

# THE MORPHOLOGY AND SEDIMENTOLOGICAL ANALYSES OF ROGEN MORAINES, CENTRAL AVALON PENINSULA, NEWFOUNDLAND

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## ABSTRACT

*This study examines the morphology and sedimentology of Rogen moraines that occupy an area of approximately 160 km<sup>2</sup> in the central Avalon Peninsula, Newfoundland. Moraine morphology is described using a digital-elevation model created for about 40 km<sup>2</sup> of the study area. A preliminary review of this model indicates that there are at least three landform types present within the study area. These are, Rogen moraine, hummocky terrain, and large-scale streamlined bedforms. A distinct northeast–southwest trend to the landscape morphology is likely a result of the underlying bedrock structure. Moraine sedimentology including clast fabrics, lithology, angularity and sedimentary structures are described using the available exposures.*

*It appears likely that the central Avalon Rogen moraines were formed by northeastward-flowing, warm-based ice. The local sediment provenance and sedimentary structures suggest that the moraines were formed subglacially. Clast-fabric data suggest that the sediment was re-deposited by sediment gravity flows. Further analysis and study of the digital elevation model, field data and air photos will be required before formative processes for the central Avalon Rogen moraine can be proposed.*

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## INTRODUCTION

Rogen moraines are subglacial landforms composed of discontinuous, subparallel to parallel ridges oriented transverse to the glacial flow (Lundqvist, 1969). Commonly, the ridges are steep-sided, regularly spaced, and variably composed of diamicton, gravel, sand and minor amounts of silt and clay. On the Avalon Peninsula, Rogen moraines have been previously described by Rogerson and Tucker (1972), Sugden and John (1976) and Fisher and Shaw (1992) as occupying about 160 km<sup>2</sup> of the lowland between Conception Bay and St. Mary's Bay (Figure 1). Across the Province, Rogen and similar moraines make up about 5 percent of glacial landforms, occurring in patches ranging in area from tens to hundreds of square kilometres (Figure 1).

In spite of their relatively common occurrence, the formation of Rogen moraines is poorly understood. Proposed depositional mechanisms include melt-out of stacked and folded debris layers in heavily compressed glacial ice (Shaw, 1979; Bouchard, 1989) and infilling of ripple-shaped cavities formed at the glacier bed by large meltwater dis-

charges (Shaw, 1983, 2002). Although the various mechanisms for the formation of Rogen moraines are discussed later, the depositional history of the moraine has important implications for i) ice-flow history of the study area and glacial dynamics, ii) aggregate potential, and iii) sediment provenance and drift prospecting.

The main objective of this study is to determine the glacial depositional process(es) that formed the Rogen moraines of the central Avalon Peninsula by sedimentological examination and through a morphological description using a Digital Elevation Model (DEM) and air photos.

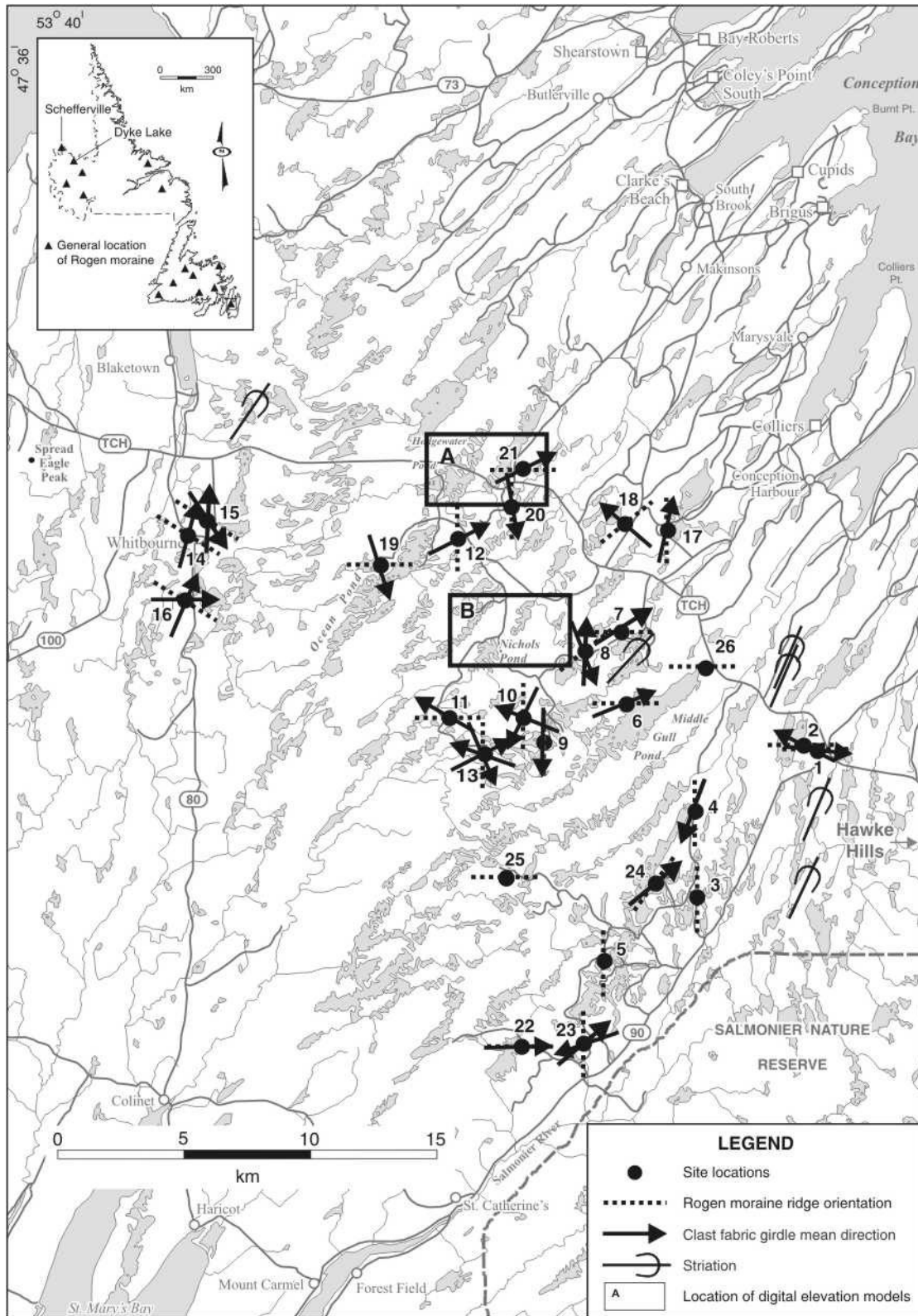
## REVIEW

### Description

Lundqvist (1969) applied the name “Rogen” moraine to the moraine he examined near Lake Rogen, Sweden. They are found in groups that occupy a few dozen to several hundred square kilometres within regional basins or troughs, generally away from predicted ice-dispersal centres. Individual moraines vary in morphology but most are 5 to 25 m

