

**PHYSICAL AND CHEMICAL CHARACTERIZATION OF SOIL  
AS THEY RELATE TO  
GEOPHYSICAL LOGGING OF EASTERN LONG ISLAND AQUIFERS**

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**Abstract**

As part of the Peconic Estuary Program (PEP), the aim of this project was to develop a comprehensive study of the hydrogeologic situation of eastern Long Island. A preliminary investigation involved geophysical logging, or lowering various nuclear and electric apparatuses into a strategic, near-shore monitoring well (or directly in ground) for the purpose of mapping confining properties of a formation. Nuclear and electric logs were performed on location and have proved to be an important part of determining stratigraphic and hydrologic correlation between measured sites. Core samples were subsequently removed from confining units to continue a more extensive soil analysis that included grain size analysis and various methods of mineral identification. Together, these methods have provided valuable information about organic and inorganic contaminant transport, nutrient flux into and out of the Peconic Bay area and its relation to the presence of brown tide (an insistent algal bloom). Studying the properties and behavior of underflow in coastal sediments will help us determine future management zones in the Peconic aquifer system.

**Introduction**

In recent years, Long Island has experienced a number of hydrogeological problems which concern residential communities primarily on the east end of Long Island in the Peconic Bay area. Some of these issues include overuse of water, salt-water encroachment, and organic and pesticide contamination. In addition, nutrient inputs from coastal aquifers are thought to contribute to the onset of brown tide bloom in the Peconic estuary system. These issues combined can strongly affect the characteristics of underground aquifers that constitute Long Island's only water supply system. In coastal environments such as Shelter Island, underflow (seepage of fresh water from the aquifer to the shore) may have a profound influence on the quantity and quality of the water

entering the estuary (Paulsen, et al., 1997). Addressing and managing these environmental problems first

requires an understanding of the hydrogeologic and hydrodynamic behavior of ground water flow in various subsurface media.

As part of an on-going project to develop a comprehensive methodology for the hydrogeologic investigation of eastern Long Island aquifers, we integrate geophysical logging and core sample characterization (Mitchell, 1976). The more commonly used logging tools that record with depth include natural gamma (detects total gamma activity), resistivity (measures electrical resistivity), and induction (measures conductivity or inverse resistivity). The logging tools we used are part of a much larger, truck-mounted device (the Geoprobe) which is also capable of collecting core and water samples using special core barriers. Examination of soils involves many different chemical and physical analyses. These include sieve and hydrometer analyses for determining grain size distribution, preparing thin sections for optical microscopy, and X-ray diffraction for mineral identification.

## **Borehole Geophysics**

### *Nuclear Logs*

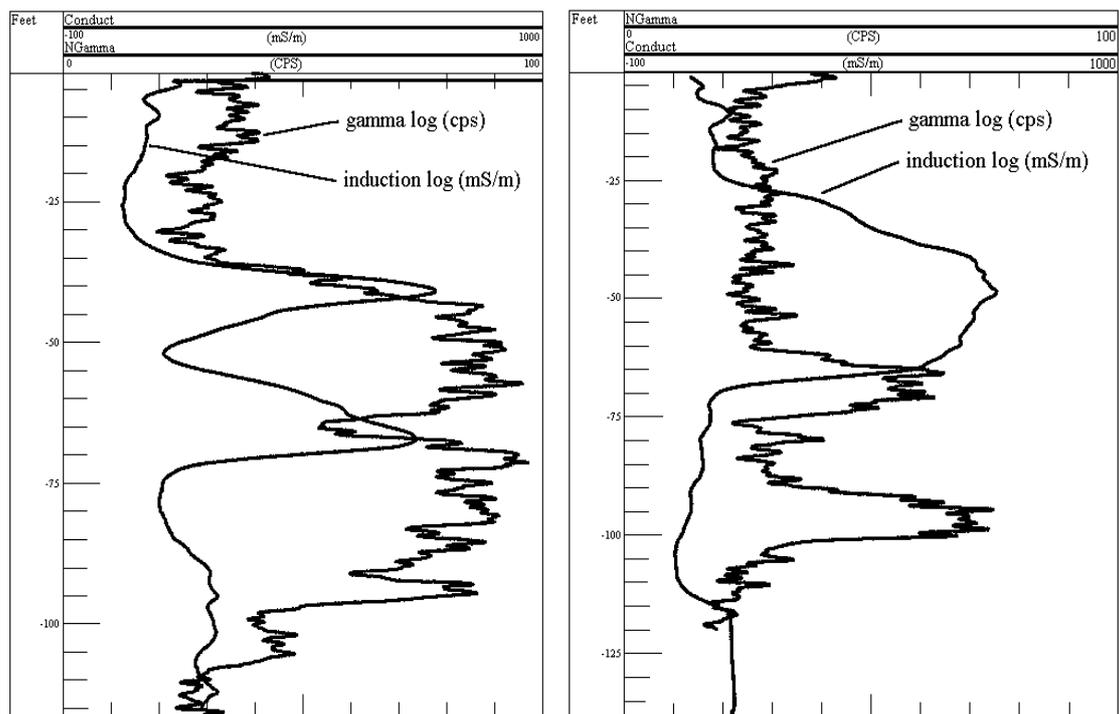
Natural gamma logs are useful in detecting gamma radiation which occur naturally in radioisotopes such as potassium-40 and the uranium-decay series that can exist in significant concentrations in subterranean formations. In practice, a gamma probe containing a scintillation crystal, sodium iodide, is lowered into a borehole, or well casing, where it detects total gamma radiation in counts per second with depth (W.S. Keys, 1997). Gamma activity is typically higher in fine-grained sediments such as shales and clays due to higher concentrations of potassium. Uranium and thorium are also more concentrated in clays due mainly to adsorption. In this way, gamma logs will normally show elevated peaks at depths with high clay content which provide extremely useful information about confining units that affect seepage behavior. A combined gamma-induction log is shown in Figure 1 which verifies a clay formation roughly between 40-60 feet and another between 65-95 feet. In Figure 2, a second gamma-induction log was measured from a well further east along the Peconic Bay showing a thinner series of fine-grained units at slightly lower depths which suggests a continuous clay wedge between the two locations. Core samples have subsequently been removed from these depths from both sites to continue soil analysis and identification. Results from soil tests have yet to be determined.

