

## Deciphering the Origin of Diamict Deposits at Ditch Plains, Long Island

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### ABSTRACT

Ditch Plains Long Island has exposed diamicts in its extensive sea cliffs and quarries. These diamicts show a preferred pebble orientation and a preferred pebble fabric when examined by the unit vector analysis. A weighting factor applied to each data set, based on individual pebble shape, improves the quantitative pebble fabric analysis approach. The following table compares the unit vectors of the four uniform Ditch Plain's data sets with the four normalized Ditch Plain's data sets.

data set:	axis:	uniform eigenvector, v1	uniform eigenvalue, s1	normalized eigenvector, v1	normalized eigenvalue, s1
A	a	(135,15)	.66	(135,15)	.663
B	a	(155,00)	.819	(335,00)	.772
C	a	(330,00)	.758	(330,10)	.721
D	a	(340,05)	.842	(340,05)	.790

Eigenvalue s1 increased by values ranging from .003 to .05 in the normalized data sets. The significantly higher s1 values in Data Sets B, C, and D of the normalized data sets imply a more strongly orientated pebble fabric than do their counterpart Data Set B, C, and D uniform data sets. One interpretation of the glacial setting at Ditch Plains considers the capping massive diamict unit (Data Set A) a flow till unit, and divides the lower stratified unit into a lodgement till unit (Data Sets B & C) and a subglacial meltout unit (Data Set D).

### INTRODUCTION

There is a clear need for further fundamental understanding of glacial sediments on Long Island, of which, one main component is diamicts. Diamicts are common Long Island features found among the outcrops at sea cliffs, quarries, and related sites. Diamicts contain a broad mix of particle sizes ranging from mud to boulder all incorporated into a poorly sorted matrix. Interpreting the origin of the diamicts relies on quantifying a pebble fabric. Only a few sedimentary studies of pebble fabrics relating to diamicts exist and there is virtually no published information on pebble fabrics within diamict deposits found on Long Island. Given that every pebble has a distinct spatial orientation within a diamict, establishing a pebble fabric requires the examination of each pebble's orientation relative to all the other pebble orientations within the deposit. Three dimensional unit vector analysis quantifies individual pebble orientations and totals these orientations into a data set. In addition, the unit vector approach converts the pebble orientations of a data set into a single unit vector and calculates eigenvalues ranging between zero and one. Eigenvalues describe the strength of pebble fabric for a data set. The closer the eigenvalue is to one, the greater the strength of preference in the orientation for the pebbles in that data set. This study examines and tabulates pebble data sets at four separate sites within the Montauk diamict of the Ronkonkoma Moraine, at Ditch Plains Long Island (fig. 1). Moreover, an eigenvalue comparison of published data sets from modern diamicts with the four Ditch Plain's data sets provides a mathematical and graphical approach for analyzing and evaluating the origin of the diamicts at the Ditch Plain sites.

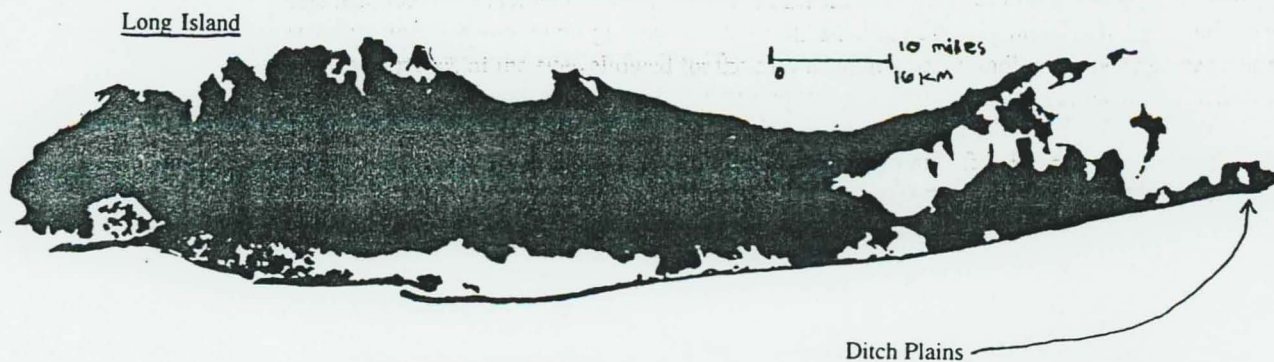


figure 1. Ditch Plains

The previously published studies on modern terrestrial diamict deposits established the strength of preferred pebble fabrics by unit vector analysis. Those studies recognized that preference in the orientation of pebble fabrics within diamicts begins with the computation of unit vectors directly based on pebbles within a data set. The unit vector approach allows comparison of calculated eigenvectors and eigenvalues in all the data sets pertaining to a site. An eigenvalue comparison plot in the previously published studies on modern terrestrial glacial sediments separates the pebble fabrics into several well defined genetic diamict types (fig. 2). The types, known as Subglacial meltout till, Lodgement till, Flow till, or Waterlain glacial sediment are distinguished by the strength of their preferred pebble fabric (Bennett & Glasser 1996). Therefore, quantitative fabric analysis by unit vector is an important mechanism for understanding the genesis of diamicts. Long Island is currently loaded with a wide variety of diamict deposits justifying continued emphasis on quantitative methods for deciphering different pebble fabric types.

