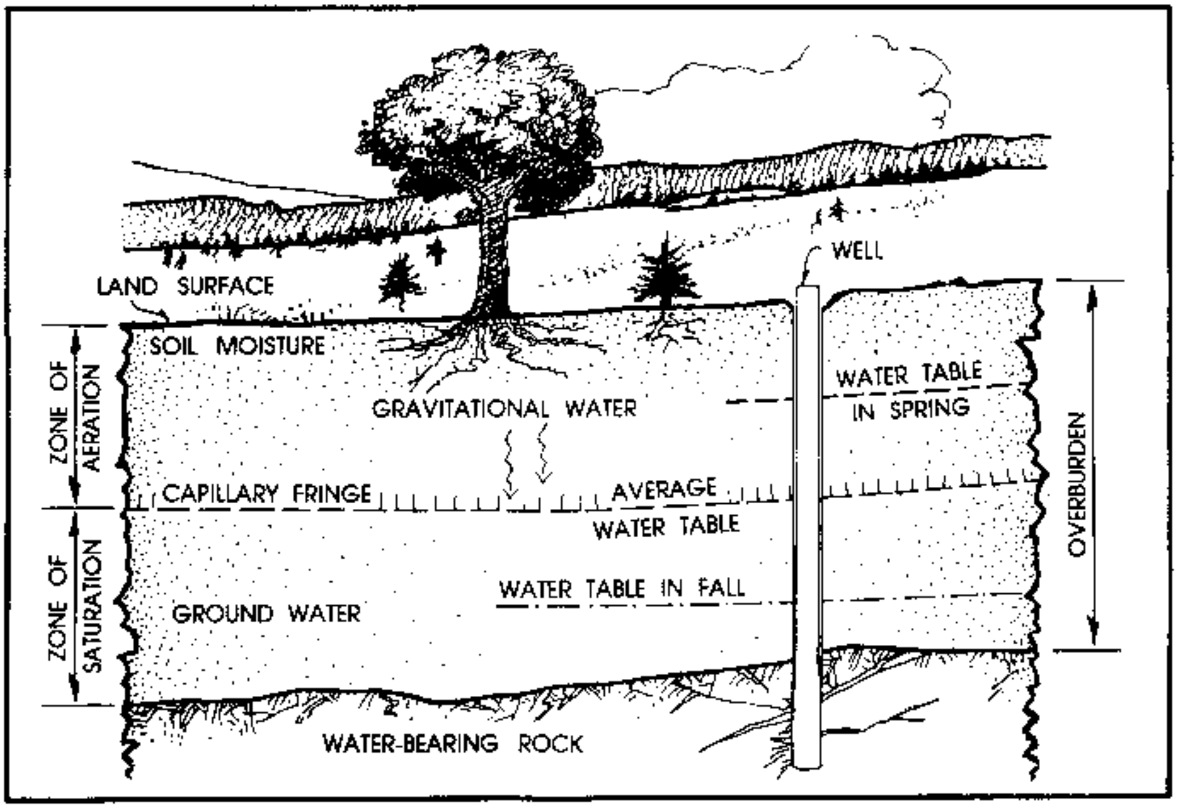
Part I

AQUIFERS AND MAINE'S GEOLOGY

A. What is an Aquifer?

An aquifer is a geologic unit capable of containing a usable amount of ground water. A significant groundwater aquifer, as defined by the Maine State Legislature (38 MRSA Chapter 3, Section 482, 4-D) as "...a porous formation of ice-contact and glacial-outwash sand and gravel or bedrock that contains significant recoverable quantities of water which is likely to provide drinking water supplies."

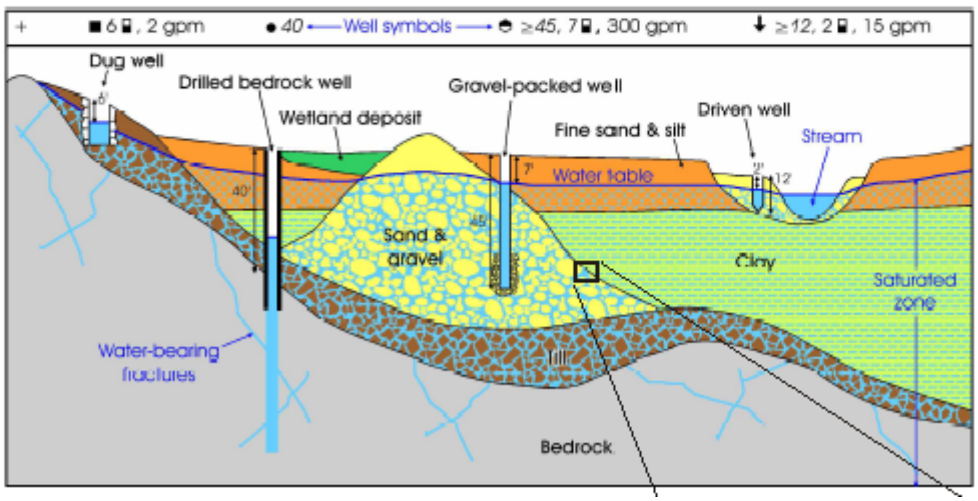


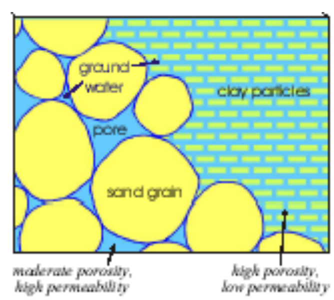
Divisions of subsurface water (*from W. B. Caswell, 1987, Ground Water Handbook for the State of Maine: Maine Geological Survey, Bulletin 39, p. 6*)

http://www.state.me.us/doc/nrimc/mgs/education/lessons/images/11.htm

In 1980 the Legislature directed the Maine Geological Survey (MGS) and the Maine Department of Environmental Protection (MDEP) to gather information on sand and gravel aquifers, including data on depth to bedrock, depth to water table, stratigraphy, and water quality (38 MRSA Chapter 3, Section 403). The law further instructed the MGS and MDEP to identify all sand and gravel aquifers capable of yielding more than 10 gallons per minute of groundwater to a properly installed well. Significant Sand and Gravel Aquifer maps are the product of that effort.

