UNEARTHING NEW JERSEY

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Department of Environmental Protection

MESSAGE FROM THE STATE GEOLOGIST

With warmer weather now blanketing the Garden State, citizens and tourists alike have begun to return to the natural beauty of our inland parks and coastal beaches. From High Point to Island Beach to Cape May and everyplace in between, New Jersey has many attractions for those who enjoy the great outdoors. For the New Jersey Geological and Water Survey (NJGWS) staff, our work is always focused on the natural attributes of our state, regardless of the season.

In this issue of **Unearthing New Jersey**, we explore the aquifers of Cape May County and examine concerns of salt water intrusion into the fresh drinking water systems in that region. More north, in Hunterdon County, our geologists have focused efforts on exploring and examining an uncommon alluvial section along the Walnut Brook in the Bernadette Morales Nature Preserve.

And then there is the Atlantic Ocean. In May 2014, NJGWS received a $400,000 federal grant to enhance our nationally-recognized offshore sand resource program to address post-Hurricane Sandy beach rebuild efforts. With these funds, staff geologists will focus efforts to examine existing sand resources in federal waters, while at the same time maintaining our successful sand resource determinations in state waters. With this new initiative, the U.S. Bureau of Ocean Energy Management, the U.S. Army Corps of Engineers and environmental agencies within New Jersey will have a more robust understanding of near shore and far shore sands available for needed beach replenishment applications.

The NJGWS continues its successful geologic mapping activities under STATEMAP, a component of the National Cooperative Geologic Mapping Program. Of special interest is the publication of "Bedrock Geology of the Franklin Quadrangle, Sussex and Morris Counties, New Jersey," co-authored by Research Scientists Richard A. Volkert and Donald H. Monteverde. This area of northern New Jersey is the home of the world famous fluorescent minerals of Franklin and Sterling Hill Mines.

Not mentioned in this newsletter is the recent borehole drilling near Sandy Hook in the New Jersey Coastal Plain. With NJDEP financial support, Rutgers University and the U.S. Geological Survey completed three boreholes in May 2014, each to a depth of just less than 300 feet. These boreholes will provide data on the stratigraphic and hydrogeologic framework in this area documenting past sea level rise and land subsidence.

Karl Muessig
New Jersey State Geologist

Well driller uses a mud-rotary drilling rig to construct a 250-foot deep sentinel observation well in the Cohansey aquifer beneath Cape May County. *Photo by S.W. Johnson*

MAPPING, MONITORING AND MANAGING CAPE MAY COUNTY'S GROUNDWATER RESOURCE

By Stephen W. Johnson, Jennifer Myers, Peter J. Sugarman, and Yelena Stroiteleva

BACKGROUND

Salt water intrusion, or the movement of water high in chlorides and sodium in an aquifer, is an important water-supply issue for all of Coastal New Jersey but especially so for Cape May County, a peninsula. Figure 1 shows the county surrounded by salt water on three sides -- to the east by the Atlantic Ocean and to the south and west by the mouth of the Delaware River and Delaware Bay. Cape May County's water needs are met by groundwater from wells within the county and not from imported water from any source outside the county. Thus it is effective water-resource management that NJDEP's Division of Water Supply and Geoscience through its Water-Allocation-Permitting Program, and in cooperation with Cape May County's major water supply companies work together to (1) map, (2) monitor, and (3)

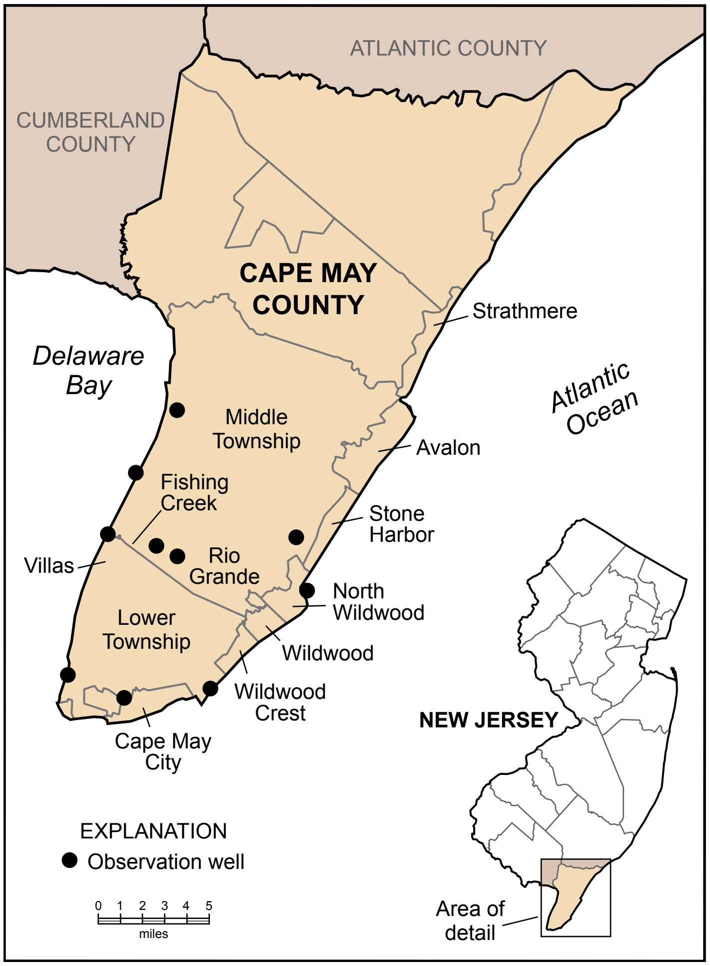

Figure 1. Location of observation wells in Cape May County and areas discussed in text.

manage the groundwater resource for optimum use and to minimize or prevent salt water intrusion from affecting the public-water-supply wells of the county.

A water allocation permit is required in order to divert more than 100,000 gallons per day (gpd) of surface and/or groundwater. The water allocation permit is the tool chosen to manage the groundwater resource. The permit regulates the taking of water and restricts the amount of water taken from the aquifers (a major water resource), requires aquifer testing and water monitoring and may set trigger-level standards (for example, 100 mg/l for chloride) for selected wells that must not be exceeded at selected wells in the permit. If trigger levels are exceeded then alternate water-supply plans are implemented. The major Cape May water suppliers all have received water allocation permits, but some are expected to be modified in near future.

Cape May County water suppliers rely chiefly on two major aquifers -- the Cohansey aquifer and Atlantic City 800-foot sand aquifer. Also important are three minor aquifers, the Holly Beach, Estuarine Sand, and Rio Grande (Water Bearing Zone) aquifers. They are pumped at much reduced rates, largely for domestic, and irrigation purposes.

The peninsular location of Cape May County, the nearness of the natural fresh-water-to-salt-water interface in the aquifers and groundwater withdrawals at wells have been the important factors in the movement of salt water with high chloride levels in all the aquifers on the Cape May Peninsula (USGS, 1962). Salt water intrusion is the most significant threat to the water supply of Cape May County (USGS, 2002), and many wells in the Cohansey and Estuarine Sand aquifer have already been affected.

Based on ground-water-modeling simulation by USGS (2009), the Cohansey aquifer at its current and anticipated enlarged usage is threatened by salt water encroachment within 50 years or less, principally near the border of Lower and Middle Townships and to the north of the Cape May Canal. Changes in pumpage locations from the Cohansey aquifer are planned based on USGS modeling and on historical chloride data collected at observation wells.