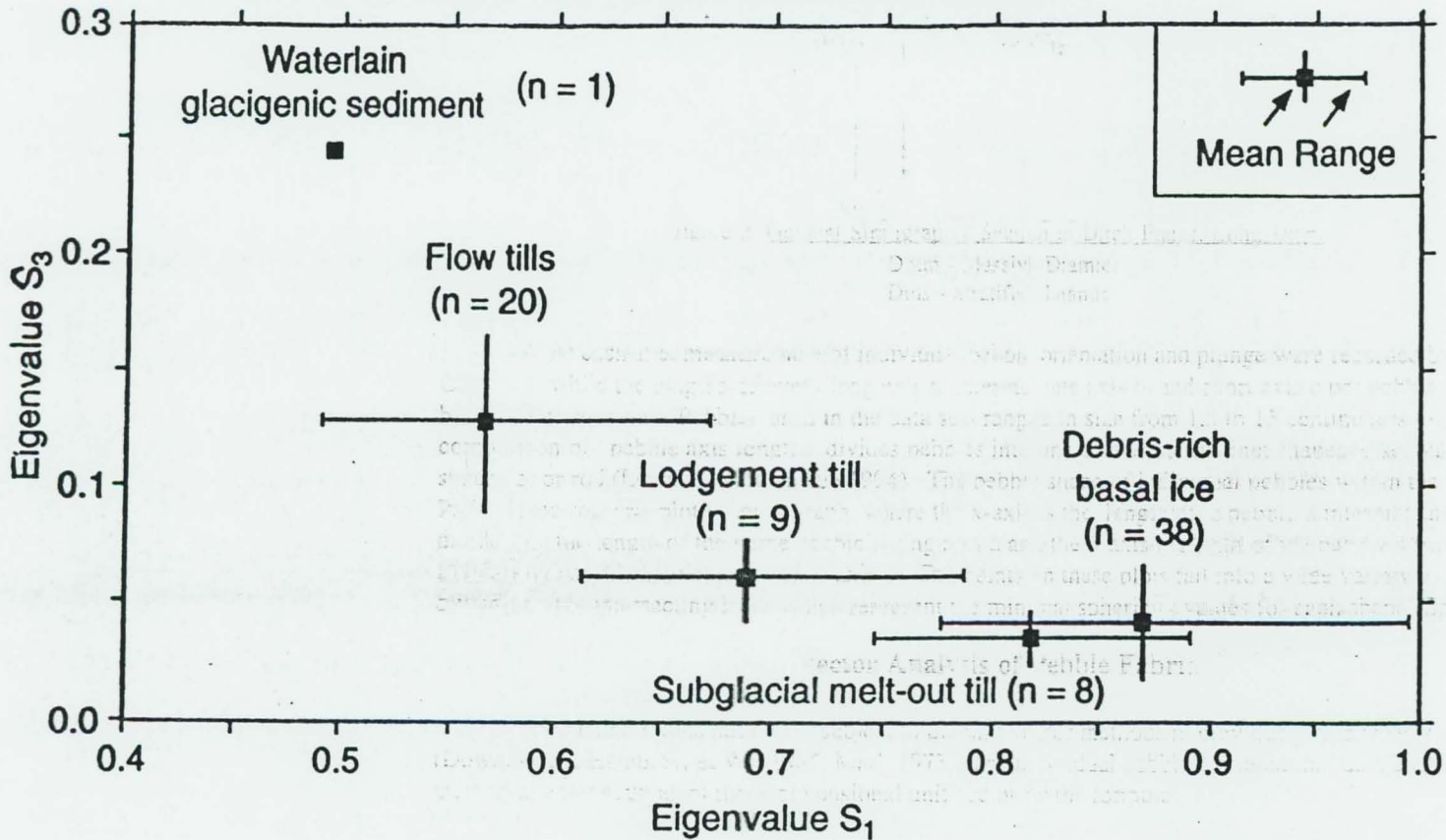


figure 2. Plot of two eigenvalues ( $S_3$  vs.  $S_1$ )

### Field Methods

Four different sites, separated from west to east by a total of 200 meters, contributed the quantifiable pebble information used in evaluating the pebble fabric strength for each of diamict deposit data sets recorded at the Ditch Plain's sea cliffs. A generalized cross section of the sea cliff exposure shows a stratified lower diamict unit in direct contact with an upper capping massive diamict unit. The nearly vertical surfaces of the sites allowed for the easy examination of individual pebbles per unit area. At each site, scored directly into the sea cliffs, was a square grid with the length of each side measuring 1 meter. Data Set A, is from the upper massive capping diamict unit while Data Set B, Data Set C, and Data Set D are from the lower stratified diamict unit found at Ditch Plains (fig. 3). Each data set compiled at the sea cliffs contains twenty five individual pebbles. The data sets measured the orientations and the axial lengths of each contributing pebble.

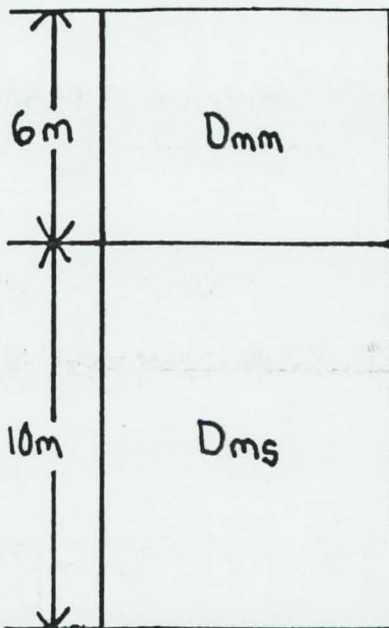


figure 3. General Stratigraphic Section at Ditch Plains, Long Island

Dmm - Massive Diamict  
Dms - Stratified Diamict

At each site, measurement of individual pebble orientation and plunge were recorded by Brunton Compass, while the lengths of every long axis  $a$ , intermediate axis  $b$ , and short axis  $c$  per pebble was record by a millimeter ruler. Pebbles used in the data sets ranged in size from 1.5 to 15 centimeters long. A comparison of pebble axis lengths divides pebbles into one of the four distinct shapes; disc, blade, spheroid, or rod (Lewis & McConchie 1994). The pebble shape of individual pebbles within the Ditch Plain's data sets are plotted on a graph where the x-axis is the length of a pebble's intermediate axis  $b$  divided by the length of the same pebble's long axis  $a$  and the y-axis is length of the pebble's short axis  $c$  divided by that pebble's intermediate axis  $b$ . The points on these plots fall into a wide variety of shapes divided by the intersecting lines which represent the minimal sphericity values for each shape (figs. 4 & 5).