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**Figure 1.** Study area, indicating location of places mentioned in the text, the location of study sites, Rogen moraine ridge orientations, clast-fabric girdle mean directions and relevant striation data. Also note the location of the two digital elevation models (A and B) shown as lettered boxes. Inset shows location of places mentioned in the text outside of the Island of Newfoundland, and also locations of other Rogen moraines in Newfoundland and Labrador.

high, 100 to 450 m wide and 0.5 km to 5 km long and are sinuous and sometimes anastomosing, evenly spaced, usually at distances similar to their widths; the intervening areas tend to be occupied by ponds or bogs, concealing the base of the ridges (Plates 1, 2 and 3). This regular pattern of moraines, ponds and bogs is easily recognizable on aerial photographs (Plate 1). Similar features have been described by Hughes (1964) as “ribbed moraine” due to a shape similar to fish scales or ribs. The ridges are commonly composed of poorly sorted diamicton and show various sedimentary structures (including sorted sands and gravels, convoluted bedding, small faults and lenses) (Lundqvist, 1969, 1989; Shaw, 1979; Bouchard, 1989; Fisher and Shaw, 1992; Hättestrand, 1997).

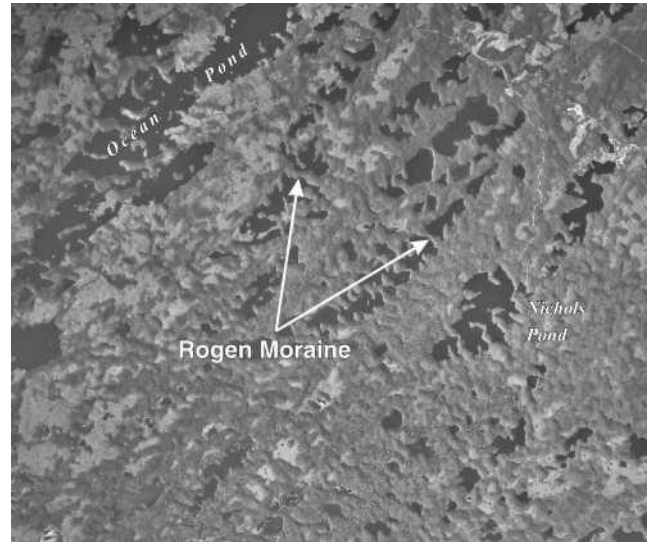
Rogen moraines are part of a sediment-landform association that is characterized by a continuum of intraglacial landforms (Figure 2; Lundqvist, 1969). The Rogen moraine component forms in areas of slow, compressive flow over a concave glacial bed, whereas drumlins form in areas of faster moving ice undergoing extension, above a convex glacier bed (Burgess and Shaw, 2003).

Rogen (ribbed) moraines are common to many regions of Newfoundland and Labrador (Figure 1) and they occupy broad topographic depressions or troughs (Ives, 1956; Henderson, 1959; Hughes, 1964). Individual tracts of these moraines commonly consist of arcuate, sinuous ridges that range in height from 10 to 30 m and are spaced 20 to 200 m apart (Ives, 1956; Henderson, 1959, 1972; Rogerson and Tucker, 1972; Bouchard, 1989; Fisher and Shaw, 1992; Batterson and Taylor, 2004). Studies in Labrador, near Schefferville (Ives, 1956; Henderson, 1959) report a scattering of boulders on Rogen moraine surfaces, and steeper proximal slopes on ridges.

### Rogen Moraine Formation

There are three common depositional models for Rogen moraine formation (Figure 3). These are; the bed-deformation model that requires a change in ice-flow direction and subglacial deformation; the shear and stack model that relies on compressive flow and ice stagnation; and the subglacial meltwater model that requires a massive subglacial flood of meltwater and subsequent glaciofluvial infilling.

The bed-deformation model suggests that Rogen moraines are a precursor to the drumlinization of transverse ridges (Boulton, 1982; Figure 3A). There are two requirements for this model; landforms produced by a previous glacial event must possess alternating sections of weak and resistant sediment, and there must be a change in glacial-flow direction. The change in ice-flow direction leads to the



**Plate 1.** Air photos of Rogen moraines on the central Avalon Peninsula. Note that the Rogen moraine ridges are linear, parallel to one another, evenly spaced, and ponds or bogs commonly occupy troughs between ridges.



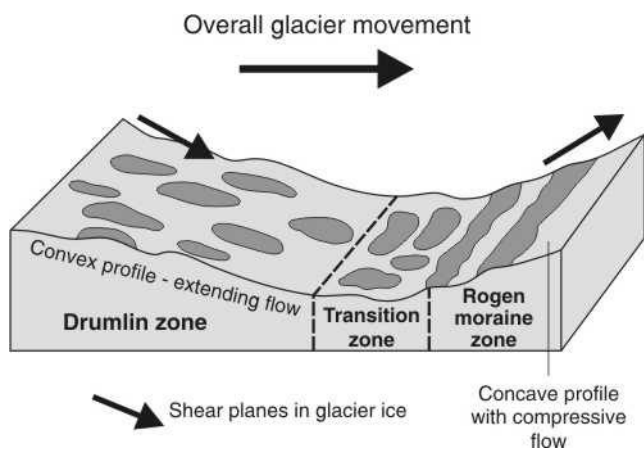
**Plate 2.** Oblique aerial view of Rogen moraines near Ocean Pond, looking south across the Trans-Canada Highway. Note the presence of ponds between the Rogen moraine.

reworking of the previously deposited sediment, moving the weak sediment down ice, and leaving the more resistant ones behind (Boulton, 1982). Lundqvist (1989) used this model to explain the formation of Rogen moraine near Lake Rogen, Sweden.

