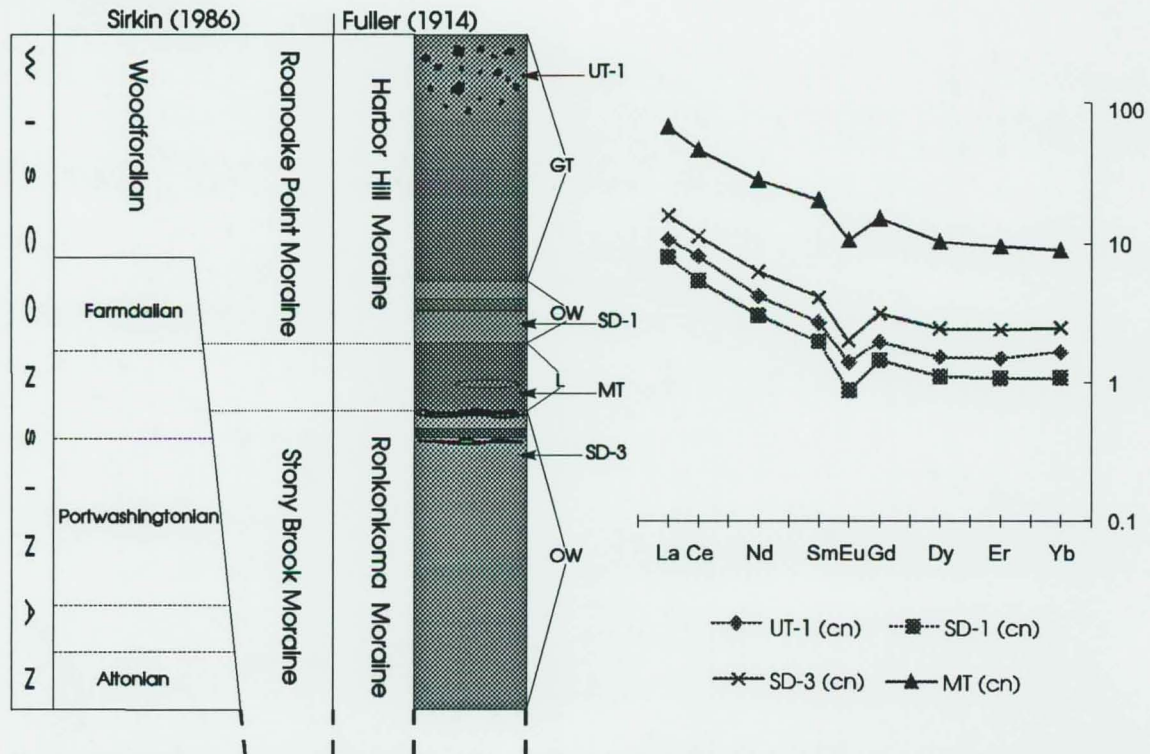


REE CHEMISTRY OF PLEISTOCENE SILT AND SAND, SETAUKET, LONG ISLAND
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Rare earth element (REE) chemistry in glacial sequences has been all but ignored. Analyses of individual glacial sands and loess have been reported, however, entire advance-retreat sequences have been neglected. The bulk chemical composition (in particular REE's) of unaltered sediment is, in general, derived from the chemical composition of its mineralogical constituents. In effect, REE chemistry will reflect the bulk mineralogy and provenance of the sediments. This relationship has been well documented in marine shales (Taylor and McLennan, 1985, McLennan, 1989). This study focuses on sand and silt from an upper glacial deposit in Setauket, Long Island. The Setauket glacial sediments have low overall abundances of REE's except for one silt sample (Figure 1). REE patterns are parallel to sub-parallel and the overall pattern shape is apparently unaffected by grain size, sorting and % quartz in the sample. Total

Figure 1.