### Vector Analysis of Pebble Fabric

The Ditch Plains data were subject to the unit vector methods in previously published studies (Dowdeswell, Hambrey, & Wu 1985, Mark 1973). The individual pebble's orientation data converts into a mathematically equivalent three dimensional unit vector by the formula:

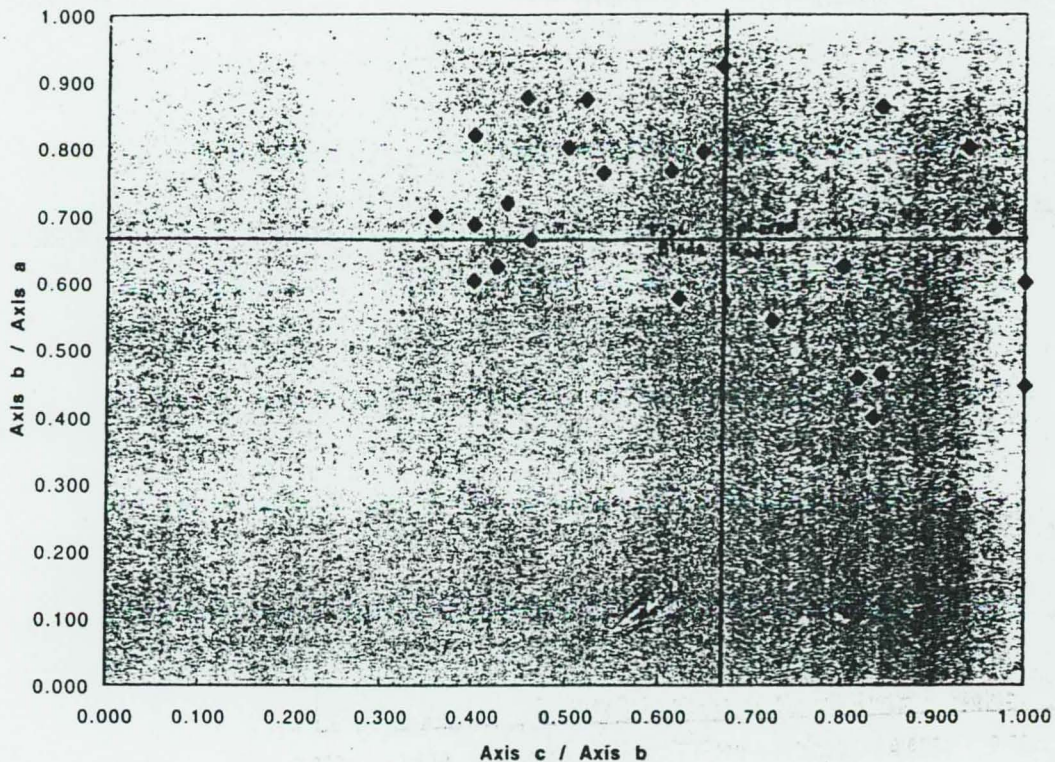
$$A = \sum_{i=1}^n X_i X_i^T$$

Where  $A$  is a  $3 \times 3$  matrix summing the vector cross product matrices of individual pebble orientations per data set.  $X_i$  is the unit vector counterpart to the  $i$ th observation axis,  $X_i^T$  is the transpose of  $X_i$ , and  $n$  is the total number of pebbles per data set. Additionally, computation produces the eigenvectors ( $v_1, v_2$ , &  $v_3$ ) and the eigenvalues ( $s_1, s_2$ , &  $s_3$ ) for each data set. The eigenvector  $v_1$  is the direction of maximum clustering about the long axis  $a$ . The eigenvector  $v_3$  is the direction of minimum clustering about the short axis  $c$ . The eigenvalue  $s_1$  represents the degree of clustering about eigenvector  $v_1$  while eigenvalue  $s_3$  is inversely proportional to the strength of the fabric's preferred plane. The eigenvalues of the associated eigenvector equal one when summed ( $s_1 + s_2 + s_3 = 1$ ). Higher  $s_1$  values in a data set reflect a stronger preference for orientation within pebble fabrics, whereas lower  $s_1$  values expose a weaker and more random preference for orientation within pebble fabrics.

The bearing and plunge of the longest axis (long axis  $a$ ) of individual pebbles within the Ditch plain's data sets are plotted on Schmidt equal-area lower hemisphere stereonet. These individual pebble orientations graphically define the pebble fabric strength by showing the degree of clustering between every pebble position plotted in each data set (fig. 6). Pebble fabrics can be well ordered or completely random depending on the data and the site.

In these stereonet each pebble counts as one pebble. Therefore all the pebbles are weighted the same and they are not adjusted for variation in pebble shapes. For example, a spheroid shaped pebble