Based on groundwater-modeling simulation by USGS (2009), the 800-foot sand aquifer at its most southern usage area in Stone Harbor should remain safe from salt water intrusion for several hundred years or longer at its anticipated usage rates. Major changes in pumpage locations for the 800-foot sand are not expected for several hundred years, however, continued monitoring of supply wells and observation wells in this aquifer is prudent to protect the resource and confirm model simulations.

Management of the ground-water resource requires knowledge of the aquifers, such as their depth, thickness, and other aquifer properties. The mapping of these aquifers, chiefly by the New Jersey Geological and Water Survey, and U. S. Geological Survey, has been ongoing for more than 100 years, since the first wells were completed in Cape May County.

MAPPING AQUIFERS

Groundwater in Cape May County occurs in the small openings or voids in the unconsolidated sediments which form the aquifer(s). Cape May is underlain by five aquifers composed of predominantly unconsolidated sands, and gravel with shells, separated by confining units composed generally of silts and clays. The aquifers are, from bottom to top, the Atlantic City 800-foot sand, Rio Grande, Cohansey, Estuarine Sand, and Holly Beach. Of these, only the Holly Beach is unconfined (Gill, 1962). Figure 2 illustrates schematically the five major aquifers, associated confining units, and estimated position of high chlorides in the aquifers.

The Atlantic City 800-foot sand is a major aquifer in the

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Kim Guadagno, *Lieutenant Governor*

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Water Resources Management
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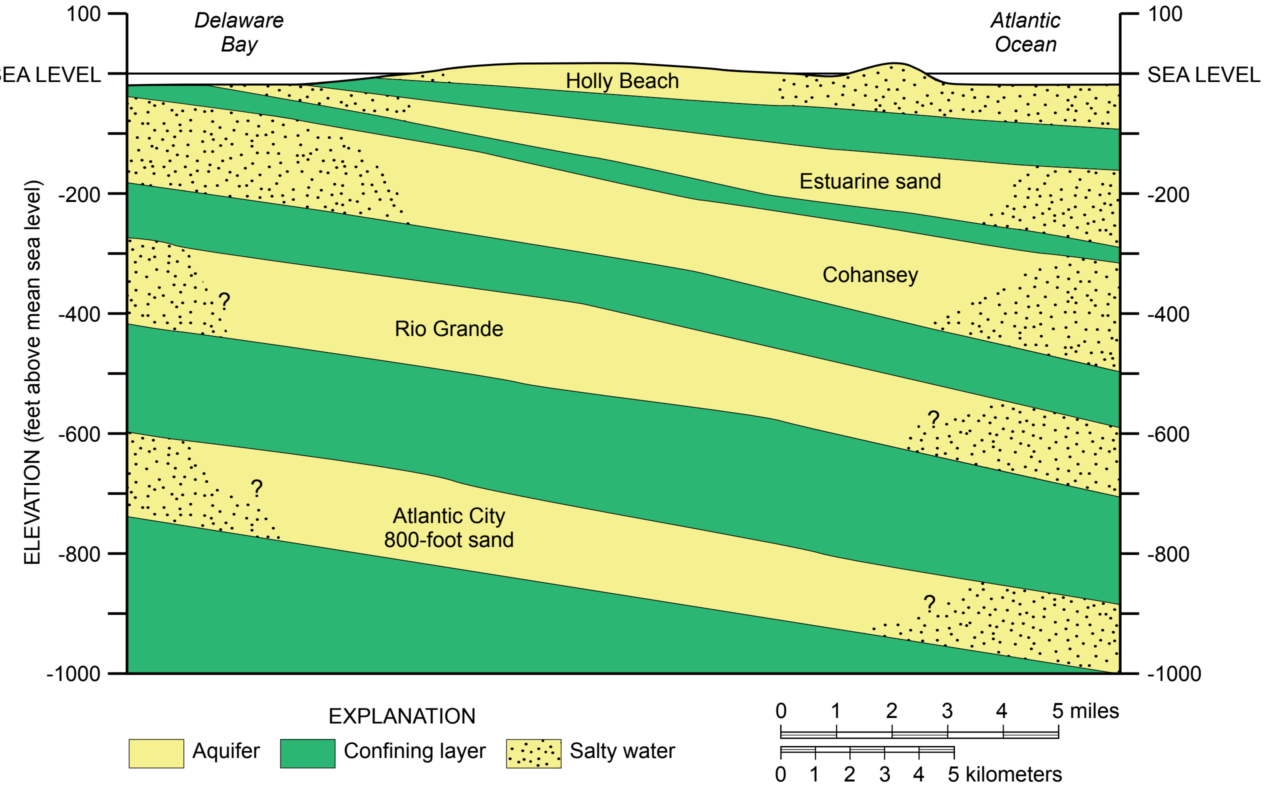

Figure 2. Generalized west to east hydrogeology section beneath Cape May County showing aquifers and confining layer. *Figure adapted from U.S. Geological Survey, New Jersey Water Science Center*

lower part of the Kirkwood Formation; it is the deepest fresh water aquifer available for water supply without treatment in most cases. (Cape May City treats well water from the 800-foot sand by reverse osmosis.) It typically consists of sands from its lower member and overlying Shiloh Marl Member of the Kirkwood Formation (Sugarman, 2001). Under Cape May City, and to the south of Avalon, there is an additional, upper sand body that thickens to south, where the aquifer is more than 200 ft thick (Sugarman and others, 2005; Zapecza, 1989). It appears to be thickest below the central spine of Cape May County, but additional investigation is needed to verify this. Throughout Cape May County and other areas, borehole geophysical logs indicate that it consists of two aquifers, an upper sand and a lower sand, separated by a leaky confining unit. Older wells (pre-1980's) commonly screened only one aquifer whereas newer wells, since the 1980's, have screened both upper and lower aquifers. The aquifer may be 200 feet or more thick if one includes the mid-confining unit (sandy clay and sandy silt) which typically is 20-40 feet thick.

The Rio Grande aquifer is a thinner aquifer, commonly 20 to 50 feet thick, in the Wildwood Member of the Kirkwood Formation, which overlies the Shiloh and Lower Members. Due to varied thickness (30 to 170 ft; Lacombe and Carleton, 2002) and lithology throughout Cape May County, its capability to supply potable water is more limited than is that of other aquifers. It is named for what is believed to be its first usage, at Wildwood City's Rio Grande Well Field, where it was first identified by USGS Hydrologist Harold Gill in the late 1950's (Gill, 1962). It is commonly salty beneath the barrier islands in the eastern part of county, and so it is not used there.

The Cohansey Aquifer, part of the Cohansey Formation, is a medium to coarse sand with inter-beds of thin clay and silt, and is the most productive aquifer in Cape May County (Gill, 1962). It is thicker towards the south-southeast of Cape May County, and is a maximum 180 feet thick in Cape May City (Lacombe and Carleton, 2002). It is confined beneath the peninsular part of Cape May County; to the north it is part of the Kirkwood-Cohansey aquifer system, a water-table aquifer. The Cohansey is chiefly used by mainland communities; it is commonly salty beneath the barrier island or, if originally fresh, there it commonly becomes salty soon after usage. The water in the aquifer is salty beneath the Atlantic Ocean and Delaware Bay and historically it was fresh beneath most of the mainland.

The Estuarine Sand aquifer is in the ? late Miocene Stone Harbor Formation, a pebbly, medium-to-very-coarse sand, with interbeds of clay-silt; thin wood or lignite beds are also found (Sugarman and others, 2007). It is the shallowest confined aquifer in southern Cape May County. Its thickness ranges from 25 to 160 feet, and it is thicker toward the south-southeast (Lacombe and Carleton, 2002). The Estuarine Sand beneath the barrier islands is salty. Only a few public-supply wells were drilled in it, chiefly at Wildwood's Rio Grande Well Field; it is used to store aquifer-recharge water on Wildwood Island.

