Late Wisconsin Glacial Geology of the Eastern Portion of Mount Desert Island

Thomas V. Lowell
Department of Geology
University of Cincinnati
Cincinnati, Ohio 45221

ABSTRACT

The areal extent and nature of glacial ice in the Gulf of Maine at the late Wisconsin maximum are the subject of ongoing debate. A contribution can be made to this issue by detailed mapping of glacial erosional and depositional features on the highest point on the Maine coast, Mount Desert Island. Such mapping showed (1) basal till on valley floors, (2) plucked bedrock and erosional cirques on the bedrock ridges, (3) subglacial meltwater channels and P-forms on ridges, (4) striated and polished bedrock surfaces on the highest mountain tops, (5) regional full-glacial south-southeastward ice flow yielding to late-glacial ice flow to due south, and (6) interbedded glacial and marine deposits. Evidence that the marine waters remained below 127 m elevation is found in cores of postglacial lacustrine sediments.

From this evidence the following glacial conditions are inferred: (1) basal ice melting and deposition below 90 m, (2) basal ice melting, freezing, and erosion above 90 m, and (3) meltwater saturation of the ice-bed interface. It is likely that the conditions changed over time, but that most of the erosion occurred as the ice streamed into the Gulf of Maine during the late phases of glaciation.

INTRODUCTION

With regard to glacial history, the Gulf of Maine (Fig. 1) lies in a critical position between southern New England and the Maritime Provinces of Canada. The controversy centers on the maximum extent of glaciation in the Gulf. Glacial geologists in southern New England have suggested that the last glacial ice extended well offshore into the Gulf. This is in sharp contrast to the suggestions of some glacial geologists in Canada who envision a late Wisconsin ice margin just off the present-day coast (Grant, 1977). Recent work in Nova Scotia (Stea and Finck, 1984; Wightman, 1980) shows that ice covered that area and perhaps a compromise between the minimum and maximum models is a more accurate estimate of the ice position in the Gulf of Maine. Although a direct test of this awaits detailed mapping and dating of deposits currently underwater, investigations of the highest point on the present coastline can provide insight. If this area was subjected to intense glacial erosion and was overrun by a thick ice mass, then a late Wisconsin terminal position well offshore would be favored. If, on the other hand, the highest areas were not covered, then a terminal position near the present shoreline would seem more likely. Glacial erosional features, glacial deposits, and bedrock weathering studies provide evidence that active glacial ice covered the highest point adjacent to the Gulf of Maine. The limits of this ice cover, thus, must have extended beyond the present coastline.

Shaler (1889) conducted the first systematic geologic study of Mount Desert Island. He noted that glacial erosion features indicate that the last glacial ice covered the hills, and concluded that wave erosional features extended to the summits of the island.

Later, Raisz (1929) adopted fluvial explanations for the topography of Mount Desert Island. He described its mountains as a dissected monadnock surrounded by a peneplain; the advancing glacial mass followed the existing drainage system, enlarging the valleys only. He also suggested that the assym-
glacials and sediments of the Mississippian period. The area is characterized by a complex geological history involving tectonics, sedimentation, and glacial processes.

Figure 1. Mount Desert Island and its regional setting.

The Late Wisconsin Ice Extent is depicted in the diagram. The map shows the maximum and minimum models of ice extent, as well as moraines. The island is located in the northeastern United States, with nearby regions such as New York, Vermont, and Canada.

**Glacial Erosion Features**

Features of glacial erosion at several scales provide the most important set of data to reconstruct former glacial activity. Large-scale features studied here include mountain asymmetry, troughs, cirques, and meltwater channels. Small-scale features include striations and friction cracks; stoss-and-lee forms are intermediate in scale.

**Large-Scale Ice-Flow Indicators**

Asymmetrical mountain profiles are the largest indicators of ice-flow direction; north slopes are gentle and smooth, and south slopes are steep. Southern cliffs are 30-160 m high and consist of bedrock steps at shearing-plane locations that are 1-5 m apart. West-to-east mountain profiles also show this asymmetry. Gentle and smooth western mountain slopes grade with a continuous, even surface to flat mountain tops, whereas the eastern slopes drop abruptly from the tops. Mountains displaying these directional imprints include Dorr Mountain, Champlain Mountain, Enoch Mountain, Halfway Mountain, The

metrical profile of ridges on Mount Desert Island resulted from thick glaciers crossing the island to the southeast.

More recently, Chapman and Rioux (1958) studied jointing and sheeting of granite on the island. They suggested that the structure of the island developed in a predominantly periglacial environment and resulted from a mature-stage fluvial drainage system. Subsequent glacial erosion modified the trend of the valleys from N10°E to N15°W.

Field work for the present study was limited to a 25 km² portion of the eastern part of Mount Desert Island (Fig. 2). A granite bedrock core provides 460 m of relief through which a series of north-south trending valleys are cut. These valleys extend completely through the granite bedrock into the metamorphic rocks which surround the core (Chapman, 1974). One valley floor to the west of the study area lies 45 m below present-day sea level and forms the only fjord, Somes Sound, on the east coast of the United States. Field work for this project was conducted primarily during the summer of 1978 (Lowell, 1980). An understanding of the glacial erosion features, both large-and small-scale, and glacial deposits permits inference of former glacial conditions and ice limits.
Glacial geology of Mount Desert Island

Figure 2. Topography and place names of study area.
Beehive, and Huguenot Head (Fig. 2). The last four are examples of roche moutonnées.