Pebble Shape: Data Set A



Pebble Shape: Data Set B

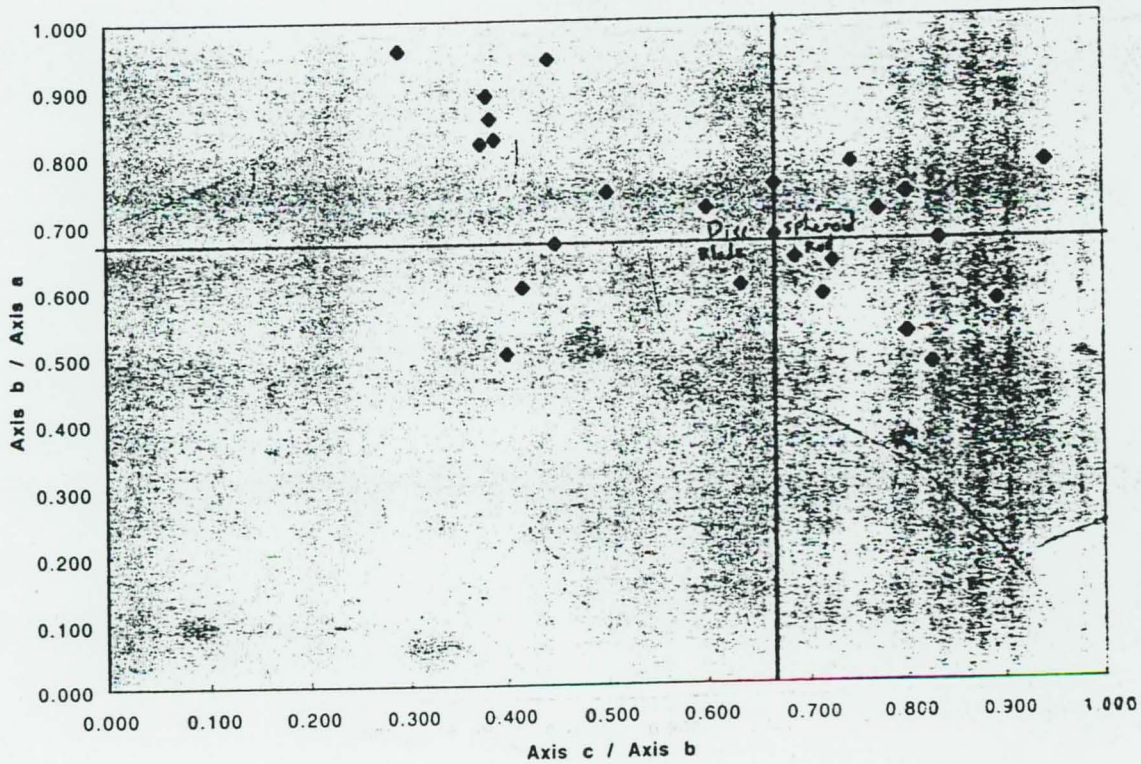
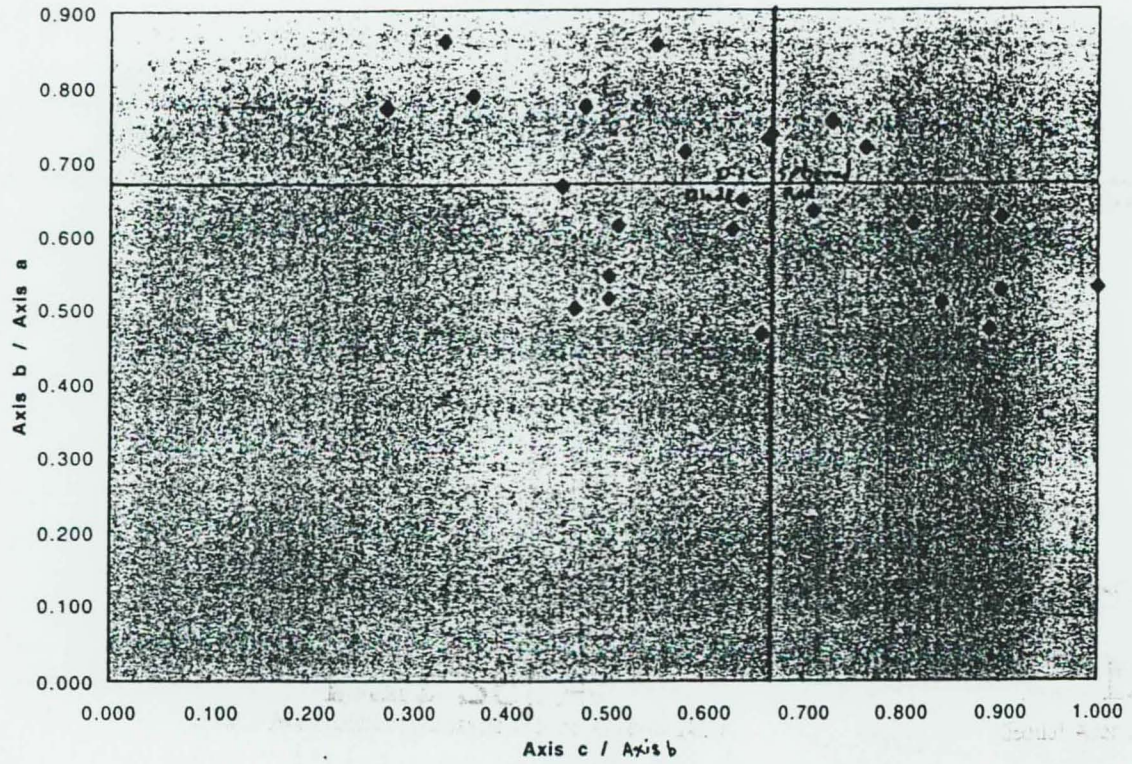