The Holly Beach is the uppermost aquifer and is a water-table aquifer correlated with the predominantly coarse sands and gravel of the Pleistocene Cape May Formation. Its maximum thickness is in southeast part of the Cape May peninsula. This aquifer is connected to the salt-water bodies of Delaware Bay, Atlantic Ocean and tidal creeks, and consequently it may be salty near these water bodies.

The aquifers are separated by confining units of varied thickness. Clay-silts of the Wildwood Member of the Kirkwood Formation separate the underlying Atlantic City 800-foot sand from the overlying Cohansey and shallower aquifers. The Rio Grande Aquifer is within this major confining bed (Sugarman, 2001).

MONITORING AQUIFERS

Groundwater monitoring is an action crucial to insure long-term viability of the groundwater resource and is performed by permittee under conditions of the Water Allocation Permit. Under the permit, the permittee is required to routinely sample its wells, lab analyze groundwater samples, measure depth to water level in the observation wells, and report the results to Division of Water Supply and Geoscience. Permits in Cape May County may require the construction of observation wells located between permittee's supply wells and locations of salt water in the aquifers used by the permittee, or alternatively, they may require monitoring existing observation wells, if there is a potential for salt water intrusion. There were ten observation wells drilled from 1968 to 1994 for monitoring the 800-foot sand, and plans are being made to modify permits to have regularly scheduled sampling/analysis performed on water from them.

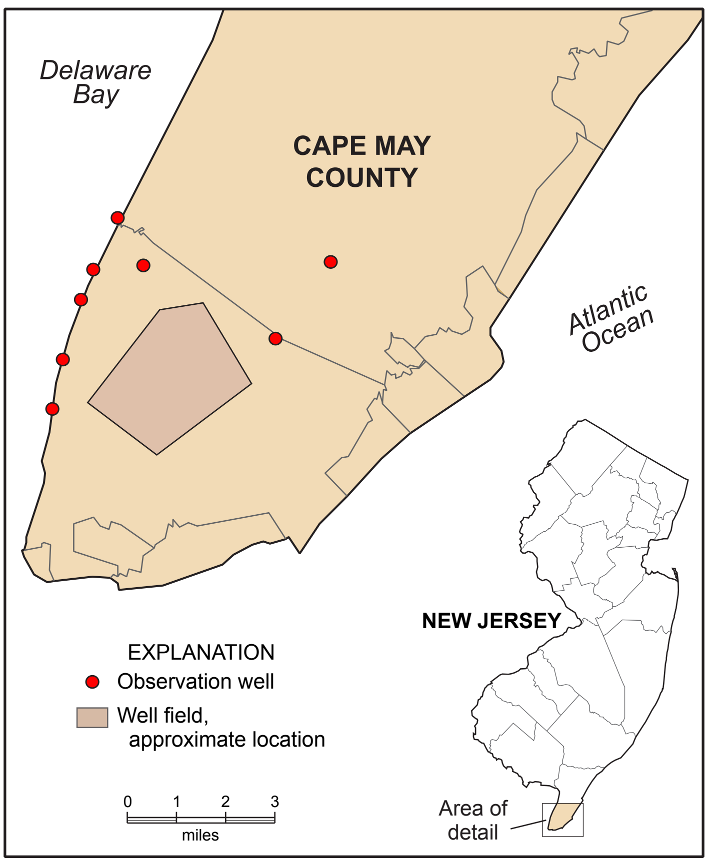

Figure 3. Well field in Lower Township, Cape May County, and recently constructed sentinel observation wells.

Figure 3 shows the locations of new observation wells drilled in the Cohansey aquifer and monitored quarterly by a Cape May County water-supply company using these wells.

Figure 4. Drillers constructing an observation well along Cape May's Delaware Bay shoreline. *Photo by S.W. Johnson*

During the construction of the observation wells, staff in the field designs and supervises its drilling and installation. The permittee funds the well-construction operations. During drilling operations, staff collects wash samples, logs the samples, oversees collection of borehole geophysical logs with drilling engineer, assists in design of the observation well, and oversees construction of the well. Staff also measures static-water levels and collects preliminary groundwater samples from well(s) and field analyzes for chlorides. Figure 4 shows mud-rotary drilling of an observation well and collecting of wash samples to describe geology, aquifer sediments and for well design. After the observation wells are constructed, they are integrated into the monitoring program of the permit and usually are sampled and their water laboratory analyzed quarterly. Water levels are measured at sampling time.

An observation well drilled in 1965 by Cape May County was found to have high levels of chlorides indicative of salt-water intrusion. The well is located at Delaware Bay near Fishing Creek west of Wildwood's Rio Grande Well Field. Additional observation wells are scheduled for construction in this area in 2014 to assess the extent of salt-water encroachment, and to identify water supply's response. Figure 5 shows time versus chloride levels in milligrams per liter (mg/l) and demonstrates classical salt-water intrusion.

One Cape May water supplier has been sampling and analyzing its observation wells for more than five quarters under a permit. Figure 6 shows the results for this well, drilled in 2012 and located east of the supply wells. It is sampled and its water analyzed quarterly for sodium and chlorides.

In addition to quarterly monitoring of the observation wells, the water-supply wells are monitored on a quarterly schedule for parameters of concern (for example, chlorides, sodium, specific conductance, water levels). This is especially important along the barrier island where the 800-foot-sand aquifer underlies aquifers that are salty. Quarterly monitoring

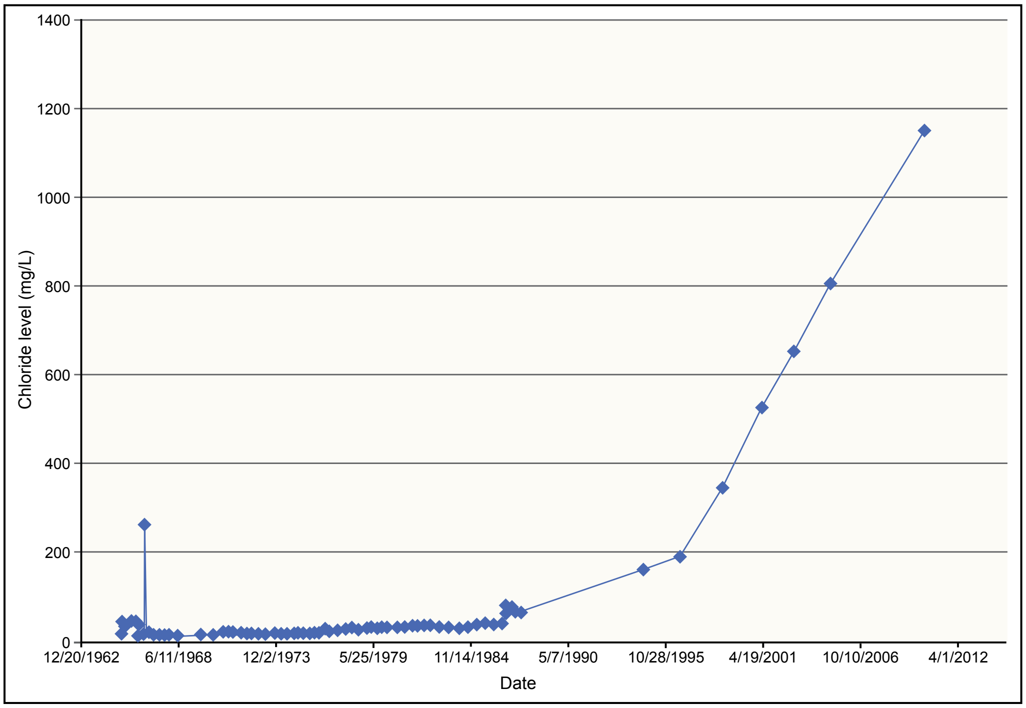

Figure 5. Time (1962 to 2012) versus chloride level in milligrams per liter (mg/l) at an observation well near Fishing Creek and the Delaware Bay. The chart shows increasing chloride levels with time indicative of the movement of salty water or salt water intrusion into the aquifer.