The sand and gravel deposits of Maine result from the action of glacial ice and meltwater. Following is a brief description of the glacial deposits and the processes that formed them.





Aquifer Side View and Porosity

http://mainegov-images.informe.org/doc/nrimc/mgs/pubs/series/aquifers/aq-sidebar.pdf

B. Glacial History of Maine

The blanket of surficial sediments that covers Maine comes mostly from contintental glaciers that once covered the state. Some materials were deposited directly by glacial ice; others were washed into the ocean or deposited in meltwater streams that flowed off the ice. The continental glaciers that spread across Maine also modified the preexisting topography. Hills were smoothed and elongated in the direction of ice movement, and valleys were carved then partly filled with glacial deposits.

Glaciers have probably covered Maine several times during the past 2 million years. These were continental glaciers in contrast to the much smaller valley or alpine glaciers that still exist in high mountainous regions elsewhere. During the onset of each glaciation, the annual snow accumulation in eastern Canada exceeded the amount that melted. The continued buildup of snow was accompanied by its compaction and conversion to glacial ice. The glacier attained great thickness and spread in all directions from its source area (near Hudson Bay during the most recent glaciation). The weight of the ice caused the glacier to deform and flow like a slow-moving river. It eventually reached Maine and advanced southward. During the warmer period that followed the peak of each glaciation, the ice sheet waned as melting exceeded ice accumulation. The position of the ice margin then retreated north, but the ice continued its internal forward motion as long as the glacier was active.

The last continental glacier that covered Maine advanced across the state about 20,000 years ago. It flowed south-southeast, past the present coastline and out onto the continental shelf. The thickness of the ice is uncertain, but it covered the highest mountains in Maine. Boulders of different composition than the local bedrock occur near the summit of Mt. Katahdin. Warming of the climate caused the last glacier to withdraw from the vicinity of the present Maine coast between about 13,300 and 12,700 years ago.

The weight of the glacier depressed the Earth's crust in Maine by about 790 feet. Even though sea level was lower 13,000 years ago than today (because more sea water existed as glacial ice), this depression caused the sea to flood coastal Maine to present elevations of up to 400 feet. The sea extended far into central Maine -- to Bingham in the Kennebec River valley and Millinocket in the Penobscot River valley. The location of the maximum inland encroachment of the sea is called the marine limit. As the glacier receded, the ocean remained in contact with it until the ice withdrew above the marine limit. As it withdrew, the glacier left behind the variety of surficial deposits that make up Maine's topography today, including those deposits now termed sand and gravel aquifers.

C. Glacial and Post-glacial Deposits as Aquifers

As the glacier withdrew, sediment and debris that had been incorporated in or covered the surface of the glacier were deposited. The aquifer characteristics of these surficial deposits resulted from their mode of emplacement and depositional environment.

D. Ice-contact and Glacial Stream Deposits

Most of the mapped "significant sand and gravel aquifers" occur as ice-contact or glacial stream deposits and consist of sand and gravel laid down in meltwater streams from the last glacier. Each type of deposit has a characteristic shape and distribution of materials. These deposits are classified according to their environment of formation. Ice-contact deposits form under, within, or adjacent to ice; glacial stream deposits laid down away from the ice margin are termed outwash.

Kames - Kames are mounds of sand and gravel with irregular, hummocky topography that were randomly deposited on, within, beneath, or adjacent to melting glacial ice. Depressions called kettle holes are found on some kames and mark the former locations of buried masses of stagnant glacial ice. The size of kame deposits is extremely variable. They range from less than 300 feet across to several kilometers. Their height varies from a few tens of feet to over 100 feet. Many of the largest kames are located on the sides of river valleys and may actually be segments of eskers, deltas, or fans. Kame terraces are special types of kames usually deposited between stagnant ice and a nearby valley wall. Their characteristic flat topped topography was created by meltwater streams flowing on their upper surfaces long enough to smooth the irregularities.

Kames generally contain more gravel than sand because they were built by fast-moving streams that washed away the fine-grained sediment. Such well sorted, coarse textured material transmits groundwater very readily, so kame deposits usually are excellent aquifers.

Eskers - Eskers, locally known as "horsebacks", are long sinuous ridges of gravel and sand that were deposited by glacial streams running in tunnels within or beneath stagnant ice. They are common both above and below the marine limit in Maine. Eskers are typically 30 to 100 feet high and 300 to 1,200 feet wide. They can usually be traced, with breaks, for many miles.

Eskers are very similar to kames with respect to composition and internal appearance. Gravel is more abundant than sand, and there are large piles of boulders from which the finer sediment has been sluiced away. The coarse texture of esker sediment transmits groundwater very readily, so eskers generally make excellent aquifers.

