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MESSAGE FROM THE STATE GEOLOGIST

As New Jersey welcomes Governor Jon Corzine and the Department of Environmental Protection greets Commissioner Lisa Jackson, the Geological Survey is pursuing several new initiatives. This issue of Unearthing New Jersey, focuses on tools and research undertaken by the Survey to provide a better understanding of the near-surface environment and the geology of the State.

Ron Witte and Don Monteverde present recent mapping work in the Delaware Water Gap National Recreation Area. Newly mapped karst landscape features including sinkholes, sinking streams, springs and caves were identified along Wallpack Ridge. In the New Jersey Valley and Ridge and Highlands Physiographic Provinces much of the potable water comes from karst terrain. These areas support ecologically sensitive resources that are easily impacted by human activity. Karst areas are also prone to ground subsidence due to the formation of sinkholes.

Laura Nicholson is working on the carbonate rock aquifers in northern New Jersey that supply approximately 8 billion gallons of water annually. Unfortunately these aquifers are vulnerable to contamination from near pollution moving down through fractures in the rock. To better understand these pathways, the Survey recently conducted studies on the fractured carbonate rocks in Hamburg Borough, Sussex County The research involved characterization of the hydrogeology of the site and two 72-hour aquifer tests to investigate specific water-bearing zones. Results suggest that under natural flow conditions a varying degree of hydrologic connection exists between the shallow and deep aquifers.

Greg Herman details new tools and methods used to develop the relationship between geology and ground water flow in a computerized hydrogeological framework. Specifically, the heat-pulse flow meter and optical televiewer are teamed with traditional borehole geophysics and geographic information systems to analyze fractured bedrock geology and ground water flow at the Heron Run Golf course in Hunterdon County. Combining this information into a hydrogeologic framework facilitates the modeling of the way that water in the aquifer moves and is stored.

John Dooley and Larry Müller provide information on the mineral prehnite which once was considered for designation as the state mineral of New Jersey. Prehnite is a green, translucent, hydrous, calcium aluminum silicate. It can be mistaken for jade and is occasionally used as an ornamental stone. It mainly occurs as a vein or filled vesicle in igneous rocks such as basalt. New Jersey has produced some of the finest specimens from localities near Paterson, Passaic County.

The Survey welcomes your feedback (http://www.njgeology.org/comments.html). Other recent geologic activities and digital publications of the Survey are noted elsewhere on the Survey's Web site. Printed maps and reports are available to the public through the DEP Maps and Publications Office (609) 777-1038, PO Box 438, Trenton, N.J. 08625-0438 and a publications price list is maintained on the Web. Unpublished information is provided at cost by writing the State Geologist's Office, N.J. Geological Survey, PO Box 427, Trenton, N.J. 08625-0427. Staff are available to answer your questions 8 a.m. - 5 p.m. Monday through Friday by calling (609) 292-1185.

Karl W. Muessig,
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Bedding surface of the Onondaga Limestone exposed along a small stream on Wallpack Ridge. The irregularly shaped depressions formed by dissolution of soluble nodular limestone. The large joints cutting across and paralleling the stream go deep into the rock. Sinkholes in the park tend to follow the same joint trends. *Photo by R.W. Witte*

KARST IN THE DELAWARE WATER GAP NATIONAL RECREATION AREA

By Ron W. Witte and Donald H. Monteverde

INTRODUCTION

Recent mapping in northwestern New Jersey detected a large number of karst features found along Wallpack Ridge in the Delaware Water Gap National Recreation Area (fig. 1). Dozens of small sinkholes, sinking streams, springs and small caves were identified. The greatest number of features were found in the Onondaga Formation, a 270 foot-thick limestone that outcrops on the northwest-facing slope of Wallpack Ridge. Less commonly, karst features also developed in older limestones along the eastern face of Wallpack Ridge.

A karst landscape typically results when carbonate rock is dissolved by rain and groundwater. It is characterized by rocky ground, caves, sinkholes, and subterranean and discontinuous surface streams. Karst is common in Kittatinny Valley and parts of the New Jersey Highlands where thick belts of carbonate bedrock underlie lowlands. It was not previously recognized in the Delaware Water Gap National Recreation Area (DEWA). However, during the last century small caves were discovered outside the park in the same limestone-rich formations found in DEWA.

Karst is a valuable natural resource in New Jersey. In the Valley and Ridge and part of the New Jersey Highlands physiographic provinces about 40 percent of potable water comes from karst terrain. Also, caves sometimes contain information about past climate, plants and animals, and human history. Karst areas are also susceptible to the impact of human activity and can be used to monitor environmental health. In addition to its value as a natural resource, karst areas are prone to ground subsidence due to the formation of sinkholes.

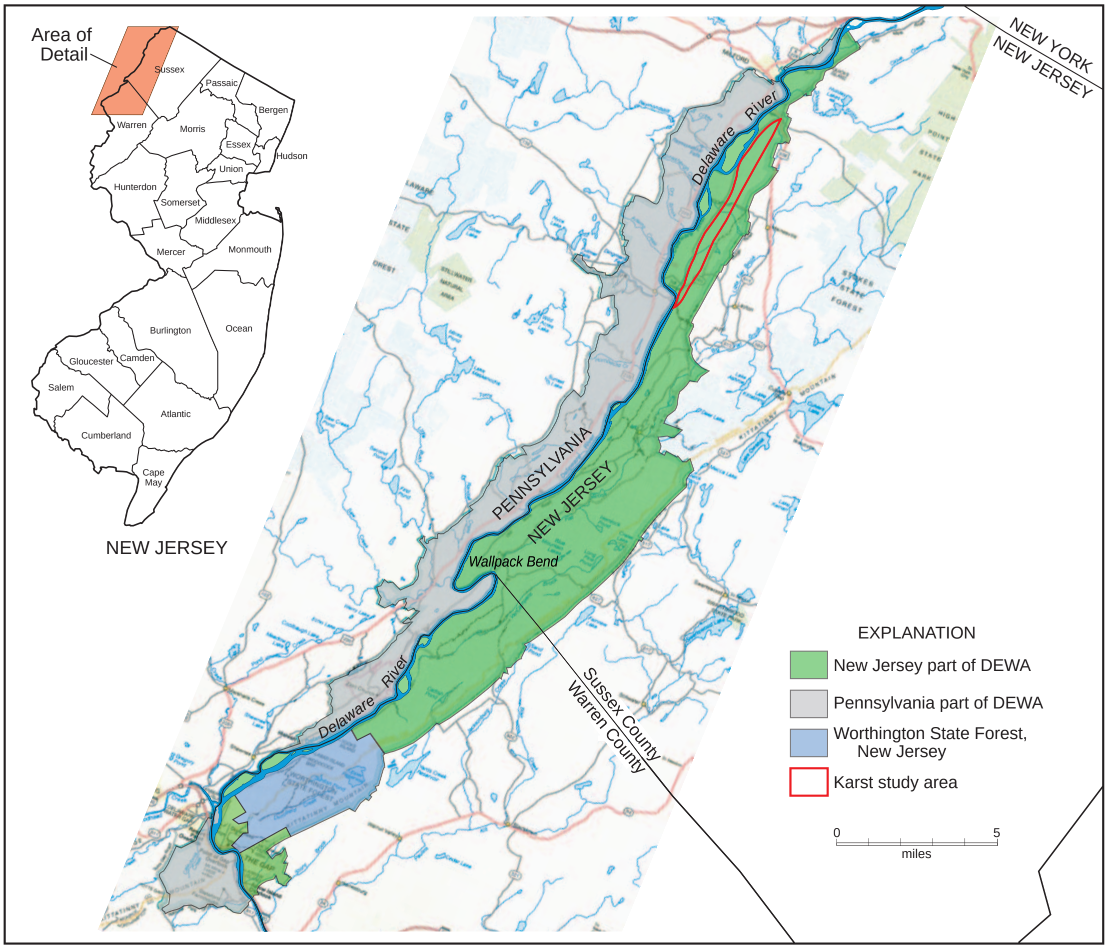

Figure 1. Location of Delaware Water Gap National Recreation Area (DEWA) in New Jersey and Pennsylvania, and karst study area.