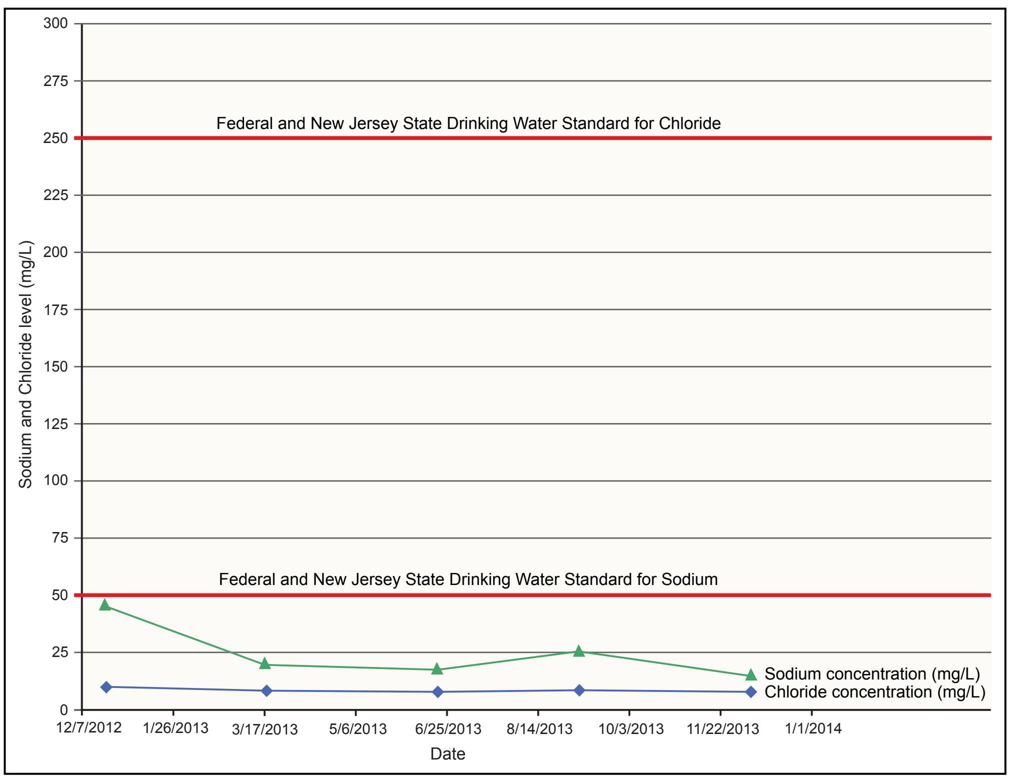

Figure 6. Chloride and sodium versus time sampling/analytical results (2012-2013) at a sentinel observation well in Lower Township, Cape May County. Water quality results are below trigger levels and meet drinking water standards. This degree of sampling and analysis will occur at each sentinel observation well specified in the permit. This is an important component of the management strategy.

and reporting insures that any well problems are quickly identified and treated by the water company. Figure 7 shows the sampling of an 800-foot sand water-supply well at a barrier island by staff of the New Jersey Geological and Water Survey.

MANAGING AQUIFERS

The Department of Environmental Protection has concluded that the most efficient way to manage the water supplies of Cape May County is by the proposed "2014 Water Supply Management Strategy" which recommends water allocation permit modifications that include updated permit requirements such as enhanced water conservation plans, establishing an adequate observation well monitoring network and schedule for each aquifer, setting water-quality-based trigger levels (example, 100 mg/l or ppm chloride) in water from observation wells subject to an elevated risk of saltwater intrusion, and the development of alternate water supply plans to implement when triggers are exceeded. Potential alternative sources of supply which were evaluated in detail in Lacombe and Carleton (2009) include, but are not limited to: 1) desalination, 2) reduction in pumpage from affected wells and/or aquifers and shifting pumpage from salt fronts to sources inland to the axis or "spine" of the peninsula, 3) conjunctive use of multiple aquifers, 4) construction of interconnections with neighboring systems and 5) creation of a hydraulic barrier utilizing treated effluent between salt fronts and pumping centers. Several permits have been modified to include the applicable requirements, including those for Avalon Borough, Cape May Court House, Lower Township, and Strathmere.

Figure 7. Yelena Stroiteleva, Hydrogeologist, and Ovidiu Petriman, Principal Geologist, collect and field analyze groundwater samples from Atlantic City 800-foot sand aquifer water-supply well. *Photo by S.W. Johnson*

The Division of Water Supply and Geoscience conveyed the elements of the draft strategy to the purveyors and County Freeholders at a meeting held on July 19, 2012 and continues to meet semi-annually with purveyors to facilitate implementation of the strategy, to evaluate its effectiveness and to refine the approach as warranted. Implementation of the strategy through updated permit requirements is the most equitable and cost-effective way to manage the resources and enable Cape May County water purveyors to meet the current and future water-supply needs of Cape May County while avoiding any adverse groundwater or ecological impacts. Based on the Department's recommendations, it is imperative for the Cape May County water purveyors to accept the need for water allocation permit modifications to insure the future protection and sustainability of Cape May County's water resources.

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$CaTi(SiO_4)(O,OH,F)$

A marine protozoan is an aqueous salty system in an aqueous salty medium, but a man is an aqueous salty system in a medium in which there is but little water and most of that is poor in salts.

-- John Z. Young (1907-1997) --
zoologist and neurophysiologist

LATE PLEISTOCENE ALLUVIUM RECENTLY UNCOVERED IN RARITAN TOWNSHIP, HUNTERDON COUNTY

By Gregory C. Herman and Scott D. Stanford

An uncommon alluvial section of sandy silt and clay containing wood fragments and charcoal overlain by several feet of flagstone gravel was recently exposed on the east bank of Walnut Brook within the Bernadette Morales Nature Preserve in Raritan Township (fig. 1). Walnut Brook flows southward from the preserve through Mine Brook Park. This site is at the foot of the escarpment on the east edge of the Hunterdon Plateau (fig. 2). The section crops out on the east bank of Walnut Brook near where the Flemington Fault has placed hard gray argillite of the Lockatong Formation in contact with soft red mudstone and shale of the Passaic Formation (fig. 2). The Lockatong, in the fault footwall, underlies uplands of the Hunterdon Plateau whereas Passaic mudstone and shale underlies adjacent valleys of the fault hanging wall. Walnut Brook drains the argillite uplands and follows fractures through a nick in the argillite ridge before spilling out on the alluvial plain underlain by red shale. The brook changes at this nick point from a narrow, braided channel in the argillite to a broad meandering stream atop the shale across the fault trace (fig. 2).