In contrast, the shear and stack model, which Bouchard (1989) proposed for Rogen moraines in western Labrador, suggests that they formed as ice is compressed up against the down-ice margin of a basin, forming shear planes and stacked slices of debris-rich ice (Figure 3B). Following glacier stagnation, the englacial sediment is lowered to the bed to form linear debris ridges.



**Plate 3.** Photograph looking southeast showing Rogen moraine ridges extending into Middle Gull Pond.



**Figure 2.** Diagrammatic representation of the landform continuum of subglacial landforms. Rogen moraine forms in areas of slow, compressive flow over a concave glacial bed. Drumlins form in areas of faster moving ice undergoing extension, above a convex glacial bed (after Burgess and Shaw, 2003).

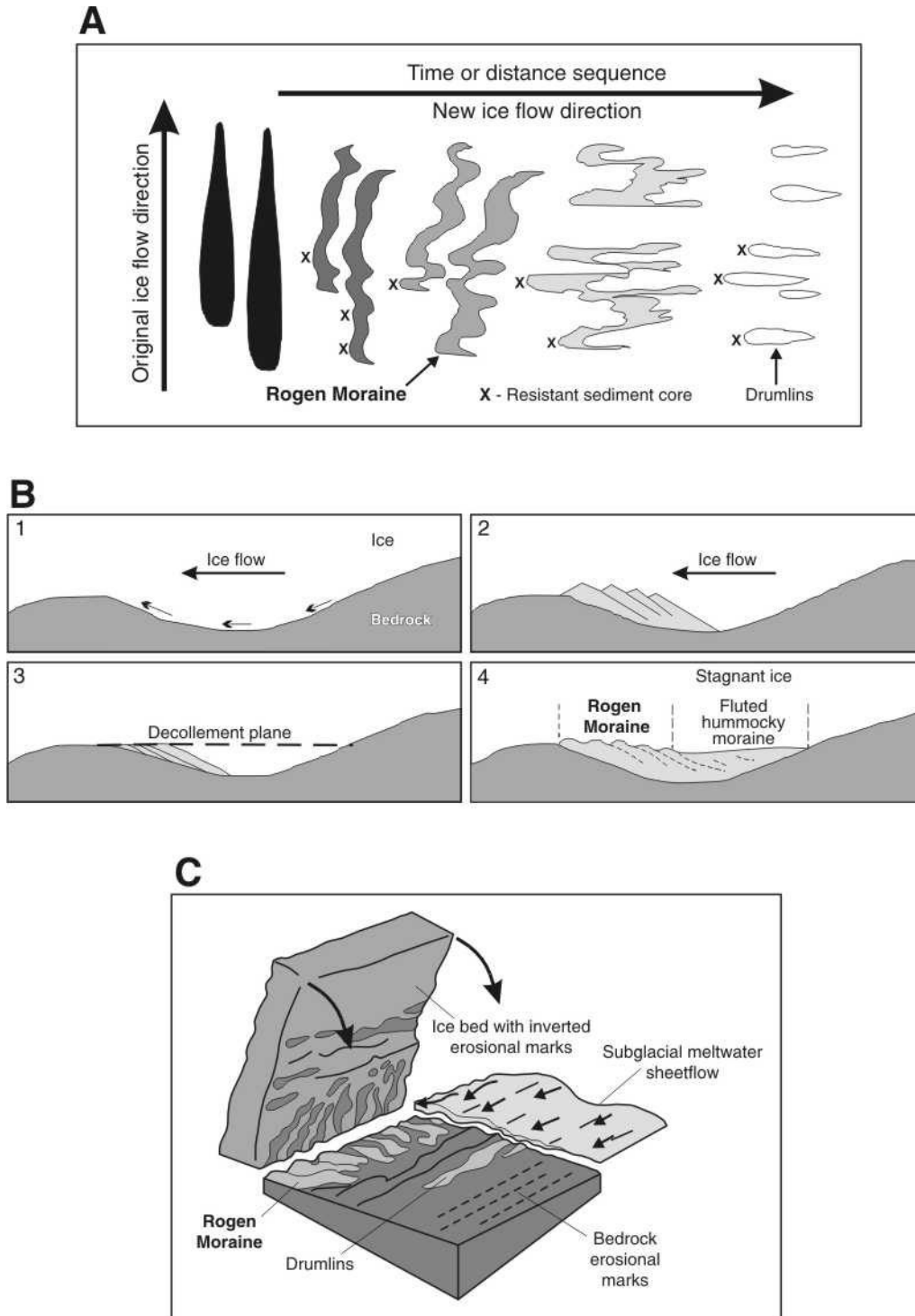
In a third model, the formation is attributed to cata-

strophic subglacial floodwaters moving through a basin (Shaw, 1983, 2002; Figure 3C). The flood erodes grooves on the underside of the thickest ice in the centre of the basin. Rogen moraines are deposited in these grooves as the floodwaters wane and deposition occurs. The overlying ice eventually stagnates. Fisher and Shaw (1992) invoked this third hypothesis for the formation of Rogen moraines on the Avalon Peninsula. They cited two observations as evidence for this mode of formation, including sedimentary evidence of debris flows and fluvial deposits within ridges.

**STUDY AREA**

The central Avalon Rogen moraine field occupies a broad lowland between Conception Bay, St. Mary's Bay, the Hawke Hills (highest elevation at 244 m) and rolling hills (highest elevation at Spread Eagle Peak, 275 m) west of Whitbourne. The basin floor lies about 180 m asl (Figure 1). The lowland occupies the Trinity Bay Synclinorium, a broad syncline that lies between the Conception Bay Anticlinorium that forms the Hawke Hills to the east, and the Spread Eagle Thrust that forms hills to the west (King, 1988).