### *Electric Logs*

Resistivity and induction logs both measure the resistivity of the formations in which they are probed (W.S. Keys, 1997). The principal difference, however, is that the normal resistivity log can be performed at any given location since it can be probed directly into the ground using direct current. During a test, an electric current is passed through two

electrodes and the voltage drop is measured between two potential electrodes which is converted to a resistivity value in ohm-m (ohm-meters). A resistivity log can be adjusted to different configurations which are related to the spacing and sequence of electrodes. An induction log can measure resistivity (or inverse electrical conductivity) in an existing well casing which, in our field work, consisted mostly of PVC pipes. For this reason, an induction log is designed to transmit an AC current into the formation outside of the casing which is then received by a coil which converts the voltage into conductivity units in  $\mu\text{ S/cm}$  (microsiemens/centimeter). Salt-water lenses will produce peaks roughly greater than  $1000\ \mu\text{ S/cm}$ . Values less than  $1000\ \mu\text{ S/cm}$  are indicative of fresh-water and is correlated to the chloride concentration which has an acceptable drinking level of  $<250\ \text{mg Cl/L}$  (Soren, 1978). In reciprocal resistivity, the converse is true. The induction probe has proved to be a very useful tool particularly in coastal settings because of its capability of measuring electrical conductivity in muddy conditions and even water.

(Images are best viewed by clicking on the image and then clicking the right mouse button and selecting view image.)



**Figure 1.** Gamma-induction log from Bay Ave., **Figure 2.** Gamma-induction log from Point St.,

Aquebogue - well PEPN3. South Jamesport - well PEPN4.

## Grain Size Analysis

*The Sieve Technique*

Perhaps one of the most fundamental techniques of soil characterization is determining grain

size distribution. Soil consistency can be determined using both the sieve and hydrometer analyses (Al-Khafaji, et al., 1992). In a sieve test, a dried soil sample is passed through a stacked series of stainless steel sieves, each sieve being half the mesh size as the one above, and shaken mechanically. A pan with no openings is placed on the bottom which collects what remains of the sample. The sample retained on each sieve is massed, recorded and plotted on a semi-logarithmic grain distribution chart which also accounts for the percent finer by weight at each recorded grain size. Depending on how wide a range of grain sizes the sample has, the amount that is retained on the bottom pan can be further broken down in a second experiment with a set of finer mesh sieves or with a hydrometer analysis.

### *The Hydrometer Technique*

When the sample can no longer be separated by the dry sieve method as the particles are too small (i.e.  $<74 \mu\text{m}$ ), a sedimentation process with the aid of a hydrometer device is used as a continuation of grain size analysis. The hydrometer test is used primarily for samples which contain a relatively large portion of silts and clays. The actual hydrometer instrument consists of a weighed, mostly hollow, bulbous glass tube which reads the density of a suspension in which it is immersed in terms of specific gravity (a measurement which normalizes density to that of water). After having

performed a dry sieve analysis on the sample, what remains in the bottom pan is used for the hydrometer test.