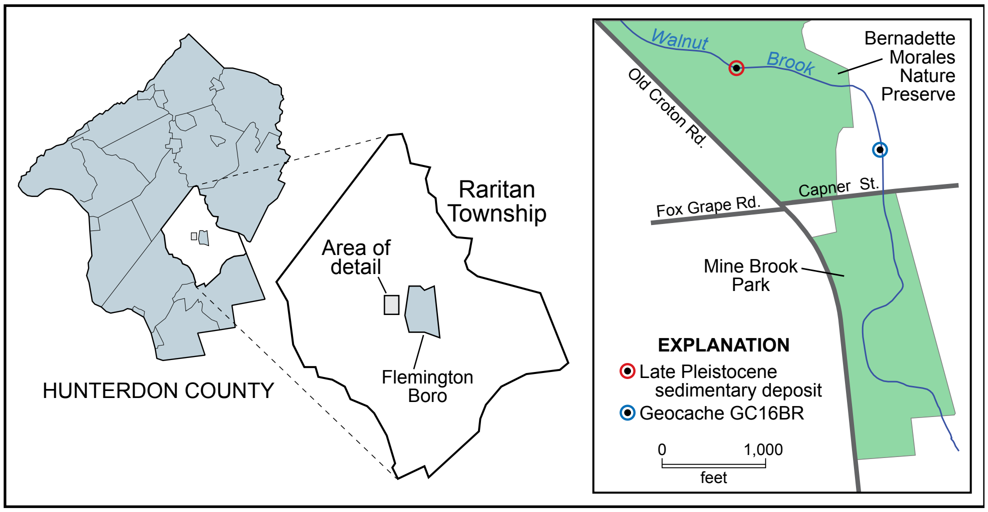

Figure 1. Location of late Pleistocene sedimentary deposit and Geographic Society of America Geocache GC16BR, Raritan Township, Hunterdon County.

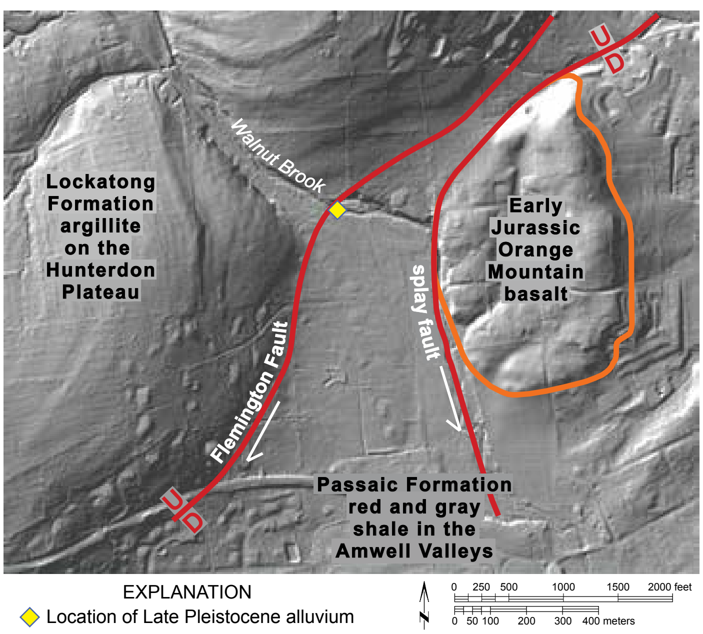

Figure 2. The late Pleistocene alluvium deposit is located where Walnut Brook crosses the Flemington fault.

The geology of the area is diverse and is one place in the Early Mesozoic Newark Basin where limestone veins of hydrothermal origin cut the base of Orange Mountain basalt, as described in the Geological Society of America Geocache GC16BR ("Two Hundred Million Year-Old Lava Flow). The alluvial deposit with organic debris was discovered by Gregory Herman, Joe Marchesani and Donna Miller on Saturday morning August 4th, 2013 while visiting the Geocache site to collect malachite (copper-carbonate mineral) and to see structures in basalt, shale, and argillite resulting from faulting. Upstream at the point of the main fault, recent channel scouring from late-summer heavy rainstorms had uncovered the thin alluvial section above weathered bedrock that forms a small bench at water level (fig. 3). The organic bed is a light-orange to light-gray sandy silt less than a foot thick containing dispersed and flattened fragments of spruce and charcoal (fig. 3). The bed forms a flat, resistant ledge resting on a thin, gray-argillite gravel bed overlying basal, discontinuous red-shale gravel (fig. 3). The largest wood fragment is about 6 in. by 2 in. and the charcoal fragments are much smaller, only a half inch at most. An abandoned channel directly east of the present channel illustrates the recent shift in the course of Walnut Brook which exposed the organic bed following removal of the overlying flagstone gravel (fig. 2). A nearby U.S. Geological Survey stream-gaging station on the Neshanic Branch of the Raritan River records the period of heavy rains preceding the scouring event.

On Friday August 9th, we went to the site to photograph details of the deposit, collect samples for age dating, and take notes for the New Jersey Geological and Water Survey. After obtaining an Upper Pleistocene age for the silt bed, a literature review of similar age units in this area containing pollen and plant material disclosed some interesting geological aspects of this discovery. Radiocarbon ages obtained for the wood and charcoal dates this sedimentary deposit as latest Pleistocene in age (fig. 4). The wood returned a radiocarbon age of 11,990±50 years BP (before AD 1950) or 13,930 to 13,760 calibrated years (laboratory number Beta 358991). The charcoal returned an analytically identical radiocarbon age of 11,980±50 years BP or

Figure 3. Photographs of the late Pleistocene bed recently uncovered in Raritan Township, Hunterdon County, along Walnut Brook. 3A) Overview of outcrop, 3B) detail of outcrop, 3C) organic bed. *Photos by G.C. Herman*

13,920 to 13,760 calibrated years (laboratory number Beta 358992). This age for the wood and charcoal indicates that Walnut Brook had formed its floodplain before about 14,000 calibrated years ago. Several other dated alluvial deposits in central New Jersey yield similar ages for the formation of modern floodplains (Sirkin and others, 1970; Minard, 1969). Pollen records indicate that open, park-like boreal forest and tundra grassland were being replaced by closed boreal spruce-pine forest at this time in the New Jersey region (Peteet and others, 1990; Maenza-Gmelch, 1997a, b; Russell and Stanford, 2000). During this period, climate was

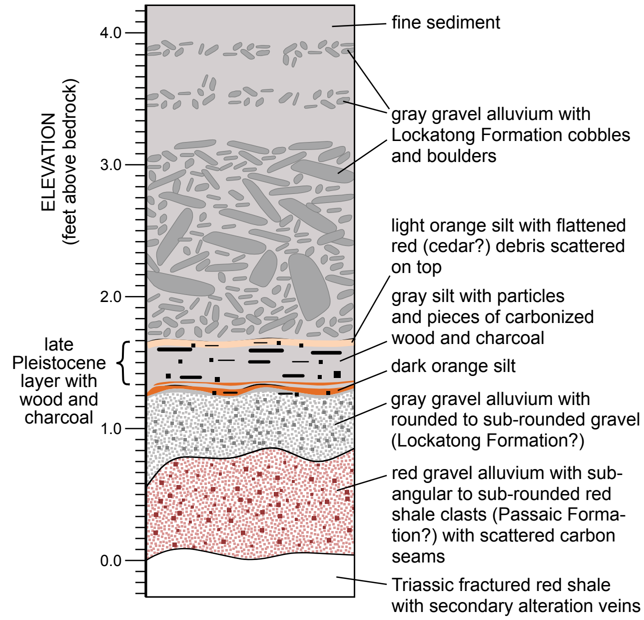

Figure 4. Stratigraphic column of the late Pleistocene organic bed and enveloping strata.

warming from tundra coldness at the last glacial maximum (about 25,000 years ago) when the late Wisconsinan glacier was at the terminal moraine 25 miles north of Flemington. As the closed forest grew, its dense root network stabilized hillslopes, reducing the amount of sediment washing into streams and debris collected at the base of slopes. The streams, no longer choked with sediment, eroded into the alluvial and hillslope debris to form floodplains. The floodplain of Walnut Brook today is inset about 20 feet into the apron of such deposits along the foot of the Hunterdon Plateau escarpment.