The study area is located in the Avalon technostrati-



**Figure 3.** Three models of Rogen moraine formation. A) Bed deformation model: It shows two ice-flow directions; one that deposited a linear ridge, and a second that deforms the ridge into secondary landforms including Rogen moraine and drumlins (after Lundqvist, 1989). B) The shear and stack model: It shows glacial ice flows up against the down-ice slope of the basin, slows down and compresses forming shear planes. Rogen moraine forms on the up-ice edge of the basin, while hummocky and fluted moraine form in the centre of the basin (B4) (after Shaw, 1979). C) The subglacial meltwater flood model: Here, Rogen moraine and drumlins are a result of a meltwater flood carving out grooves in the underside of a glacier, and later the same flood deposits the sediment that make up these landforms (after Shaw, 2002).

graphic zone (Colman-Sadd *et al.*, 1990). Bedrock consists of late Precambrian and Palaeozoic sedimentary and igneous rocks (King, 1988). The oldest rocks are the Hadrynian Harbour Main Group that consist of felsic volcanic, rhyolite, basaltic flows, and pyroclastic rocks. The Harbour Main Group extends along the eastern edge of the Rogen moraine field and is fault bounded at the Peak Pond Fault, south of the Avalon Wilderness Reserve. This group is overlain by the Drook and Mistaken Point formations that consist of tuffaceous siltstone and sandstones of the Conception Group. The youngest rocks are from the St. John's Group and include thinly bedded, graded sandstones and minor tuffaceous rocks of the Trepassey Formation (King, 1988).

There is a distinct northeast–southwest lineation to the topography of the central Avalon Peninsula, reflecting the structure and differential resistance of the underlying bedrock. Multiple ridges and troughs are oriented in this direction. The Rogen moraines tend to occupy the troughs, and are oriented perpendicular to the trough long axis (Figure 4). River valleys, such as that occupied by the Salmonier River, also follow this structural control.

## GLACIAL HISTORY

Evidence of glaciation on the Avalon Peninsula during the late Wisconsinan is widespread. Catto (1998) has identified three phases; initial glaciation, glacial maximum and deglaciation. Initial glaciation was marked by the development of several ice-dispersal centres. Ice flowed radially out of these centres and in several places two or more centres coalesced with one another. The lack of erratics from the centre of the island has been used to suggest that the Avalon Peninsula supported its own independent ice cap (Catto, 1998). During the glacial maximum, ice covered the entire Avalon Peninsula. A lowering of global sea level allowed the development of the extensive ice-dispersal centre over St. Mary's Bay (Henderson, 1972; Rogerson and Tucker, 1972; Catto, 1998). This ice-dispersal centre dominated the Avalon Peninsula with the predominant ice-flow direction being generally northward into Conception and Trinity bays. This flow direction has been recorded in the orientation of the Rogen moraine of the central Avalon Peninsula. Deglaciation was accompanied by a rise in sea level, leading to instability of the St. Mary's Bay ice cap, and its eventual break up. Small ice caps likely persisted along upland ridges of the major peninsulas for some time after collapse of the St. Mary's Bay ice cap. The final deglaciation of the Avalon Peninsula occurred by 10 ka BP, based on the oldest basal radiocarbon date from Golden Eye Pond in the Hawke Hills (Macpherson, 1996).

