KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-SECOND ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2009
Franklin & Marshall College, Lancaster PA.

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Students: *JOE CATALANO*: Union College; *ISIS FUKAI*: Oberlin College; *STEVEN HOCHMAN*: Pomona College; *JOSHUA T. MAURER*: Mt Union College; *ROBERT NOWAK*: The College of Wooster; *SEAN REGAN*: St. Lawrence University; *ASHLEY RUSSELL*: University of North Dakota; *ANDREW G. STOCKER*: Claremont McKenna College; *CELINA N. WILL*: Mount Holyoke College

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Faculty: *JOHAN C. VAREKAMP*: Wesleyan University and *ELLEN THOMAS*: Yale University & Wesleyan University
Students: *ALANA BARTOLAI*: Macalester College; *EMMA KRAVET and CONOR VEENEMAN*: Wesleyan University; *RACHEL NEURATH*: Smith College; *JESSICA SCHEICK*: Bryn Mawr College; *DAVID JAKIM*: SUNY.

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Keck Geology Consortium: Projects 2008-2009
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Project Director: ***JOHAN C. VAREKAMP***: Wesleyan University
Project Faculty: ***ELLEN THOMAS*****:** Yale University & Wesleyan University

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Research Advisor: Donald Barber

A 3.5 KY SEDIMENTARY RECORD OF THE GREAT SALT POND ON BLOCK ISLAND, RI
*CONOR VEENEMAN***:** Wesleyan University
Research Advisor: Johan Varekamp

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BLOCK ISLAND, RI: A MICROCOSM FOR THE STUDY OF ANTHROPOGENIC AND NATURAL ENVIRONMENTAL CHANGE

JOHAN C. VAREKAMP: Wesleyan University
ELLEN THOMAS: Yale University & Wesleyan University

INTRODUCTION

Block Island (RI) is a beautiful islet (~ 7 by 3 miles) located 12 miles from the Connecticut-Rhode Island shoreline, east of Long Island Sound (LIS) (Rosenzweig et al., 2002). It consists of a northern and southern hilly region made up of morainal material, connected by two sandy spits covered with dunes (tombolos), enclosing Great Salt Pond (Woodworth, 1934; Boothroyd and Sirkin, 2002). The western tombolo (towards Block Island Sound) is breached so that ocean waters can enter the Pond. More than 300 fresh water ponds and lakes are present on the island, the largest of which are Sachem Pond and Fresh Pond (Fig. 1).

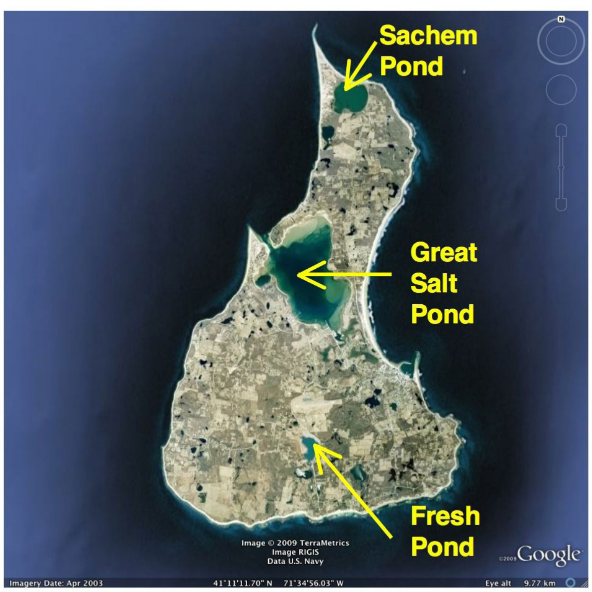

Figure 1. Block Island, with the central Great Salt Pond and the many ponds and lakes.