Stoss-and-lee forms, superimposed on the mountain profiles, are smaller but more widespread indicators of ice-flow direction. Typically 1-2 m high, these forms occur throughout the study area where bedrock sheeting and topography conditions are favorable. On the north side of Dorr Mountain (Fig. 2), a faint series of eastward trending stoss-and-lee forms are superimposed on a strong southward trending set. The large cliffs and lee faces are products of glacial plucking, whereas the smoother slopes result primarily from glacial abrasion.

**Small-Scale Ice-flow Indicators**

Striations provide a means of identifying former ice-flow directions and variations in those directions. In this study, distinction is made between stria tion direction and stria tion trend. Stria tion trend refers to the stria tion orientation measured with respect to north. This value always falls between 0°, due north, and 180°, due south. Stria tion direction is assigned only when field evidence permits a unique determination of ice-flow polarity. Stoss-and-lee forms 5-10 cm high are the primary field evidence used to separate the two. Age associations between multiple striations are determined through the use of geometric and crosscutting relations.

Within the study area, striations trend northwest-southeast to north-south (Fig. 3) with minor variations reflecting topographic control. For example, on Dorr Mountain striations partly wrap around the ridge parallel to ridge alignment.

At the few exposed stria tion locations along Otter Creek (Figs. 2, 3), stria tion trends parallel to valley trend, but show changing flow directions. Other examples of this phenomenon occur on the north shore of Compass Harbor (Fig. 3). Here, recent removal of unconsolidated sediment from the bedrock surface has revealed four stria tion sets. The oldest stria tion direction is 130°, and subsequent directions are 155°, 185°, and 215°. A few meters seaward of this location only the oldest, strongest stria tion sets of 130° and 155° remain; the faint, younger stria tions have been removed by wave erosion of the bedrock surface. In the northern part of the study area, the ice flow changed from northwest-southeast to north-south.

In addition to stria tions on near-horizontal surfaces, stria tions occur on vertical and near-vertical surfaces throughout the study area. These stria tions do not always trend horizontally across the vertical rock surface; many stria tions dip at some angle to the horizontal. For these stria tions, the trend recorded was the rock surface strike.

Although extensive stria tion mapping was not conducted on Cadillac Mountain (Fig. 3), spot checks at the summit showed stria tions trending northwest-southeast. This ubiquitous occurrence of striated surfaces in the study area indicates strong glacial abrasion at all elevations. This pattern requires a complete ice cover that was erosive at its base. If intense erosion can only occur some distance behind the margin of an ice sheet (Sugden and John, 1976), then Mount Desert Island must be at that distance from the former ice margin. The ice-flow patterns followed topography to some extent and became reoriented from a northwest-southeast to a north-south direction during the later stages of flow.

Friction cracks are widespread in the study area. They are best developed on the southern end of ridges aligned parallel to ice flow. For example, the Beehive lies south of Enoch Mountain (Fig. 2) and displays the highest density of friction cracks in the study area.

The friction cracks in the study area are of three different types. Crescentic gouges, comprising most of the friction cracks, range in width from 5 to 150 cm and in depth from 0.5 to 15 cm. A typical goug e measures 25 cm wide and 3 cm deep. Rare lunate fractures are smaller than crescentic gouges; typically, they are 10 cm wide and 2 cm deep. Chattermarks also occur in limited numbers and range from 3 to 10 cm in width. Crescentic gouges and lunate fractures furnish information about ice-flow trend. A line bisecting the horns of these features parallels ice-flow direction, and the primary fracture dip determines the flow direction (Harr is, 1943). Typical directions of inferred ice-flow range between 130° and 170°, with extreme values from 10° to 245°. At locations where friction cracks and stria tions occur together, the trends of both typically agree within 10°, with a maximum difference of 50°. Stocum (1978) reported similar observations from a detailed study on the north slope of The Beehive. There he showed that 78 percent of 151 measured friction cracks indicate ice-flow direction between 160° and 190°.

**Glacial Troughs**

The pronounced topography of Mount Desert Island exists because of a highly resistant granite core. Processes of fluvial erosion have been more effective in removing the surrounding, weaker rocks than in removing the hornblende granite (Chapman and Rioux, 1958). However, fluvial processes alone are not an adequate explanation for the high relief present today. Ten or twelve through-going valleys cut the resistant bedrock almost to, and in one case below, present-day sea level; this represents up to 400 m of relief. One example of such relief, Otter Creek valley, will be described below in detail and the evidence used to support a model of trough valley formation.

**Description of Otter Creek Valley.** Otter Creek valley, which extends from Otter Cove through The Gorge to the Great Meadow and Bar Harbor (Figs. 2, 4a-d), cuts deeply into the granite bedrock and lies between Huguenot Head and Champlain Mountain on the east, and Dorr and Cadillac Mountains on the west. The 7.5 km north-south profile (Fig. 4e) is low and flat with the watershed divide at an elevation of 40 m located 600 m south of The Tarn. Lowell (1980) presents a more detailed description of the valley profiles.