Outwash Plains - Outwash plains generally occur above the marine limit in Maine. They are large, flat, gently sloping plains composed of sand and gravel that was carried beyond the glacier margin by meltwater streams. They commonly occupy parts of river valleys, where they stand at higher elevations than modern flood plains and river terraces.

Outwash plains are composed of sand and gravel in varying proportions. Outwash typically consists of alternating beds of different, but well sorted, particle sizes. Such sediment transmits groundwater fairly readily, so outwash plains generally make good aquifers.

E. Glacial-Marine and Glacial-Lake Deposits

Deltas and Subaqueous Outwash - Deltas formed where glacial streams emptied into a lake or the ocean. Most of the deltas in Maine were built to elevations that mark the marine limit, but a few are at lower elevations. The tops of deltas are flat and gently sloping, while their backs commonly have steep slopes that were in contact with glacial ice. Delta tops may also exhibit the abandoned channels of the streams that used to flow across them. Eskers or kames connect with the back sides of many deltas and indicate the positions of feeder channels. In association with deltas are deposits of sand and gravel which were laid down as meltwater streams from the ice entered under the water. This material is called subaqueous outwash and is usually found as moraines and fans. A fan is basically a delta that never reached the water surface. A moraine is a ridge of till formed at the toe of the ice margin.

Glacial-marine deltas and fans in Maine contain very large deposits of sand and gravel. Most are at least 40 to 60 feet high and they may cover several square miles. Most of the gravel in a delta is found in the topset beds (top of the delta). Foreset beds (below the topset beds) usually consist of sand or gravelly sand. The beds near the bottom of the delta (bottomset beds) are composed of fine sand and silt.

Although the sediment composing a delta is finer grained than that of kames or eskers, it is usually well sorted. Such sediment transmits groundwater fairly readily, so deltas generally make good aquifers.

Fine-Grained Deposits - Meltwater streams and currents from the last glacier carried large quantities of silt and clay in suspension. This material washed into the ocean or into glacial lakes, where it settled to the bottom. The subsequent emergence of the coast has exposed extensive deposits of glacial-marine sediment in coastal Maine extending far inland along the Kennebec and Penobscot River valleys. These glacial-marine sediments form a blanket over till and glacial stream deposits. Glacial marine deposits may be massive or show distinct bedding. Interbedded silt and fine sand layers are common. The surface of these deposits may be quite sandy or pebbly, the fine material having been removed by wind or water currents.

Glacial-marine deposits generally make poor aquifers because they are so fine-grained. However, areas with significant amounts of sand or areas that have been reworked by wind or water action may supply sufficient groundwater for domestic purposes.

F. Glacial Till

Most of the areas mapped as "surficial deposits with less favorable aquifer characteristics" are covered by glacial till. Till is deposited directly from glacial ice. It is the oldest and most widespread surficial material in Maine. It occurs both above and below the marine limit. Till generally overlies bedrock, but there are areas where it overlies sediments that were deposited by glacial meltwater. Till is a random mixture of sand, silt, clay, and stones and rarely exhibits pronounced stratification. Sand is the dominant grain size in most Maine tills although silt and clay size particles may dominate where the source rock for the till is fine grained sedimentary or micaceous metamorphic rocks.

Two major types of till occur in Maine - basal till and ablation till. Basal till, also called hardpan, was laid down at the base of a glacier. It is fine grained, compact and difficult to excavate. It generally contains more silt and clay and fewer stones than ablation till.

Ablation till or melt-out till was deposited by the settling out of sediment from melting glacial ice. It is sandy, loose, and easily excavated. Most ablation till is very stony and contains large boulders, and may grade into sand and gravel due to meltwater sorting the till.

Till is generally a poor aquifer. However, large diameter dug wells in till do supply sufficient quantities of water for domestic purposes, particularly where the till is especially sandy, but yields exceeding 10 gpm are usually not available from till.

G. Post-Glacial Stream Deposits

Since glacial ice receded from Maine, streams have been reworking glacially deposited surficial material. Stream alluvium is water- deposited sediment found on flood plains and terraces along modern rivers. Surface exposures on flood plains indicate that they are composed of fine-grained material, mostly silt to fine sand. Coarse-grained sediment is found in the stream channels themselves and along the floodplains of youthful, upland streams. Stream-terrace deposits generally consist of sand and gravel. Many stream terraces were probably formed by the erosion and redeposition of coarse glacial-stream sediments.

Coarse-grained stream alluvium transmits groundwater fairly readily and may locally be an important aquifer. The fine-grained floodplain deposits do not transmit water as readily and usually make poor aquifers.

H. How are Aquifers Mapped?

Mapping sand and gravel aquifers requires gathering as much information about the sand and gravel deposits and their water-bearing characteristics as possible, and interpreting that data with respect to how well the deposits will yield water to a well. These data include collection of any existing information, surficial geologic mapping, seismic refraction studies, and installation of observation-wells and test borings.

A great deal of information about an aquifer may already be available. Water-company exploration data, consultant reports for major construction projects, Department of Transportation records, domestic well-drillers records, town well inventories done in conjunction with comprehensive planning, observation wells installed at contamination sites, previously published maps, gravel-pit owners records, even foundation holes and septic system construction, all provide valuable information. Where there are gaps in the data, door-to-door well inventory is conducted.

Geologists visit gravel pits, stream banks, road cuts and other exposures to describe materials and identify deposits. This information, together with aerial photography and previously published maps, allows the geologist to characterize and define the boundaries of favorable surficial deposits.