Figure 4. Pebble shapes

Pebble Shape: Data Set C



Pebble Shape: Data Set D

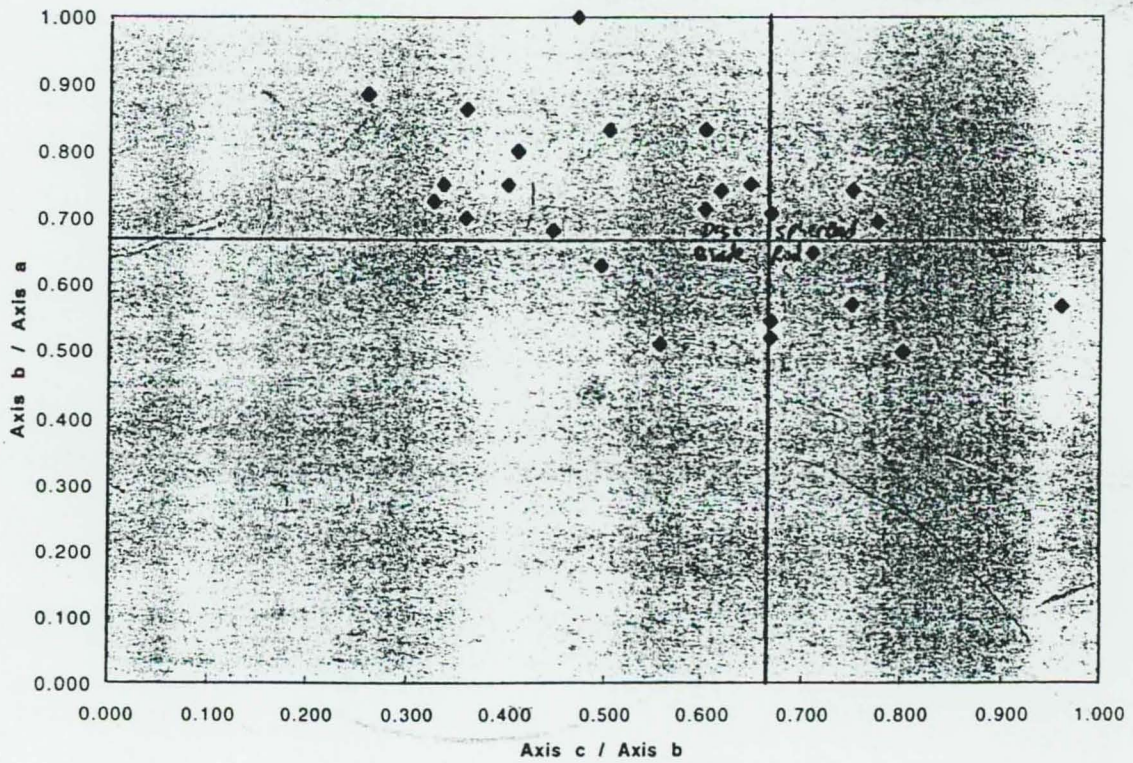
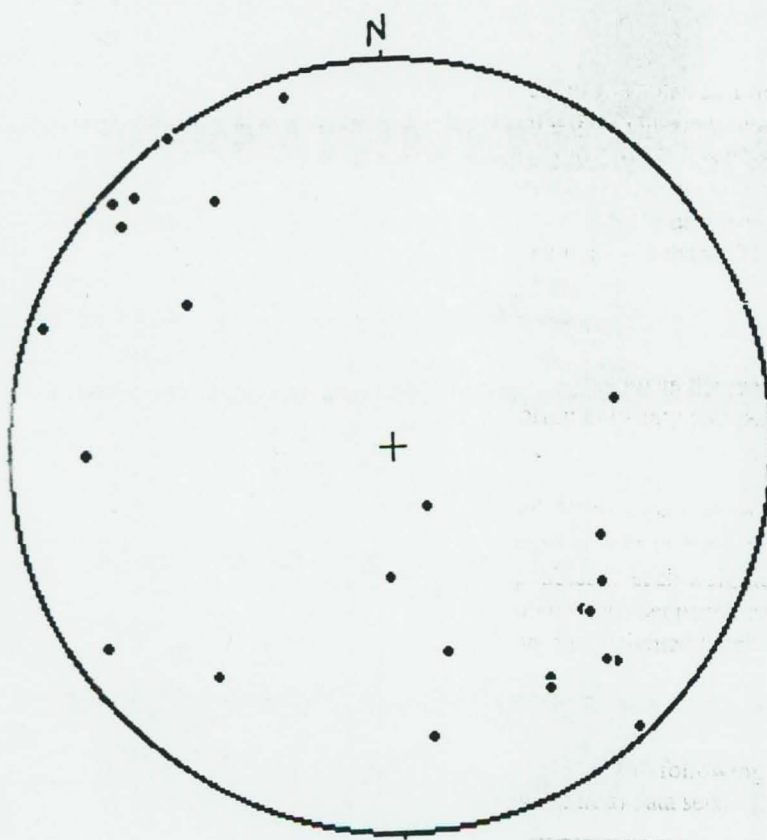
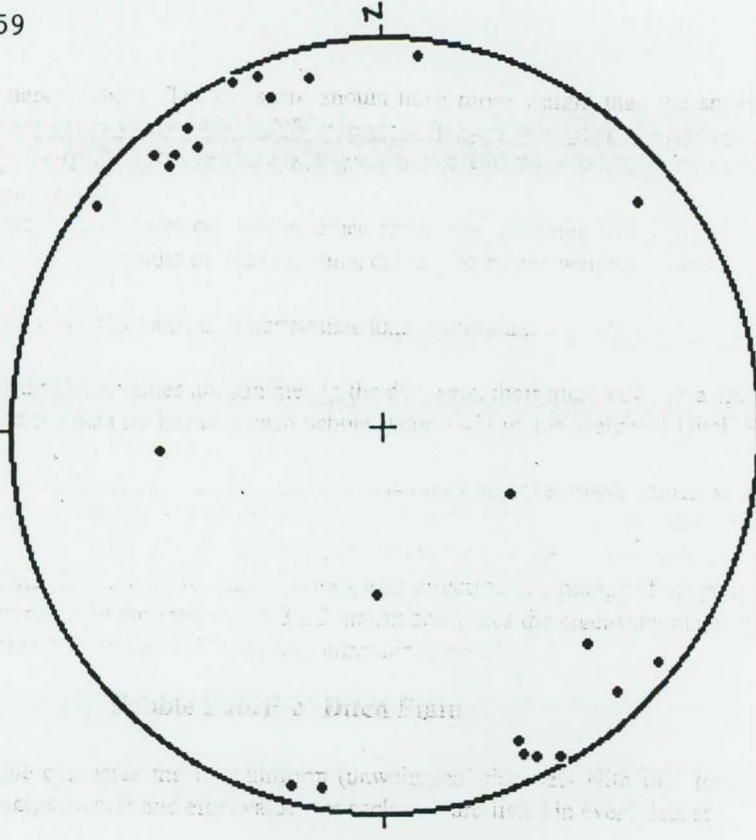