## METHODS

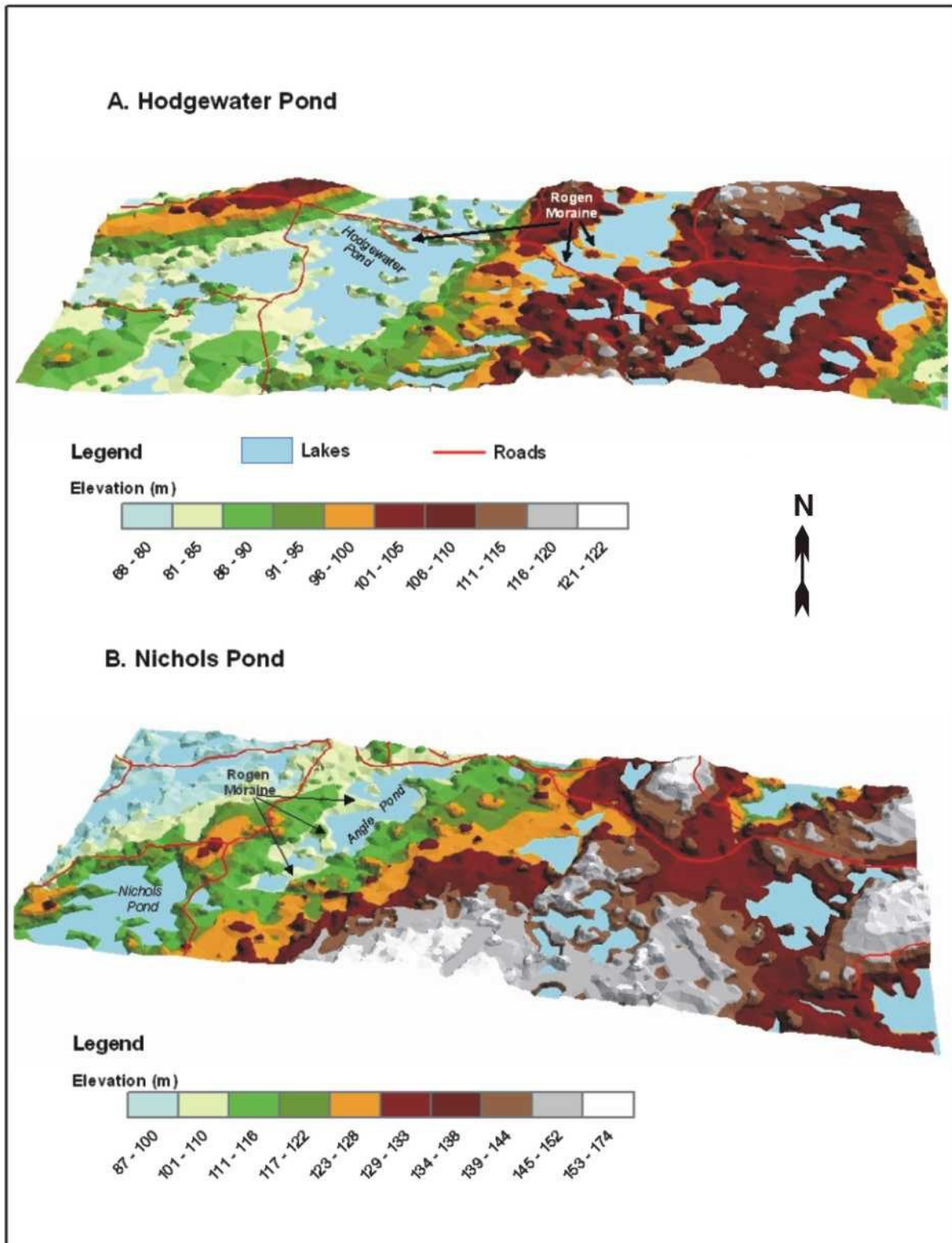
### FIELD WORK

Field data were collected during an eight-week period between June and August 2004. The internal composition of the Rogen moraine ridges has been recorded at 26 exposures, and surface pits were dug to depths of 1 m. Natural exposures were rare and mainly occurred along logging and cabin roads. They ranged in height from 3 to 16 m but most were between 5 and 8 m high. Typically, they cut through ridge crests in gravel pits or road exposures. As logging is active in the area and cabin development ongoing, all roads, whether paved or gravel, were driven or walked in a search for sediment exposures. Standard stratigraphic and sedimentological observations were made following the procedures and standards of Krumbein (1939), Hart (1994), Benn and Evans (1998), Allen (1999) and Larsen and Piotrowski (2003). Sediment observations included sediment texture, compactness, stoniness, colour, clast lithology, and clast fabric. The presence or absence of striated clasts was also noted. Exposed bedrock was extremely rare in the study area, but where observed, it was examined for the presence of striations.

### DATA ANALYSIS

#### Digital Elevation Model Production

Digital elevation models (DEMs) were created for this study from digital topographic maps at scales of 1:5000 and 1:2500. A total of 59 map sheets were converted to DEMs covering an area of approximately 40 km<sup>2</sup> in the northeast corner of the study area. The DEM was created using ArcMap's 3-D Analyst extension. A triangulated irregular network (TIN) of elevation points (Kumler, 1994) was used to model the continuous landscape surface of the map area. A large amount of virtual memory is required to draw these models within ArcMap; therefore the TINs were converted to a raster dataset and viewed within ArcGIS 8.3. Some elevation errors are assumed because the shapefiles obtained were digitized versions of contour maps created using photogrammetry. Errors may have been produced in the transfer of data from analogue to digital format. Slight alterations in the locations of the contour lines and spot heights are expected. Also, errors occur in the production of the TIN, when the computer calculates the area and location of the elevation triangles. Artificial flat areas, where patches of the land surface are assigned the same elevation value, are common. The resolution of this digital elevation model is therefore compromised to some degree both horizontally and ver-



**Figure 4.** A) This digital elevation model (DEM) shows well-developed Rogen moraines near Hodgewater Pond. Note the series of parallel ridges within the localized troughs. B) Digital elevation model of Rogen moraines near Mahers. Note the transition from easily recognizable Rogen moraines in a trough up into hummocky terrain at the top of the slope. Note that the scale of these models is not uniform, and vertical exaggeration is approximately 10 times.

tically. The cell size resolution of these models is between 5 and 10 m.

## PRELIMINARY OBSERVATIONS

### Geomorphology

Preliminary visual interpretation of the DEM (Figure 4) and air photographs has led to the classification of three distinct landform types: Rogen moraine, hummocky terrain and streamlined bedforms. Further analysis of the DEM will be necessary to generate morphometric descriptions of these individual landform types.

### Rogen Moraine

Rogen moraine commonly occurs in northeast–southwest-trending linear troughs (Figure 4). Generally the moraines are oriented perpendicular to the troughs, and are 0.5 to 5 km long, 35 to 250 m wide and 5 to 30 m high. Individual ridges are spaced between 200 and 320 m apart, and ponds or bogs commonly occupy the depressions between them (Plate 1). At least two forms of Rogen moraines are observed in the DEM, which occupy approximately 20 percent of the area covered by the DEM. An example of the first is located in the area surrounding Ocean Pond and is composed of well-developed moraine ridges that are continuous, evenly spaced, and oriented parallel to one another. They form relatively small patches, no larger than 5 km<sup>2</sup>, between areas of streamlined bedforms and hummocky moraine. In contrast, the second form of Rogen moraine are highly dissected, discontinuous, and unevenly spaced ridges that mostly occur in the southeast part of the DEM where they cover an area greater than 10 km<sup>2</sup>.

### Hummocky Terrain

Hummocky terrain covers about 20 percent of the DEM, and consists of a series of randomly oriented ridges and knobs. Based on visual interpretation of the DEM, these features range from 50 to 90 m wide, 100 to 300 m long, and are commonly located on ridges between tracts of Rogen moraine.

### Large-scale Streamlined Bedforms

Streamlined bedforms are prominent features in the northeast corner of the DEM. These bedrock structures are linear features trending northeast–southwest, and they are generally wider at the northeast end. These landforms range from 600 to 3000 m wide, range between 25 and 100 m high above the surrounding landscape, and are generally between 2 and 7 km long.

### Landform Transitions

There are two types of transitions from Rogen moraines to other landforms. First, there is a gradual lateral transition

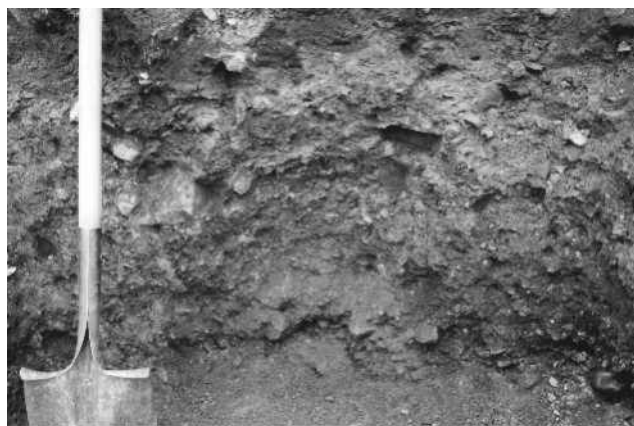
from the Rogen moraine in the troughs to hummocky terrain situated on top of the bedrock ridges, where the hummocky terrain is an extension of the Rogen moraine. At the margins, individual hummocks are spaced farther apart than the Rogen moraine ridges, their heights are more subdued, and they are shorter in length, more sinuous and randomly arranged (Figure 4). The second transition is abrupt, occurs at the ends rather than the sides of the Rogen moraine-occupied troughs. The moraines are confined to troughs, becoming less common as elevation increases out of the troughs, normally at the base of a streamlined bedform.