The boundaries of favorable surficial deposits do not necessarily coincide with the aquifer boundaries. In some areas, a thin cover of favorable coarse-grained material may overlie fine-grained sediments, till or bedrock. If the thickness of the coarse-grained material below the water table does not exceed 10 feet, a well in that material would not be able to sustain a yield of 10 gpm, so the area would not be mapped as aquifer. In other areas, fine-grained sediments or till may overlie favorable coarse-grained sediments and the deposit may not be recognized as aquifer.

Seismic-refraction studies are conducted to determine the saturated thickness of a deposit by establishing the depth to water table and bedrock surface. Single-channel seismic surveys using sledgehammer blows as a sound source are used where depth to bedrock is expected to be less than 75 feet. For areas which have deeper deposits, greater than 75 feet to bedrock, multi-channel seismic surveys using explosives as a sound source, with the greater energy source and more sensitive equipment, are used. The multi-channel seismic survey has the additional advantage of providing the topography of the bedrock surface at a site.

Installation of monitoring wells and drilling of test borings provides direct information about a deposit's aquifer characteristics. The exact depth of the water table and bedrock surface can be measured. Sediment samples collected during drilling provide precise stratigraphy. These sediment samples can be analyzed to determine how easily they transmit water. This allows an estimate of how much water a well in that material would yield. Additionally, monitoring wells allow samples of ground water to be collected and analyzed for water quality and enable fluctuations in water levels in the aquifer to be measured.

The data from these investigations are then put on one map. A geologist familiar with the area is then able to delineate the boundaries of an aquifer.

Explanations and definitions taken directly from the GEOLOGY FACT SHEET

[MGS (*MAINE GEOLOGIC SURVEY)* *http://www.state.me.us/doc/nrimc/mgs/mgs.htm*]
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For further activities: *http://www.state.me.us/doc/nrimc/mgs/education/lessons/act11.htm*

BEDROCK GEOLOGY OF NEW HAMPSHIRE

New Hampshire was once covered by an inland sea. Over time, sand, silt, and mud-lime was deposited on the sea bottom. This sediment was gradually buried, pressed together, or compacted, and forced together into sedimentary rock layers. These rocks are made from other rocks, plants and animals. When pressure squeezes water from the particles, the particles are clumped together forming the sedimentary rocks.

Plate movement below the earth's surface is constantly moving. The internal pressure below the the inland sea caused the land to rise. The inland sea began to moved back, as the land was pushed up. The sedimentary rocks, which were at the bottom of the sea, were forced up into mountain-like folds (folded mountains), as the earth's surface is squeezed together.

The pushing and squeezing of the sedimentary rock created layers of metamorphic rock formations. Metamorphic rocks were either igneous or sedimentary that have changed in appearance through pressure and heat. The White Mountains are these type of rock.

At the same time, volcanic action, from thousands of feet below the earth's surface, caused the molten rock to push upward into the cracks in the crust. This volcanic action caused the formation of our granite rocks, which are igneous rocks. This rock has become solid, from the molten stage, either inside the earth or on the surface.

After the land surface stopped changing and erupting, the land began to collect soil. Plant succession began to take place. The natural process of weathering and erosion began to occur. The granite, beneath the topsoil, was exposed.

About 1 million years ago, the climate of the earth was going through a cooling period. Mountain glaciers were forming in the White Mountain snowfields. The snowfields never melted, because the temperatures were too cold. More snow packed together, which slowly became "rivers" of slow-moving ice called glaciers.

In far northern Canada, large masses of ice were also forming. These were known as continental ice sheets. The Wisconsin Glacial Stage, 50,000 years ago, moved down from Canada and covered New Hampshire's landscape. This Continental glacier carried rocks and soil within the ice. Every time the glacier melted it dropped dirt, small rocks, and boulders. Geologists think that the glacier expanded and retreated four times before melting 12,000 to15,000 years ago.

Source:
http://www.govwentworth.k12.nh.us/goals2000-4WebSite/geo/geology/nhbeginning.html

BEDROCK GEOLOGY OF NEW YORK

The crust of the earth is solid rock, tens of kilometers thick, made up of individual rock bodies that vary in size, shape, orientation, composition, color, and texture. Together they make up the bedrock, which is present everywhere, although commonly masked by surficial deposits.

The bedrock geologic map gives a vertical view of the pattern made by the eroded edges and surfaces of the rock bodies that crop out in the State. It is, however, only a two-dimensional view of three-dimensional rock bodies. The cross sections below the map show samples of the third dimension as inferred from the surface configuration of rock bodies and other information that may be available from drill holes or geophysical measurements.

Map patterns result from the intersection of topography and individual rock bodies. Most rock bodies are originally tabular and horizontal, but deformation changes their orientation and shape by tilting, folding, crumpling, and breaking. Map patterns can tell us much about the three-dimensional configuration of bedrock in different regions. For example, the rock bodies in western New York are layers of sedimentary rock, of greatly different thicknesses, that are tilted down to the south less than 1 degree. The broad bands on the map in that area are the patterns made by stacked layers that have been beveled at a low angle by erosion. (Visualize a layer cake sliced at a low angle instead of the usual vertical.) Widths of outcrop bands are controlled by the thicknesses of individual map units, the topography, and the low dip. Stream valleys account for the jagged details in the pattern. Steeply dipping faults are omitted from the geologic map except where they separate rock bodies of greatly different ages. This avoids unnecessary congestion on the map, especially within the Adirondacks where such faults abound.