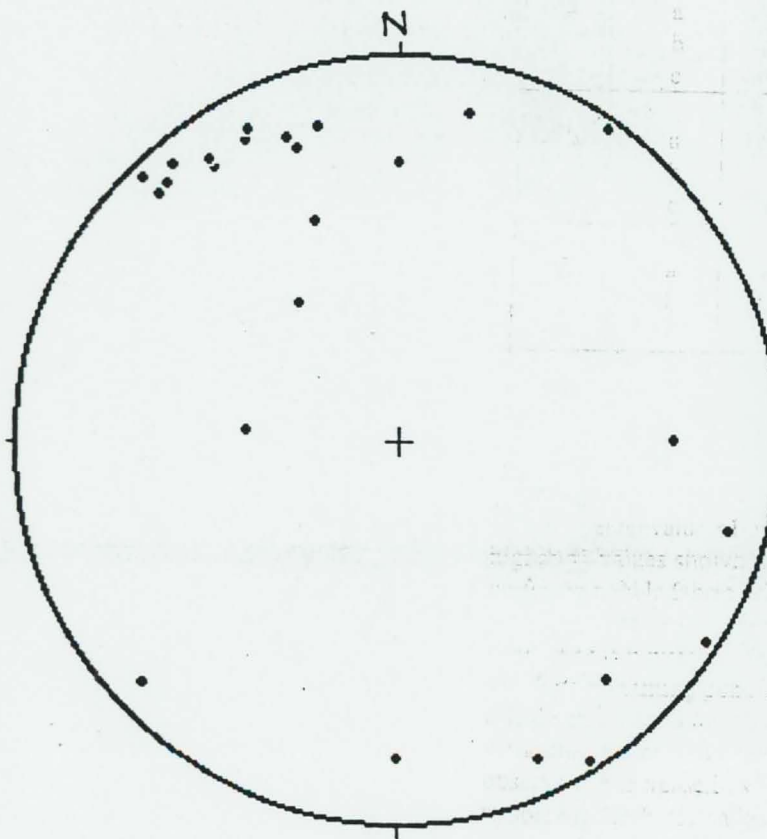
Figure 5. pebble shapes continued



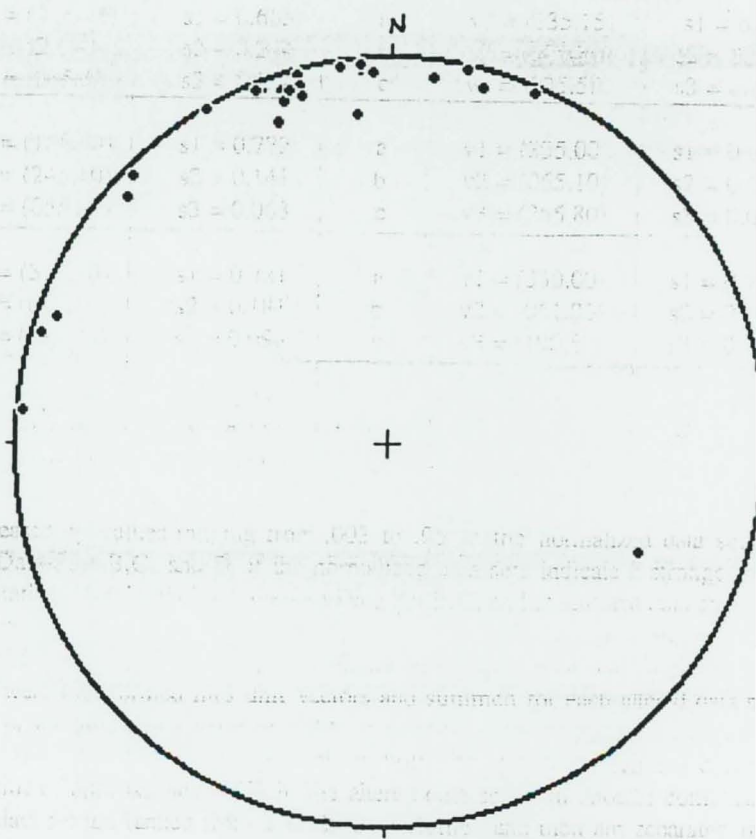
**Data Set A:**  
(Equal Area Lower Hemisphere Projection of axis a)



**Data Set B:**  
(Equal Area Lower Hemisphere Projection of axis a)



**Data Set C:**  
(Equal Area Lower Hemisphere Projection of axis a)



**Data Set D:**  
(Equal Area Lower Hemisphere Projection of axis a)

Figure 6. Stereonets

counts as much as a rod shaped pebble. The rod shape should have more weight than the spheroid because the rod points in two clear but opposite directions. Which direction the spheroid arrived from or which way it currently points is difficult to determine because it is not elongated. For this reason, a weighting factor for individual pebble shape is necessary.

The data from Ditch Plains therefore was modified to include a pebble weighting factor based on the pebble's shape. The following formula defines the value calculated by the weighting factor,  $w_i$ :

$$w_i = (\text{long axis } a - \text{intermediate axis } b) / \text{long axis } a$$

When the weighted pebble values are summed in the data sets, their total value is a fraction of the original twenty five pebbles per data set because each pebble value ( $w_i$ ) in the weighted Ditch Plain's data sets counts as less than one pebble. The reason for this is that only the ideal pebble, an infinitely long and infinitesimally skinny rod equals one, whereas other less ideal pebbles achieve lower values, as assigned by  $w_i$ . Within the pebble fabrics of diamicts, perfect spheroids and perfect disc shaped pebbles have the most randomness in their orientation so those shapes each score  $w_i$  values of zero. Although the number of pebbles in each weighted data set becomes reduced, the long axis direction and plunge of the pebbles making up the data set becomes increasingly emphasized. A 3 x 3 matrix computes the eigenvectors and eigenvalues on the weighted Ditch Plains data sets establishing four normalized matrices.

### Pebble Fabric at Ditch Plains

The following table compares the four uniform (unweighted) data sets with the four normalized (weighted) data sets. Both eigenvector and eigenvalues for each axis are listed in every data set.

