measurements of sand bed thickness for sections Y and Z within the Bisson pit.

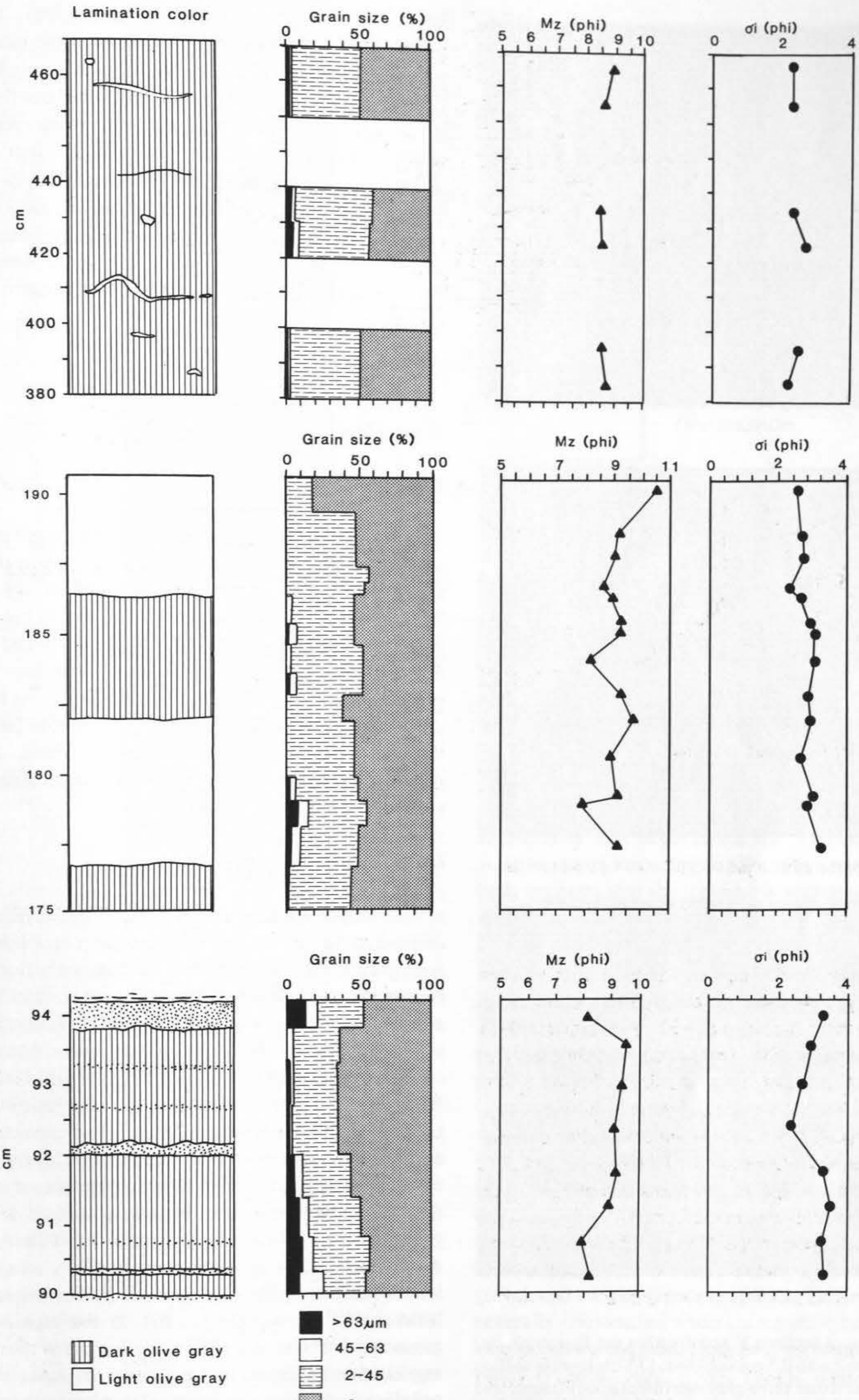


Figure 9. (b) Grain size analyses for selected zones of section Y.