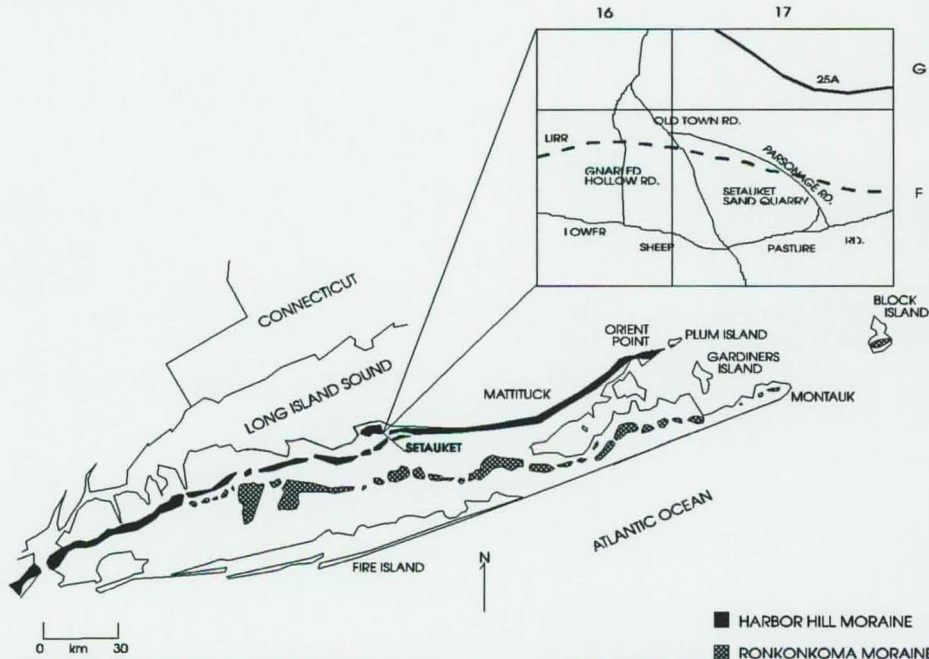
REE abundances for all samples show a positive relationship with these same parameters. This relationship in addition to petrography and USGS well log data, suggests that the silt (MT) located between the upper and lower outwash in the study area may represent a loess, deposited between a retreat and re-advance of the latest Wisconsinan glacier on Long Island. The results of this study provide data required to place stratigraphic constraints on the Setauket glacial sequence in terms of the known glacial stratigraphy on Long Island.

The Setauket glacial sediments are located on the north shore of Long Island in an abandoned sand quarry (Figure 2). These sediments (till, outwash sand, silt, clay) are thought to have been deposited by the latest Wisconsinan glacier to reach Long Island (Fuller, 1914, Sirkin, 1986). The direction of advance of this glacier is currently unresolved. Two prevailing hypothesis describe very different advance patterns and associated source terranes. Fuller (1914), provides one of the earliest more comprehensive descriptions of the glacial stratigraphy on Long Island. This description identifies four separate glacial stages corresponding to Pliocene mid-continent stratigraphy. According to Fuller only the uppermost sediments on Long Island (Ronkonkoma and Harbor Hill moraines) were deposited during the Wisconsinan. Glacial scour marks on Connecticut bedrock reported by Sanders and Merguerian (1991 and

1992), suggest at least three separate glacial advances from two directions (NNE, NW, NNE). An alternate hypothesis describes most of the glacial sediments on Long Island as Wisconsin in age (Sirkin, 1986). Sirkin suggests that the apparent change in direction is due to the lobate nature of the glacier. Within Sirkin's stratigraphy the Setauket glacial sediments are part of the Stony Brook and Roanoake Point moraines.

Grain size analysis, petrography and REE chemistry were employed in this study to

Figure 2.



address three basic questions: 1) Do REE patterns vary within glacial sediments thought to be deposited by a single advance or individual lobe?, 2) If there is significant variation what is the source of the variation? (e.g. sorting, grain size, weathering), 3) What is the mineralogy of the sediments and how does that effect the REE patterns? Representative samples were collected from the Setauket sand quarry. A suite of samples was selected based on stratigraphic position and estimated grain size in order to best represent the variety of lithologies common in a typical glacial sequence (till, outwash, silt (loess)). Each sample selected for analysis was dried at 80 °C overnight. The dried sample was then split for REE, grain size and thin section analysis. The samples to be analyzed for REE's were powdered in an agate mill and 200 mg of rock powder were fused with lithium metaborate in graphite crucible at 1100 degrees C for 20 minutes. Fused beads were then dissolved in 30 ml of 1N HNO₃ and mixed REE spike. A bulk separation of REE's was accomplished by passing the spiked solution through a cation exchange column using HCl and HNO₃ chemistry. The REE's were then separated into cuts of 1) La and Ce, 2) Nd, 3) Sm and Eu, 4) Gd and 5) Dy, Er and Yb. This separation was accomplished by α -Hiba (di-methylsuccinic acid) chemistry to facilitate mass spectrometry. Isotope dilution analyses were performed on an NBS design 15 cm radius of curvature mass spectro-meter. Total analytical error for REE abundances is less than 1%.