Data Set:	Axis:	Uniform Eigenvectors (Azimuth, Plunge)	Uniform Eigenvalues	Axis:	Normalized Eigenvectors (Azimuth, Plunge)	Normalized Eigenvalues
A	a	v1 = (135,15)	s1 = 0.663	a	v1 = (135,15)	s1 = 0.66
	b	v2 = (244,51)	s2 = 0.214	b	v2 = (236,36)	s2 = 0.236
	c	v3 = (035,35)	s3 = 0.124	c	v3 = (025,50)	s3 = 0.104
B	a	v1 = (155,00)	s1 = 0.772	a	v1 = (335,00)	s1 = 0.819
	b	v2 = (245,10)	s2 = 0.141	b	v2 = (065,10)	s2 = 0.117
	c	v3 = (055,80)	s3 = 0.063	c	v3 = (255,80)	s3 = 0.063
C	a	v1 = (330,10)	s1 = 0.721	a	v1 = (330,00)	s1 = 0.758
	b	v2 = (062,10)	s2 = 0.181	b	v2 = (061,06)	s2 = 0.168
	c	v3 = (195,75)	s3 = 0.098	c	v3 = (190,80)	s3 = 0.074
D	a	v1 = (340,05)	s1 = 0.790	a	v1 = (340,05)	s1 = 0.842
	b	v2 = (070,04)	s2 = 0.196	b	v2 = (071,09)	s2 = 0.146
	c	v3 = (210,85)	s3 = 0.015	c	v3 = (230,80)	s3 = 0.012

Eigenvalue  $s_1$  increased by values ranging from .003 to .05 in the normalized data sets. The higher  $s_1$  values shown in Data Sets B,C, and D of the normalized data sets indicate a stronger and more preferred pebble fabric orientation than do their counterpart Data Set B,C, and D uniform data sets.

In order to assess the affect on fabric analysis due to the reduction in the number of pebbles resulting from weighting pebble shapes, we randomly reduced the initial number of starting pebbles per data set. The remaining pebbles were transformed into unit vectors and summed for each altered data set. We calculated eigenvectors and eigenvalues both prior to and then following the application of the pebble weighting factor. By using the same unit vector approach on both the altered and original data sets, we observed an increase in  $s_1$  value of approximately 5% in the altered data sets. In another comparison, the pebbles in each normalized data set are ranked from 1 to 25 by volume and then are separated into two groups. One group included the first twelve largest volumes of the data while the other group held the last thirteen smallest volumes. The  $s_1$  eigenvalues were compared between the two groups of the data set and

normalized data set itself. As expected, higher  $s1$  values were found for the two separated groups when compared to  $s1$  eigenvalue of whole data set. We also substituted the intermediate axis  $b$  for long axis  $a$ , in each data set and found no appreciable change in  $s1$  eigenvalues for these data sets. From this we conclude that the weighting factor is a robust statistical approach and that the weighting factor improves the pebble fabric analysis method overall because the shapes of each pebble are held accountable for their individual influence on the strength of the whole pebble fabric.

### Comparison With Published Data

Statistical confidence in the eigenvalue method leads to direct comparison with previously published results on fabrics from modern terrestrial glacial sediments. A plot of the eigenvalue  $s3$  versus eigenvalue  $s1$ , from the uniform Ditch Plains data sets compares directly with the results of published data (fig. 7). The plot of eigenvalue  $s3$  versus eigenvalue  $s1$ , shows the published data as individual points representing the mean eigenvalues of that data, while the range of the first standard deviation of the published data is shown by length of the cross bars around each data point. In addition, the plot shows the position of each of the Ditch Plain's data sets relative to the published data reported. Data Set A appears to be a flow till, as the data point falls within one standard deviation of the published data for flow tills. Data Set B and Data Set C, both fall between a flow till and a lodgement till. Data Set D appears to fall below the range of a subglacial melt out till.

A similar  $s3$  versus  $s1$  eigenvalue plot compares the same published data with the normalized Ditch Plain's data set's (fig. 8). On this graph Data Set A still appears to be a pure flow till, however the data set's position moved closer towards the lodgement till range. Data Set B's position changed enough so that now its position is within one standard deviation of a pure lodgement till. Data Set C's position moved and now it lies as a pure lodgement till. Data Set D, shifted downward and to the right of its previous position, it still plots as a subglacial melt out till.

### Discussion

Based on the relative positions of the normalized data sets versus the published data, the simplest interpretation of the overall glacial setting at Ditch Plains would regard the capping massive diamict unit (Data Set A) as a flow till unit, and divides the lower stratified unit into a lodgement till unit (Data Sets B & C) and a subglacial meltout unit (Data Set D). Therefore, one working model is that the lower stratified diamict unit represents a diamict deposited during a glacial advance and the capping massive diamict represents deposition during a glacial retreat.

Further conclusions based on these data are deficient mainly because of the ambiguity concerning the orientation and fabric strength of diamicts originating from debris flows or from other depositional processes. For example, if a debris flow pebble fabric derived from a flash flood in a desert region has the exact eigenvalues as a diamict fabric in a glacial environment, then the unit vector approach is less effective as an interpretative tool for the origin of the deposit. In addition, the thickness of the lower stratified diamict and apparent absence of jointing are not consistent with lodgement origin. Thus combining the unit vector approach with other sedimentological and stratigraphic approaches strengthens the confidence of the vectorial approach when applied to understanding the origin of deposits.

### Conclusion

On the basis of this study, quantitative pebble fabric analysis is an important tool for deciphering the origin of diamicts throughout Long Island. Further testing and integration with stratigraphic information will strengthen the interpretive capability of pebble fabric analysis. Future goals for continued research with quantitative fabric analysis are improvement of the pebble shape weight factor, calculation of the eigenvalues based on triaxial information rather than on just using the long axis  $a$ , continued comparison of Long Island eigenvalue data plots with published eigenvalue data plots for modern terrestrial glacial deposits, and to find out more about pebble fabric development and pebble fabric strength of diamicts in a wider variety of depositional environments.