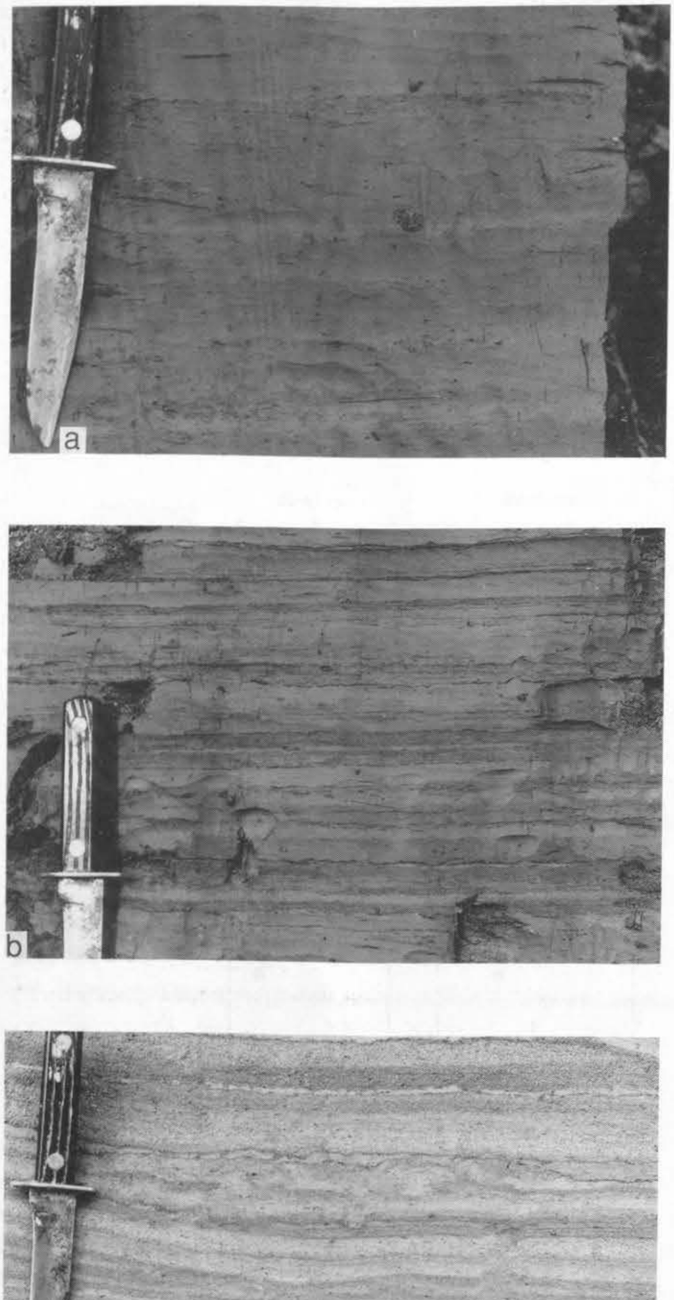


Figure 10. Photographs of sections Y and Z within the Bisson pit. (a) Faintly laminated silt unit with 0.5 cm sand bed, 175 cm level in section Z. (b) Laminated gray and dark olive-gray silts (lithofacies Fl) separated by 0.5 to 1.0 cm sand laminae, 90 cm level in section Z. (c) Multiple graded sand beds separated by 1 cm silt laminae, 80 cm from the base of section Y.

45 to 50% silt, and 40 to 50% clay; Fig. 9b). Thin, faint, light gray laminae (ca. 1 mm) also occur in the mud, but in minor proportion. Dropstones are found in this unit, but not in abundance. Sand grains are dispersed throughout the sediment, and do not occur in discrete laminae. Invertebrate fossil remains and related trace fossils are also found in this unit, however shells are commonly disintegrated or leached away leaving molds. Exposures of this unit commonly display blocky jointing in the upper meter. Manganese/iron oxide staining that probably results from ground water flow along the vertical joint planes gives a steel-gray to black coloration to jointed surfaces of this sediment.

DISCUSSION

Facies Assemblages

The deposits in the Webber and Bisson pits can be organized into four facies assemblages that, in this paper, are named for the specific morphostratigraphic unit in which they occur. These include the end moraine, submarine fan, submarine plain, and shallow marine facies assemblages. The facies assemblages contain lithofacies, such as Sp or Sm, common in both the end moraine and submarine fan assemblages. This is attributable to similar processes that were operating across facies assemblage boundaries in the glaciomarine environment. A model of the relationship between lithofacies and facies assemblages in this study area is shown in Figure 11.