The Congress recognized the value of karst and passed two acts to ensure its protection on federal lands. **The Federal Cave Resources Protection Act of 1988** 1) secures, protects, and preserves significant caves on federal lands for the perpetual use, enjoyment, and benefit of all people, and 2) fosters increased cooperation and exchange of information between governmental authorities and those that utilize caves located on Federal lands for scientific, education, or Recreation purposes. **The National Cave and Karst Research Act of 1988** 1) furthers the science of speleology (caving), 2) centralizes and standardizes speleological information, 3) fosters interdisciplinary cooperation in cave and karst research programs, 4) promotes public education, 5) promotes national and international cooperation in protecting the environment for the benefit of cave and karst landforms, and 6) promotes and develop environmentally sound and sustainable resource management practices. This act led to the founding of the **National Cave and Karst Research Institute** (NCKRI) which operates under the auspices of the National Park Service (NPS).

These two acts provided the basis for a cooperative effort among the New Jersey Geological Survey, U.S. Geological Survey, and National Park Service (NPS) to study and protect karst in the Delaware Water Gap National Recreation Area.

Geologic research on federal lands is allowed only after a permit is issued by the NPS. Unauthorized collecting, exploring, and mapping of natural and cultural resources are strictly prohibited and punishable by fines and imprisonment. Inflicting damage to park resources is similarly punishable. To further protect DEWA's karst resources, the location of features discussed in and photographed for this article are shown at a regional scale.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

Long, narrow, and slightly sinuous, Wallpack Ridge extends 25 miles from Wallpack Bend on the Delaware River to Tristates in New York State (fig. 2). Its width varies between 0.67 and 1.7 miles and its highest elevation is 928 feet. Topography is knobby, typically consisting of short, rocky northeast-trending ridges and benches. Wallpack Ridge may be divided into three sections (southern, middle and northern) based on the ridge's topographic trend. The southern and northern sections trend about 055 degrees while the middle trends about 026 degrees. The middle is also the widest section because its rock formations are inclined much less steeply than those in the lower and upper parts. On either side of Wallpack Ridge lie Minisink (west) and Wallpack (east) Valleys. Both valleys are narrow,

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deep, and trend southwest following belts of weaker rock. The valleys were also the former sites of a planned hydroelectric and water storage project by the Army Corps of Engineers. A dam constructed at Tocks Island would have flooded Minisink Valley upstream to Port Jervis, New York, and Wallpack Valley upstream to Layton. The reservoir would have provided storage capacity of nearly 250 billion gallons. After years of controversy, Congress deauthorized the project in 1992. Kittatinny Mountain (fig. 2) is a prominent ridge that forms the eastern border of the study area. It separates Minisink Valley from Kittatinny Valley, and runs from the Shawangunk Mountains in New York southwestward through New Jersey into Pennsylvania. It rises as much as 1500 feet above the floor of Minisink Valley and is underlain by a very resistant quartzite and quartz-pebble conglomerate. The lower area northwest of the mountain that extends to Wallpack Valley is included with Kittatinny Mountain.

Bedrock in the Wallpack Ridge area consists of Silurian and Devonian sedimentary rocks that dip northwest and form a southwest-trending monocline (fig. 3). These sedimentary rock formations contain both carbonate and siliciclastic (sandstone,

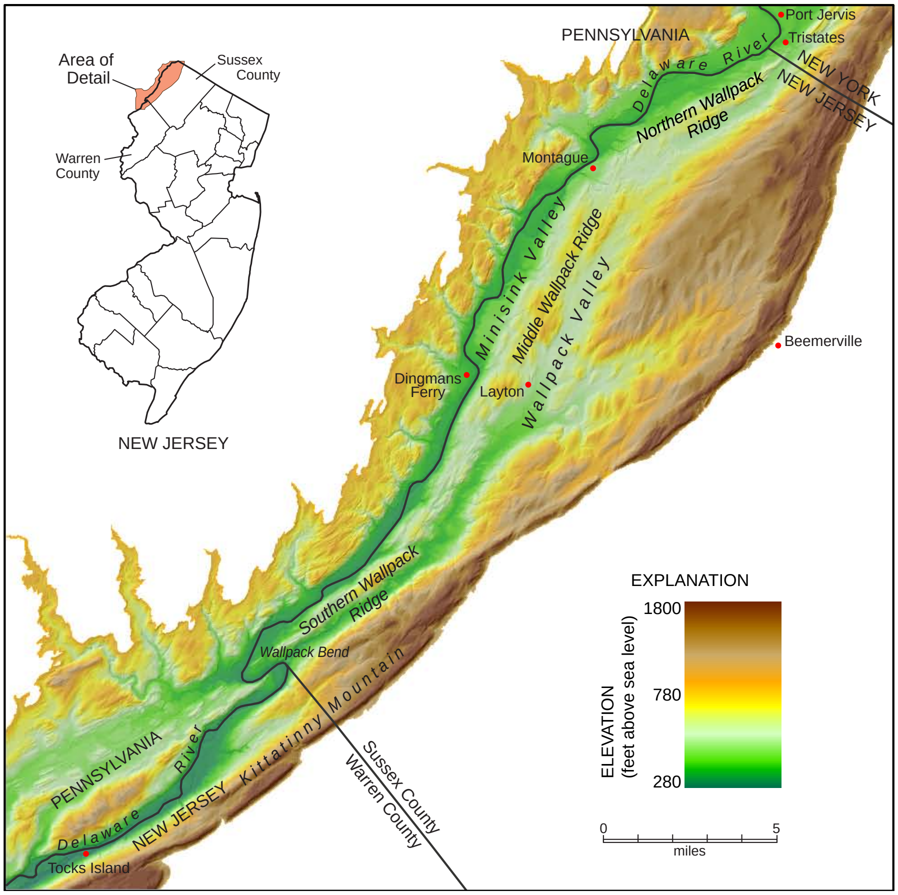


Figure 2. Shaded-relief map of Wallpack Ridge and surrounding areas.