The idea behind the hydrometer analysis is relating the settling velocities of the equivalent spherical diameters of the individual particles, the mass and diameter of the particles, and the viscosity of the fluid in which they are suspended (Al-Khafaji, et al., 1992). This relationship was first established by G.G. Stokes in 1850 and can best be expressed as:

$$D = K \sqrt{\frac{L}{t}}$$

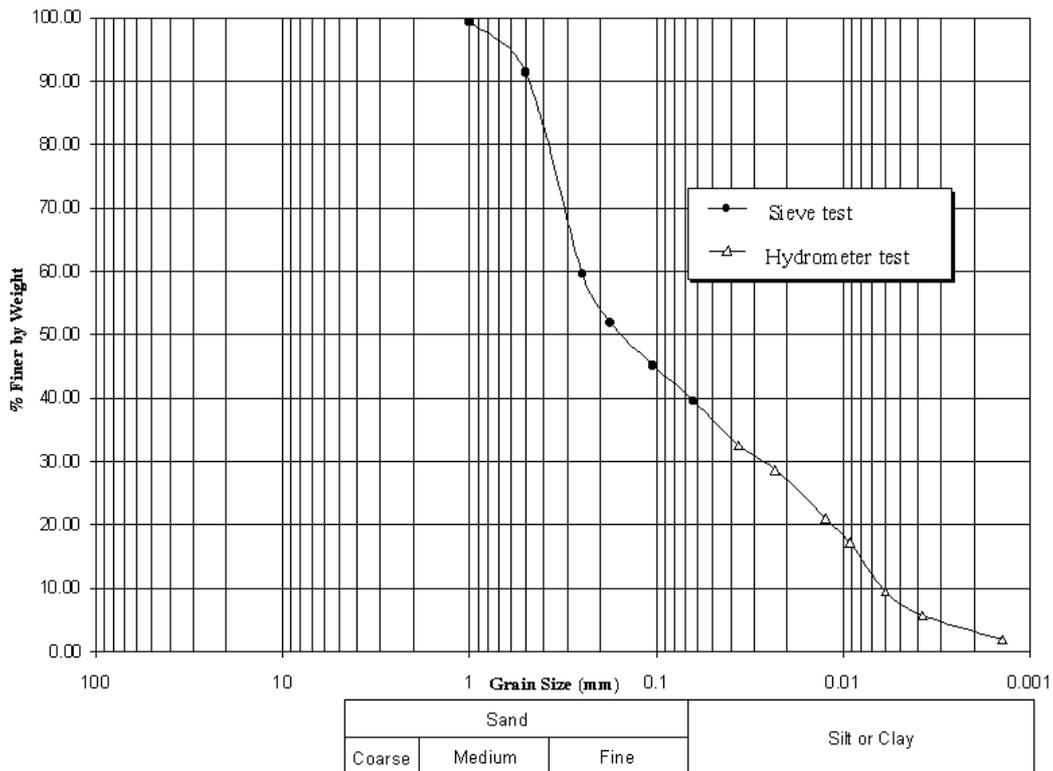
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where  $D$  is the equivalent diameter of the particle in mm,  $K$  is a constant which depends on both the temperature of the suspension and the specific gravity of the particle,  $L$  is the relative depth (cm) which is the distance between the top of the suspension and the base of the hydrometer, and  $t$  is the time (min). Most of the samples obtained in this study were poorly sorted because of the large range in grain sizes. A typical grain size distribution curve for this project is illustrated in Figure 3 from Calverton (50'-75') which required the use of both the sieve and hydrometer analyses.

In most site investigations, hydrometer measurements are not routinely conducted to characterize the finer fractions of the soil. The integration of sieve and hydrometer techniques provide important data on the distribution of silt and clay that significantly influence gamma activity, electrical conductivity and hydraulic conductivity.

(Images are best viewed by clicking on the image and then clicking the right mouse button and selecting view image.)



**Figure 3.** Grain size distribution for Calverton (50'-75').

### Thin Section Analysis for Coarse-grained Samples

A limitation of grain size analysis is that it does not provide any information on the mineral composition of soils. Thus, following grain size analysis, the particularly coarse-grained samples collected were made into thin sections for observation under a polarizing microscope. Each sample was disaggregated and oven-dried before being mixed with a two-part epoxy resin on a glass slide. The mounted sample is then heated to remove air pockets in solution and allowed to dry overnight. The samples are then coarsely trimmed down using a grinding wheel followed by polishing with successively smaller grit-size emery paper and lastly a series of finer, abrasive powders (Mitchell, 1976). Sections are typically no greater than 30  $\mu$  m thick before grains or crystals begin to overlay one another. Once samples have been primed, they are observed under plane polarized light so that individual grains may be seen. Mineral identification is accomplished based on size, shape and orientation of distinctive grains. Polarizing light, or affecting light into defined wavelengths, is for the purpose of differentiating pore spaces, large grain particles and clay fraction as well as outlining grain boundaries.