End Moraine Facies Assemblage

The end moraine facies assemblage consists primarily of diamicton (lithofacies Dmm, Dmm(r), and Dms) interbedded with gravel and sand units, and is a composite feature constructed by glacial and fluvial processes. Structures within the diamicton support deposition and deformation by active ice and include oriented boulders, recumbent folds, and subhorizontal and arcuate foliation which may possibly be thrust faults. In addition, folds and thrust faults found in the interbedded sand probably result from ice-thrust deformation. The diamicton layers in the end moraine deposits are not continuous layers, but are tabular and wedge-shaped, suggesting disturbance or transport by ice shove. Diamicton bodies abruptly upwarped downglacier suggest deformation by loading. Andrews and Smithson (1966) and Andrews (1975) suggest that cross-valley moraines on Baffin Island are formed by the squeezing of water-soaked till from beneath the ice margin pinned on the proximal side of the moraine. Similarly, the drift ridge in front of the rapidly advancing Hubbard Glacier in southeastern Alaska consists of fine proglacial sediment incorporated and later squeezed out in front of the glacier in its advance across the fiord (L. Mayo, public commun., GSA, 1986).

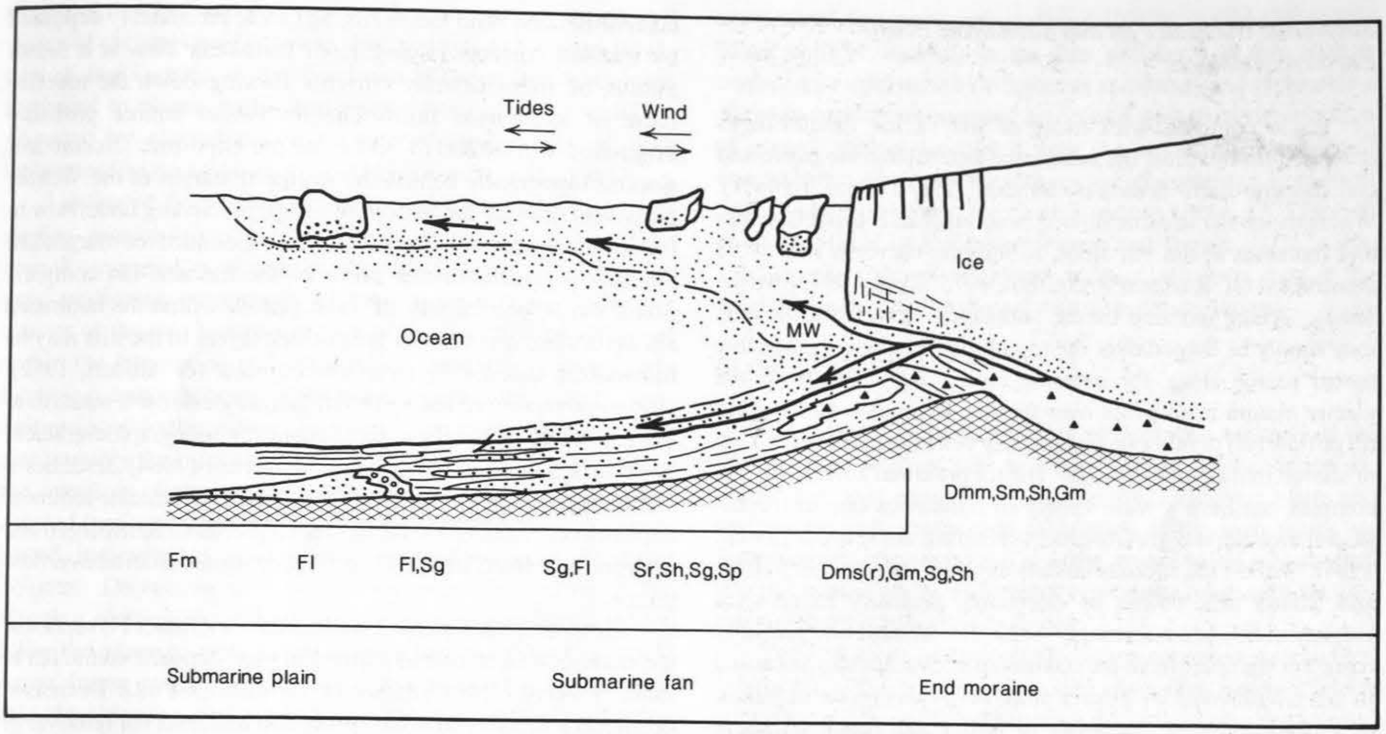


Figure 11. Proposed model of the relationship between lithofacies and facies associations for the lower Androscoggin River valley, Maine.

