LONG ISLAND CLAST ORIENTATIONS

AND WHAT THEY TILL US

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Long Island glacigenic surface deposits, where exposed, are ideal for geologic field studies of Pleistocene glacial settings. Numerous outcrop exposures, found scattered throughout the island, delineate many of the deposit types associated with a full spectrum of glacial facies currently observable at active continental ice sheet margins. By directly field sampling axial orientations of a number of clasts in a particle distribution (e.g. a section of a stratigraphic layer) and with vector analysis of this orientation data we can classify the degree of preferred orientation for the total population of clasts in a specified volume. A clast fabric distinguishes the preferred axial orientation of particles for a particular section in a stratigraphic unit. The overall preferred axial orientation for a large outcrop unit may be inferred only after many isolated clast fabrics within the unit are amassed. Clast fabric analysis, despite limitations, is a useful tool in Long Island glacigenic sediment studies because, in its mathematically robust form (eigenanalysis) it allows quantification of otherwise descriptive fabrics. Glacial deposits (e.g., tills) described by clast fabrics convey the degree of relative strain preserved within a volume of an outcrop unit. Analysis in the field, combined with theory, has enabled us to document glacially induced deformation at Ditch Plains, Long Island.

Just as geologic features in modern sedimentary environments are later preserved in hard rock, stratigraphic and structural features typical of Pleistocene deposits can be observed in the ice of modern day continental ice sheets (figure 1.). Pictured in figure 1 is debris-rich stratified basal ice in the basal zone of a glacial ice sheet. This ice sheet is composed of several subhorizontal planar units, each with a distinct depositional setting and glaciotectonic regime. Beginning directly above the base of the glacier bed - ice sheet contact is a thick ice layer containing meter-scale wavy subparallel bedding loaded with clasts and finer sediment. This unit is cut off at its top by a subhorizontal slip plane. Above the slip plane is a thick varved unit composed mainly of a mixture of ice and fine sediment. This sequence of varves has a very tightly folded subhorizontal fold axis (notable at its base), apparently the result of being glaciotectonically thrusted across the slip plane. Overlaying the thrusted varved unit may possibly be a channel which has been filled with a mud and ice matrix supporting large clasts. Directly above the channel fill unit is a thin sequence of stratified mud, sand, and ice mainly arranged in undeformed subhorizontal planar layers. Visible meter-scale offsets in otherwise subhorizontal planar layers of stratified ice and sand overlay the undeformed thin stratified unit. These offsets are characteristic of shear zones in brittle hard rock. The shear zone is capped by a thick unit of ice. A uniformitarian interpretation suggests that clast orientations generated in the basal zones and margins of modern glacier settings should be similar to those preserved in the strata of typical Long Island Pleistocene glacial environments.

Long Island's surface and shallow surface deposits are derived from the glacial processes which were active during the Pleistocene. Many of these deposits contain sediment mixtures of poorly sorted particle sizes and varying shapes that sedimentologists call diamicts. In the field diamicts can be massive, stratified, laminated, imbricated, reworked, resedimented, sheared, or include clast pavements. Diamicts canspan an extremely broad (clay to boulder) range of particle sizes and frequently includes clasts within a matrix of finer materialor a matrix of finer material within supporting clasts.Diamicts may also have graded clasts within a matrix or may have particles support by graded clasts (Benn and Evans, 1998).

***Figure* 1. An important environment for generating clast fabrics is the basal zone of glacial ice. Features visible in the stratified ice include unconformities, minor folding, and offsets. <u>Note</u>: the thick debris-rich units in the ice. Photo by D.A. Evans, with person for scale (Benn and Evans, 1998).**

Clast Fabric Analysis of Ditch Plains Glacial Sediment

Preferred clast orientations produce fabrics that vary with depositional setting. Investigators suggest that diamict units which include non-random oriented glacigenic clasts provide clear evidence of relative strains in that unit (Bennett, et al., 1999; Dowdeswell et al., 1985; Lawson, 1979). Clast fabrics in glacigenic settings range from weakly organized clast orientations produced by water-lainglacigenic sedimentation (preserved during outwash deposition) to highly uniform lineations generated by well developed shear zones (preserved during subglacial melt-outdeposition).