In the Adirondack Mountains the map pattern shows once-tabular rock bodies now swept into broad folds. This deformed-rock pattern is typical of highly metamorphosed "basement" rock. One can easily visualize this rock pattern continuing in the basement as it passes beneath the blanket of sedimentary strata that surrounds the Adirondacks. The pattern of small blocks along the eastern border of the Adirondacks results from faulting that dropped crustal blocks down into a giant staircase.

The Taconic Mountains east of the Hudson River Valley are huge slices of crust that were thrust into that area from the east. The heavy toothed lines show the edges of these thrust sheets. The earth's crust in this region was "telescoped" when a volcanic island arc collided with the edge of the continent, causing the Taconian orogeny. This collision compressed the layered rock and sediment of the intervening sea, thrusting them westward onto the continent as huge, stacked -slices. The slices, which generally dipped east in a shingled arrangement, were contorted considerably in the process. When completed, the stack extended from New England past the western edge of the Hudson Valley. In the Catskill Mountains, the western edge of this transported rock remains buried beneath Devonian rock. Erosion has reduced the original thrust sheets to patches, creating windows to the rock beneath.

The legend on the facing page shows the formations and rock types in each map unit. The legend has two major parts based on divisions of geologic time, Proterozoic and Paleozoic-Mesozoic. Highly deformed Proterozoic rock bodies of the basement are buried beneath younger Paleozoic rock in most of the State, but crop out in the Adirondacks and the Hudson Highlands. Southeast of the Highlands, basement relationships become more complex as one approaches the deformed and metamorphosed root zone of the ancestral Appalachian Mountains (see cross section FGH beneath the geologic map). The Paleozoic-Mesozoic part of the legend applies to the wide expanse of sedimentary rock formations that blanket the State west of the Hudson River and south of the Adirondacks. The blank areas with yellow tint represent gaps in the rock record-geologic times not recorded by rock because of erosion or non-deposition.

Surficial material is ignored on generalized bedrock geologic maps, but it is shown here in several areas of the Adirondacks and over all of Long Island, where is it so thick that it masks all clues to the bedrock geology.

SURFICIAL GEOLOGY OF NEW YORK

Bedrock generally is covered by a skin of soil and other loose material, especially in regions with humid climates. This cover material results as weathering breaks down the surface rock. The loose materials may remain in place or be eroded, transported, and deposited by water, wind, or glacial ice. In 90 percent of New York State, bedrock is buried by surficial deposits that are more than one meter thick. Most of these deposits were left by a continental glacier-an ice sheet that was perhaps 2 km thick.

Till is the most abundant glacial deposit. It is an unsorted mixture of mud, sand, gravel, cobbles, and boulders that the glacier spread over the countryside. Till can be up to 50 meters thick. It is generally thickest in valleys and thinnest over highlands. *Moraines* are elongate ridges or strings of hills that formed at the edge of the glacier and are composed of sand, gravel, or till. The Ronkonkoma and Harbor Hill moraines on Long Island dominate that landscape. The Valley Heads moraine dams the south ends of the Finger Lakes. *Glacial lake beds* are broad ontal layers of mud (deep water) and sand (shore zone) that were deposited in that formed in front of the glacier as the ice melted. *Outwash* is sand and gravel deposited by meltwater streams that flowed from the front of the glacier. these kinds of deposits have a wide range of thicknesses. In places, they be piled one on top of the other.

http://gretchen.geo.rpi.edu/roecker/nys/nys_edu.pamphlet.html

SURFICIAL GEOLOGY OF RHODE ISLAND

Like the rest of New England, Rhode Island is largely covered by sand and gravel dating from the latest ice age. Bedrock crops out in small scattered occurrences, or in roadcuts and building foundations and mines. This map ignores the surface coating for the living rock beneath, except for a small area on the coast and on Block Island to the south, in Long Island Sound.

The whole state lies in the Avalon terrane, a block of crustal rocks that once lay off the North American continent in Late Proterozoic time more than 550 million years ago. Two chunks of that terrane are separated by a major shear zone running down the west edge of the state. The Hope Valley subterrane is on the west (in light brown) and the Esmond-Dedham subterrane is on the right covering the rest of the state. It in turn is broken in two by the light-toned Narragansett basin.

These subterranes have been intruded by granites and other igneous rocks in two main orogenies, or mountain-building episodes. The first was the Avalonian orogeny in the Late Proterozoic, and the second includes the Alleghenian orogeny, from the Devonian through the Permian Periods (about 400 to 290 million years ago). The heat and forces of those orogenies left most of the state's rocks metamorphosed. The colored lines in the Narragansett basin are contours of metamorphic grade where this can be mapped.

The Narragansett basin formed during this second orogeny and is filled with largely sedimentary rocks, now metamorphosed. Here is where Rhode Island's few fossils and coal beds are found. The green strip on the south shore represents a later Permian intrusion of granites near the end of the Alleghenian orogeny. The next 250 million years are years of erosion and uplift, exposing the deeply buried layers that now lie on the surface.

http://geology.about.com/library/bl/maps/blrhodeislandmap.htm

SURFICIAL GEOLOGY OF VERMONT

The full explanation of Vermont geology can be downloaded at:
http://www.anr.state.vt.us/DEC/geo/vtgeoindex.htm

The Geology of Vermont by Barry L. Doolan (7.4 mb pdf)
published by Heldref Publications in 1996 in Rocks and Minerals Magazine, Vol. 71, No. 4.