There are probably several origins for the diamicton in the end moraine complex. Some of the lithofacies Dmm is probably undisturbed lodgement till. In some locations, the diamicton referred to as Dmm(r) is nearly the same texturally, however fissility is usually lacking and thin sand partings and lenses are present. It is possible that this facies represents lodgement till which has been remobilized by ice-shove or slumping and has incorporated sand during transport. Diamicton lithofacies Dms is interstratified with sand and appears to be reworked along the margins of the deposit. These diamictons are interpreted to be either flow tills or debris flow deposits that originated either on a debris-covered ice foot or along the crest of an end moraine.

The occurrence of the sand and gravel facies within the moraine is attributed to meltwater deposition from a submarine outwash fan adjacent to, or draping over the moraine crest. The glaciofluvial sediment may also have been deposited in a subglacial regime in an esker tunnel or conduit (Sharpe, 1987) that fed the submarine fan. Multiple intercalations of the fluvial sediments with massive diamicton in the ridge exposures suggest that the ice margin was fluctuating near the grounding line. Studies by Stemen (1979), Jong (1980), Lepage (1979, 1982), and Smith (1982) demonstrate that in general, the coastal moraines in Maine are composed of any available materials at the ice front, and most commonly stratified drift. Thus, relative size of the moraines and complexity of the stratigraphy is probably a function of the available sediments and the amount of oscillation of the ice front. Multiple oscillations of the ice margin, and not rapid retreat, are necessary to produce complex stratigraphy and larger moraines. The occurrence of current-scoured pits and molding on till surfaces underlying coarse sandy beds suggests that the ice margin withdraws or the glacier bed decouples to allow sandy beds to be deposited. The accumulation of stratified diamicton in debris flows also requires temporary removal of the grounded ice margin from the moraine ridge or slumping of the moraine front before reincorporation into the moraine by the ice front. Such marginal fluctuations are common for tidewater glaciers and have been documented on a yearly cycle for the Columbia Glacier in southeastern Alaska (Meier, 1984).

The end moraine facies described in this study may be compared to the morainal bank lithofacies described by Powell (1981) from Glacier Bay, Alaska. In Glacier Bay, small moraines (push moraines) may be formed by advances of the ice margin in winter over previously deposited sediments on the fiord floor. The sediments can be a mixture of fiord-floor mud, gravel, and various diamicton facies. Larger morainal banks are generally constructed when ice retreat is halted at bedrock pinning points on the fiord floor or in a constriction or bend in the valley (Powell, 1981, 1983, 1984). The construction of the moraine in the Webber Pit was likely enhanced by slowed retreat as the tidewater glacier margin was pinned on the bedrock ridge (Retelle and Konecki, 1986b).

Submarine Outwash Fan and Submarine Plain Facies Assemblages

As is common with most of the facies assemblages described for this area, the submarine fan, submarine plain, and end moraine share common elements (Fig. 11 and Table 1). Where meltwater streams flowed from subglacial tunnels across end moraines at the sea floor, submarine outwash fans were constructed (cf. Rust and Romanelli, 1975; Rust, 1987; Sharpe, 1987). Along moraine crests, submarine outwash sediments may simply be draped over the top of the moraine or grade to a tunnel source along the moraine crest. Additionally, if the glacier margin readvances over the fan, diamicton (lodgement till or flow till) or other sediments may be emplaced over the top or shoved into a moraine ridge. The ice proximal zone of the fan complex can have a wide variety of lithofacies due to fluvial, glacial, marine, and gravity processes acting in the area (Powell, 1984). Within the submarine fans exposed in both the Webber and Bisson pits, bodies of diamicton, probably redeposited lodgement till, lie conformably within fluvial beds and probably represent slumping from the end moraine. Slumps can be caused in this environment by glacier push, berg calving, earthquakes, or current-induced slumping of water saturated sediment (Powell, 1983; Schwab and Lee, 1983).