In an east-west direction, the valley displays different widths at different locations (Fig. 4a,b,c). At Great Meadow the
Figure 3. Striation map of study area.
valley is 900 m wide, whereas to the south at The Tarn the valley attains its narrowest width of 150 m (Fig. 4a). Farther south, the valley widens in a step-like manner, first to 600 m wide, then to 1.3 km (Fig. 4b), and finally to 1.5 km (Fig. 4c).

Otter Creek valley also varies in the shape of its cross-valley profiles. Near The Tarn, the valley cross-section shows a flat floor between steep walls (Fig. 4a). Two meltwater channels (see below) accentuate the relief, but the 2-m deep lake (The Tarn) is not in itself the cause of the flat floor. To the south, an asymmetrical profile is present (Fig. 4b). However, south of Dorr Mountain, valley sides have nearly symmetrical profiles (Fig. 4c). Only a small part of the profile near the bottom of Otter

Figure 4. Cross valley (A-A', B-B', C-C') and longitudinal (D-D', E-E') profiles of Otter Creek valley. See Figure 6 for location of profiles.
Creek valley may result from unconsolidated deposits. From north to south in the valley, steep symmetrical walls (Fig. 4a) are replaced with asymmetrical walls (Fig. 4b), which give way to gentle symmetrical walls (Fig. 4c).

**Model of Formation.** Otter Creek valley, with its through valley form, glacial striations throughout, parabolic cross-section, deeply-incised bedrock, irregular floor, and open ends, matches the definition of an open trough (Sugden and John, 1976, p. 129). Open-ended glacial troughs, particularly those of Mount Desert Island, were assigned the term dorr (Chadwick, unpub. manuscript). The term is reintroduced here to describe Otter Creek valley and other open-ended troughs.

The dorr's on Mount Desert Island have been attributed to glacial modification of existing fluvial valleys. Raisz (1929, p. 140) suggested that submature to mature fluvial topography resulted from uplift and stream rejuvenation. Subsequent glacier ice flowed through fluvial saddles and eroded the valleys to their present depths. Further, Chapman and Rioux (1958) suggested that mature fluvial development produced valleys trending N10°E and that glacial erosion subsequently caused a shift of the valleys to a N15°W trend.

However, these theories which attribute the formation of Otter Creek valley to fluvial erosion are inadequate for several reasons. First, the small drainage area available on Mount Desert Island would not provide the water necessary to incise the valleys to their present depth. Second, fluvial erosion could not produce the flat longitudinal or U-shaped cross-valley profiles present today. Third, it is unlikely that fluvial erosion would produce several parallel, closely spaced troughs that exist across Mount Desert Island. Therefore, an alternate explanation for the overall topography of Otter Creek valley and other dorr's on Mount Desert Island is that they were formed by glacial activity.

Shaler (1889, p. 1005-1009) suggested that glacial exploitation of bedrock weaknesses caused the trough formation. Convergent ice flow in the northern portion of the valley increased glacial erosion, whereas divergent ice flow in the southern portion of the valley lessened glacial erosion (Shaler, 1889). Sugden (1968, 1974) and Sugden and John (1976) refer to this as selective erosion. In addition to ice-flow speed, selective erosion also depends on areal changes in the thermal conditions of glacial ice and bedrock structure. Glacial erosion of bedrock depends largely on quarrying activity, as abrasion is not a major factor in overall surface lowering (Boulton, 1974, p. 63). The depth of quarrying or plucking depends on exploitation of structural weaknesses in bedrock. For granite bedrock, quarrying can be quite important because the major structural weaknesses are widely spaced sheeting planes and joints. Overburden removal by quarrying sets up internal stresses that can cause dilation cracks in the bedrock thus allowing continued quarrying (Lewis, 1954; Harland, 1957; King, 1970). The process allows continued production of bedrock fractures during glaciation. This constitutes the positive feedback mechanism King (1970) envisioned.

In addition to rock structural weaknesses, glacial erosion may involve subglacial water. The effects of basal meltwater on erosion are difficult to assess, but may be considerable (Boulton, 1974, p. 63). Holte dah (1967) demonstrated fluvial erosion at trough heads. The presence of meltwater at the glacier bed has several other important functions: (1) Confined water exerts hydrostatic pressure that controls the effective pressure of the overlying glacier ice. Effective pressure controls whether glacial erosion or glacial deposition occurs (Boulton, 1972, 1974). (2) Water freezing within bedrock fractures loosens the rock. (3) Water freezing onto basal ice incorporates loose rock into the glacier bed. (4) Water in subglacial cavities controls the stress distribution in bedrock. For subglacial cavities filled with water, overburden stress is transmitted equally to the rock, but in subglacial cavities without water, stresses are distributed unequally to the rock and fracture is likely (Boulton, 1974, p. 63).