### **Distinguishing Types of Minerals in Clayey Samples Using X-Ray Diffraction**

An important goal of our soil characterization is identifying the predominant minerals in samples which have a relatively large clay fraction. This will help distinguish the samples between different clay layers (Gardiners, parts of Magothy, etc.) in order to develop an undivided stratigraphic map over a large area. This will give a better understanding of regional, subsurface hydrologic behavior. The best and most commonly used method for clay mineral identification is

X-ray diffraction in which crystals are bombarded by X-radiation and eventually absorbed by the atoms which in turn re-radiate as dipoles in all directions (Moore, et al., 1989). Since some of the scattered radiation are in phase with one another, they can be understood as reflections from the incident beams. The resultant reflection was interpreted by W.L. Bragg in 1912, producing Bragg's Law:

$$n\lambda = 2d \sin \theta$$

where  $n\lambda$  is the integral number of wavelengths,  $d$  is the spacing between layers of atoms and  $\theta$  is the angle between the incident beam and the atomic plane. The  $n$  component corresponds to the order of reflection where  $n=1$  for first-order reflection and so forth, although angles in which  $n>1$  are only apparent reflections. An X-ray diffraction chart will produce intensity peaks at different orders of reflection for each existing mineral and the consequent angles are converted to  $d$ -spacings using Bragg's equation.

In diffraction analysis for this project, a sample is fractionated into two parts: those greater than 2  $\mu$  m and those less than 2  $\mu$  m. Centrifugation and separation of particle sizes is accomplished with the aid of the following table developed by Moore and Reynolds (1989).

**Table 1** - *Settling times for centrifugation of soil particles*

Particle Diameter Sp.G. Centrifuge Speed Time

( $\mu$  m) Mineral (RPM) (min)

5 2.65 300 3.3

**2 2.65 750 3.3**

0.2 2.50 2400 35.4

Particle fractions 2  $\mu$  m or less are used for X-ray diffraction analysis. Following the centrifugation at 750 rpm in 3.3 minutes, the supernatant liquid is removed. A second centrifugation is then applied to collect any sediment which remained within this supernatant liquid. What remains at the bottom of the centrifuge tube is subjected to a sequence of chemical pretreatments which include the removal of iron oxides, carbonates and organic materials (Jackson, 1958). While many of the samples collected on Long Island are particularly high in Fe content (due to fresh water infiltration), the most important removal procedure is for iron oxides. Samples of this kind tend to have outer iron coatings on individual grains which must be expunged, or the resulting diffraction pattern will produce Fe peaks which are not indicative of the grain composition. Iron removal involves a solution of sodium citrate, sodium bicarbonate and sodium dithionite which act to keep the iron residue in solution. The solution is heated in a water bath at 80° C for 15 minutes and centrifuged. The iron is subsequently removed with the supernatant liquid.

Organic removal begins with acidification and extraction of carbonates. A solution of HCl is added until digestion of carbonates is complete, or until the pH is less than or equal to  $\sim$ 5.8. Once the solution is acidified, the sample is ready for oxidation of organic matter using 30% hydrogen peroxide and placed on a hot plate. The hydrogen peroxide is allowed to decompose so that oxidation of all the organic material is complete. After several washings of de-ionized water, the solution is centrifuged. What remains at the bottom of the centrifuge tube can then be extracted using a thin glass pipette and deposited on a glass slide to be dried overnight. The sample is then ready to be placed in a diffractometer to be subject to the bombardment of X-radiation.

An example of an X-ray diffraction pattern (Calverton at 83'-92') in Figure 4 shows peak and intensity values typical of high-Fe chlorite which, for example, has a first-order reflection at  $\sim$ 14.2 angstroms (i.e. 001 at  $\sim$ 6°). Characteristic peaks for quartz and illite are also evident on the chart as labeled. A sample comparison of diffraction patterns for Calverton (83'-92') and a Deer Park sample (280') is shown in Figure 5. Calverton clearly contained significant high-Fe chlorite while Deer Park was comprised mostly of kaolinite. While it is important to know the basic compositional make-up of any given sample, the procedure is a powerful tool for identifying any number and range of minerals particularly for fine-grained sediments.