The dominant sediment types of the submarine fan assemblage are the sand and fine sediment (mud) lithofacies. Theoretically, strong subglacial meltwater traction currents with high suspended sediment concentration (Powell, 1984; Mackiewicz, et al., 1984) disperse coarse gravel to sand from tunnel mouths across fan delta surfaces and along the sea floor until the inertia of the current can no longer be sustained within the marine waters of the fiord or sea bottom. Differences in density between the saline marine waters and the sediment-charged meltwaters would likely be reduced during the melt season because of the increase of freshwater near the ice front during the melt season (Gilbert, 1982; Stewart, 1982; Domack, 1984). At the same time, finer, and less dense sediments would separate from the tractive underflow and disperse at levels in the water column that are of equal density as either interflows, or overflows. Additionally, underflows may be generated from slumping of sands that pile up at the fan head or along the moraine. All three phases of flow have been observed in the modern glaciolacustrine environment (cf. Gustavson, 1975; Smith, 1978). In the marine setting, overflow plumes issuing from subglacial sources have been observed in many fiords and inlets (Sharma and Burrell, 1970; Hoskin and Burrell, 1972; Gilbert, 1982; Powell, 1983; Elverhoi, 1984; Mackiewicz et al., 1984). Powell (1984) and Mackiewicz et al. (1984) point out that interflows and underflows are not well understood in the modern environment and are modeled from observations in Pleistocene sediment assemblages (cf. Rust and Romanelli, 1975).

In the Webber and Bisson pits, ice frontal position, and hence distance from the ice margin to site of deposition, can be constrained for coarse fan sediments. Coarse-grained gravel and current-bedded sand facies (Sr, Sp) were presumably deposited by traction currents issuing from meltwater flow at a tunnel mouth, or from turbidity currents flowing down the moraine bank or submarine fan. The meltwater source probably originated within 200 to 300 m of the exposure. Northward-sloping topography behind the northern margin of the Webber pit would provide an upsloping ramp, precluding underflow to the southern margin of the pit once the grounded ice margin had retreated a short distance north of the moraine-fan complex. Some sands, particularly those dispersed within the laminated silt layers and one- to two-grain-thick layers in the silts may be transported distally by overflow currents (cf. Gilbert, 1982). However, repetitive sequences of laterally extensive massive to graded sandy beds (Figs. 7b,c) require a topographic gradient back to a source at a fan head. Elverhoi (1984) describes a similar topographic control on laminated glaciomarine sediment deposition in front of the Kongsvegen glacier in Spitsbergen and interprets the interlaminated muds as deposited from an overflow plume.

Laminated fine grained sediments (lithofacies Fl) represent the transition from coarse laminated sand deposits on the fan to more massive clayey silt above (lithofacies Fm). Decreased occurrence of sand laminae up-section indicates the removal of proximal meltwater source, although lateral to the central axis of the fan, the deposition of fine, laminated sediments was probably coincident with coarse-grained deposition. The graded nature of the light gray member of the laminated silt couplet may reflect either distal turbidite deposition or sedimentation from an overflow plume with some cyclical sorting of the fine sediment. Similar laminated muds in the glaciomarine environment have been interpreted as varves (Stevens, 1985, 1986), rhythmites (Domack, 1984), and cyclopels (Mackiewicz et al., 1984).

Stevens (1985) interprets the occurrence of laminated glaciomarine muds in Sweden to represent annual ice-proximal deposition of a fine-grained sediment couplet from an overflow plume. Size separation, which defines the varves, results from the stratification of the marine water body during the meltwater runoff season. The coarser-grained sediments of the couplet would reflect increased meltwater discharge and better developed stratification in spring and early summer, while the darker, finer laminae would represent decreased runoff and sedimentation of floccules when the pycnocline was higher in the water column.

Domack (1984) also suggests that rhythmically laminated sediments in the Puget Sound Lowlands may be the result of seasonal deposition in proximal locations from underflow and overflow. Thickness and grain size of beds and laminations and variations within them may reflect seasonal and diurnal changes in meltwater flux and other cyclical processes such as tidal currents (Domack, 1984).