Finally, subglacial topography influences glacial erosion. Valley floors, with limited relief, are not effective erosion locations. However, bedrock protrusions or escarpments are easily eroded because two or more bedrock surfaces are already free. Crosby (1928, p. 1170) noted that "...a glacier, if it is to do much erosive work by plucking, must have an escarpment to gnaw at or its (erosion) output will be limited mainly to impalpable rock floor..." Linton (1963) describes this as the ability of a glacier to "bite down," and uses the term to describe glaciated terrain because it is so characteristic of glaciation. One location that glaciers "gnaw at" is the down-ice (lee) side of a resistant mountain range. Erosion, first occurring on the down-ice side of the mountain range, would remove material at the escarpment site. This erosion site would migrate opposite to ice-flow direction and would eventually form a valley or trough, and for a small mountain range, erosion could cut through the entire range to produce a dorr. Formation of such a dorr might require several glaciations, such that each successive cycle of erosion would begin where the previous one left off. I propose that Otter Creek valley (Fig. 3) is a dorr resulting from selective glacial erosion of the Cadillac Mountain granite pluton.

The size of the valley reflects equilibrium conditions between ice discharge and erosion. For a given ice flow, there is a certain equilibrium size; a smaller ice discharge will have minor erosional impact. Haynes (1972) has reported this relationship in the troughs of outlet glaciers. The southern symmetrical portions of Otter Creek valley result from complete rock removal and thus complete adjustment. However, in many sections the valley profile indicates that an equilibrium size has not been reached (Fig. 4). Huguenot Head (Fig. 3) was the site of active erosion during the last glaciation and represents the trough head. The Tarn represents a smaller dorr within Otter Creek valley. Future glacier activity will erode Huguenot Head backward to produce an effective cross-sectional area that can discharge ice through Otter Creek valley. Evidence of erosion by this plucking process indicates that pressure melting conditions existed at least as high as Huguenot Head (222 m).
Some estimation of the conditions under which the intense erosion occurred can be gathered from the work of Rothlisberger and Iken (1981). They indicate that optimum conditions for plucking are sufficiently and suitably jointed bedrock, large amplitude of water-pressure fluctuations, and a high basal shear stress (for cavity formation). The granite bedrock of Mount Desert Island has abundant fractures, and the evidence of glacial plucking is common. Thus, if the mechanism suggested by Rothlisberger and Iken (1981) operated on Mount Desert Island, then we can infer that basal conditions included large amplitude water-pressure fluctuations and a high basal shear stress.

Although erosion seemingly must occur some distance back from the ice margin, the present understanding of the processes of plucking and the exact conditions present on Mount Desert Island do not allow quantification of the distance between the ice margin and the site of the plucking. However, because of the desirability of large water-pressure fluctuations and high basal shear stress, I suggest that the intense plucking described here occurred as the ice underwent accelerated flow during drawdown conditions that have been suggested for the Gulf of Maine region (Denton and Hughes, 1981). The conditions suggested by Rothlisberger and Iken (1981) are consistent with that view.

**Glacial Cirques**

**Description.** Several topographic features that exhibit the morphology of basins or theaters occur on Mount Desert Island's mountains. The basins are entirely bedrock expressions and, except for one basin, they have no associated deposits. Steep faces on south-trending ridge lines mark the backwalls of these basins and bedrock arms extend from the faces to form the sides of the basins. Although the basins have similar morphology, overall dimensions vary.

The best-developed basin lies between The Beehive and Enoch Mountain (Figs. 2, 5) and faces east. The west and north walls of the basin rise steeply from the basin floor for 55 m, and the south wall, 50 m high, grades into the gentle north slope of The Beehive. Superimposed on the steep walls are 1 to 5 m high stoss-and-lee forms oriented north-south.

Three basins of different size lie on the south ridge of Dorr Mountain (Fig. 5). The smallest is situated at an elevation of 170 m. The south ridge forms the east and north walls of the basin, and rockslide debris rests against the basin's 20 m high north wall. A second bedrock ridge forms a common boundary for the west wall of this basin and the east wall of a second, larger basin. The north wall of the second basin rises from the basin floor, and within 5 m of the wall top, bedrock steps display striations with a 150° trend as do striations north of and above the basin. A third basin contains the first and second basins; however, definition of the third basin is poor. All of these interrelated basins face south from Dorr Mountain.

Another basin on the north end of Champlain Mountain (Fig. 5) faces southeast. Similar in morphology but somewhat smaller in size than the other basins, this basin floors at 150 m above sea level. A bedrock lip and three walls enclose the 20 m by 20 m partially wet floor. In the center portion of the wall, P-forms (Sudgen and John, 1976) are etched into the wall to a height of 5 m above the floor. Along the top of the south wall, friction cracks trend southeast parallel to the basin trend. All of these basins have similar morphology, orientation and associated features, thus they likely have a similar origin.

**Discussion.** The significance of the above features requires a critical examination of their origin. First, however, classification of the basin is necessary. Evans and Cox (1974, p. 151) have defined the morphology of a cirque as:

A hollow open downstream but bounded upstream by the crest of a steep slope (headwall), which is arcuate in plan around a more gently sloping floor. It is "glacial" if the floor has been affected by glacial erosion while part of the headwall has developed subaerially, and a drainage divide was located sufficiently close to the top of the headwall for little or none of the ice that fashioned the cirque to have flowed in from outside.