SURFICIAL GEOLOGY OF MASSACHUSETTS:
Cape Cod Region

The principal aquifers on the Cape and Islands are moraines and outwash deposits, which derive their water from local precipitation. The broad outwash plains are mainly composed of sand and gravel, which, in places, is mixed with till and ice-contact deposits, silt, and clay. Yields for 24-in.-diameter wells in outwash deposits generally range from about 200 to 700 gal/min. However, yields of 1,000 to 2,000 gal/min have been reported for some wells on Cape Cod, Martha's Vineyard, and Nantucket. In general, supplies of water for homes, cooling, and small businesses can be developed in most areas of outwash on the Cape and Islands from wells that are 1.5 to 2 in. in diameter with 3 ft of screen set about 10 ft below the water table.

Ground-water flow systems can be identified in areas of outwash on the Cape and Islands from the configuration of the water table. On Cape Cod, bays and streams divide the ground-water system into six areas or cells, each of which has a water-table mound (Guswa and LeBlanc, 1985). The altitude of the water table generally is highest, (about 5 to 60 ft above sea level) near the center of each cell and lowest (0 ft at sea level) near the coast. Ground water flows in the direction of the greatest hydraulic gradient, which is from the center of the mounds to the ocean. Locally, flow can be towards ponds, swamps, or streams. Under natural conditions, the six cells are hydraulically independent of one another. The steady-state flow through the total Cape Cod aquifer system, as estimated from computer-model analyses (Guswa and LeBlanc, 1985), is about 270 Mgal/d. On Martha's Vineyard, the ground water flows mainly in one cell, which has a water-table mound that reaches an altitude of 18 to 19 ft above sea level near the center of the island. Several smaller cells are located in Edgartown and on Chappaquiddick Island. On Nantucket, the water table forms several low mounds, the largest of which reaches an altitude of 12 to 14 ft above sea level halfway between Nantucket Harbor and Siasconset.

The moraines are composed of both poorly- and well-sorted sand, silt, and clay that were transported in the glacial ice and left behind when the ice retreated. The textural composition of moraines generally varies more over short distances than does the textural composition of outwash deposits. The Gay Head moraine on Martha's Vineyard consists largely of clay and silt with some sand and lignite. Because the textural variability causes permeability variability and because the unsaturated zone is greater in the moraines than the outwash plains, exploration for water supplies has been discouraged in the moraines. Yields of 2,000 gal/min are obtained from 24-in.-diameter gravel-packed wells in the most permeable zones of the moraine in Barnstable. However, wells drilled in nearby areas have penetrated thick layers of silt and clay and are reported to have been unproductive (Guswa and LeBlanc, 1985, p. 3-4).

In addition to the outwash and moraine deposits, deeper and older preglacial sand and silt are present on Martha's Vineyard and Nantucket. However, these deposits would probably yield less than 100 gal/min and could yield water with elevated iron and (or) chloride concentrations. Bedrock beneath unconsolidated deposits on Cape Cod and the Islands consists of metamorphic rocks, such as schist and gneiss, and igneous rocks, the surface of which generally slopes southeastward from about sea level on the northwestern shore of Buzzard's Bay to as much as 1,600 ft below sea level at Nantucket (Oldale, 1969). The depth to bedrock beneath glacial sediments on Cape Cod ranges from about 80 to 900 ft below sea level. Bedrock is much less permeable than the overlying sediments, commonly contains seawater, and is not considered to be part of the aquifers of Cape Cod or the Islands.

http://ma.water.usgs.gov/basins/capecodgw.htm

SURFICIAL GEOLOGY OF CONNECTICUT:

Surficial Geology from the Hudson Valley to the Massachusetts Coast
Stephen C. Daukas

http://www.pdfdownload.org/pdf2html/pdf2html.php?url=http%3A%2F%2Fwww.worcestermineralclub.org%2Farticle15.pdf&images=yes

This first in a series of articles on the landforms and tectonics of New England and New York,
by member Steve Daukas, begins with a closer look at the Connecticut River Valley. We start
with a broad overview of the forces that combined to form the topography of the region, the
geomorphology of the Connecticut Valley, its relationship to Glacial Lake Hitchcock, and the
evolution of the Connecticut River's course and drainage patterns from the Pleistocene through the Holocene.

Connecticut River Valley & Glacial Lake Hitchcock

The Connecticut River Valley is a prominent feature of the Massachusetts landscape. The "valley", as it is known to those who live there, was a good place to farm and locate industry
because of good soils and access to markets via the Connecticut River. Those who live in the
valley are familiar with the river's banks and coves, as well as the annual spring flooding along the flood plane. This is also the location of Glacial Lake Hitchcock, a lake formed by ice melting during the Pleistocene that occupied the valley prior to the present-day river.

One of the best ways to see the Massachusetts part of the Connecticut Valley is from the top of Mt. Tom, a 2000+ acre State Reservation with amazing views, or from the top of

Mt. Holyoke from the porch of the Summit House providing exceptional views of the CT River and the Pioneer Valley. The now famous *Oxbow Lake* was painted from atop Mt. Holyoke by Thomas Cole in 1836.

Introduction

Central New England in general, and the Connecticut Valley in particular, represents an area
both familiar and unknown to many of its tourists and inhabitants alike. The familiar include
well-known views, indeed some famous, from the area's summits, and many of the town centers and local farms do, in fact, appear on post cards and calendars. Tourists triple their numbers during fall's colorful display and apple-picking season, and everyone enjoys the fairs, festivals, and parades throughout the year. What isn't known to many is the region's relationship to ancient events - continental collisions, mountain building, volcanoes, the creation of a new ocean, and the weathering away of much of the evidence - that is often met with fascination and disbelief once brought to light. Even those who visit the several dinosaur parks in the valley are not fully aware of the opportunity for learning of Earth's history that the valley represents.