Laminated fine-grained sediment couplets in Muir Inlet, Alaska (Mackiewicz et al., 1984, Cowan et al., 1988) termed cyclopels, are typically 0.5 to 1.0 cm thick and are interpreted to be deposited from suspension loads of interflow and overflow plumes at a rate of 2 to 3 cycles per day, accounting for up to 9 meters of cyclopel mud per year. Variabilities of cyclopel thickness at any location in the fiord and between locations were attributed to plume width and extent from the ice, which is governed by a combination of strength and timing of both meltwater flux and tidal currents (Mackiewicz et al., 1984).

Laminated fine sediments in the Webber and Bisson pits display general thinning- and fining-upward trends that have been documented in other areas discussed above. Similarly the gray, or lighter, component of the couplets is generally the coarser of the two laminae and displays a fining-upward trend within the lamination and up-section. Very thin (mm), light laminae commonly occur in the upper, apparently structureless, unit assigned to the submarine plain lithofacies. This suggests that possibly the light layer may be the result of size sorting in the overflow plume as suggested by Stevens (1985). Light-colored laminae appear to be more graded, though still poorly sorted, indicating a crude grain size organization in the water column. Decreasing influence of the plume is shown by the thinning of the light laminae except during conditions which allow the plume to extend farther from the ice front. This could occur during periods of increased melt and/or low or receding tide (Mackiewicz et al., 1984). "Normal" distal sedimentation comprises the deposition of finer mud, which is the dark laminae of the couplet. This may be accomplished by flocculation of fine material when the freshwater plume is less extensive and fine clay-size particles can interact with saline waters.

Shallow Marine Facies Assemblage

Distribution of lithofacies in this assemblage primarily reflects the underlying parent material, topography of the landform and surrounding landforms, and processes of erosion and deposition which are likely a function of water depth. Subtidal, lagoonal, and beach environments are included in this facies assemblage. Water depth or relative sea level in the region is related to isostatic rebound and eustatic sea level changes. At this stage of retreat of the ice sheet, isostatic effects dominate, and emergence of the formerly submerged marine terrain occurs (Stuiver and Borns, 1975; Belknap et al., 1986; Belknap, 1987). Sediments range in size from coarse gravels to fine massive muds. Along the moraine crest in the Webber pit (sections A and B) a veneer of poorly sorted, sandy, openwork gravel overlies deposits of diamicton. Broken shell fragments, most commonly those of *Mytilus edulis*, are commonly found in the gravel. Poorly sorted, massive, silty sand drapes the slopes of the moraine and interfingers with massive silt along the moraine. Sand of a similar texture overlies massive marine mud along the southern margin of the Webber pit and also in most of the exposures in the Bisson pit.

The most complex exposure of shallow marine sediments is composed of massive and structureless silty clay grading upward to massive sand beds separated by thin silt laminae. The rich in situ fauna at the base of the sands is distinctly a shallow water, or intertidal, fauna consisting of mussels with attached barnacles. Black sulfidic staining in the fine sediments in this zone is common in tidal marsh or lagoonal sediments and represents a micro-reducing environment associated with the decomposition of organic matter associated with the organisms in the fossil assemblage. Similar assemblages are documented from local deposits in the Pejepscot area of Topsham (Attig, 1975) and in many localities in the state (Stuiver and Borns, 1975; Smith, 1985), and represent important relative sea level data if the assemblage can be associated with a shoreline deposit.

CONCLUSIONS

The glacial and glaciomarine stratigraphy exposed in the Webber and Bisson pits is organized into four facies assemblages: end moraine, submarine fan, submarine plain, and shallow marine. Individual lithofacies within each facies assemblage are often common to other assemblages, demonstrating the transition in sedimentary processes between the ice margin and the adjacent sea floor.

The end moraine assemblage is a composite of interbedded subglacial, submarine outwash, and mass flow deposits which contain evidence of deformation by an active, fluctuating, grounded ice margin.

The submarine fan sediments originate at fan heads along the former ice margin and grade distally to the sea floor. Along the ice margin the fan contains submarine outwash gravel and sand and diamicton deposited by mass flow. Distal and lateral to the ice margin, fan sediments consist of sand deposited by turbidity current, and possibly underflow and rhythmically bedded silt deposited from overflow plume suspension. Structureless fine-grained sediments comprise the marine plain assemblage and represent sedimentation from suspension distal and lateral to the effects of underflow currents and overflow plumes.

The shallow marine assemblage is a texturally variable but ubiquitous deposit developed during regression of the inland sea. The deposits occur either in transition with the underlying marine units or lie unconformably over an erosional contact.

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