The term cirque commonly implies a present or former cirque glacier (Haynes, 1968; Flint, 1971; Davies, 1972; Embleton and King, 1975; Sudgen and John, 1976, p. 199). Raisz (1929, p. 159) suggested a multi-stage glacial sequence for formation of the Amphitheater on Penobscot Mountain west of the study area. Although the morphology of the basins in the study fit the definition of a cirque, there is no evidence to indicate subaerial development. Therefore, the basins may be called cirques, but the application of the term glacial does not apply as defined above because of the lack of subaerial headwall development.

Except for the basin near The Beehive (Fig. 5), the small size of the basins in the study area casts some doubt on their having been sites of active cirque glaciers. Moreover, all these basins face south or southeast at relatively low elevations. Thus they are not likely sites to produce glacier ice. The lack of similar features facing northward suggests climate did not control their development. Therefore, an alternative for the cirque glacier hypothesis is needed.

The presence of glacial erosional features such as striations and friction cracks in, near, and above the basins indicate active erosion at these locations during the last glaciation. Furthermore, the presence of P-forms on one basin wall indicates the presence of subglacial meltwater (Dahl, 1965; Holtedahl, 1967) which aids glacial quarrying. The orientation of these basins allowed removal of rock in the down-glacier direction. Ice, flowing at a full-bodied stage, would conform to the topography of the bedrock ridges, enclosing the ridge without a cavity. As the ice moved past the southern end of a ridge, a tensile force would be created at the ice-bedrock interface (T. J. Hughes, pers. commun., 1979). This tensile force could remove loose portions of bedrock from the ridge. As the tensile force is concentrated at that position, bedrock erosion would also be concentrated, causing the formation of an indentation or basin on the southern
Glacial geology of Mount Desert Island

Figure 5. Surficial geologic map of the study area.
or lee ends of the ridges. Therefore, since an alpine glacier origin is unlikely, I conclude that the cirques in the study area are glacially produced beneath an ice sheet where pressure melting and plucking could occur.

**Glacial Meltwater Channels**

**Description.** Two major and two minor gorges are cut into bedrock at high elevations between ridges of the study area. The largest gorge, located between Cadillac and Dorr Mountains (Figs. 2, 5), displays a striated and polished east wall above an elevation of 322 m. Below this elevation, bedrock surfaces are either fresh and angular where rockfall and rockslide are active or it is smooth and undulating. The mass wasting activity produces an accumulation that partly covers the gorge floor.

Below the debris is an unknown thickness of diamicton with a flat east-west upper surface. The diamicton floor drops to the north or south from the central portion of the gorge floor. Debris is also accumulating against the west wall 150 m west of the east wall. Fresh, angular surfaces extend to the top of the west wall where the surface is smooth and planar. Just above the top of the wall a 200 m wide platform extends west to the western summit of Cadillac Mountain (Fig. 2).

A similar but smaller gorge lies between Huguenot Head and Champlain Mountain (Fig. 2). Both possess striated and polished surfaces adjoining smooth, undulating water-worn surfaces, active rockslide and rockfall, flat diamicton-covered floors, and platforms situated to the west of the gorges.

Two smaller gorges, similar in form to each other, occur near The Beehive (Fig. 5); the first, located between The Beehive and Halfway Mountain, has a floor that is 100 m wide at 135 m elevation. Striated and polished bedrock walls extend only 3 to 4 m above the floor, marking the vertical extent of the gorge. The diamicton cover along the floor of the gorge extends north into the depression containing the pond called The Bowl (Fig. 2) and extends south into a V-shaped continuation of the gorge. Within the continuation, an underfit stream erodes diamicton. The second gorge lies between the east side of Champlain Mountain and Enoch Mountain (Figs. 2, 5). Vertical gorge walls trend southeast in the northern part of the gorge. However, within 40 m to the south, the walls trend south. The floor of the gorge is at 110 m elevation and is diamicton covered. The southern end of the gorge terminates abruptly at the cirque north of The Beehive. The gorge opens into the top portion of the north wall of the cirque. These two small gorges both possess diamicton-covered floors and bare rock walls similar in morphology to the larger gorges described above.

**Discussion.** Derbyshire (1962) classified three major types of glacial drainage channels on a genetic basis: marginal, submarginal, and subglacial. Some characteristics of subglacial channels include: flat diamicton-covered floors, steep ice-molded walls, occasional gradient reversals, and irregular longitudinal profiles (Sissons, 1961, 1962; Derbyshire, 1962; Sugden and John, 1976). The gorges on Mount Desert Island exhibit flat diamicton-covered floors, oversteepened walls that allow rockslide activity, striated and polished surfaces, and smooth and undulating surfaces. Therefore, I conclude that these gorges are subglacial meltwater channels.

The transition between striated and polished surfaces, and smooth undulating surfaces produced by fluvial erosion, marks the boundary between active ice and water. In order for the transition to be situated on the channel walls, the ice and water must both be present simultaneously; this implies active ice. Furthermore, in order for diamicton deposits to remain on the channel floor, its deposition must have occurred during late ice dissipation to have avoided erosion by glacial meltwater. Therefore, final ice dissipation probably involved a thin, active ice cover. Since the meltwater must have flowed down to the 322 m elevation, the ice thickness must have been higher than that elevation.