Many urban dwellers travel to Block Island to visit a natural environment, barely touched by human hand. Nothing is further from the truth, however. Shell middens and other remnants of a Native American village dated at ~ 2500 BP are situated on the northern fringes of the Great Salt Pond (GSP), and remains of later settlements occur around GSP. Native Americans started corn agriculture ~1100 AD, leaving about 2/3 of the island covered by brush oak forests (Bellantoni, 1978; Tveskov, 1992; Jaworski, 1990). Adriaen Block named the island in 1613 (after himself), although it is uncertain whether he actually landed there, and the name is seen on maps dating back to the 17th century (Fig. 2; Varekamp, 2006; Varekamp and Varekamp, 2006). After the European settlement in 1661 the Native American population of about 1000 people dwindled to about 50 in 1774, with a single last survivor present in the 1870s (Livermore, 1877). The forests disappeared even more rapidly, with timber becoming rare by1750 (Livermore, 1877; Hammond, 2002).

Figure 2. Map of 1635, showing Adriaen's Eylant just east of Long Island.

Great Salt Pond has been closed off from the sea several times, and temporarily became a brackish/fresh water pond (Great Pond). Humans breached the western tombolo repeatedly in order to allow marine shellfish to settle and be harvested (Livermore, 1877; Hale, 2002). Major geomorphological changes occurred during historical times when large storms and hurricanes moved over the island (Livermore, 1877; Downie, 1998), and we can assume that similar changes occurred in prehistoric times. The landscape has changed irreversibly from its pre-human days, with the present vegetation, re-grown on an almost tree-less island, very different from the post ice-age land cover (Hammond, 2002). More recently, the arrival and rapid multiplication of invasive species such as the sea weed *Codium* (Dead Man's Fingers) have affected the ecosystem in Great Salt Pond (Hale, 2002), and human sewage from boating activities and aquaculture activities may have caused the onset of eutrophication (Herron and Green, 2007).

Sediment accumulating in the ponds and lakes, in fresh water bogs and salt marshes, and in Great Salt Pond provides a detailed record of these environmental changes, including changes in climate, geomorphology, and relative sea level, as well as the effects of human actions (e.g., deforestation, eutrophication). The composition of organic matter in pond and lake sediment reflects these changes in land use. There are no major industries on the island but atmospheric deposition of pollutants (e.g., mercury) has cast its chemical shadow of industrial society (Varekamp et al., 2003, 2005). Small fringes of salt marshes rim GSP especially along its northern border, and these environments contain a record of the rate of recent relative sea level rise (Varekamp and Thomas, 1998). The sediment in GSP contain the shells of calcareous micro-organisms (foraminifera) as well as snails and bivalves, and the assemblages of these organisms together with stable isotope studies of their shells provide an insight into the changing salinities and temperatures of the GSP waters. Faunal and N-isotopic studies indicate in how far eutrophication has impacted the bay. Carbonate shell material can be used for radiocarbon dating, and the more recent record of pond sediment can be dated with ^{210}Pb and ^{137}Cs. Once cores have been dated and Hg concentrations measured in these dated cores, the Hg concentrations in other cores can be used as a chemostratigraphic marker to date the sediment. Catastrophic events such as hurricanes leave behind sand layers in the muddy sequences, which can be dated and correlated with the historical record. Studies of cores from different depositional environments thus may provide a comprehensive picture of natural and human-induced environmental change over the last millennia.

RESEARCH ON BLOCK ISLAND (SUMMER 2008)

The Keck research program was conducted during 4 weeks in late June and early July. During weeks 1 and 3 we lived in two apartments on Block Island, and in weeks 2 and 4 we carried out laboratory research at Wesleyan University (Middletown, CT) (Fig. 3). During the first week we explored Block Island and looked at outcrops of glacial and peri-glacial deposits, took water samples, and measurements of temperature, salinity and oxygen levels as well as grab samples and push cores on Great Salt Pond (including Trim's Pond) and Fresh Pond (Fig. 3). We used a 'Dutch corer' in the eastern Block Island Salt Marsh, described the vegetation and elevation, measured elevation of the marsh surface within the tidal framework, and took surface samples in the marsh. We also took a core in Great Swamp, a fresh water bog on the southern half of the island.