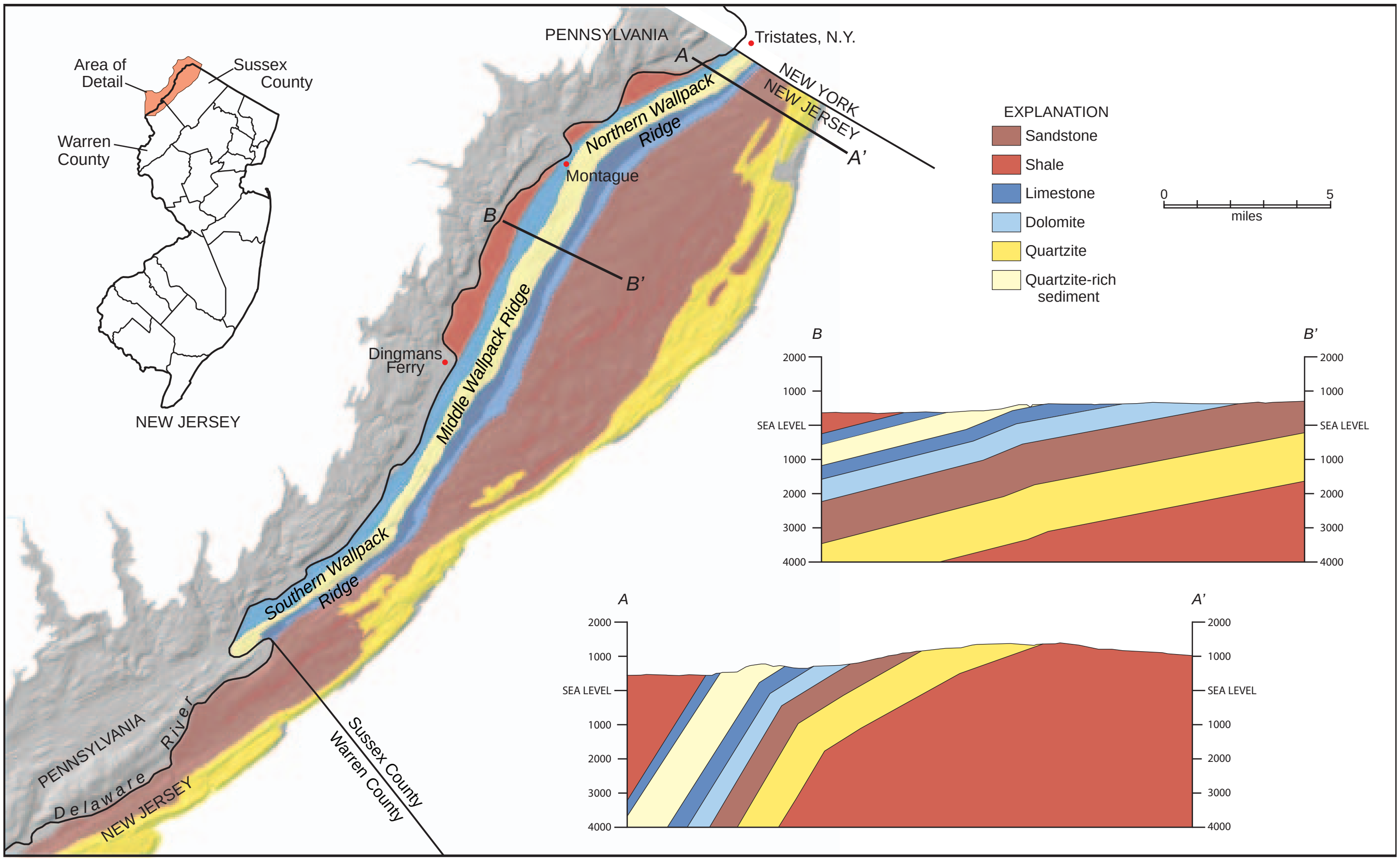


Figure 3. Bedrock geology of Wallpack Ridge and surrounding area.

siltstone, and shale) rocks. These units are subdivided into fifteen different geologic formations, but can be grouped into five different lithologic types when studying karst at larger scales. The basal and oldest sedimentary rock in the Wallpack region is the Poxono Island Formation, which underlies Wallpack Valley. This 600-foot thick formation consists of dolomite, clayey dolomite and locally quartz sandstone. In New Jersey the Poxono Island is known only from drill hole samples because it is completely covered by glacial outwash and alluvium. .

Overlying the Poxono Island Formation is an approximately 300-foot thick package of limestone. Sediments from seven different formations are grouped together and they portray great sedimentological variability. The lower 100 feet of this unit is a very uniformly thin bedded, fine-grained limestone to clayey limestone. The upper 200 feet contains a more heterogeneous rock assemblage of interbedded clayey- to coarse-grained limestone and locally quartz siltstone, sandstone and conglomerate rich lenses. Less commonly found are dolomite and chert. This complete limestone unit dips northwestward and generally crops out along the east facing Wallpack Ridge.

Quartz-rich sedimentary rock upholds the spine of Wallpack Ridge and lies atop the limestone group. Comprising six different formations and totaling 875 feet thick, it is dominated by siltstone and shale. This quartz rich group begins with 100 feet of dominantly shale, clayey limestone and minor fine-grained limestone and then changes to more than 150 feet of siltstone and shale. The middle unit changes along strike from a coarse-grained sandstone and chert in the south to silty limestone in the north. On average, it is 150 feet thick across Wallpack Ridge. Siltstone dominates the upper 475 feet of this group of formations. Silty limestone interbeds become more common near the top.

A second and final limestone group overlies these sediments. This 270-foot thick unit is entirely within the Onondaga Limestone. It was originally divided into a southern, Buttermilk Falls Limestone and northern, Onondaga Limestone. However, recent work suggests that the entire unit is the Onondaga Limestone. It is characterized by medium bedded, fine-grained limestone to clayey limestone. Locally it is nodular and black chert becomes common near the top of the unit. The Onondaga forms the west-facing flank of Wallpack Ridge and topographically forms a dip slope that extends down to the Delaware River.

Overlying the Onondaga Formation is the Marcellus Shale, which comprises the fifth and final lithologic group. The Marcellus is about 900 feet thick and generally underlies Minisink Valley, but is concealed beneath thick deposits of glacial outwash and alluivium. The shale is thin- to thick-bedded, and locally sandy.

KARST IN THE PARK

Karst features in the New Jersey part of DEWA include sinkholes, sinking streams, springs, and a few very small caves. Most of these are found in the middle section of Wallpack Ridge in the Onondaga Limestone (fig. 2).

Sinkholes - Sinkholes are the most common karst features in DEWA. As much as 15 feet deep and 45 feet in length, they formed where the Onondaga Limestone is overlain by glacial till and in places, eolian (wind deposited) sand. Most are oval shaped with their length 1.5 to 2 times their width. The orientation of the long axis of the sinks is usually parallel to primary joints found in the local rock. Sinks may occur alone or in small groups that typically are aligned with local joints. Also, most sinkholes are not found along streams or in places where they may receive surface runoff.

Sinkholes are found throughout the Onondaga Formation with most located along the middle to upper part of its dip slope. They are mostly found in two topographic settings. 1) Many lie adjacent to the up slope side of a rocky ridge (fig. 4). These sinks are rock-walled or at least partially lined by outcrop. 2) Additional sinks are found along topographic benches (fig. 5). Many of these occur in closely-spaced groups where rock outcroppings are uncommon. In rare instances, several closely-spaced sinks that formed along cross joints are found on gentle slopes.

Figure 4. Sinkhole on the up slope side of a rocky ridge. *Photo by R.W. Witte*

Figure 5. Sinkhole along topographic bench. *Photo by R.W. Witte*

Sinking streams and springs – Many small tributaries that

Figure 6. Dingmans Ferry Spring. *Photo by R.W. Witte*

flow over the Onondaga Formation disappear or emerge at various places along the stream's course. At most points where this happens, the rate of seepage or discharge is small. Often these streams disappear over the course of a few hundred feet. Mostly, water moves through small joints, but sometimes seepage loss or discharge is much more dramatic. The Dingmans Ferry Spring, for example, discharges from a hillside through a one meter-wide hole (fig. 6). Closer inspection reveals that this subterranean stream flows through a large open joint before appearing on the surface. During periods of high flow, discharge can be greater than 100 gallons per minute.

Brau Kettle is an unusual spring. During dry parts of the year (fig. 7a) the kettle resembles a small sinkhole, while during periods of greater precipitation (fig. 7b) it fills with water and discharges to a nearby creek bed. About 1800 feet upstream from Brau Kettle approximately 80 percent of stream flow disappears into an opening about 2 feet in diameter. The remaining water seeps into the stream bed within the next 200 feet. Downstream, the creek bed is typically dry except during periods of heavy precipitation. Whether this sinking stream is the source for Brau Kettle remains to be investigated.

Caves – Several small caves have been discovered in park. Most have openings that are just large enough for a person to fit through, and then quickly diminish in size. No large subterranean caverns have been discovered, although the size of a few sinkholes suggest that bigger caves may exist. If larger caves are found in DEWA they could provide a rare opportunity to determine past climate change in northern New Jersey by studying the chemistry of their formations.

KARST FORMATION

Most of the karst features in DEWA lie in the middle section of Wallpack Ridge between Dingmans Ferry and U.S. Route 206. Many factors contribute to the formation of karst in this area. Most importantly is that the Onondaga Limestone is susceptible to dissolution by water. Because rock formations that topographically lie above the Onondaga consist largely of siliclastic rocks, water that drains through them becomes slightly acidic. Rain water seeping through organic-rich soil in the area also becomes slightly acidic. Over time these waters dissolve the calcium carbonate that makes up the Onondaga Limestone. Where water flow is concentrated along joints and fractures, larger conduits are formed and eventually a cave may develop. The shallow dip of the limestone beds also promotes dissolution by creating a larger surface area of limestone. In this section of the Wallpack Ridge the thin to medium-thick beds of the Onondaga dip about 10 degrees or less. Elsewhere, the limestone dips as much as 85 degrees, most notably in the southern and northern sections (fig. 3). Because of this slope difference, the width of the exposed Onondaga here is up to twice as great as elsewhere. Although the primary conduits of subsurface flow are joints, some beds of the Onondaga are more prone to dissolution due to a higher calcium carbonate content. These beds will dissolve preferentially and increase the size of the subterranean passageways.