**SURFICIAL GLACIAL DEPOSITS**

The surficial glacial deposits (Fig. 5) have a depositional pattern reflecting the basal glacial conditions and the subsequent marine invasion and deglaciation. In the sections that follow, the term till is used since the diamictons here are all interpreted to be glacial in origin.

**Till**

**Areal Occurrence.** The most extensive surficial glacial deposit in the study area is till, and the distribution of till is largely dependent on elevation and topography. Below elevations of 90 m, a nearly continuous till cover lies on the floor of Otter Creek valley (Fig. 5), whereas above this level till is rare and exists only as small patches in depressions. The higher till patches vary from a few square meters in size to areas as large as the depression containing The Bowl (Fig. 5). Although a continuous till cover does not exist at higher elevations, scattered erratic pebbles, cobbles, and boulders are present.

Till in the study area generally forms a blanket cover with little or no surface morphology. The present till morphology is erosional, not depositional. Intermittent streams, with channels that originate in zones of bedrock weakness, have cut through the till blanket separating it into discrete lobes. Its thickness is typically 3-4 m and reflects the underlying bedrock topography; bedrock knobs ranging from 10 to 100 m long protrude through the thin till cover. The lobes do not extend completely across the valley; a break-in-slope near 50 m elevation marks the lower end of the till lobes. At this location, emerged marine sediments overlie the till deposits.

The only location where the till forms independent topography is near Otter Cove where it forms a moraine (Fig. 5). Fine-grained emerged marine deposits (see below) also overlie this moraine which has stratified lenses intermixed with the till.

**Description.** To obtain representative samples of the till, five trenches were dug along existing scarps in Otter Creek
Glacial geology of Mount Desert Island

Valley (Fig. 6); Lowell (1980) provides a complete description of trench location, stratigraphy, and sample information. In summary, these show that a textural change occurs between different locations in the valley. Till exposed in the north or central portion of the valley is compact to very compact, light olive to olive color, and silty to sandy in texture. Average grain-size distribution for this till is 10% gravel, 36% sand, and 54% silt and clay. However, till exposed in the southern portion of the valley is loose, light olive to tan in color, and sandy in texture. Average grain-size distribution for this till is 20% gravel, 49% sand, and 31% silt and clay.

Till fabric (TF) analyses were performed in five of the trenches (Lowell, 1980). Six till fabrics, obtained by measuring 50 stones with a minimum long (a-axis) to intermittent axis ratio of 2:1, are plotted as rose diagrams (Fig. 6). Whereas TF-6 was taken from a horizontal face to verify sampling procedure, all other measurements were taken from vertical faces.

TF-1, from 1.8 m depth, shows a random or weak bimodal fabric, whereas TF-2, from 3.5 m depth, shows a strong preferred east-west orientation. TF-4 and TF-6, from a depth of 1.4 to 1.6 m, both show a northeast-southwest trend; these two fabrics come from 1 m above a bedrock surface that bears striations trending 22°.

Samples of 100 randomly selected cobbles and pebbles from trenches 2-5, and of 25 stones each from other exposures constitute the clast data (Fig. 7). For each stone the following observations were recorded: length of three mutually perpendicular axes (a,b,c); roundness, presence or absence of fracture, presence or absence of striations, striation pattern, and clast lithology. The b:a axis ratio and the c:b axis ratio were calculated; these ratios allowed placement on a Zingg (1935) diagram, which gave a shape classification of each stone. The clast analysis provides insight into the origin of the till.

The total clast sample (650 stones) shows the following trends (Fig. 7). Disk-shaped clasts are slightly more numerous than spherically shaped clasts (38% compared to 28%). Clast roundness shows a normal distribution with a slight preference toward rounded clasts. Fractured clasts, those displaying at least one angular surface, represent 85% of the sample population. Striated clasts, representing 29% of the total sample, are further classified according to striation pattern (random, 39%; sub-random, 30%; sub-parallel, 20%; and parallel, 6%). Classification of the till clasts by lithology is based on mapped bedrock units (Chapman, 1974). Gabbro and diorite rocks comprise 43%; hornblende granite 18%; the metasedimentary Bar Harbor Formation 14%; and the metamorphic Ellsworth Formation 12% of the sample clasts.

Discussion. The nature of the till deposits suggests a subglacial origin. The oriented fabrics suggest a change from compressive conditions in the center of the valley, which produced transverse fabrics, to extensional conditions in the southern portion of the valley, with fabrics parallel to ice flow. This agrees with the stress conditions necessary for effective erosion in the trough. The shape, striated surface, and fractured portions of the clasts also indicate a subglacial origin for the till (Boulton, 1978). The change in texture reflects active entrainment and deposition.

Given this origin, we can infer some subglacial conditions based on the area distribution of the till. Since the primary sites of deposition are located below 90 m above sea level and sites above that elevation are generally till free, that elevation may mark a transition in basal conditions. At the lower elevations, the thicker ice is more likely to be the site of entrainment and deposition. The higher elevations are erosion and entrainment sites only. The distribution of erosion features supports this concept (Fig. 8).