## INTERNAL COMPOSITION

### Sediment Characteristics

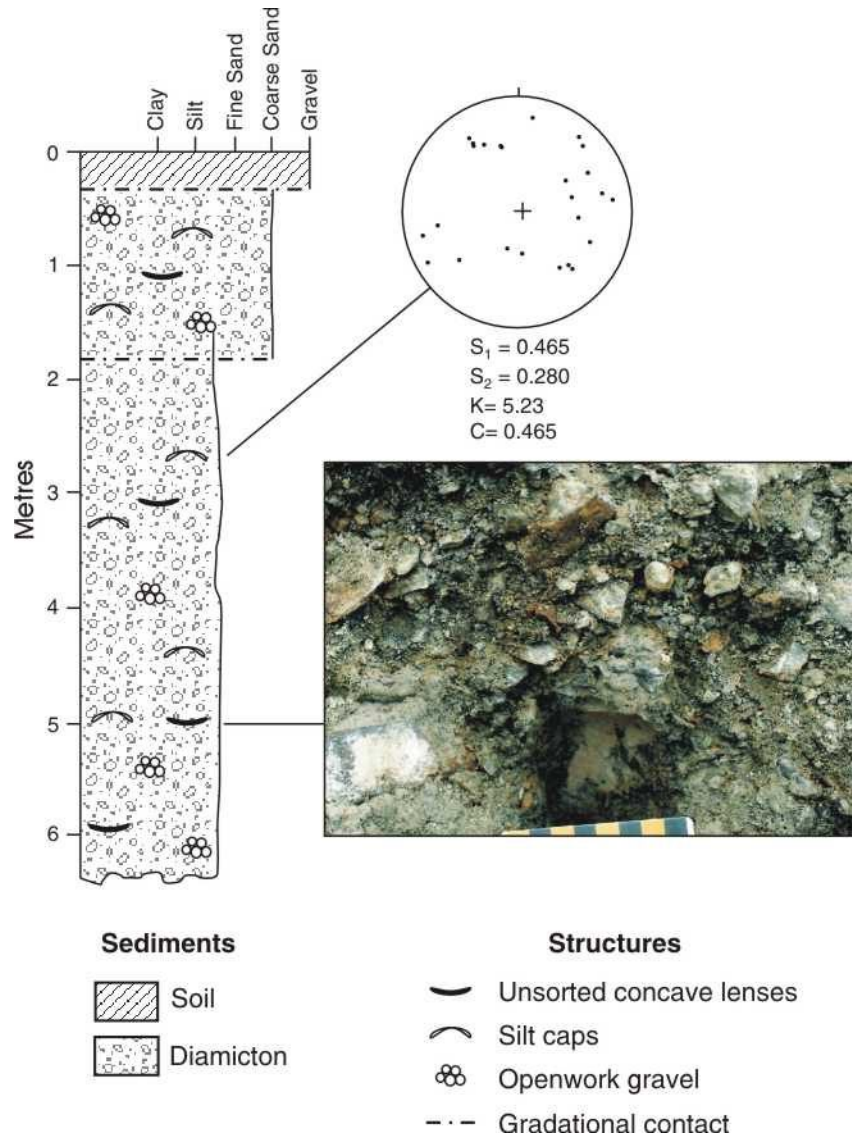
Twenty-six exposures were logged, 13 through Rogen moraine and 10 through hummocky terrain. There is no apparent difference in sediment exposed in the two terrain types and therefore separate descriptions are not necessary. Excavations along the sides and near the crests of ridges typically revealed a relatively consistent exposure of olive grey (5Y6/1) poorly structured, relatively compact diamicton with a silty sand matrix (Plate 4). Stone content varies from about 25 to 80 percent, and clast diameter ranges between several centimetres and a few metres, but averages around 10 cm. Faceted clasts are found at 70 percent of the sites. Clasts were exclusively local sedimentary rocks. Some sorted sediments form normally graded to massive openwork lenses of gravel and coarse sand that are preferentially located underneath large clasts. The lens shape tends to mirror the underside of the clast, whereas lens thickness shows a proportional relationship with clast diameter, varying between a few millimetres and >10 cm thick.

Boulder lines or rows were observed at 10 percent of the exposures, commonly comprising similar-sized clasts



**Plate 4.** A typical exposure within Rogen moraine, showing non-sorted, massive diamicton, with a silty sand matrix. The height of this exposure is approximately 80 cm.





**Figure 5.** Sedimentary log for the exposure at Site 4. The profile shows the upper and lower diamictons, and a weak girdle fabric typical of the Avalon Rogen moraines. The photograph shows an openwork lens between two clasts, and a silt cap where a clast was removed, directly above the scale bar (in centimetres).

and one clast thick, and underlain by openwork gravel lenses that extend the length of the line. Boulder lines and clasts are capped by silt, the thickness of which increases proportionally with the size of the underlying clast, varying from a few mm to 5 cm thick. In places, thin layers of sand overly the silt. Diamicton exposures also contain inclusions of clay and silty clay, between 5 and 15 cm in diameter, and the inclusions may contain coarse gravel.

At 6 of the 26 exposures, two different diamicton units were defined, distinguished mostly on the basis of matrix texture, stoniness, and the occurrence of gravel lenses, e.g., Site 4, northeast of Hawcos Pond (Figure 5). Four of the 6 exposures were located in Rogen moraines, and two in hum-

mocky terrain. The upper of the two diamictons resembled the single diamicton observed at the other 20 sites (described previously). The lower diamicton was supported by a sandy silt matrix, clasts were predominantly subangular and of local provenance, and the percent stoniness was less than the upper diamicton, but was still greater than 50 percent. There appeared to be less openwork gravel lenses associated with the lower diamicton; however, silt caps were common.