Figure 7a. Brau Kettle in dry part of year. *Photo by R.W. Witte*

Figure 7b. Brau Kettle in wet part of year. *Photo by R.W. Witte*

Finally, the lack of pronounced cleavage (the tendency for rock to split along closely-spaced parallel planes) in the middle section of Wallpack Ridge may have encouraged the flow of water through the joint system. In the Onondaga this could have accelerated the rate at which the formation dissolved.

There are no known dates for the age of the karst features in DEWA or the nearby caves. Because the DEWA sinks formed on late Wisconsinan glacial deposits, we can estimate a maximum age at about 20,000 years based on the age of the late Wisconsinan glaciation in northern New Jersey. The age of the subsurface passages that lie beneath the sinks is unknown, but they existed prior to the last ice age. Because glaciers remove rock and soil, all sinks older than the last glaciation have been destroyed. If large enough caves are discovered, their formations will tell us their age and provide clues about DEWA's karst history.

FUTURE WORK IN DEWA

About half the karst area covered by the Onondaga Formation has been mapped and about three dozen sinkholes located. A busy field season is planned for 2006. Exploration and mapping of the Onondaga Limestone along Wallpack Ridge will continue and a full inventory of karst features within the New Jersey part of DEWA completed. Division of the Onondaga into its four recognized members and the search for volcanic ash (bentonite) marker beds will be a main emphasis in 2006. Preliminary data shows that part of the Onondaga in New Jersey differs from that described in Pennsylvania and New York.

$Ca_2Al_2Si_3O_{10}(OH)_2$

NEW RESEARCH IN GROUND-WATER FLOW IN CARBONATE FRACTURED-ROCK AQUIFERS

By Laura J. Nicholson

Carbonate fractured-rock aquifers in New Jersey include limestone and dolomite. These are the most productive bedrock aquifers in the state, supplying approximately 5 billion gallons of water annually. Many of the wells in these aquifers tap productive water-bearing zones several hundred feet below the ground surface. These wells are vulnerable to contamination from near-surface pollution such as industrial wastewater discharges or chemical spills because ground-water moves from shallow to deeper parts of the aquifer through fractures in the rock. In northern New Jersey, the downward movement of ground-water contaminants has compromised countless bedrock supply wells. Carbonate-rock aquifers are especially vulnerable to contamination because pollutants can travel quickly through enlarged fractures and openings that formed by the natural process of chemical weathering when rock dissolves in a manner similar to the formation of caves and caverns. The vulnerability of supply wells from near-surface pollution is dependent upon the interconnection of the shallow and deep fracture zones. Currently the nature of this interconnection is poorly understood.

To better understand the pathways that contaminants travel, NJGS recently conducted research in fractured carbonate rocks in Hamburg Borough, Sussex County in the Valley and Ridge Physiographic Province. Funding was provided by the New Jersey Department of Environmental Protection (DEP) Hazardous Waste Spill Fund, administered by the Division of Science and Research. The study area is on a hill slope underlain predominantly by dolomite of the Allentown and Leithsville Formations which, in some places, is covered with a thin layer of glacial sand and gravel. Rock layers at the site dip at an angle of approximately 45 degrees to the northwest. The eastern edge of the site is bordered by a steep escarpment with the Wallkill River at its base.

The rock outcrops at the site are some of the most visually interesting in New Jersey, recording a time approximately 500 million years ago when the region was covered by shallow tropical seas. They contain numerous fossils including stromatolites, cabbage-shaped algae that grew in the warm shallow water. About 20,000 years ago the exposed rocks were polished by glaciers that passed through the area. In some places, shallow grooves or 'striae' were etched into the rock surface by gravel carried beneath the heavy continental ice sheet as it advanced southward (fig. 1).

Figure 1. Outcrop showing stromatolites (circular features) and glacial striae (horizontal lines). *Photo by G.C. Herman*

Field work for the study involved two phases. Initially, a thorough characterization of the hydrogeology of the site was made through geologic mapping, conventional borehole geophysical techniques, the collection of water-level data, and an optical televiewer that provided a visual record of the drilled portion of the aquifer. Several wells were logged using a heat-pulse flow meter. The flow meter measured the rate and direction (upward or downward) of ground-water flow in the well bores and provided information on the interconnection of water-bearing zones. These methods were instrumental in establishing a preliminary hydrogeolgic framework for the site that included the delineation of separate shallow and

Figure 2. DEP fields crew installing a packer. *Photo by L.J. Nicholson*

deep fracture zones.

A second intensive phase of field work was conducted in June 2005. Four packers, impermeable balloon-like seals emplaced within the borehole between shallow and deep fracture zones, were installed in selected wells (fig. 2). Two 72-hour aquifer tests were then successfully conducted, one with packers inflated and one without. In each test, the deep water bearing zone of Well 1A was pumped at a rate of 100 gallons per minute (gpm) and drawdown, the lowering of the water level in response to pumping, measured in six observation wells. The use of packers in the first test allowed for an evaluation of the flow system under "natural conditions" that is, any vertical movement of ground water from shallow to deep fracture zones occurred solely through the aquifer formation and not through the borehole. The second test was conducted after the packers were deflated, allowing ground water in the shallow zone to reach the deeper pumped zone via a "shortcut" down the well bore.

Development of a detailed hydrogeologic framework and analysis of the aquifer tests have yielded insight into the complex carbonate fractured-rock flow system. One result is a better understanding of the extent to which the well borehole increases drawdown in shallow parts of the aquifer by creating an artificial pathway for water to flow downward to the pumping source. The hydrograph in figure 3 shows the water level in the shallow and deep fracture zones for three wells, pumping well 1A and observation wells OW-2 and OW-3, during the two tests. While each test was conducted, the lower water-bearing zone was pumped at 100 gpm. The first aquifer test began on June 7 after packers were inserted in the three wells and water levels above and below them were allowed to stabilize. On June 10, after 72 hours of discharging, the pump was shut off and water levels began to recover. On June 12, when water-level recovery was complete, all of the packers were deflated and the water levels above and below them were again allowed to equilibrate. On June 13, the second test was conducted with the packers deflated; the pump shut off on June 16 and the testing ended on June 17. Water levels were monitored throughout the test at a minimum of three-minute intervals using automatic data recorders supplemented with manual measurements .

In wells 1A and OW-3, the presence of the open borehole greatly increased drawdown in the shallow aquifer. In pumping well 1A, only 3.9 feet of drawdown occurred in the shallow zone above the inflated packer in Test 1, compared with 38 feet in Test 2 when the packer was deflated. Correspondingly, drawdown in the deeper zone in well 1A was less in Test 2 as the pump drew additional water from the shallow zone. In OW-3, no drawdown in response to pumping was observed in the shallow zone during Test 1, while 3.5 feet of drawdown occurred beneath the inflated packer. In the second test, approximately 2 feet of drawdown occurred in the well. These results suggest that under natural flow conditions there is little if any hydrologic connection between the shallow and deep aquifer zones in the vicinity of OW-3. This hypothesis is further supported by the large change in the water level in the deep zone (14 feet) observed upon both inflation and deflation of the packer, indicating that the water levels in the two zones are not at equilibrium with each other. There are no known contaminants at the research site, but if any were present, the open borehole might allow them to travel more rapidly through the aquifer and be introduced into areas that would otherwise remain unaffected.