During the weeks in the laboratory we split and extruded cores, sliced them into samples, dried the mud (we needed the ventilator fans!) for geochemical analysis, sieved it for foraminiferal analysis, and weighed many samples (wet mud, dry mud, sieved mud). And we ground samples for geochemical analysis, and got the first mercury concentrations as well. We took time off for a visit to the Pequot Museum, with a tour by Kevin McBride, the archeologist and a talk on the archeology of Block Island

The third week we returned to Block Island, for the serious work of vibra coring Great Salt Pond with a rented work-boat (The 'Ace Boat'). The weather

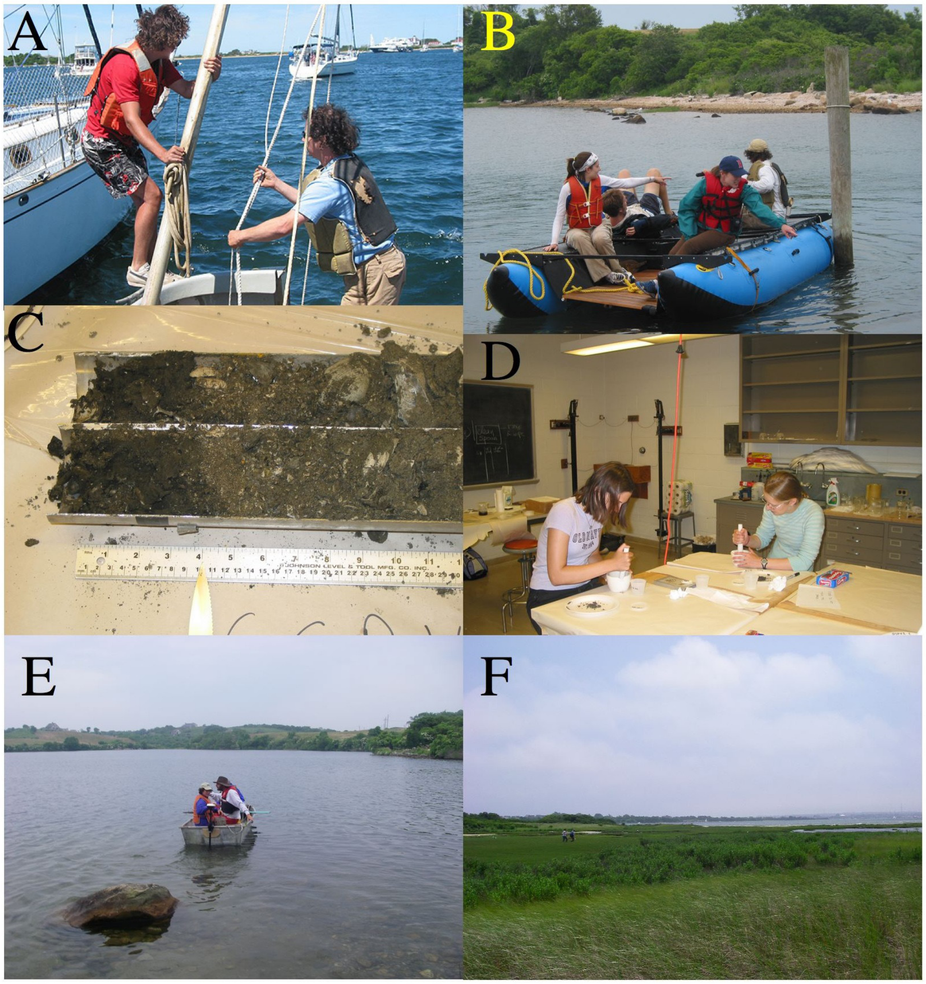

Figure 3: A. Joel la Bella and Conor Veeneman handling the vibra-corer while trying not to hit a yacht, Great Salt Pond. B. Rachel Neurath, David Jakim, Joel LaBella and Sarah Gillig on Great Salt Pond in the pontoon boat. C. The upper part of our first vibra-core (GSPV-1), showing dark (somehat eutrophic) sediment with slipper limpets overlying older material with abundant and diverse bivalves. D. Jessica Scheick and Rachel Neurath grinding away on samples at Wesleyan University. E. Joel LaBella and Joop Varekamp on Fresh Pond. F. The small figures are Emma Kravet and Rachel Neurath, about to be chased away by nesting sea gulls, in Block Island Salt Marsh.

was windy which makes vibracoring uncomfortable, and entails dangers of trying not to hit multi-million dollar yachts, but we were successful in the end and took 4 vibracores home. We also took more grab samples and water samples and measurements, and took cores and grab samples in Sachem Pond. Then we collected more marsh cores (western Block Island Salt Marsh, Andy's Way Marsh), fresh water peat cores (West Beach Swamp, Clayhead Swamp), and looked at periglacial deposits along the southern bluffs of the island and along the east coast.