(Images are best viewed by clicking on the image and then clicking the right mouse button and selecting view image.)

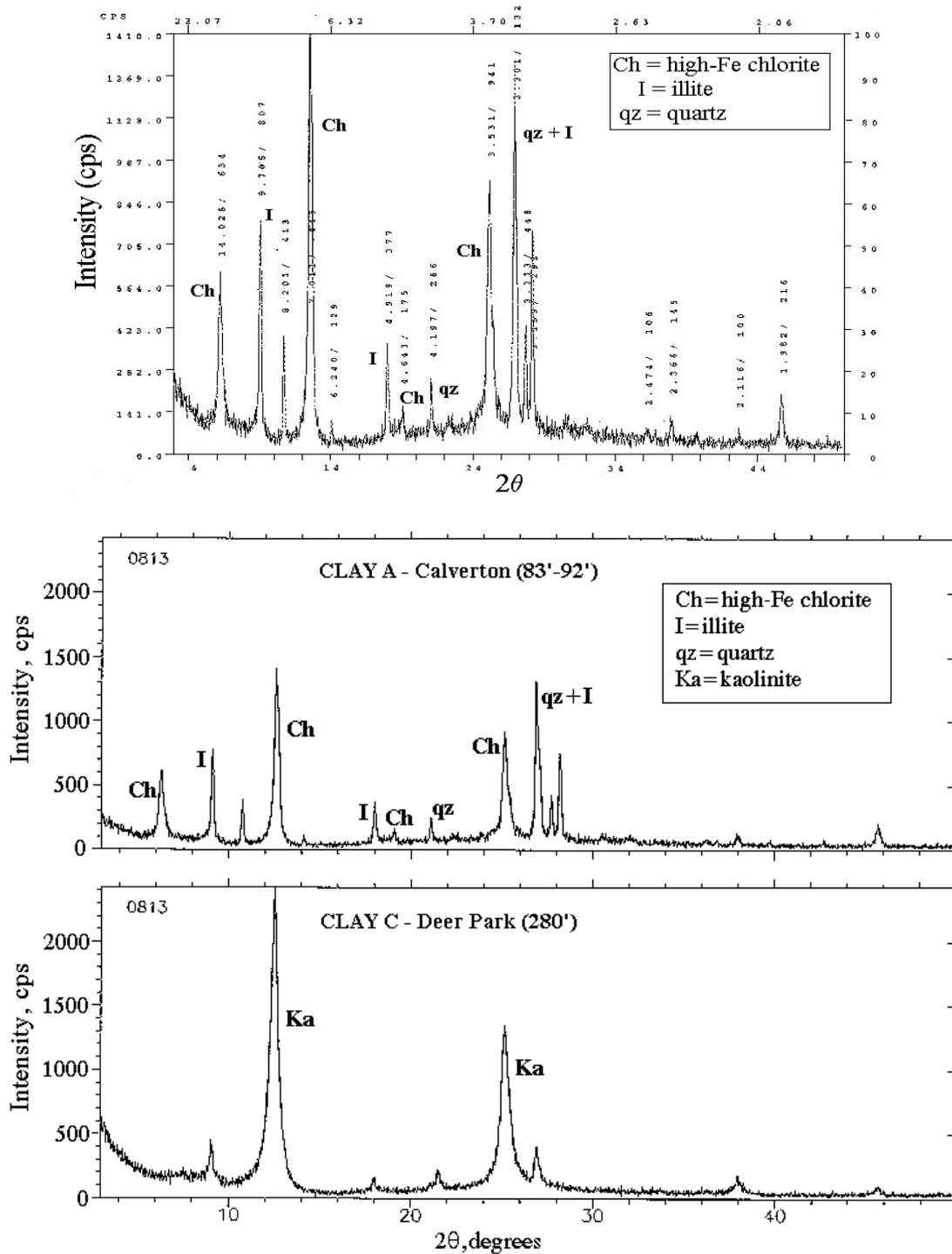


Figure 5. Comparing diffraction patterns for Calverton (83'-92') and Deer Park (280').

## Summary

In this study, geophysical logging and physical and chemical soil analyses are combined to provide effective tools in developing an extensive investigation of the behavior of subsurface fluid flow in near-shore as well as off-shore environments. While geophysical logging alone can provide quick and quantitative information on subsurface lithology, it is limited in its ability to delineate hydrogeologic interfaces that are not associated with drastic changes in gamma activity or electrical conductivity. This is the motivation for core and grab sampling which helps confirm the identity of individual units and how they may relate to samples obtained at other locations. As this is an on-going project, we are continuing to develop an efficient and cost-effective methodology for soil and ground water investigations at this time.

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