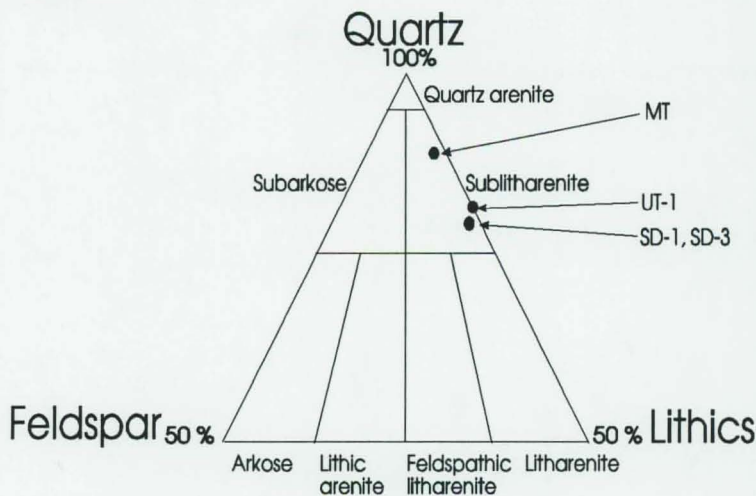
Examination of Chondrite normalized REE plots of the data (Figure 1) suggest that there is virtually no change in the overall REE pattern between samples. All four samples display light REE (LREE) enrichment, a Eu-anomaly and heavy REE (HREE) depletion, a pattern typical to upper continental sedimentary rocks (Taylor and McLennan, 1985). Variation in Σ REE abundance between samples is however, significant. The three most depleted patterns consist of a till and two outwash samples (UT-1, SD-1, SD-3). The most enriched pattern is derived from a very fine silty-sand (MT) deposited between the upper (SD-1) and lower (SD-3) outwash (Figure 1).

To explain the variation in Σ REE a grain size analysis was performed on split samples of the Setuaket sands. A sieve range was selected in order to identify the major grain size ranges between 2.83 mm-0.0625 mm. Samples were then weighed and agitated in a Tyler shaker unit for 30 minutes. The volume of sediment captured in each sieve was weighed and recorded. The graphic mean grain size and graphic standard deviation (sorting) were calculated using the technique from Folk (1968) (Table 1). Grain sizes range from coarse to very fine sand and silt and sorting from well to very poorly sorted. The most interesting results reported are for the very fine sand and silt sample (MT). This sample is the most poorly sorted, which is not obvious upon inspection in the field. The rest of the samples are close in grain size and sorting.

Sample	Mean Grain Size	Sorting
UT-1	0.93 ϕ (crse. sand)	moderate
SD-1	1.08 ϕ (med-crse. sand)	well sorted
MT	3.48 ϕ (vf. sand-silt)	poorly sorted
SD-3	1.5 ϕ (med. sand)	poorly sorted

In addition to grain size and sorting, mineralogy may have an effect on REE abundances. To address this potential, thin sections were made from a third split and a point count was performed using parameters based on the methodology of Dickinson (1970). A

Figure 3.