THE FORMATION AND EVOLUTION OF BLOCK ISLAND

Long Island and Block Island share a history of glaciation and deglaciation, reflecting the interplay between rising global sea levels when the large glaciers started to melt, rising of the land as a result of glacial rebound after the melting of the ice sheet, and sedimentation. At the Last Glacial maximum, the Laurentide Ice Sheet extended from the southern coast of Long island, to Block Island, and on to Nantucket and Cap Cod (Sirkin, 1996; Boothroyd and Sirkin, 2002; Balco and Schaefer, 2006). Block Island was in an 'interlobate position', between a lobe of the ice sheet extending to Long Island, and another lobe extending to Cape Cod (Balco and Schaefer, 2006). The southern, more hilly area of Block Island (maximum elevation ~180 ft, Beacon Hill; 108 feet, Pilot Hill) and the smaller (and lower) northern hilly part consist of material emplaced by terminal and recessional moraines (Sirkin, 1996; Balco and Schaefer, 2006).

The morainal material (till) consists of non-layered, very poorly sorted sediment, containing boulders (including large blocks of fossiliferous Upper Cretaceous sediment), gravel, sand, and fine material. In addition, stratified gravel, sand and silts were deposited on the outwash plains in front of the glaciers. An upper morainal unit with a brownish color and common granitic boulders ('New Shoreham Drift') was left by the glaciers of the youngest ice age (Laurentide Ice Sheet, Wisconsinian Glacial), and covers a lower moraine ('Montauk Drift') with dark grey colors and more metamorphic boulders. The upper moraine is overlain by abundant outwash material, documenting erosion by rushing fresh water streams (Sirkin, 1996). It is not clear whether the lower moraine dates back to an earlier glacial episode (early Wisconsinan, ~ 60 kyr or Illinoian, 130-140 kyr), or whether it represents an only slightly older lobe of the Laurentide Ice Sheet (Boothroyd and Sirkin, 2002).

Periglacial deposits include loess, dunes and varved lakebeds, which formed in periglacial lakes during the retreat of the ice sheet. Some of these lakes were very large, such as Glacial Lake Connecticut, which existed where we now find Long Island Sound, and a lake in Block Island Sound (~ 18 kyr BP; Stone et al., 2005). A small lake was present on Block Island, as shown by the presence of varved lake beds in a drumlin in the Indian Neck area of Block Island (in the eastern tombolo). The lake beds probably represent about 100 years of deposition, with pollen assemblages representative of a tundra climate (Sirkin, 1996).

The large periglacial lakes in the Long Island and Block Island Sound basins drained through 'holes' in the moraines, probably mainly between Long Island and Block Island, but the mode of draining (gradual or catastrophic) and its timing are under debate (Varekamp et al., 2005). The moraines on Block Island show broad, deep erosion channels carved by streams rushing from the lakes into the Atlantic Ocean (Sirkin, 1996; Boothroyd and Sirkin, 2002). Block Island Sound and Long Island Sound were then flooded by the sea, with a slowly decreasing area remaining above sea level in Block Island (Sirkin, 1996; Coleman and McBride, 2008). When the rate of sea level rise started to decline at about 6000 years BP, Block Island may have consisted of two smaller islands with prominent ridges (Sirkin, 1996), separated by a NW-SE running glacial channel (present location of the deeper part of Great Salt Pond).

With further retreat of the ice sheet, fresh water bogs developed in which peat was deposited, and ponds formed, in which fine-grained, organic-rich sediment accumulated. The lake beds and fresh-water peats contain pollen assemblages, documenting the typical southern New England post-glacial pollen stratigraphy reflecting post-glacial warming and its typical succession of vegeation. The 'Herb Pollen Zone' (tundra conditions) is followed by the Spruce, Pine and Oak zones, showing that the island became covered by forests when the climate warmed (Sirkin, 1996; Dunwiddie, 1990). During the remainder of the Holocene, sand was reworked by waves and winds, leading to the formation of dunes, spits and tombolos. Salt marshes formed along the edges of Great Salt Pond. It may be significant that the basal sediment in Fresh Pond is dated at 14,400 BP and consists of freshwater materials: Block Island was already an island during that time!