We have studied such sediments at one site on Long Island. Our field area, Ditch Plains, is roughly 7 kilometers west of Montauk Point on the south fork of eastern Long Island (figure 2.). Along the Ditch Plains beach front, the Ronkonkoma Moraine resists erosion caused by ocean surf and other weathering processes. Spaced along several kilometers of the shoreline, bluffs and vertical exposures outcrop at heights as great as 10 to 15 meters. We interpret the general stratigraphy to include two distinctive diamict deposits. A massive upper diamict unit overlies a lower stratified diamict unit (figure 3.) (Klein, et al., 1998).

***Figure 2*. Field area at Ditch Plains, Long Island.**

***Figure* 3. Interpreted portion of a south facing sea cliff at Ditch Plains, where the contact between two general diamict units is indicated by a dashed horizontal line. The photograph shows the bottom meter of a 6 m thick massive diamict unit (**Dmm*) which is probably a flow till. The matrix of this massive diamict deposit* (Dmm*), composed mainly of sand sized particles, supports a range of clast sizes up to and including cobbles. This massive unit caps a 10 m thick stratified diamict unit (*Dms*) of which the top 6 m is visible. This unit (Dms) is most likely a lodgement till or a subglacial melt-out till. It is composed mainly of sand size particles, and supports a range of clast sizes up to and including boulders. The large clasts exposed in the stratified diamict unit are predominantly subhorizontal and oriented N-S. The solid line drawn below the stratified diamict separates the cliff from modern beach deposits and other recent erosional features. The redsquare frame is one meter on a side, the size a typical sampling surface used to collect 25 clast orientations-the raw data used in the analysis of each clast fabric.*

In clast fabric analysis, each pebble studied is approximated by a triaxial ellipsoid with three mutually orthogonal principal axes (long, intermediate, and short). We record the bearing and plunge direction of these principal axes. The *in-situ* measurement of principal axial orientations for a given number of clasts (vectors) in a clast distribution is transformable into a three-dimensional orientation tensor (Mark, 1973). The elements of the orientation tensor, defined in a 3 x 3 symmetric matrix, indicate the degree to which a given pebble axis (usually the long axis) tends to point N-S, E-W, and vertically. Shape can play a significant role in the determination of a clast orientation. For example, the shapes that approach spheroids are a major hindrance in measurement of preferred axial direction because equidimensional axial lengths make it impossible to uniquely define principal axes. However, rod-like shapes have an obvious principal long axis orientation providing a set of unique vector components that contribute to a more robust orientation tensor.

The analytical solution obtained by eigenanalysis determines three normalized eigenvalues (a maximum, an intermediate, and a minimum) and assigns one eigenvalue to each one of three mutually perpendicular preferred eigenvector directions. These eigenvectors can be thought of as the most, intermediate, and least preferred pebble-vector directions (all mutually perpendicular). The corresponding normalized eigenvalues describe the degree of preference for each of these directions. For example, and eigenvalue of one would mean that all axes point exactly that way, while an eigenvalue of zero would indicate that they are all 90 from that direction.

An equal-area steronet projection is a dependable graphical representation of clast orientation data. The equal-area projection plots the orientations as points and the density of such points can be contoured indicating the degree of preference for direction. We plot on equal-area steronet projection the long axis of 150 clast orientations examined at six closely spaced vertical surfaces within the stratified diamict unit (figure 4.). In addition, eigenanalysis of the same 150 clast orientations found a maximum eigenvalue (S_1) = .79 for the eigenvector direction ($\mathbf{V_1}$) = (342 , 06). This strong degree of preference, subhorizontal and just west of north in a direction, for the clast fabric orientation of the stratified diamict of Ditch Plains is consistent with sheardue to glacial advance from the north.