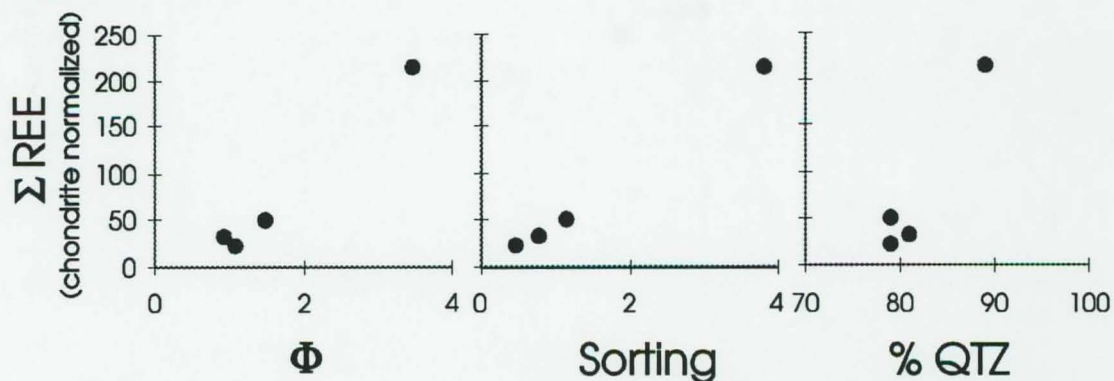


minimum of 300 points were counted for each thin section at a grid spacing determined by the surface area of the thin section. Grains were divided based on criteria modified from Dickinson (1970) and Folk (1968) and are plotted on a Quartz-Feldspar-Lithic fragment diagram with a classification scheme from Folk (1980) (Figure 3). All the samples plot within the Sublitharenite region of the diagram indicative of their high Quartz/Feldspar ratio. The dominant lithic fragment identified in all samples is sandstone. The silt sample is

unique in that it is composed of mainly quartz grains (89.1%) and contains a significant amount of muscovite counted here as matrix.

Despite the parallel to sub-parallel shape of REE patterns from the Setauket sediments there is variation in the total REE abundance that must be accounted for. REE's in sediments are known to be affected by grain size and sorting (Taylor and McLennan, 1985 and McLennan, 1989). A general relationship exists such that finer grained sediments (e.g. shale) tend to be enriched in REE's as compared to more coarse grained sediments (e.g. sandstone) owing to the concentration of REE-enriched clay minerals. This relationship would seem to apply to the Setauket sediments as is evident from a plot of graphic mean grain size (ϕ) versus Σ REE (Figure 4). In general, a relationship between Σ REE and sorting is not clear. There is a positive trend between Σ REE and sorting for the Setauket sediments. Well-sorted sediments tend to have lower overall REE abundances (Figure 4). In addition to the apparent trends between REE's, grain size and sorting, there is also a relationship between Σ REE and % quartz. Contrary to expectations, the sample with the highest % quartz (MT; 89.1%) also has the greatest Σ REE (Figure 4). Quartz is generally thought to contain almost no REE's and act solely as a dilution factor for Σ REE in sediments (Taylor and McLennan, 1985). This being the case, the presence of a REE-rich phase(s) is necessary to account for the relatively high Σ REE in the MT sample. If

Figure 4.



it is assumed that the REE content of quartz and sandstone fragments in MT is equivalent to the ΣREE in SD-1 (lowest abundance sample), the ΣREE of the remaining phases present can be calculated:

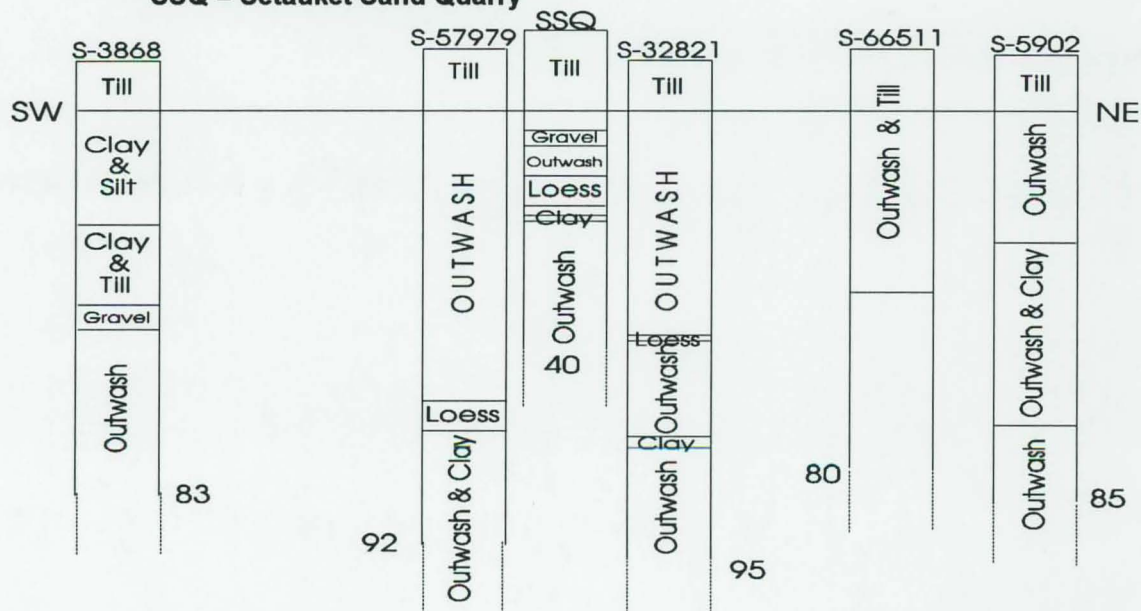
$$\Sigma\text{REE}_{\text{MT}} = \{(\Sigma\text{REE}_{\text{Qtz phases}} * .738) + (\Sigma\text{REE}_{\text{Remaining phases}} * .262)$$