Aquifer test results indicate that there is a greater degree of hydrologic connection between the shallow and deep water-bearing zones in the vicinity of OW-2 than elsewhere at the site. This finding highlights the difficulty of determining ground-water flow paths in this complex carbonate fractured-

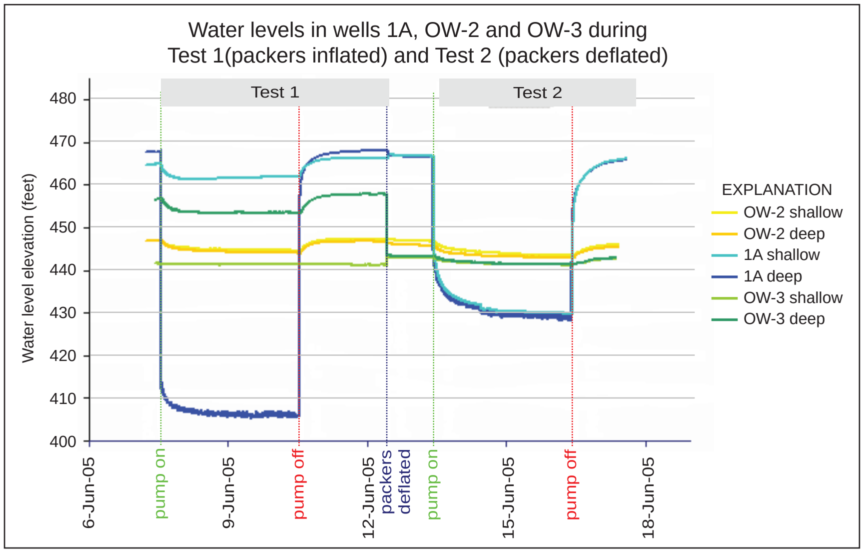


Figure 3. Hydrograph showing water level in shallow and deep fracture zones for three wells during two tests.

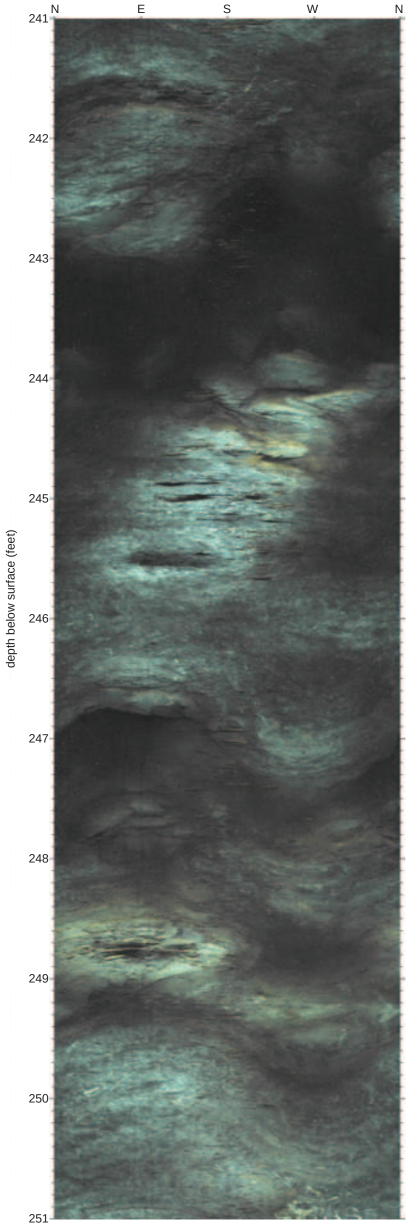


Figure 4. Unwrapped borehole section showing cavities in the dolomite.

rock aquifer. In Test 1, the amount of drawdown in the shallow and deep aquifer zones at OW-2 was similar, 2.1 and 3.0 feet respectively, indicating that both zones responded to the pumping in a hydrologically-similar manner. Also, drawdown during the second test, 2.8 feet, did not vary much from the initial test. This suggests that the presence of the open borehole had little effect on movement of ground water from the shallow to deep zone because ground water traveled readily through naturally-formed fractures and openings in the rock. A log of OW-2 appears to confirm this. It reports large fractures and clay-filled cavities, especially below a depth of 240 feet. NJGS borehole televiewer data also show numerous cavities in the rock (fig 4). It is possible that, at depth, OW-2 taps the Leithsville Formation which is known to have cavernous zones capable of high well yields.

NJGS research is providing a better understanding of ground-water flow in fractured carbonate-rock aquifers. Test data is being analyzed to determine properties such as the rate at which ground water flows vertically through the aquifer. Other topics of investigation are ground-water/surface-water interaction between the aquifer and the Walkill River, and the potential to use small ground-water temperature changes observed during the testing as indicators of the source of water to a well. It is hoped that insights gained at this representative site will help protect water supplies from contamination and remediate existing problems. For example, the research may be used to help establish methods to determine where separate aquifer flow zones are present. Requirements may then be made that new supply wells in those areas be cased into the deeper pumped zone to minimize potential impacts to the ground water. Where contamination of the aquifer has already occurred, results of this research may assist DEP in better determining travel times for pollutants and thereby formulate more cost-effective clean-up and monitoring plans.

HYDROGEOLOGICAL FRAMEWORK OF THE BRUNSWICK AQUIFER AT THE HERON GLEN GOLF COURSE, HUNTERDON COUNTY

By Gregory C. Herman

The New Jersey Geological Survey (NJGS) uses borehole geophysical data, geographic information systems, and computer-aided drafting software to examine how subsurface geologic features contribute to the storage and movement of ground water. Ground-water supply and pollution studies often rely on detailed subsurface information to depict paths of water flow through geological materials and to help constrain the physical extent of contaminant. The NJGS recently acquired a heat-pulse flow meter (HPFM) and an optical televiewer (OPTV) that provide unprecedented insight into how ground water flow relates to specific bedrock features. They have been used in conjunction with traditional borehole geophysics in over 100 wells at 40 field sites since 1998 (fig. 1). Using the Hunterdon County Heron Glen Golf Course as an example, this article summarizes how the NJGS combines map and subsurface information to develop a computerized hydrogeological framework. Jason Pierce, superintendent of the golf course and Penelope Althoff, consultant, provided access to the facility and wells. Don Monteverde of the NJGS helped map the bedrock.

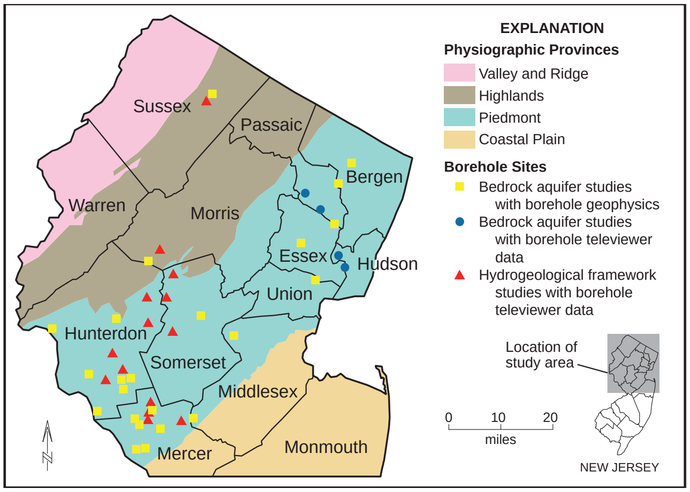


Figure 1. Locations of bedrock aquifer investigations, hydrogeological framework studies, bedrock core locations and a radionuclides in ground water study in northern New Jersey.

Heron Glen is located midway between the Flemington and Hopewell faults in the central part of the Newark basin (fig. 2). The area is underlain by the upper part of the Passaic Formation within the middle of the Brunswick aquifer. Borehole geophysical tools were run in three 6-inch water wells drilled to about 400 feet below land surface during 2001 to 2002 as part of the water-supply plan at the golf course.