Emerged Glacial Marine Deposits

Emerged glacial marine deposits are the youngest glacial deposits in the study area, and their distribution is restricted to the floor of Otter Creek valley (Fig. 5). This study has noted the distribution and field description of these deposits, but no attempt was made to investigate, in detail, the late-glacial marine chronology and its extent.

Areal Distribution. Emerged marine deposits are primarily restricted to the lower portions of Otter Creek valley. An eroded bench in a 10 m thick deposit near 85 m elevation on Canon Brook (Fig. 2) may mark the upper limit of the last marine invasion in Otter Creek valley. Along the floor of the valley, emerged marine deposits form a nearly continuous cover from Otter Cove in the south to Compass Harbor in the north (Fig. 5); this gives Otter Creek valley its flat floor. Increased relief in the southern portion of the valley results from active gully erosion of up to 10 m in the emerged marine deposits. In most trenches and test pits, the thickness of the marine deposits is less than 50 cm. The varying thickness of the emerged marine deposits results from, as well as influences, topography.

Physical Description. Emerged marine deposits exhibit a wide range of textures. Commonly, the deposits are light tan to olive in color, silt-sized, compact, and massive. Grain-size analyses of the sediment show that the material is 3 percent sand, 87 percent silt, and 10 percent clay. This silt locally contains dropstones up to 20 cm in diameter. However, other exposures of the emerged marine sediments show textures ranging from fine sands to boulder deposits. For example, trench 5 contains a well-sorted pebble-cobble gravel and well-sorted coarse sand over a stony till unit.

Relation to Other Deposits and Discussion. The stratigraphic relationship between emerged marine deposits and glacial till deposits varies. In many localities the marine deposits lie above the tills. However, in trench 4 in the moraine in Otter Creek valley (Fig. 6), marine silt and clay are interbedded with a loose sandy till. Furthermore, folded clay beds, isolated, tilted clay stringers and clay balls, and abrupt unit contacts indicate glaciotectonic contortion of marine sediments. Near the junction of Route 3 and Otter Cliff Road (Fig. 2) an abandoned borrow pit shows marine silt and clay at the base of the pit under a loose sandy till. This marine unit extends south from the pit to

113
Figure 6. Locations of till fabrics (TF) and trenches. Circle on rose diagrams represents 10% of count (n=50). Heavy lines are locations of profiles shown in Figure 4.
become the surface unit to Otter Cove, and it is the same unit comprising the uppermost material in trench 4. Marine sediments both over and incorporated into till indicate that till deposition occurred contemporaneously with the marine sediments. The inclusion of clay in till and the areal distribution of the deposits suggest a slight readvance of glacier ice into the marine waters.

An exposure in Otter Cove (Fig. 2), located at Fabbri Memorial (Fig. 6) illustrates the stratigraphic relationship. The uppermost unit of imbricated cobble gravel overlies a compact clayey silt that contains dropstones. The clayey silt grades downward to a silty sand resting conformably on sandy till. Slump deposits extend from the exposed till to striated bedrock 6 m lower. This section displays emerged marine deposits overlying till and striated bedrock and reflects the general sequence of events.

Postglacial Lacustrine Sediments

Description of The Bowl Core. The Bowl (Fig. 2), which has a surface elevation of 127 m, was cored to provide chronological control on deglaciation and to provide a maximum elevation of marine submergence. Drainage into the pond is from the north along a bedrock gully containing till that extends under the pond.

Sounding of water and probing of the sediment showed that bedrock topography and sediment accumulation control the lake-bottom configuration. The northwest portion of The Bowl, although adjacent to steep bedrock slopes, is shallow because of accumulation of sediment derived from the inlet stream. The deepest location sounded (10.7 m of water) is east of the inlet 55 m from the north shore to the east of the inlet location; this was the coring site.

At the coring site, a three-section 7.5 m core was obtained with a 5 cm modified Davis piston corer through pond ice, and retained in the aluminum core tubes until extruded in the laboratory. The core stratigraphy is described below from bottom to top. Dents in the core tube suggest that refusal occurred on a stone rather than on bedrock; therefore, the total depth of sediments overlying bedrock is unknown, but it is at least 7.5 m. The lowest material, which is interpreted as till, underlies a gray sandy-silty material, above which lies a sand unit that contains rare fresh-water diatoms of the genera *Stauroneis*, *Tabellaria*, and *Frustulia*. The sand unit underlies a mixture of sandy gravel

---

**Figure 7. Clast analysis of various till samples from study area.**

<table>
<thead>
<tr>
<th>Shape</th>
<th>Disk</th>
<th>Sphere</th>
<th>Rod</th>
<th>Blade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundness</td>
<td>Angular</td>
<td>Sub-angular</td>
<td>Sub-rounded</td>
<td>Rounded</td>
</tr>
<tr>
<td>Fractured</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Striated</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Striation pattern</td>
<td>Parallel</td>
<td>Sub-parallel</td>
<td>Sub-random</td>
<td>Random</td>
</tr>
<tr>
<td>Lithology</td>
<td>Hornblende granite</td>
<td>Biotite granite</td>
<td>Gabbro &amp; Diorite</td>
<td>Bar Harbor Fm</td>
</tr>
</tbody>
</table>

---

115
and sand containing minor amounts of unidentified plant fibers and freshwater diatoms of the genera *Cymbella, Pinnularia, Diploneis, Gyrosigma,* and *Fragilaria.* A gray silt that becomes darker and laminated away from the base overlies the sandy gravel and sand. Freshwater diatoms of the genera *Cymbella,* *Fragilaria,* *Gomphonema,* and *Pinnularia* were identified in a sediment sample taken from below the lowest distinct laminations within the gray silt unit. Within the laminated gray silt unit is a 2 cm thick zone of plant fibers that underlies gray-tan silts that grade upward into organic gyttja.