$$105 \text{ ppm} = \{(12 \text{ ppm} * .738) + (\Sigma\text{REE}_{\text{Remaining phases}} * .262)$$

$$\Sigma\text{REE}_{\text{Remaining phases}} = 366.96 \text{ ppm}$$

Where $\Sigma\text{REE}_{\text{Qtz phases}} = 12 \text{ ppm}$, .738 is the percentage quartz-rich phases in MT, $\Sigma\text{REE}_{\text{Remaining phases}}$ is the unknown and .262 is the percentage lithic grains, feldspar and non-void space matrix. This simple calculation suggest that the remaining phases, which are dominated by muscovite must contain a $\Sigma\text{REE}_{\text{max}}$ of 366.96 ppm, which is a reasonable value for muscovite (Taylor and McLennan, 1985). The absence of mica and presence of dominantly sandstone as a lithic fragment in UT-1, SD-1 and SD-3 can account for the very low ΣREE . The stratigraphic location (between outwash sequences), grain size, high quartz content and relatively enriched REE pattern suggest that the silt sample may represent a loess deposit. However, high

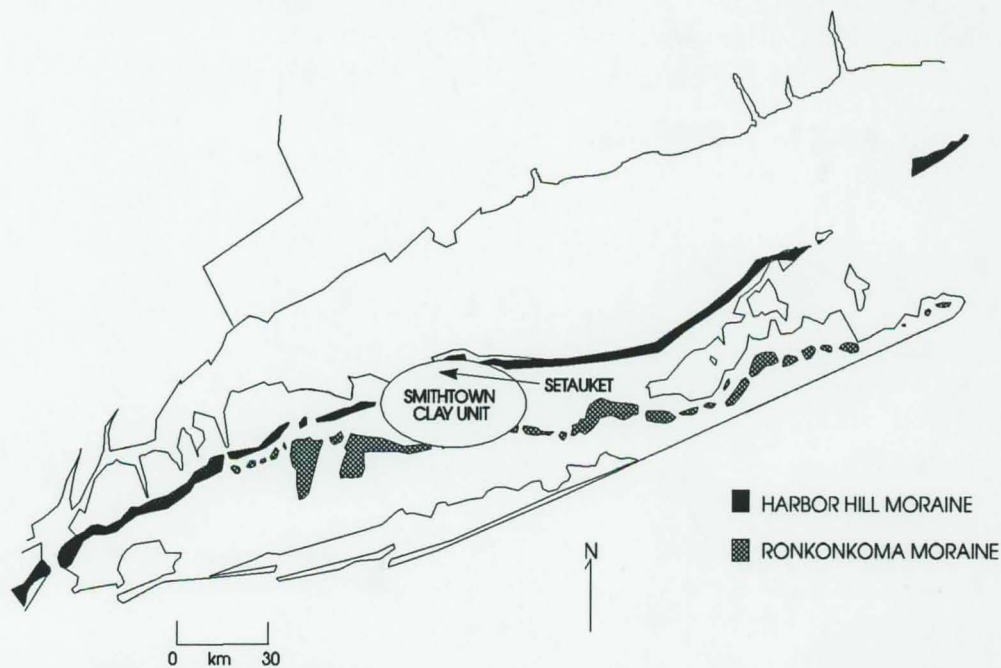
Figure 5. Horizontal transect distance = 1.27 miles.
SSQ = Setauket Sand Quarry



muscovite content and poor sorting is uncommon for a loess.