The wells are cased to about 50 feet below land surface and then are open holes. John Curran logged borehole diameter, natural gamma-ray radioactivity of the geological formation and electrical resistance/conductance of both the formation and borehole fluids. Fluid temperature and electrical logs provide a good first measure of where water is entering and exiting a well in the subsurface (fig. 3). The OPTV was run in well *N* and nearby well *QNS* (fig. 2). The OPTV provides a 3D digital photographic record of the borehole walls (fig. 4) and 3D orientation of the borehole. Fractured, massive red mudstone and siltstone, and thin beds of gray and black shale were observed in OPTV records that correlate with units mapped in outcrop (figs. 2 to 4). Subsurface correlation of strata through the well field relied on gamma ray logs. The HPFM was run in wells *B* and *N* while nearby supply wells (*F* and *M*) were pumping at a combined rate of about 500 gallons per minute (gpm) over a five-hour period each day. The HPFM is used to measure rates of fluid flow between 0.3 to 10.0 ft/min, or about 0.5 to 15.0 gpm respectively, for 6-inch wells. The HPFM has been tested by the NJGS to be about 80% accurate and is used for developing flow profiles for the penetrated extent of the aquifer (fig. 3). Flow profiles illustrate points of entry and exit of ground water in open wells having cross flows, that is, water flowing between different, semi-confined water-bearing zones having different hydraulic heads.

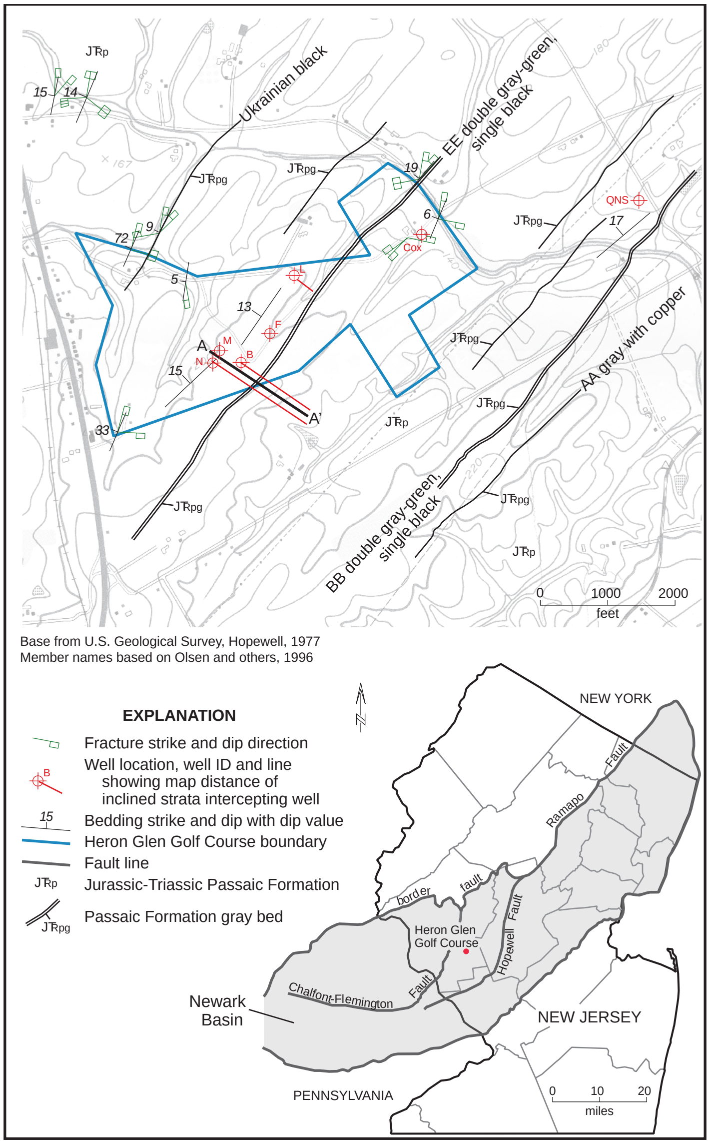


Figure 2. Location and site map of Heron Glen Golf Course.

Ground water is primarily stored and transmitted along fractures between bedded strata and in strata containing networks of secondary pores (fig. 4) created by the dissolution of secondary minerals that once filled voids. Consequently, many red beds are highly porous and convey significant volumes of groundwater. The conductive beds are continuous in the subsurface (fig. 5) but sandwiched between thick, relatively impermeable confining layers. The confining strata are composed of massive red mudstone that lack abundant secondary minerals and associated porosity. The confining layers also include thin gray and black beds that, together with conductive beds, form a series of stacked, bed-parallel aquifers and aquitards (figs. 3, 4). Pervasive, non-bedding fractures including joints, mostly dip steeply eastward at about 70º and strike subparallel to the strike of bedding and nearby faults. These fractures provide paths for ground water to leak through aquitards into the adjacent water-bearing intervals. The vertical boundary between stratified water bearing and confining intervals often correlate with abrupt changes observed in fluid temperature and electrical conductance of the borehole fluids (fig. 3).

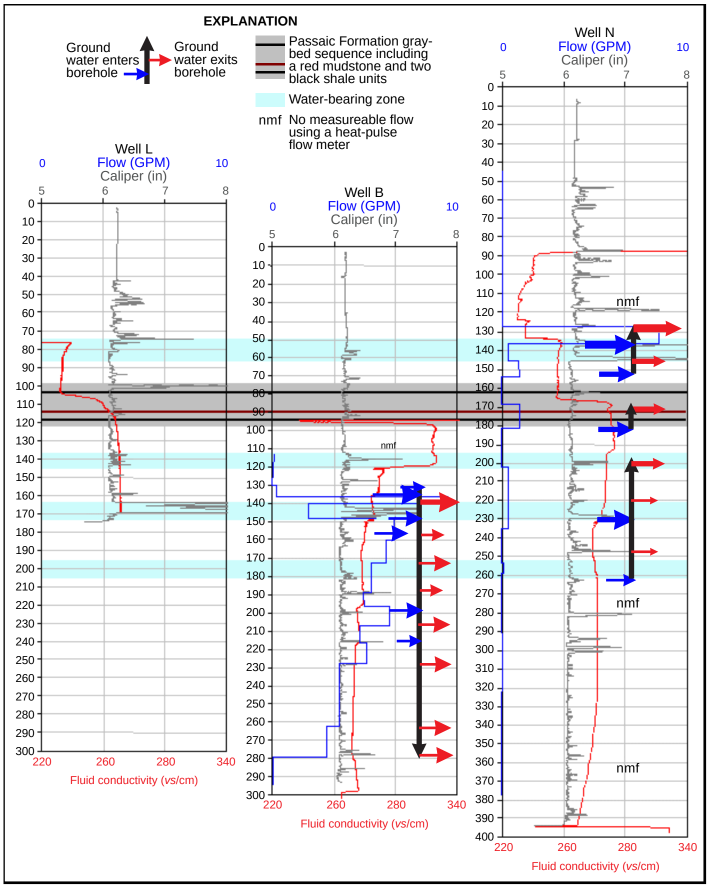
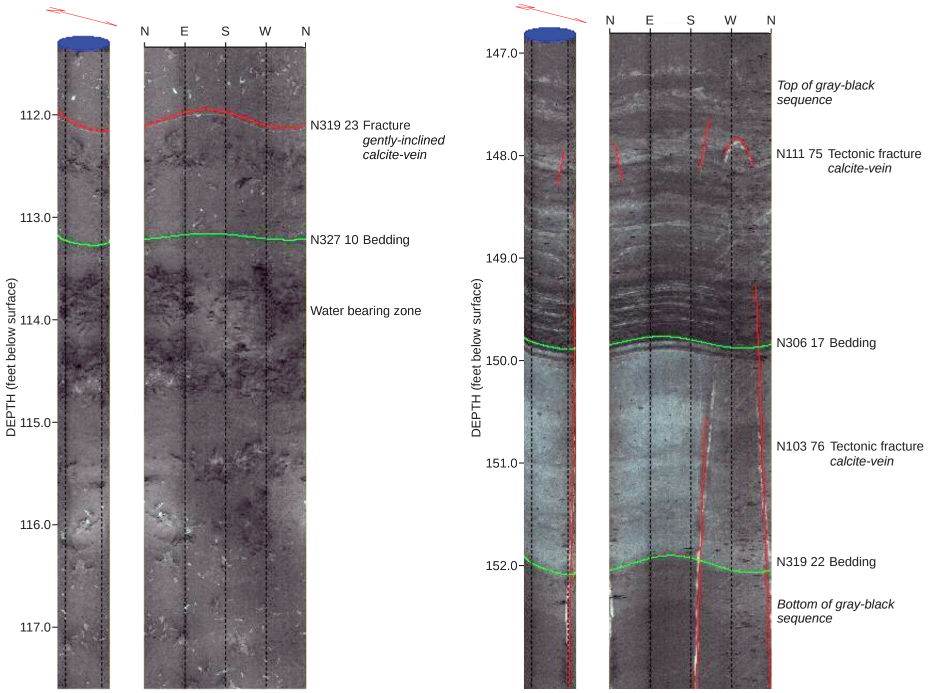


Figure 3. Borehole flow analysis showing integrated caliper, fluid conductivity and HPFM logs in conjunction with water-bearing zones.