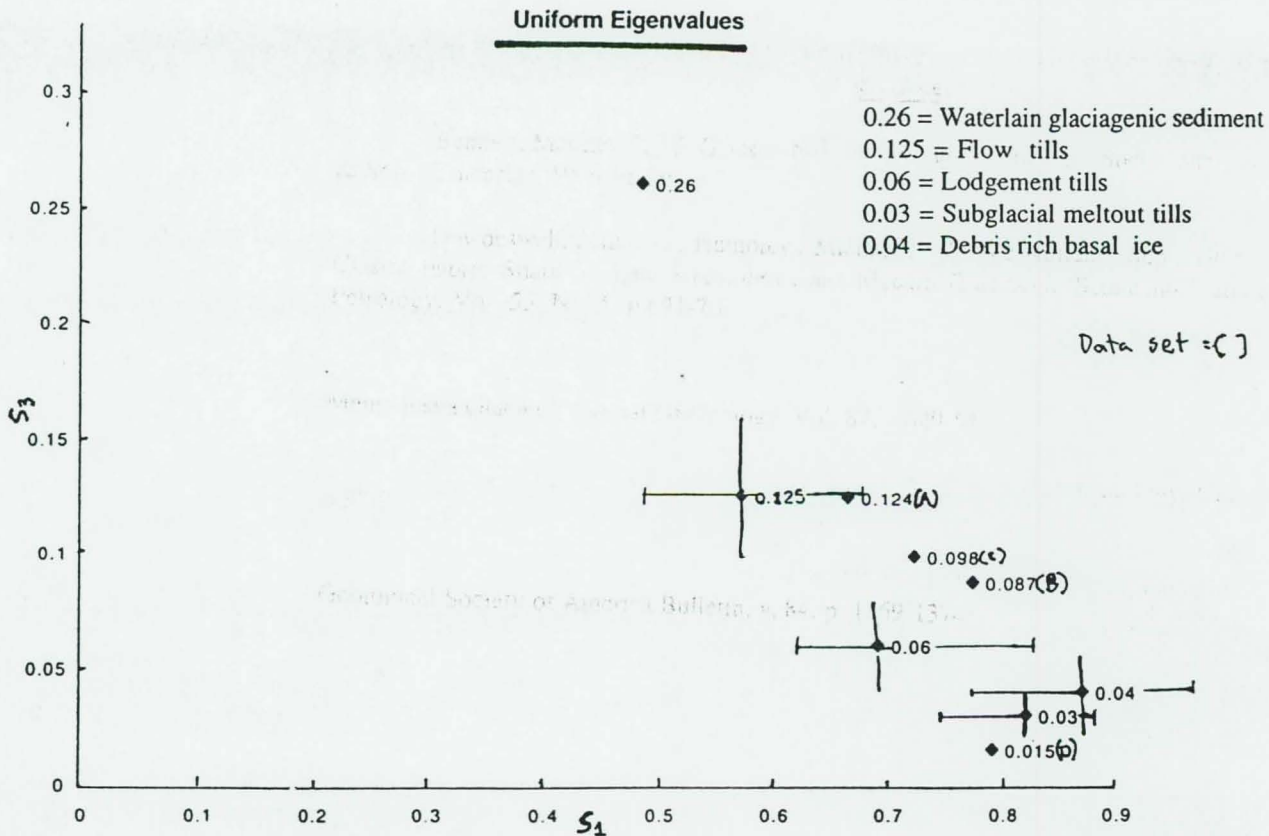


Figure 7:

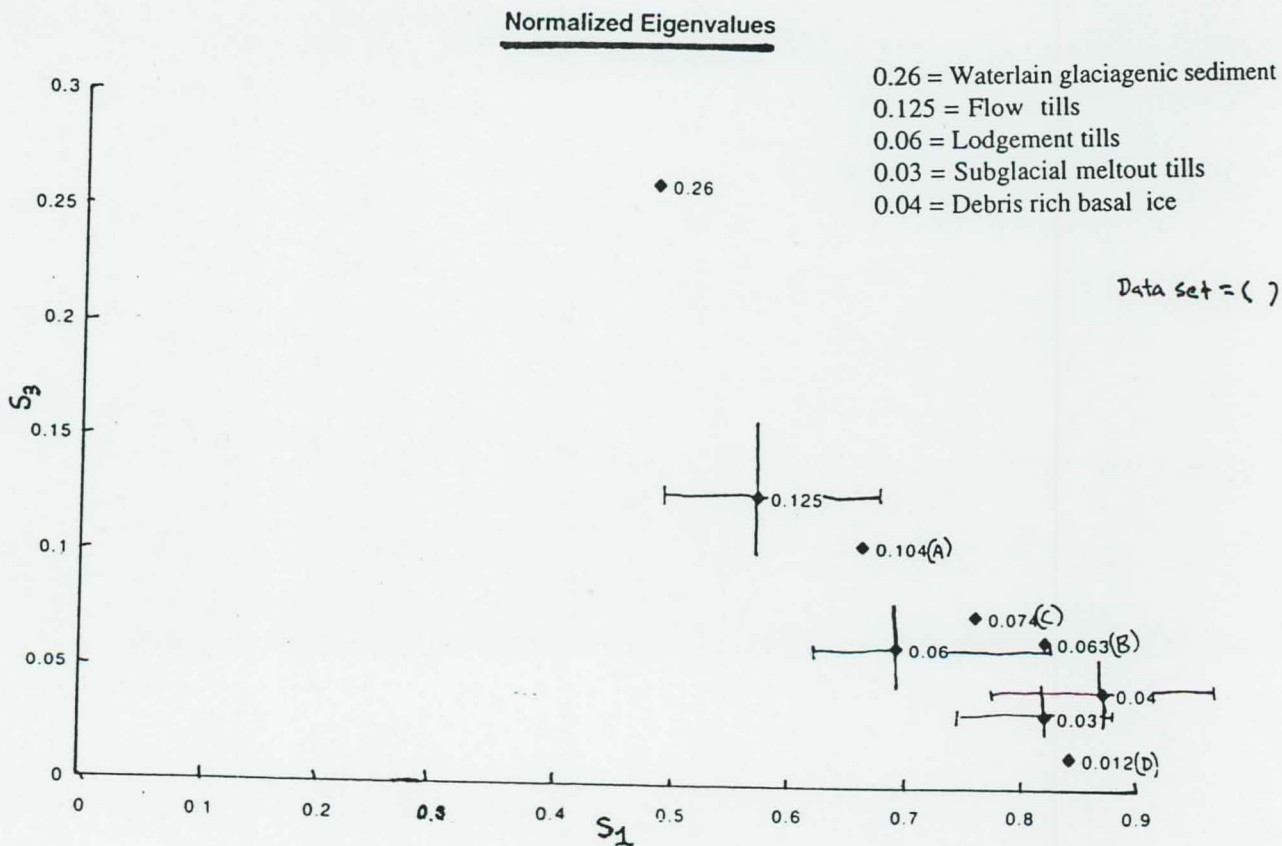


Figure 8:

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