In an effort to confirm the lateral extent of the MT unit, USGS well logs were examined. A list of wells and well log data within a 2 mile radius of the Setauket sand quarry were furnished by the Coram office of the USGS Water Resources Division. Five wells were selected along an SW-NE transect between the SUNY Stony Brook campus and Port Jefferson Harbor. These logs were interpreted and a stratigraphic sequence was constructed (Figure 5). From this sequence it can be determined that the MT unit is present in most if not all the wells. There is also an outwash-clay-outwash sequence present in all but one well. This sequence occurs below the MT unit with in the lower outwash. This same sequence is described in a number of wells correlated by Krulik and Koszalka (1983) and has been identified as the Smithtown clay unit (Figure 6). The Smithtown clay is thought to be a glacial-lacustrine clay deposited within the Ronkonkoma moraine (Stony Brook moraine in the Setauket area, after Sirkin, 1986). If the Setauket clay is a lateral extension of the Smithtown clay it would follow that the MT unit may be a loess. The MT silt would then represent erosion of any till that was deposited in the Setauket area during the recession of the Ronkokoma/Stony Brook moraine. The USGS well log data helps to constrain the stratigraphic context of the Setauket sands.

Figure 6.

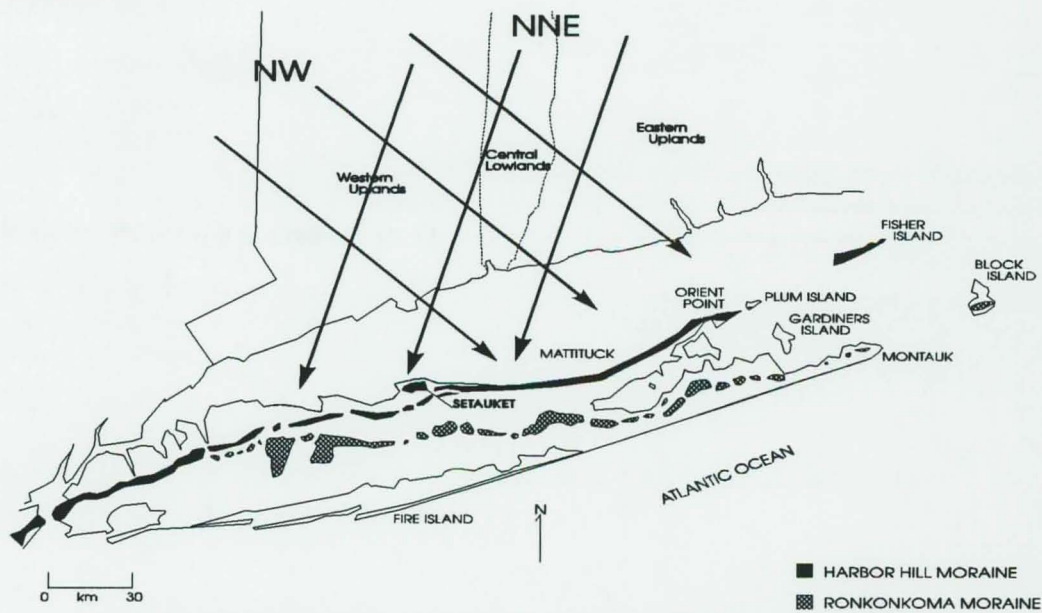


The petrography of the Setauket sediments may offer additional information regarding their stratigraphy and provenance. A high quartz/feldspar ratio and muscovite in the matrix suggests that the Cretaceous sands, which lie unconformably below the Pleistocene deposits, may be a source for the Setauket sediments. Cretaceous sediments would have been eroded and re-deposited as outwash and ice shove tills. Clay-poor till capping the Setauket sequence is in agreement with this interpretation. This type of depositional regime does not rule out the Connecticut bedrock as an additional source of sediment. Sandstone, schist, and meta-crystalline quartz are ubiquitous in the Setauket sands. The presence of these lithic fragments requires a central Connecticut source and a NNE-SSW advance pattern. It is reasonable to expect that in addition to the shoved Cretaceous sediments, scoured sediments along the path of the glacier would also be deposited in a moraine. The mineralogy of erratics deposited by the latest Wisconsinan glacier to reach Mattituck supports this contention. The dominant boulder type at Mattituck is Hartford Basin arkose consistent with a NNW-SSE glacial advance direction (Griffin, 1992). The results of this study and the Mattituck study can be compared to existing

glacial advance models based on work by Sanders and Merguerian (1991, 1992) and Sirkin (1986).