The unique nature of the late Pleistocene beds at this site along the trace of the Flemington Fault raises the prospect that this sedimentary sequence may be selectively preserved here because it was deposited at the base of a fault scarp. The flashy hydrologic nature of Walnut Brook insures that the currently exposed beds will be eroded soon, but perhaps systematically unearthed elsewhere laterally along the fault trace as the overlying flagstone gravel bars and alluvium are periodically removed and deposited. A preliminary examination of the organic bed and subjacent gravels shows that silt-sized and sand-sized organic particles are distributed throughout the silt bed and perhaps even in the subjacent gravels. We intend to periodically revisit the site to monitor the exposure of this late Pleistocene sedimentary sequence and examine the distribution of organic material underlying this organic layer more closely. The range of sizes of charcoal matter within the organic bed indicate charcoal sources from nearby fires, although the finer matter may originate from more distant sources. About the time that the organic bed was deposited, humans were arriving in eastern North America and mastodons and mammoths were facing extinction. Some have attributed the extinction to hunting by the newly arrived humans. Others think a meteorite impact or warming climate was the culprit. Perhaps this deposit and others like it may one day shed light on the debate.

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$CaTi(SiO_4)(O,OH,F)$

THE WEDGE: TITANITE

By F.L. Müller

From golf clubs to fly rods to white paint to aircraft components, and strengthened steel, titanium has become an important element in our society because of its light weight, resistance to corrosion, and strength. New Jersey has important titanium-bearing minerals in its varied geology. Titanium occurs in the magnetite ores of northern New Jersey. An important ore of titanium, ilmenite, was discovered and mined commercially from a placer deposit in southern New Jersey. It was mined there successfully for many years by several companies. Ilmenite occurs on the beaches together with other resistate, titanium-bearing minerals such as anatase, brookite, rutile, and titanite. Titanite constitutes a range of x to 1.5 percent of the heavy mineral suite (McMaster, 1954). Of great interest to collectors, however, is the mineral titanite.

Figure 1. Three honey-brown titanite crystals from Limecrest Quarry, Sparta Township, Sussex County (9X magnification). *Photo by J.H. Dooley*

Titanite occurs in the calcsilicate bodies (rocks with the significant amounts of silica and calcium) of the Highlands where it is abundant in the pyroxene gneiss and the pyroxene granites. It is ubiquitous in the Lake Hopatcong Intrusive Suite of rocks. Quarries throughout these bodies of rock have long been the source of titanite crystals for collectors—

Figure 2. Titanite (8X magnification) crystal from Limecrest Quarry, Sparta Township, Sussex County. The crystal matrix is quartz and pyroxene gneiss. *Photo by J.H. Dooley*

notably the Hamburg Quarry and the Limecrest Quarry, near Sparta, in Sussex County. (Both of these quarries are closed to visitors without special permission.) Titanite occurs at Franklin in Sussex County (Dunn, 1995) particularly at the Trotter Mine, and at the Sterling Hill Mine, Ogdensburg Boro, Sussex County. Titanites at the Sterling Hill Mine, for the most part, are very small euhedral crystals. Here they are brown, a shade resembling root beer. These crystals of titanite occur in the rhodonite skarn and are associated with calcite, actinolite, genthelvite and rhodonite. A large titanite crystal, however, was found in calcite and measures 2.5 centimeters (Leavens and others, 2009). In the 1970’s in Limecrest Quarry, I collected titanite crystals which were in pyroxene that measured 20 millimeters, and I measured a titanite mass of approximately 50 millimeters collected by John Dooley of NJGWS on a field trip to the Hamburg Quarry. In 1905 at the Franklin Iron Company, euhedral crystals of titanite were found as much as 1.5 inches (~ 40 mm) in size. Frondel reports crystals as much as 15 centimeters (Dunn, 1995). At the abandoned Swayze Iron Mine in Hunterdon County the calcsilicate protolith is the host to abundant microcrystals of titanite. These are good examples of the common occurrence of titanite in New Jersey.

A nesosilicate, with the chemical formula of CaTi (SiO_4) (O,OH,F), titanite’s crystal lattice will allow many other elements to substitute into the crystal such as Al, Mn, Na, Nb, Sn, U, Th and REEs .These can make up as much as 10 percent of the mineral (Bonewitz, 2008). Titanite crystallizes in the monoclinic system, and can form contact twins and penetration twins which can resemble crosses (Berry and Mason, 1959). But its common wedge-shaped crystals led early workers to call the mineral sphene, which is after the Greek *sphenos* for wedge. This term is still used by some collectors and jewelers. Because of its chemistry, the name titanite was firmly established for this mineral in 1982 by the International Mineralogical Commission on New Minerals and Mineral Names.

The colors of titanite vary from the aforementioned brown to clear, red, black, blue, pink, green, and yellow; this is a function of the elements substituting in the crystal structure. Brilliant red titanite crystals have been found at Fort Lee, Bergen County, and soft honey yellow crystals were found at the Griggstown copper mine, Middlesex County, and the Limecrest Quarry. Commonly titanite is translucent to transparent. Weak pleocroism can be readily observed in thin section study of a crystal. Brilliant color flashes are seen in faceted stones of gem-quality titanite. This is due to the strong optic axis dispersion (r > v) and a weak inclined dispersion (Pistone and McAtamney). The mineral makes a poor jewelry stone because of its inadequate hardness (5 to 6 on the Mohs scale of hardness) and its brittleness, but gemstones cut for jewelry are beautiful, rare, and expensive. Thus titanite is usually faceted simply to please collectors. The specific gravity of titanite is 3.5 to 3.6. Therefore in a sedimentary environment, it occurs with other heavy minerals (those minerals with a specific gravity higher than that of quartz, S.G. 2.65). Titanite has a distinct {110} cleavage. Its streak is white, and it has an adamantine luster. The luster and crystal shape (especially in cross section) are the usual clues which point to its identification.

Although titanite is a very common rock-forming mineral in New Jersey, most people, even mineral collectors, are unaware of it, because its grains are only visible with a hand lens or a microscope (the jeweler's loop with a ten-power lens usually suffices for a field identification).

Crystals of titanite containing uranium and thorium are of special interest to geologists. Using the rates of decay of these radioactive elements in the crystal lattice of some of these crystals, scientists can calculate their age of crystallization. This mineral, and also zircon (both common in igneous and metamorphic rocks) are also used by geologists to estimate the temperature and pressure under which the rocks were formed: "When applied to natural sphene of unknown origin or growth conditions, this thermobarometer has the potential to enable estimation of temperatures with approximate uncertainty of $\pm 20^{o}$C throughout the temperature range of interest (600 to 2000^{o}C). The zircon-in-sphene thermobarometer can also be used in conjunction with the zircon-in-rutile thermobarometer to estimate both pressure and temperature of crystallization" (Hayden and others, 2008).