**Radiocarbon Age and Discussion.** In order to obtain a radiocarbon date, 10 cm of material was removed from the lowest organic-rich (6%) layer of The Bowl core. The date (11,335 ± 125 yr B.P.; SI-4043) reflects the beginning of significant postglacial organic accumulation. Diatoms and plant fibers, which are below the radiocarbon sample location in the core, indicate ice-free conditions before 11,335 ± 125 yr B.P.

A second radiocarbon date was obtained from nearby Sargent Mountain Pond. Sargent Mountain Pond, at 355 m elevation, lies between Penobscot Mountain and Sargent Mountain, 5 km due west of The Bowl. During coring, it was discovered that the coring apparatus could not cut through a lake-bottom mat of aquatic moss; as pressure was applied, the moss mat pushed through the soft underlying sediments and acted as a strainer which allowed disrupted sediment into the core tube. At a depth where the underlying sediment was firm enough to resist the moss, the core tube cut through the moss and retrieval of undisturbed gravel was possible. The depth of recovered gravel was 9.8 m below the water-sediment interface in 3.5 m of water. The total carbon of the gravel sample was used for radiocarbon dating.
and yielded a date of 13,230 ± 360 yr B.P. (SI-4042). The large errors resulted from the low (~1%) carbon content (Robert Stuckenrath, written commun., 1979). This date only constrains the glacial history by showing that ice must have covered this elevation until at least 13.2 ka (i.e. subaerial conditions could not have existed at 21 ka). A third radiocarbon date of 12,250 ± 160 (Y-2241; Stuiver and Borns, 1975) from the west side of Mount Desert Island dates a portion of the marine invasion.

A consideration of these dates suggests the following chronology for Mount Desert Island. Sometime prior to 13.2 ka, the highest portion of the island became exposed. Subsequent to this, around 12.2 ka, marine waters rose against the island and left deposits. From the spatial relationship of these deposits it seems likely that the marine waters removed all the remaining ice from the valley floors. Significant organic accumulation in the lacustrine environment lagged the marine invasion on the order of 1 ka.

The Bowl core has a second important aspect. The exclusive occurrence of freshwater diatoms indicates that the marine invasion was restricted to elevations below 127 m.

SIGNIFICANCE OF THE EVIDENCE FROM MOUNT DESERT ISLAND

From the nature of glacial erosion features and glacial deposits on Mount Desert Island, I conclude that a late Wisconsin ice sheet overran the island. The absence of weathering zones or tors on higher mountains, as well as the presence of freshly striated bedrock and plucked faces near the summit of Cadillac Mountain, indicates that ice covered Cadillac Mountain to sufficient thickness to produce erosional features and striated bedrock surfaces at all altitudes. Bedrock quarrying occurred as meltwater locally froze onto the glacier base. The age of this ice cover is assigned to the late Wisconsin because postglacial lacustrine sediments yield dates of 11,355 ± 125 (SI-4043) and 13,250 ± 360 (SI-4042) yr B.P., and because detailed bedrock surface studies (Lowell, 1980) indicate no differences in length of bedrock weathering since the last ice cover. These dates bracket deglaciation at Mount Desert Island only. The available evidence does not indicate when this glacial cover began.

Specific late Wisconsin ice conditions deduced from the field evidence are: basal melting in the valley bottoms that allowed deposition of basal till, a melted ice base over the ridges that allowed localized freezing and quarrying, and ice covering Cadillac Mountain and filling adjacent bays to a thickness of at least 600 m (Fig. 8).

As eustatic sea level rose, sea water rapidly removed ice from the valleys through tidal flushing within the valley confines. Interbedded marine and glacial sediments indicate minor fluctuations of glacier ice into marine waters during deglaciation. Maximum marine submergence must have been less than 127 m. Final deglaciation of Mount Desert Island was controlled by a marine transgression.

ACKNOWLEDGMENTS

The Maine Geological Survey funded portions of the field work. Mr. Bob Roth of Acadia National Park assisted with several aspects of the study. Mary Hodgkins identified the diatoms. Melissa Bass typed the present manuscript. Tom Weddle, Geoff Smith, and Ralph Stea reviewed this work and made many helpful suggestions. Special thanks go to George Denton who suggested, supervised, and pushed this project in the right direction.

REFERENCES CITED


Grant, D. R., 1977, Glacial style and ice limits, the quaternary stratigraphic record, and changes of land and ocean level in the Atlantic Provinces, Canada: Geographie Physique et Quaternaire, v. 31, p. 247-260.


Harris, E. E., 1943, Friction cracks and the direction of glacial movement: Jour. Geology, v. 51, p. 244-258.