Based on eigenanalysis (Table 1.), we locate the minimum and maximum eigenvalues for the stratified diamict unit clast fabric on a plot that includes fields from previously published glacigenic clast fabric data (Dowdeswell et al., 1985; Lawson, 1979) (figure 5.). Classifying the mode of deposition for till with confidence using these graphical approaches is insufficient (Bennett, et al., 1999). However, the stratified diamict clast fabric at Ditch Plains lies between the lodgement till and subglacial melt-out till fields defined by Dowdeswell et al. (1985) and Lawson (1979). This implies that the clast fabric may have been emplaced and preserved by some combination of these or other glaciation processes.

Clast fabrics attributing clast orientation to a volume are subject to sampling bias especially when clast orientations are recorded from unexcavated outcrop. Field measurement produces a bias in favor of clast orientations that are normal to an outcrop surface producing a sampling bias that is a function of the orientation of the outcrop surface and the most preferred direction of the *in situ* clast fabric. The bias is greatest for those pebbles best suited to field analysis (those that are rod-like in shape). The sampling bias can affect perceived fabric strength(eigenvalues) enough to influence interpretation of setting but the effect upon fabric orientation (eigenvectors) is generally small. The effects of the surface bias can be mitigated with careful sampling and interpretation. The affect of the sampling bias is small for the stratified diamict at Ditch Plains.

Figure 4. a.***)*** **The equal-area steronet projection of a scatter plot showing the 150 clast orientations recorded in the stratified diamict unit (**Dms) *at Ditch Plains* **b.*)* Equal-area steronet projection of the same 150 clast orientations contoured at 2% intervals for 1% area. The contour plot of these clast orientations unambiguously suggests a subhorizontal preferred direction just west of north.**

Eigenvalues	Eigenvectors
$S_1 = .7922$	$\mathbf{V_1} = (342 , 06)$
$S_2 = .1498$	$\mathbf{V_2} = (072 , 01)$
$S_3 = .0581$	$\mathbf{V_3} = (178 , 84)$

***Table 1*. Normalized eigenvalues and eigenvectors obtained for 150 clast orientations recorded in the stratified diamict unit (Dms) of Ditch Plains.**

Figure 5. **The minimum eigenvalue (**S_3*) vs. the maximum eigenvalue (*S_1*) for the clast fabric of the stratified diamict unit (*Dms*) (small open circle) superimposed on a plot of previously published glacigenic clast fabric data. Each large oval encloses an individual glacial deposit field (one standard deviation from the mean value of a deposit). The mode of the stratified diamict plots between the lodgement till and the subglacial melt-out till fields as defined by Dowdeswell et al. (1985) and Lawson (1979).*

Conclusions

Clast fabric analysis of Long Island glacigenic sediment is an ideal way to observe relative differences in glacial settings because it allows us to overcome many of the limitations associated with descriptive or quantitative clast fabrics by careful sampling and analysis techniques. Glacial tills, quantified by eigenanalysis, reflect the degree of relative strain preserved within a volume of an outcrop unit. The clast fabric analyzed in the stratified diamict unit at Ditch Plains, suggests that the preferred clast orientation (342 , 06) of that unit may be parallel with Pleistocene ice flow direction which is consistent with modern examples of glacially induced shear in the basal zone on a continental ice sheet. Local clast orientation studies are well suited for resolving lateral and vertical geomorphological variation produced by glacial deformation. For instance, clast fabrics generated by a single large deforming ice sheet lobe should create different clast fabrics then those derived from deformation induced by several smaller ice sheet lobes. A close look at clast orientation generated during the Pleistocene on Long Island potentially elucidates a more complete picture of the complex strain histories and sedimentation processes associated with continental ice sheet glaciation.

References

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