Every day new uses of titanium are being discovered and utilized. Even though the mineral titanite does not occur in economically significant amounts to be considered an ore in New Jersey, it is present but greatly disseminated here and is of interest to geologists and collectors. Microcrystalline titanite is abundant and the hobbyist can still find nice samples. Remember that most areas are on private property and permission is necessary to search for them. Another method of building a collection of titanite is to go to mineral shows because specimens collected years ago are turning up for sale at almost every show. Look for specimens labeled Limecrest, Hamburg, Franklin, or Sterling Hill. Many specimens I've seen recently are large enough so that one does not even need to use a hand lens for identification.

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$CaTi(SiO_4)(O,OH,F)$

FROM THE ARCHIVES: ILMENITE

By Ted Pallis

Ilmenite is a weakly magnetic titanium-iron oxide mineral which is iron-black or steel-gray. It is named after the locality of its discovery in the Il'menski Mountains, near Miass, Russia.

Ilmenite is a common accessory mineral occuring in metamorphic and igneous rocks. It occurs in large concentrations in layered intrusions where it forms as part of a cumulate layer within the silicate strata. Ilmenite generally occurs within the pyroxenitic part of such intrusions.

In 1956, an investigation by the New Jersey Geological Survey of monzanite placers identified upper Tertiary sediments in the northern part of the New Jersey Coastal Plain as an ilmenite province. The Cohansey Formation, which is located throughout the Coastal Plain, is ilmenite-rich at its northern extent in the vicinity of Lakehurst Boro, Ocean County. Exploratory drilling by four companies resulted in the discovery of four ore bodies. Subsequently two heavy mineral ilmenite mines were established near Lakehurst.

Ilmenite was a source of paint pigments. The Glidden Company, a paint manufacturer, opened an ilmenite ore facility in the Legler section of Jackson Township, Ocean County in 1960. Glidden operated its ilmenite surface strip mine at the site for 11 years until it sold the property in 1972. The Manchester ilmenite mine was operated by Asarco in Manchester Township, also located in Ocean County. It was just north of Lakehurst and was mined until it closed in March of 1982. All ilmenite produced by Asarco was mined under contract to DuPont.

Ilmenite mining in New Jersey consisted of dredging, extracting a sand slurry, dewatering, separating the ore-bearing sand from extraneous materials, and then final processing. About 96 percent of the sand was returned, following extraction of the fine ilmenite particles.

The following photographs from the NJGWS archives document the exploration and mining of ilmenite in New Jersey. The pictures are from about 1955-1972.

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Photos from F. J. Markewicz

Photo 1. Drag line, Glidden ilmenite quarry, Lakehurst Boro, Ocean County.

Photo 2. Glidden ilmenite quarry, Lakehurst Boro, Ocean County.

Photo 3. Ilmenite drill rig, unknown location.

Photo 4. NJGS geologist, Frank J. Markewicz, bagging ilmenite samples, Colliers Mills, Ocean County.

Photo 5. Photomicrograph of rutilated leucoxene. Note the fine meshwork of twinned crystals (275x magnification). From “Geology of Selected Areas in New Jersey and Eastern Pennsylvania and Guide Book of Excursions,” Seymour Sublitzky, ed.

NEW PUBLICATIONS

TECHNICAL MEMORANDUM (TM)

NEW REPORT. TM 13-3, Using the Stream Low Flow Margin Method to Assess Water Availability in New Jersey's Water-Table-Aquifer Systems, Domber, Steven, Snook, Ian and Hoffman, Jeffrey L., 2013, 76 pages., 7 figures, and 2 tables. Available for download.

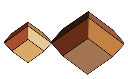
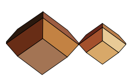
GEOLOGIC MAP SERIES (GMS)

NEW MAP. GMS 13-3, Bedrock Geologic Map of the Franklin Quadrangle, Sussex and Morris Counties, New Jersey, Volkert, Richard A. and Monteverde, Donald H., 2013, scale 1 to 24,000, size 36x60, 2 cross-sections, and 4 figures. $10.00. Available for download.

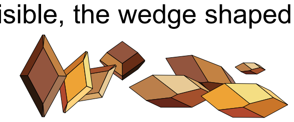
NEW MAP. GMS 13-4, Bedrock Geologic Map of the Newfoundland Quadrangle, Union, Morris and Sussex Counties, New Jersey, Volkert, Richard A., Herman, Gregory C., and Monteverde, Donald H., 2013, scale 1 to 24,000, size 34x60, 2 cross-sections, and 6 figures. $10.00. Available for download.

NEW MAP. GMS 13-5, Bedrock Geologic Map of the Plainfield Quadrangle, Union, Middlesex and Somerset Counties, New Jersey, Volkert, Richard A., Monteverde, Donald H., and Silvestri, Shay Maria, 2013, scale 1 to 24,000, size 30x50, 1 cross-section, and 4 figures. $10.00. Available for download.

NEW MAP. GMS 14-1, Geologic Map of the Hopewell Quadrangle, Hunterdon, Mercer, and Somerset Counties, New Jersey, Monteverde, Donald H., Herman, Gregory C., and Stanford, Scott D., 2014, scale 1 to 24,000, size 35x48, 1 cross-section, and 3 figures. $10.00. Available for download.


$CaTi(SiO_4)(O,OH,F)$


In 1982, the International Mineralogical Association Commission on New Minerals and Mineral Names adopted the name "titanite," for the calcium titanium neosilicate mineral, $CaTiSiO_5$, discrediting the previous name "sphene" (from the Greek *sphenos*, meaning wedge). Titanite is one of a few minerals with very high relief and very high order interference colors. When visible, the wedge shaped crystals are diagnostic.



Banner photos by J.H. Dooley

LET'S PLAY: GUESS THE MINERAL

Here it is:

$NaCa_2(Mg,Fe)_4Ti(OH)_2[Si_6Al_2O_{22}]$

If you think you know what mineral this is, send your answer to: njgsweb@dep.nj.gov

NJGWS SIGNS COOPERATIVE AGREEMENT WITH U.S. DEPT. OF INTERIOR

By Jane Uptegrove

On May 12, 2014, NJGWS entered into a cooperative agreement with the U.S. Department of Interior, Bureau of Ocean Energy Management (BOEM), for a $400,000 federally-funded study to identify sand resources offshore New Jersey that can be tapped for beach replenishment and coastal restoration projects. This grant is part of the federal government's commitment to help coastal states recover from Hurricane Sandy. New Jersey is one of 13 Atlantic coastal states that will receive funds for cooperative agreements with BOEM. New Jersey and New York received the largest grants as the two states most affected by Sandy. The research effort will evaluate NJGWS' existing data to identify sand resources in federal waters (fig. 1) that could be tapped for coastal restoration projects. In particular, NJGWS will produce a sand resource map for the area offshore Monmouth County and analyze sand resources offshore northern Ocean County, likewise building toward an Ocean County offshore sand resource map. In addition, NJGWS will provide technical support to BOEM to assess existing offshore sand resource data collected in federal waters offshore the entire NJ coast, and plan the data acquisition survey to fill data gaps.

Identifying additional sand source areas provides NJDEP, BOEM, and the U.S. Army Corps of Engineers with more options for selecting offshore sand sites that best match the sand quality of specific beaches, are compatible with offshore sediment transport patterns, have fewer biological impacts, and take into account other stakeholder interests. BOEM and NJDEP are committed to this approach to support a sustainable beach nourishment program.