Interval flow velocities were measured in each well and combined with the subsurface geology to construct a borehole flow analysis diagram (fig. 3). The diagram



Red Mudstone

Black Shale

Figure 4. Red Mudstone: A wrapped (left) and unwrapped (right) view of porous red mudstone of the Passaic Formation at the Heron Glen Golf Course. Numbers to the right indicate the direction of structural dip (inclination) and the bearing and dip of measured beds and fractures. Black Shale: A wrapped (left) and unwrapped (right) view of red and gray-green mudstone overlain by dark gray to black shale in the Passaic Formation. Numbers to the right the same as for Red Mudstone.

shows that under these pumping conditions, groundwater is exchanged between stratified water bearing zones at rates up to 10 gpm in the observation wells. Moreover, two wells with less than 500 feet of separation at the land surface have cross flow in opposite directions! One explanation for this may be the variations in topographic elevation over the recharge areas for the flowing intervals of each well. This is illustrated using a hydrogeological profile of the well field (fig. 5). This profile includes a summary of the borehole flow analysis together with the well construction information and depicts the wells in spatial arrangement with relevant surface and subsurface features. This hydrogeological framework illustrates where the upper and lower boundaries of each flowing interval project upward along stratigraphic dip to intersect the land surface. In both cases, the maximum rate of fluid flow measured in each well show the same linear relationship with respect to elevation differences over the recharge interval. For example, well *N* has upward cross flows up to about 3 gpm between depths of 130 to 260 feet below land surface (fig. 3), and a positive hydraulic potential stemming from an 11-ft increase in elevation change from the top and bottom of the flow interval (fig. 5). In contrast, well *B* exhibits downward cross flows up to 10 gpm between depths of 130 to 280 feet below land surface (fig. 3), and a negative hydraulic potential stemming from a 40-foot decrease in elevation change from the top and bottom of the flow interval (fig. 5). Therefore, both wells have about 1 gpm flow for every 4-foot difference in topographic elevation change over the respective recharge zones, regardless of the flow direction.

It is important to remember that borehole flows in this study were measured under local pumping conditions. Therefore, observed flow rates are probably higher than those expected for non-pumping conditions or periods of hydraulic recovery because all of the wells penetrate the same water-bearing zones and flow rates in these zones are accelerated by pumping (fig. 5). The direction of cross flows during pumping may also vary from those occurring under non-pumping conditions. However, based on the geometry of the semi-confined water-bearing strata relative to surface topography, natural (non-pumping) cross flows are expected to occur along the directions observed in each well from topographic considerations alone.

In summary, subsurface geophysical logs, especially the HPFM and OPTV, can provide valuable insight into the structural framework of aquifers penetrated by wells with

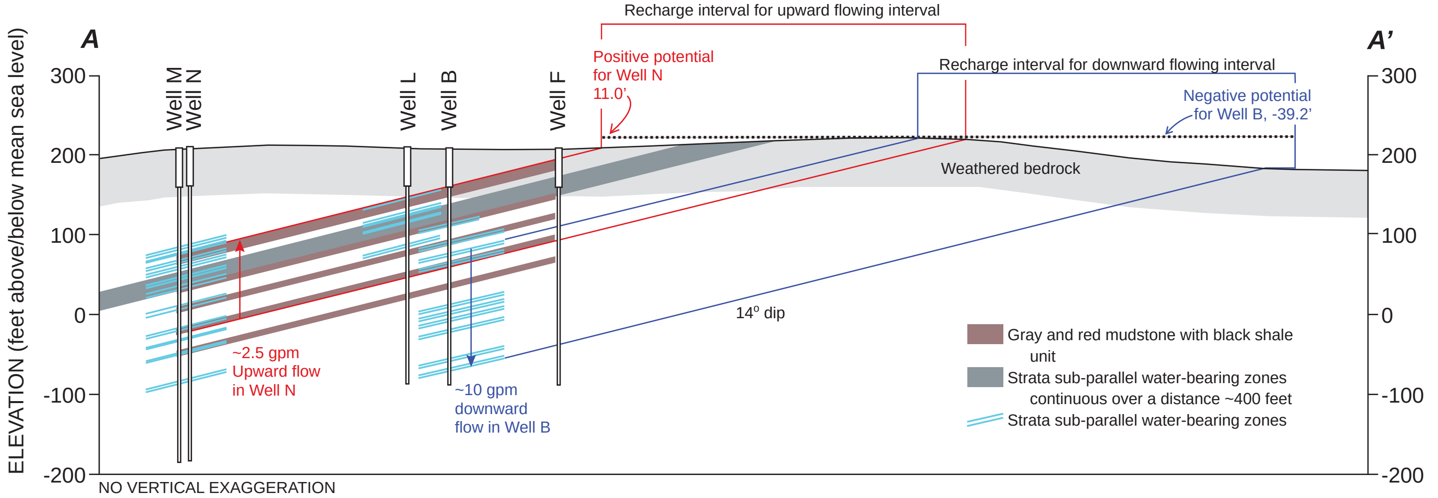


Figure 5. Profile view of the hydrogeological framework of the Brunswick aquifer in the vicinity of the Heron Glen Golf Course.

uncased boreholes. However, cross flows measured in wells need to be evaluated with respect to the specific hydraulic conditions under which the data were gathered. Rates of fluid flow in, out, and between water-bearing zones can be expected to vary depending upon pumping conditions, including variations in the rates and length of pumping cycles. The linear relationship between interval flow values and topographic elevation changes over the reported recharge interval may have only local significance, but can serve as a point of comparison for study in similar aquifers.

PREHNITE PRIMER

By John H. Dooley and Larry Müller

It was once suggested that prehnite be designated as New Jersey's state mineral. The proposal never crossed the governor's desk, however, and although other minerals may seem a better choice prehnite remains the state's unofficial mineral.

Prehnite is a hydrous, calcium aluminum silicate having the empirical chemical formula: $Ca_2Al_2Si_3O_{10}(OH)_2$. It was discovered by Colonel Hendrik von Prehn, an eighteenth century Dutch governor of the Cape of Good Hope colony in South Africa. The type locality for prehnite is the Karoo dolerites (diabase), Eastern Cape Province, South Africa. Incidentally, prehnite is the first mineral to be named after a person.

Prehnite mainly occurs as a vein or amygdule (a gas cavity or vesicle in an igneous rock) mineral in basaltic rocks that were subjected to hydrothermal fluids (less than 150°C or 300°F) or low-grade burial metamorphism. It can occur in hydrothermal veins in granites, syenites, gneisses, marble, and calcsilicate metamorphic rocks.

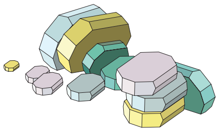
Prehnite often occurs in association with zeolite minerals and is occasionally referred to as a zeolite. Zeolite minerals, however, are tectosilicates (like quartz) whereas prehnite is classified as a phyllosilicate (sheet minerals such as mica). Actually its lattice structure is intermediate between chain (inosilicates) and layered (phyllosilicates) silicates. Prehnite and zeolites will yield water when heated, although unlike the zeolites, prehnite will not rehydrate (regain lost water).