<u>Events Leading to the Pleistocene</u>

Central New England & Massachusetts

The Connecticut River Valley occupies a lowland area (ancient syncline - graben) located between two higher elevations (ancient anticlines - horsts); the Berkshire Highlands (to the west) and the Bronson Hill Upland, also known as the Worcester Plateau (to the East). This valley is in the center of a larger region, extending from eastern New York State eastward to the Atlantic Ocean, formed where the supercontinents Laurentia and Gondwana began their collision during the final formation of Pangaea, about 417 million years ago. Crystalline basement rocks were formed during the late Devonian through the Carboniferous with etamorphic activity continuing into the early Permian and are the eroded remains of the late Silurian's and early Devonian's Acadian Orogony, a mountain building event whose peaks were once as imposing as the Alps are today.

The formation of Pangaea involved several terranes at the margins of both Gondwana and Laurentia (separated by the closing Iapetus Ocean) that formed as early as 550 millions years ago after the break up of Rodinia, the previous supercontinent. These terranes started to become sutured to the continent during the earlier Taconic Orogony of the Ordovician. The Bronson Hill Upland (or Worcester Plateau) is one of the Laurentain terranes that began as a volcanic island arc. Other volcanic and plutonic terranes begun in the Ordovician include those thought to be of Gondwanan origin: the Meguma (SE portion of Cape Cod), the Avalon (SE MA inclusive of Boston), the Nashoba (a thin wedge trending SW to NE east of Worcester) and the Merrimack (Worcester west to the Bronson Hill volcanic belt). The makeup of the general area is actually more complex than described, with five of the six Laurentian terranes omitted, as well as all of the various belts making up these terranes.

By the end of the Permian, about 250 million years ago, the Iapetus Ocean had completely
disappeared and the final assembly of Pangaea was complete. Fifty million years later during the Jurassic (see image at left), the Connecticut Valley region was among the sites where Pangaea began rifting apart giving rise to volcanism and igneous formations that dot the area today. This newly forming basin was only part of a larger mountainous region resembling the Basin and Range region in Nevada. The Connecticut Valley Border normal fault forms the eastern boundary of this particular basin, and marks a drop of thousands of feet to the valley floor to the west (filled with thousands of feet of sediment since that time). Farther to the east, another rift valley had formed and continued to open, eventually The Continents Rift Apart During the Jurassic, 200 MYA giving birth to the Atlantic Ocean (lower left of center). The location of this new ocean left parts of the old Gondwana continent behind - the terranes mentioned above - as part of New England. Given the rather involved history of the area, the geology is quite complex and difficult to interpret.

The Connecticut Valley area is underlain by a collection of metamorphic and intrusive rocks
from the formation of Pangaea, and continental sedimentary rocks, extrusives, and intrusives
from the Mesozoic. Metamorphism is estimated to have been as deep as 25 km (15 miles). By
the late Cretaceous, the area is thought to have been eroded to a peneplain with the "ancient"
Connecticut River flowing through the basin formed during Mesozoic rifting. Many of the domes in the Connecticut Valley, such as the Shelburne Falls, Pelham, Monson, and Warwick, are eroded remains of the earlier fault-block mountains and associated volcanism.

The Pleistocene Forward

Massachusetts and the Connecticut Valley

Glacial and interglacial periods have left their mark on the general area. Deposition of sands and gravels from receding glaciers cover much of eastern Massachusetts, and till from the Illionian ice sheet (140,000 years ago) has been identified. Marine sediments were deposited during the Sangamon interglacial period, about 125,000 years ago, followed by the Wisconsinian glacial period about 80,000 years ago. Much of the topography we see today is a result of this latter ice sheet's modification of preexisting features.

Sometime between 25,000 and 15,000 years ago, the Wisconsinian ice sheet began its retreat. As the ice sheet retreated, higher elevations melted first, leaving the ice-filled valley to
become a constantly changing mix of ice, melt-water and sediment eroded from the uplands.

The Connecticut Valley - *Glacial Lake Hitchcock*

Melting glacial ice often forms proglacial lakes, lakes between the retreating glacier and natural barriers that block the meltwater's course downstream. New England had many glacial
lakes, but the largest of these was Glacial Lake Hitchcock. At its largest, the lake extended from Rocky Hill, Connecticut, northward approximately 220 miles into Vermont and reached a maximum width of 20 miles. The lake included long islands (ridges) of volcanic origin. The dam at Rocky Hill was approximately 1 mile wide, blocking the entire valley, and consisted of stratified drift deposited as coalescent deltas in a glacial lake at 135 feet above sea level. As the water flowed over the dam, a shallow outlet was incised and the lake's elevation stabilized for a short time. This channel is known as the Dividend Brook outlet. The present day Dividend Brook is located in the southern part of Rocky Hill adjacent to the Industrial Park and the Town's Fire Headquarters, and has two ponds (Upper & Lower Dividend Pond). The New Britian spillway, just west of Rock Hill, eventually took over as the outlet of the lake.

Streams draining the watershed deposited sediment into the lake from both the surrounding
highlands and the glacier itself. Deposits consist of sand and gravel (deposited at the mouths of tributaries as the streams' competence diminished) as well as finer sediment from suspended loads that settled into clay layers farther from their source. Varved clay layers record the annual freeze-thaw cycle of the glacial lake. In addition, large erratics entombed by ice calved from the retreating glacier were deposited as the ice-rafts melted.