### Clast Fabrics

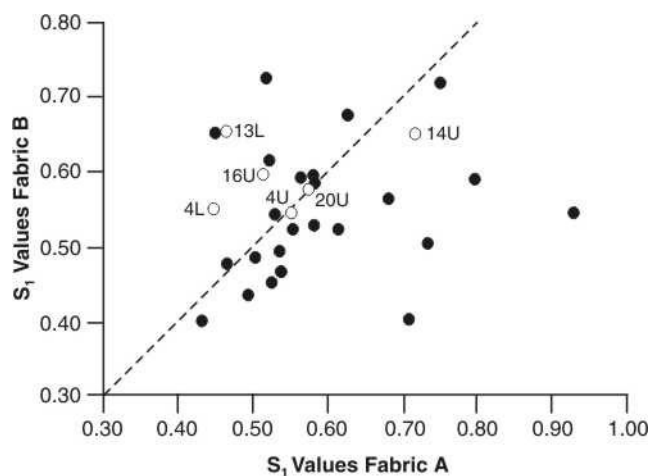
Clast fabric data from stony diamictons may be difficult to interpret. Clast interaction during deposition of stony

diamicton is common, and therefore the orientation of individual clasts represent those interactions rather than the direction of ice flow in tills or slope aspect in gravity flow deposits (e.g., Benn and Evans, 1998). This may explain the within-site variability of clast fabric data (Figure 6). Also, clast lithology influences fabric measurements. Local bedrock of the central Avalon Peninsula produce clasts that easily break along fractures and bedding planes, thus elongated clast shards tend to develop. Measurement of these clasts may be problematic in that the clast orientation may not necessarily represent ice flow, but the fracture plane of the clast.

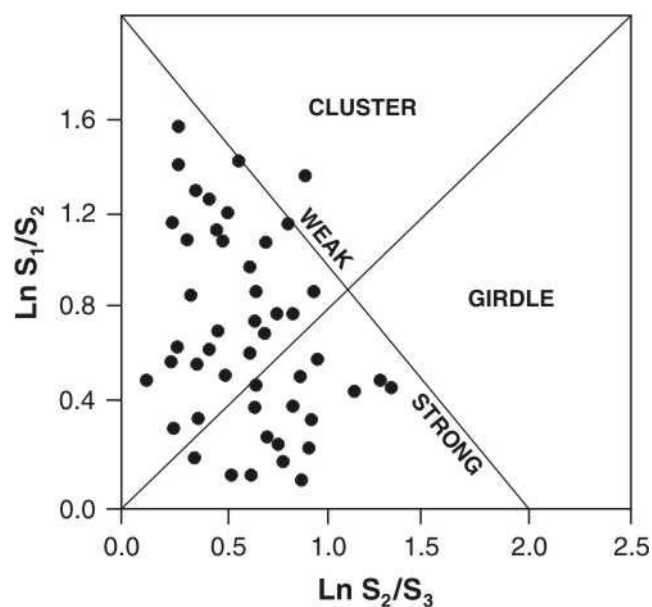
A total of 57 clast fabrics (25 clasts each with a length–breadth ratio of at least 3:2) were measured on diamicton exposures. A minimum of two fabrics were measured at each site, in different faces where possible, and in both diamictons where observed. Statistics expressing the shape and strength of the clast fabrics were calculated using Georient 32 v 9 following the methods of Woodcock (1977). Eigen vectors ( $V_1, V_2, V_3$ ) show the direction where maximum clustering of clast orientations occurs, as well as the planes perpendicular to the preferred fabric orientation, whereas Eigen values ( $S_1, S_2, S_3$ ) describe the degree of clustering around Eigen vectors. The fabric strength parameter is  $C$ , ( $C = \ln(S_1/S_2)$ ) and is considered weak when  $<1$  and strong when  $>3$  (Woodcock, 1977). The shape parameter is  $K$ , ( $K = \ln(S_1/S_2)/\ln(S_2/S_3)$ ) and clusters occur when  $K > 1$  and girdles when  $K < 1$ . Clusters have a narrow range of dip and direction values, whereas girdles show a broad range in direction values, and a narrow range of dip values (Woodcock, 1977).

Based on their  $S_1$  and  $K$  values, 12 fabrics from 11 sites have moderately strong clusters ( $S_1$  values 0.61–0.92,  $K$  values 1.18 to 3.72) indicative of ice-flow direction in primary tills (Dowdeswell and Sharp, 1986; Hart, 1994; Hart and Roberts, 1994). An  $S_1$  value of 0.6 was used to filter the clast fabric results in order to easily distinguish between those fabrics that fall within the range of values considered to be moderately strong clusters. Half of these fabrics display a mean direction in the northeast quadrant, the other half are distributed throughout the other three quadrants. When compared to nearby striation data, 3 sites show close correspondence between fabric and striation direction, while the remaining 9 fabrics deviated from striations by  $20^\circ$  to  $70^\circ$ . Most of the fabrics show ice flow oblique to ridge orientation. The 12 fabrics generally have steeply dipping clasts, with a mean dip angle of  $53^\circ$ .

The remaining 45 fabrics have weak to strong clusters and girdle shapes (Figure 7) ( $S_1$  values 0.40–0.80,  $K$  values



**Figure 6.** A scattergram showing  $S_1$  values for paired clast fabrics measured at a single site, and  $S_1$  values from fabric pairs measured from two diamictons at the same site. Note the inconsistency of results, which is likely a result of the variance in stoniness within the diamictons and/or the depositional processes.



**Figure 7.** Shapes of clast fabrics from diamictons within landforms of the central Avalon Peninsula. Note that the fabrics measured within the Avalon Rogen moraine are weak clusters or girdles.

0.15 - 6.06). The mean azimuth for these fabrics ranges between  $16^\circ$  and  $307^\circ$ , whereas the mean plunge is consistently steep at  $41^\circ$  to  $79^\circ$ . About 40 percent of these fabrics have mean directions roughly parallel to the ridge crests from which they were measured; the remainder were oblique.

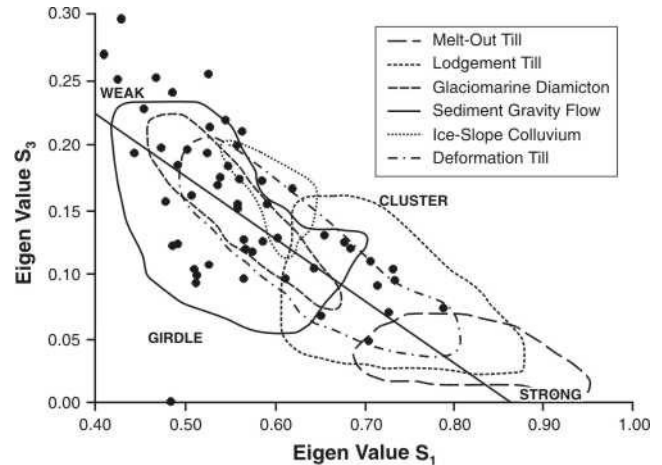
A plot of  $S_1$  against  $S_3$  values for each of the 57 fabrics suggests that most are similar to fabrics measured from sediment gravity flow or deformation till deposits (Figure 8). There was no distinct difference between fabric data measured in sites from Rogen moraine ( $n=27$ ) or hummocky terrain ( $n=23$ ), with less than 30 percent in each having  $S_1$  values  $>0.6$ . Similarly, a comparison of fabrics from sites with multiple diamictons showed no marked difference between  $S_1$  value strength (0.52 vs. 0.58 for lower vs. upper) and roughly 70 percent of fabrics in both diamictons plot in the sediment gravity-flow envelope of Figure 8.