The sequence of all these events is well established (e.g., Stone et al., 2005) but there is a large uncertainty regarding the exact timing of key events. In the standard view (e.g., Stone et al., 2005) the sea penetrated into Block Island Sound and Long Island Sound by 15 ka BP, but this date is based on complex cross-correlations to events on land which may not be accurately dated. We dated oysters directly above the contact of marine sediments and lake beds in vibracores from eastern Long Island Sound, and found that the sea entered Long Island Sound at about

10,000 BP, not long after the end of the Younger Dryas (Varekamp et al., 2005). Studies of glacial, periglacial and post-glacial deposits on Block Island have not been undertaken since 1990, and data collected on Block Island will be useful in determining the record of post glacial sea-level rise and crustal rebound, as well as document natural and anthropogenic environmental changes during the Holocene.

We have collected sediment cores and samples, and made a start with research to reconstruct the environments of Block Island in fresh water ponds and Great Salt Pond.

RESEARCH PROJECTS

Alana Bartolai (Macalaster College) studied cores from GSP and picked foraminifera from a push core in great detail, and measured stable isotopes ($^{16}O/^{18}O$; $^{12}C/^{13}C$) on the foraminiferal tests. From these data she derived a model of changing temperatures and salinities in GSP over the last 1000 years, searching for evidence for the Medieval Warm Period and Little Ice Age. She used the GSP age models developed by Connor Veeneman.

David Jakim (New Pfaltz SUNY) studied the varved lake clays of periglacial lakes and ponds. His studies were interrupted by health problems.

Emma Kravet (Wesleyan University) studied 20 surface samples and 3 cores from the salt marshes along GSP, and determined the local foraminiferal intertidal zonation. The tidal ranges in GSP are smaller than in marshes along Long Island Sound, but the marsh environments have much in common. Emma used chemical stratigraphy (peak of Hg pollution) to constrain the ages in her marsh cores using the age model developed by Rachel Neurath, and determined the organic content of the core samples. She dated the establishment of the marshes, and interpreted the faunal trends and age data within a sea level rise scenario.

Rachel Neurath (Smith College) used cores from Fresh Pond, some of the fresh water bogs, GSP and Sachem Pond for Hg analysis. The Fresh Pond cores provided excellent records and one core was dated by ^{210}Pb-^{137}Cs (another core from West Beach being processed for the same) for the last 100 years. The Hg accumulation rates were calculated from the age models and sediment parameters, and the cores from the 'high marshes' along GSP provide the cleanest signals of in situ atmospheric Hg deposition in BI. The Fresh Pond record shows modest Hg pollution during the 19th century, increasing in the 20th century, and then the effects of the Great Depression (less pollution), followed by enhanced Hg deposition during the war economy of the 1940's and the rest of the 20th century.

Jessica Sheick (Bryn Mawr College) studied the isotopic composition and abundances of organic matter in the cores from Fresh Pond, Sachem Pond and one core from GSP. The changes in N/C values, $\delta^{13}C$, and $\delta^{15}N$ show the trends in landscape evolution and primary productivity over time, with heavier Nitrogen in the more recent sediment (cattle and human waste), changes in productivity in GSP over time, and effects of deforestation.

Conor Veeneman (Wesleyan University) studied the geological evolution of the island from core studies in GSP (vibracores and push cores). He determined ages from oyster beds with ^{14}C, and established a general stratigraphy and age model. He picked foraminifera from the marine sections and measured stable isotope ratios of carbon and oxygen at Yale University to derive fluctuations in temperature and salinity in the GSP over about 4000 years. Combination with data from LIS provides a comprehensive model of rebound and sea level rise for BI over the last 14,000 years. In the GSP muds, Connor found a thick sandy layer with exotic foraminifera, bryozoans and snails, which is interpreted as the 1938 hurricane depositional layer.

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