Differing clay colors show changes in erosion sources. Reddish-brown indicate Triassic sedimentary sources while blue-gray to grey-brown indicate predominantly igneous and metamorphic sources from the uplands. The reddish-brown deposits indicate sediment coming
from the glacier that occupied the Triassic lowland. However, sediment showing colors of an
olive-brown could be attributed to a rind or cement formed from iron-rich leachate introduced
into sediment layers not originating from Triassic sources. Once the glacier retreated as far north as the Chicopee and Westfield Rivers, sediment from the igneous uplands was able to flow directly into the glacial lake forming familiar fluvial landforms.

The basins and valleys in the uplands show terraces, ridges, and knob-and-kettle topography
giving evidence of eskers, filled crevasses, kames, and other ice-contact deposits. As waters
drained off these higher elevations, they encountered ice blocks and deposits of till at lower
elevations. The drainage patterns were chaotic as numerous local base-levels were formed,
destroyed, and formed again. It was these streams that contributed large quantities of

sediment in the form of deltas that prograded into the glacial lake.

Studies of the varved clay layers throughout the valley in 1927 (by Ernst Antevs) suggested the lake existed for about 4000 years and later radiometric dating gave an age of 3,700 years. 12,700 years ago, the Rocky Hill dam failed draining the lake as far north as the Holyoke Range. 300 years after the Rocky Hill failure, the remainder of the lake drained when the sediment dam located at the Holyoke Range also failed.

The Connecticut Valley - *The Connecticut River*
Once the weight of the Wisconsinian Ice Sheet had been unloaded via melting, the northern
region of the valley rebounded. Uplift has been calculated at roughly 4.2 feet per mile (northward) based on vertical displacement of shoreline features (wave-cut benches, beaches,
topset and foreset beds, etc.) in Western Massachusetts, with similar rates calculated for the
Connecticut portion of the basin.

After the lake water had drained, the Connecticut River essentially followed the same pre-glacial course through the ancient Jurassic rift valley, incising itself some 160 feet through the former lake bottom sediments and passing through several pre-existing gaps cut across sedimentary and basement rock (consequent channels) formed as a result of uplift during the Miocene (24 million years earlier).

As a result of deltas prograding into the now drained glacial lake from tributaries such as the Deerfield and Millers River, the river's course detoured around these obstacles. In the case of the confluence of the Connecticut with Millers River at Millers Falls, MA (visible from Route 2), the Connecticut River diverted to the west towards Greenfield, then followed a path south along the western edge of Rocky Mountain (through present day Greenfield), eventually heading eastward through the Deerfield Gap to its original course. This path has also subsequently been abandoned with the river now following along the eastern side of Rocky Mountain (the western edge of the ancient delta).

The southern wall of Barton's Cove (just west of the Millers confluence) is a result of the Connecticut River cutting across a narrow ridge of Triassic sandstone and shale (the Lily Pond Barrier) forming a large fall. More than one nick point existed along this detour, some
migrating upstream while others remained stationary, leaving a series of cut terraces. Construction of the current dam across a nick point down-stream formed Barton's Cove by flooding, previous to which plunge pools were visible at the base of the ancient waterfall.

These plunge pools were called "lily ponds" and the name was adopted to describe features in the area. The Lily Pond Barrier was responsible for the formation of proglacial Lake Upham that extended northward approximately to the Canadian border until such

time as the Connecticut cut its way through weaker formations at Turners Falls thus draining the lake.
The current path of the Connecticut River is located where basal infiltration weakened that portion of the waterfall allowing a collapse where a third plunge pool was probably located.

As the Connecticut River continued to incise the ancient lake bed, it also meandered cutting (non paired) erosional terraces at ever lower elevations, eventually establishing a flood plain widening southward (less resistant rock) reaching some 3 to 4 miles in width. Erosion and deposition continues across the active flood plain today, which bears witness to regular flooding.

In the Spring of 1840, the Connecticut River was swollen and in a high flood stage. Anticipating a change in the river's course, Professor Edward Hitchcock (pioneering geologist, president of Amherst College, and for whom the glacial lake was named) led a contingent of students to the top of Mt. Holyoke where they there witnessed the river cut across a meander neck forming the *Oxbow Lake* at Northampton MA.

1936 saw similar extensive flooding in the valley allowing the Connecticut River to cover the
majority of the ancient floor of glacial Lake Hitchcock. Reports of the day indicate that Hadley, MA, located 3 miles north of the oxbow formed in 1840, was in danger of being destroyed by the river cutting through the town forming another meander cutoff. Fortunately, the flood abated and Hadley was spared. A quick view of the river's present course shows other possible locations where new cutoffs might form, including Vernon, VT, Glastonbury and Rocky Hill, CT.

Summary
As noted in the introduction, the Connecticut Valley is a scenic region that has much to offer
those who live and visit there today. With the overview of valley's long history presented above, it is easy to see that the valley has quite a bit to offer those interested in how and why the landscape got to be the way it is today. The complexities of the valley attest to its long history of involvement with all the "big stories" we have heard about - continental drift, plate tectonics, super continents, volcanoes, dinosaurs - and represent an amazing opportunity to observe evidence of those stories first-hand.

The next installment will take us to the French King bridge, along the Montague Delta, to Baton's Cover, and finally to Poets Seat tower atop Rocky Mountain a Jurassic-age volcanic
ridge overlooking Greenfield to the West and the CT River to the East.

TAKEN FROM: **Surficial Geology from the Hudson Valley to the Massachusetts Coast by Stephen C. Daukas**