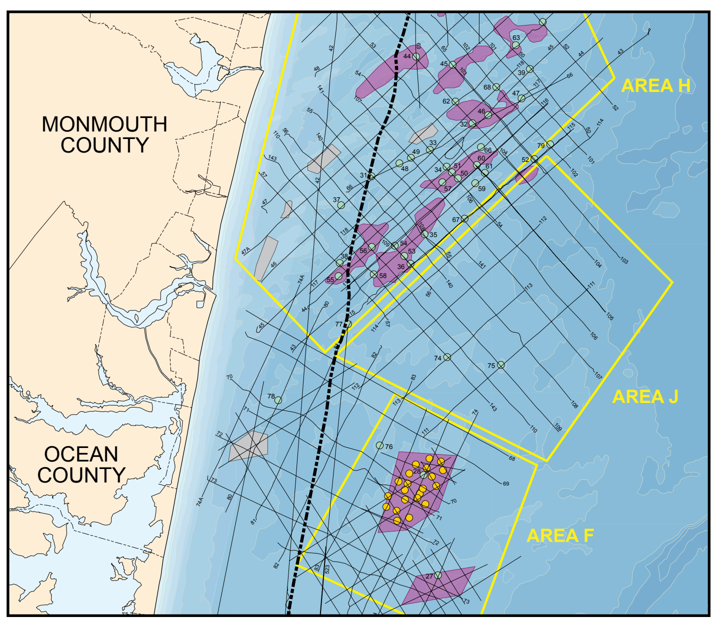
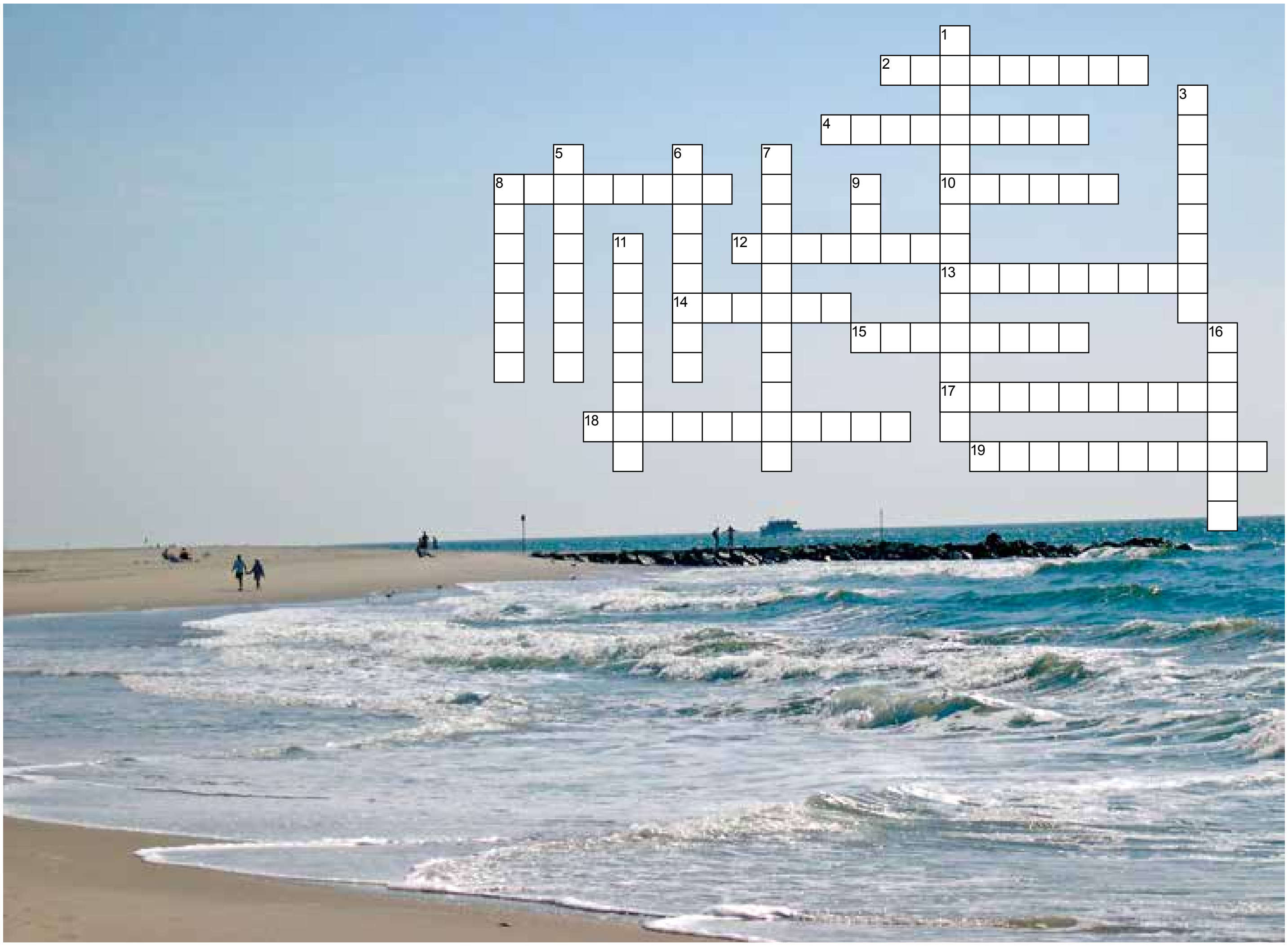


Figure 1. Detail from state-wide sand resources map showing past research. State waters are to left of dashed line (three-mile limit) and federal waters to the right.

CROSSWORD SHORES



Down the shore (as we would say in Jersey), where the Atlantic Ocean and the Delaware Bay meet, Cape May City, Cape May County. *Photo by Z. Allen-Lafayette*

ACROSS

2. Stretch of land nearly surrounded by water
4. Meteroid that has fallen to the Earth
8. Deposited by running water
10. Titanite
12. Grain bounded by perfect crystal faces
13. Salt-water encroachment
14. Treeless plain characteristic of subarctic regions
15. $CaTi(SiO_4)(O,OH,F)$
17. Steep, abrupt face of rock marking the outcrop of a reisistant layer
18. Rock beds alternating with others of a different character
19. Land adjacent to river channel that is covered with water when the river overflows its banks

DOWN

1. Material in a loosely aggregated form
3. Solid material recently deposited from suspension
5. Breaking of a mineral along its crystallographic planes
6. Having an unusual ability to attract
7. Subsurface water in the saturated zone
8. Water-bearing stratum of permeable rock
9. Gallons per day
11. Form of open-pit mining in which the digging machinery and processing plant are on a floating barge
16. Three-dimensional regularity of a crystal structure

"The water that occurs below the surface of the land is invisible and relatively inaccessible and has consequently always possessed an aspect of mystery. What is the mode of its occurrence; what is its quantity; whither does it come; is it stationary or in motion? If in motion, what is its destination and its rate of movement, and what are the forces that propel it through the earth? What chemical work does it perform upon the rocks through which it moves? What causes it in some places to ooze almost imperceptibly from the ground and in other places to gush from the rocks in great volume – clear, cold, and pure, or boiling hot, or bubbling with various gases, or supercharged with dissolved minerals which it deposits on the surface? These are some of the questions that confront the hydrologists who endeavor to look below the surface. They are questions of almost infinite complexity, involving a great amount of physics and chemistry and almost the whole field of geology."

-- Oscar E. Meinzer, "Physics of the Earth IX," *Hydrology*, 1942, p. 385 --

CROSSWORD PUZZLE ANSWERS. Across: (2) Peninsula, (4) meteorite, (8) alluvial, (10) sphene, (12) euhedral, (13) intrusion, (14) tundra, (15) titanite, (17) escarpment, (18) interbedded, (19) flood plain. **Down:** (1) Unconsolidated, (3) sediment, (5) cleavage, (6) magnetic, (7) groundwater, (8) aquifer, (9) gpd, (11) dredging, (16) lattice.