## DISCUSSION

The Rogen moraines of the Avalon Peninsula show similar morphometric and sedimentological characteristics to examples of Rogen moraines described elsewhere (Lundqvist, 1969, 1989; Shaw, 1979; Bouchard, 1989, 1992; Hättestrand, 1997). The Avalon Peninsula Rogen moraine field also occupies a similar topographic setting to these other examples. Also, a similar landform transition has been observed on the Avalon Peninsula, although a transition to drumlins does not occur.

The local origin of the sediment within the Avalon moraines implies a short transport distance, a characteristic of sediment transported subglacially by warm-based ice (e.g., Bennett and Glasser, 1996). Other evidence of subglacial transport are faceted clasts, and bimodal or multimodal grain-size distributions (Boulton, 1978; Benn and Balantyne, 1994). Faceting has been observed in 70 percent of the sediments within the Avalon moraines, but the grain-size analysis has yet to be completed, therefore it is tentatively suggested that these sediments were deposited subglacially by warm-based ice.

There were few sedimentary structures found within the moraines and they are not diagnostic of a particular depositional environment. The openwork gravel lenses that were observed in the Avalon Peninsula moraines are similar to those described by Shaw (1982a), who linked these structures to the melting out of till from stagnating ice. However, Fisher (1989) described similar features, which he interpreted as the result of winnowing of fines during turbulence produced by subglacial fluvial erosion. Boulder lines or rows occur in 10 percent of the sites. These structures are commonly assigned a lodgement origin (c.f., Dreimanis, 1989) although Hiscock (1991) suggests a range of potential formative processes, including deformation, melt out and sediment-gravity flows. Differentiation of these processes will require further work on pavement clast fabric and morphology. Silt caps or clasts may be interpreted in one of two ways; as draped beds comparable to those observed within the Sveg tills of central Sweden (Shaw, 1979, 1982b) pro-



**Figure 8.** Plot of  $S_1$  versus  $S_3$  Eigen values from diamictons within the central Avalon Peninsula. Envelopes for different depositional environments have been drawn (after Dowdeswell et al., 1985 and Batterson, 2003). Most of the fabrics measured in this study fit within the sediment gravity-flow envelope.

duced by the direct meltout of debris-rich ice onto underlying clasts, or the result of downward percolation of meltwater during the Holocene. No clear evidence was found to support one interpretation over the other.

Clast-fabric measurements as discussed previously are not diagnostic of depositional process, although they may be used along with sedimentological evidence to suggest a depositional environment. The large number of clast fabrics falling within the sediment gravity-flow envelope suggests that this may be a process involved in the deposition of the Avalon Peninsula Rogen moraine. Common structures associated with sediment gravity flows include elevated “floating” clasts, reverse grading, crude laminations, patches of mud matrix, and washed lenses of silt, sand, or gravel. Sediment gravity flows are generally clast- to matrix-supported, contacts between sediment types are commonly sharp and slightly erosive, and clast fabrics are disorganized (Nemec, 1990; Benn and Evans, 1998). The sediments of the Avalon Peninsula Rogen moraines commonly exhibit washed lenses of gravel and coarse sand, and the blocky silt and/or clay inclusions are similar to the patches of mud matrix described by Nemec (1990).

Three models for Rogen moraine formation are described. Currently, based upon the studies undertaken so far, there is insufficient evidence to accept or reject any of these models for the formation of the Avalon Rogen moraine. The bed deformation model requires that previously deposited landforms be remoulded by a subsequent ice flow perpendicular to the flow that deposited them, therefore evidence of subglacial deformation would be expected

(Boulton, 1982); evidence of subglacial deformation structures were not observed in this study. The shear and stack model of Rogen moraine formation, largely through meltout, is suggested by the presence of silt caps and open-work gravel lenses found within exposures. Similarly, most of the clast fabrics measured within these sediments fall within the sediment gravity flow and melt-out till envelopes. These characteristics might come through shearing and stacking of glacial ice, followed by *in situ* melting. The subglacial meltwater model cannot be rejected. The presence of sorted lenses suggests the presence of water during formation, although the lack of glaciofluvial sediments to support a depositional mechanism or a surface lag of boulders or truncation of beds to support an erosional mechanism may argue against this model, but further analysis of the sedimentological and morphological data is required to either accept or reject this model.

## CONCLUSIONS

The orientation of the Rogen moraine ridges as observed within the DEM, coupled with limited clast fabric and striation data, indicate the moraines were formed by northeastward-flowing ice. This preliminary work concerning the genesis of the Avalon Peninsula Rogen moraine has concluded that several mechanisms may be involved in their genesis. It is apparent, based on the observation of open-work gravel lenses and silt caps that water was involved at some stage in the formation of the Rogen moraine. The local origin of the sediments within the Rogen moraine ridges and inferred short transport distances suggest that the sediment was transported and deposited subglacially. It is also important to note the similarity between Rogen moraine and hummocky terrain internal composition. Based on their internal composition it is not possible to distinguish between Rogen moraine and hummocky terrain, therefore it is likely that these landforms were developed under the same conditions and within the same glacial event.

## FUTURE WORK

Further work for this project will include an in-depth analysis of the digital elevation models, aerial photography, and internal composition of the Avalon Rogen moraines, as a means of understanding the external morphology, formative processes, and timing of the Avalon Rogen moraine genesis. It is anticipated that further analysis of the digital elevation models will enable a clear differentiation between Rogen moraine, hummocky terrain, the streamlined bedforms and the unclassified terrain, as well as any other type of landform that may be present in the central Avalon Peninsula.

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