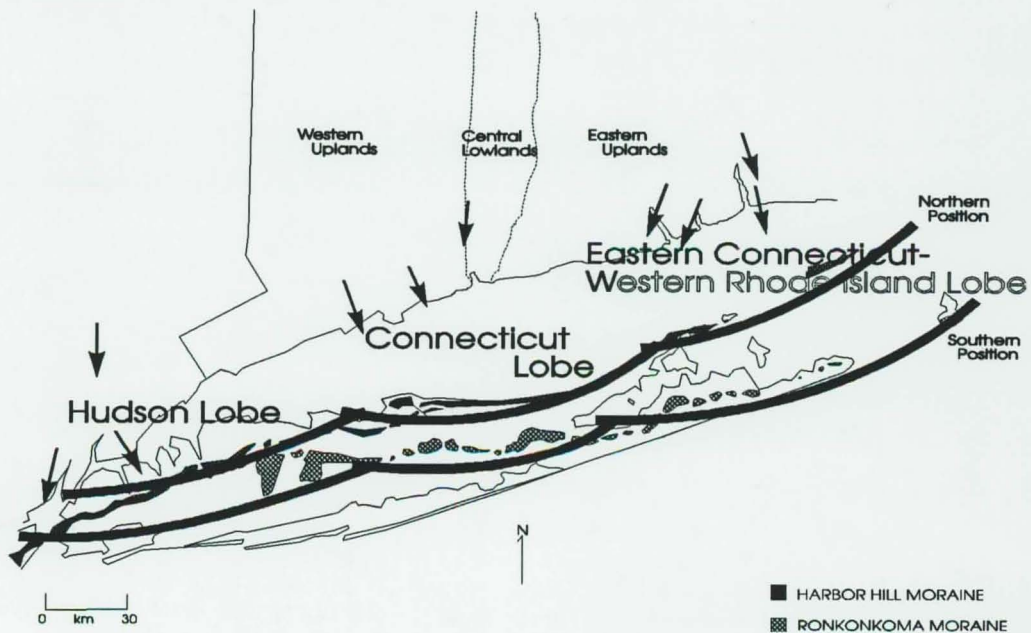
The glacial advance model of Sanders and Merguerian is based in part on the stratigraphy of Fuller (1914) and glacial scour marks in New York and Connecticut bedrock. The model identifies three (possibly four) separate glacial advances from two directions. Three sets of striations are described the first set from the NNE-SSW, the second, which overlap the first, from the NW-SE and the last set again cross-cuts the second set from the NNE-SSW (Figure 7). In this model it is essential that the sediments in Mattituck be younger than the Setauket sediments. If this model is correct, the latest Wisconsinan advance (NNE-SSW) did not reach eastern Long Island. The boulders at Mattituck were deposited by an NW-SE trending glacier and the Setauket sediments were deposited earlier by a NNE-SSW trending glacier.

Figure 7.



The Sirkin model employs a lobate glacial front to account for conflicting bedrock

Figure 8.



striations and similar provenance over a wide area (Figure 8). This model is derived primarily from the morphology of glacial features on Long Island. There is also evidence from a provenance study of heavy minerals in the upper two tills on Long Island, that suggests a lobate advance pattern (Dermer, 1981). The Sirkin model suggests that the Setauket and Mattituck sediments are coeval and were deposited by the 'Connecticut lobe' of a single glacier. Both models account for the high quartz/feldspar ratio of the Setauket sediments if the quartz is derived from Cretaceous sediment. As a result, it is difficult to reasonably conclude which glacial advance model is most accurate. A more detailed study of the sediments and stratigraphy between Setauket and Mattituck is required.

Regardless of which glacial advance model is applied to the Setauket sediment, valuable information has been gained as to the REE chemistry of a glacial sequence. The REE patterns from the Setauket sediments are parallel to sub-parallel and are typical of upper crustal sedimentary rocks and sediments. The total abundance of REE's does vary between samples owing to grain size and concentration of REE enriched phases. Additionally, it is reasonable to suggest that total REE abundances may be used to help discriminate a loess deposit from outwash and till samples.

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