Photograph of prehnite (green) displaying its botryoidal (having the form of a bunch of grapes) character in minute stalacitites. *Photo by J.H. Dooley*

New Jersey has produced some of the finest prehnite specimens known. The classic locale in New Jersey is the Paterson area, although excellent specimens have also been collected at Bergen Hill, Great Notch, Lambertville, Montclair, and Millington. Collectors, mineralogists, and lapidaries prize this mineral. Its pleasing green color, luster, variety of crystal habits, and associations with other minerals is very appealing. Green, translucent to semitransparent, prehnite can be mistaken for jade and is occasionally used as an ornamental stone.

Entering "prehnite" in an internet search engine provides more than 150,000 results. Many of these sites show photos of the mineral specimen and its ornamental uses in jewelry. Ladies and gentleman, start your engines!

Prehnite [$Ca_2Al_2Si_3 0_{10}(OH)_2$] was named for it's discoverer Hendrik von Prehn. It was the first mineral named for a person. Prehnite is a calcium aluminum silicate. It is a mineral constituent of the mafic igneous rocks and zones of contact metamorphism in New Jersey. The typical forms of prehnite are reniform masses, veins, fan-like structures, stalactites, stalagmites, and granular masses. It's color ranges from dark green to apple green, gray, white, yellow or pink.



By F. Larry Müller
Banner photos by J.H. Dooley

NEW PUBLICATIONS

NJGS OPEN-FILE MAP SERIES (OFM)
NEW MAP. Bedrock Geology of the South Amboy Quadrangle, Middlesex and Monmouth Counties, New Jersey, Sugarman, Peter J., Stanford, Scott D. and others, 2005, scale: 1 to 24,000, size 35x36, 2 cross-sections. OFM 65. $10.00

NEW MAP. Surficial Geology of the Caldwell Quadrangle, Essex and Morris Counties, New Jersey, Stanford, Scott D., 2005, scale: 1 to 24,000, size 36x57, 5 cross-sections, 1 figure, 40-page pamphlet. OFM 66. $10.00

ENVIRONMENTAL EDUCATION
BOOKLET REPRINT. Earthquake Risk in New Jersey, Dombroski, Daniel R., Jr., 1998, revised 2005, 14 p., 3 illus., 3 tables. $1.00

BOOKLET REPRINT. New Jersey Rocks and Sediments, Dooley, John H. and Harper, David P., 1996, revised 1998 and 2005, 20 p., 5 illus., 2 tables. $1.00

WORLD WATER MONITORING DAY

By Stephen W. Johnson

World Water Monitoring Day (WWMD) is a global education and outreach event designed to promote personal stewardship and individual involvement in the protection of our Earth's water resources. The New Jersey Geological Survey has participated in WWMD events since 2003. During the 2005 WWMD held at Batsto State Park, NJGS made presentations to seven student groups (about 140 students) representing several high schools, student environmental clubs, and junior high school groups (fig. 1).

Figure 1. Jane Uptegrove discussed soil samples obtained on site by geoprobe with high school students participating in World Water Monitoring Day activities. *Photo by S.W. Johnson*

Figure 2. Plexiglas ground water model. *Photo by S.W. Johnson*

A plexiglas ground water model (fig. 2), was used to explain the water cycle, ground water movement, recharge of ground water, connection of ground water to surface water, and pollution of ground water and surface water.

NJGS staff demonstrated the use of a drill rig and a "geoprobe" (fig. 3) to collect soil and ground water samples. Students were also shown how to sample soils, measure depth to water within an aquifer, and draw a sample from an aquifer. Having watched the demonstrations, they were given the opportunity to use the tools of the trade to draw water samples and take water-level measurements.

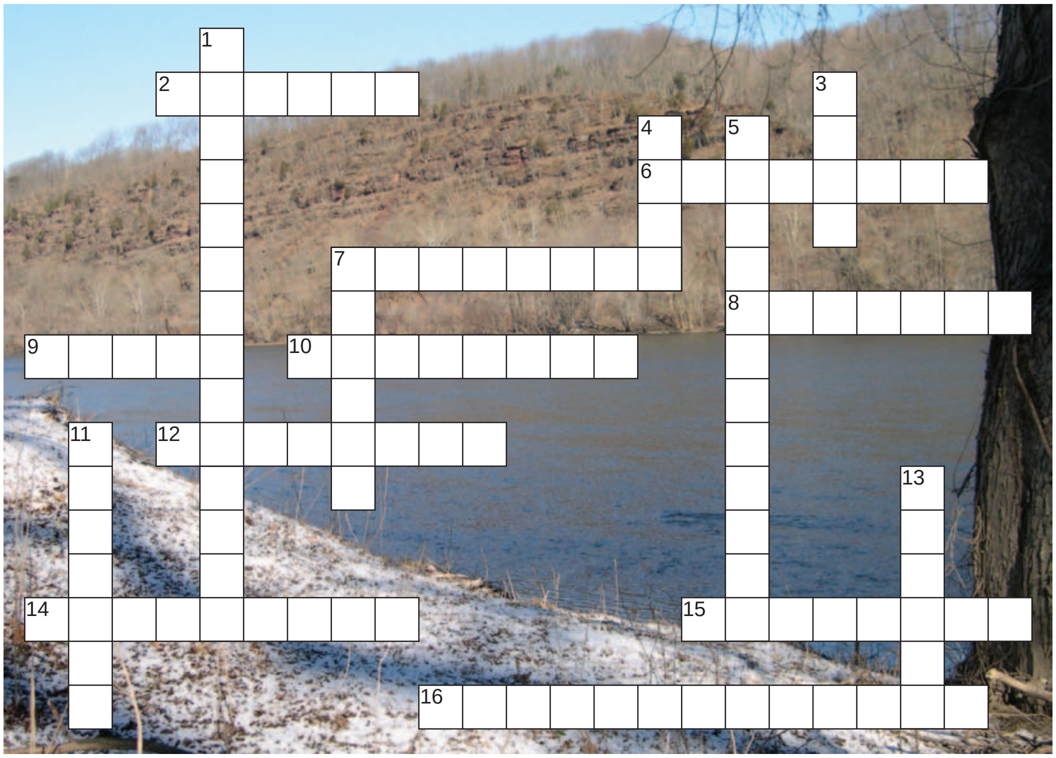
Figure 3. Greg Steidl used the geoprobe to collect a soil core. *Photo by S.W. Johnson*

$Ca_2Al_2Si_3O_{10}(OH)_2$

ROCKS, EH?

Geologists from the University of Quebec at Montreal (pictured) and the SOQUEM mining company in Quebec visited New Jersey in November, 2005, to view billion-year-old metamorphosed zinc and iron deposits in the Highlands for comparison with similar deposits in Canada. Providing geologic expertise was Rich Volkert, New Jersey Geological Survey (back row, second from right), Earl Verbeek, Sterling Hill Mining Museum (back row, far right), and Bob Metsger, retired, New Jersey Zinc Company (not pictured). *Photo courtesy SOQUEM Mining Company*

CROSSWORD CLIFFS



Delaware Cliffs, Holland Township, Hunterdon County. *Photo by Z. Allen-Lafayette*

ACROSS

2. Inflatable seal used in aquifer testing
6. Gas cavity of vesicle in an igneous rock
7. Circular depression in land surface caused by collapse of roof materials over solution cavern
8. Deposit of sand and gravel left by a glacial meltwater stream
9. Topography characterized by sinkholes, caves, and underground drainage
10. Lowering of the water level due to pumping
12. New Jersey's unofficial state mineral
14. $CaCO_3$
15. Deposit of sand or gravel left by a stream on it's flood plain
16. Primitive algael mats

DOWN

1. Limestone and dolomite
3. A stone, commonly pale to dark green in color
4. Opening beneath the surface of the Earth formed by dissolution of carbonate bedrock
5. Water of magmaticorigin
7. Place water flows out of ground surface
11. Mineral formed in cavities, typically resulting from low grade metamorphism
13. Glacial grooves

CROSSWORD PUZZLE ANSWERS. Across: (2) packer, (6) amygdule, (7) sinkhole, (8) outwash, (9) karst, (10) drawdown, (12) prehnite, (14) limestone, (15) alluvium (16) stromatolites. **DOWN:** (1) carbonate rocks, (3) jade, (4) cave, (5) hydrothermal, (7) spring, (11) zeolite, (13) striae.