Geology

Geology is the science of the composition of the earth's crust, including the study of rock structure and formation. The natural processes that shape the land--uplifting, erosion, sedimentation, and cracking--are as vigorous today as in the past. Because they affect physiography, topography, quality and quantity of groundwater, drainage patterns, mineral resources, soil content and depth to bedrock, understanding these geologic processes is essential to sound resource management.

The rock base of Dutchess County consists of younger unconsolidated materials (glacial and recent deposits) overlying older consolidated material (bedrock). A study of the county's geological history reveals how these materials were formed and what types of bedrock and glacial deposits are present today.

The geologic structure of Dutchess County is complex. Its history extends over one billion years as a continuous process that has included several periods of major mountain building, ocean invasion and retreat, and glaciation. These events are part of the dynamic evolution of the earth's crust. Externally, natural elements of weather and water continually erode the surface; internally, heat creates pressure to further change the shape of the land.

Dutchess County's geological development can be discussed in terms of four eras: Proterozoic, Paleozoic, Mesozoic, and Cenozoic. The activities and formations that occurred in the county during each of these eras are listed in the appendix.

Bedrock

The bedrock of the county is divided into five groups:

- Hudson and Housatonic Highlands gneisses and uprooted blocks of gneiss,
- Wappinger group,
- Poughquag quartzite,
- Austin Glen graywacke and shale, and
- Pelitic rocks.

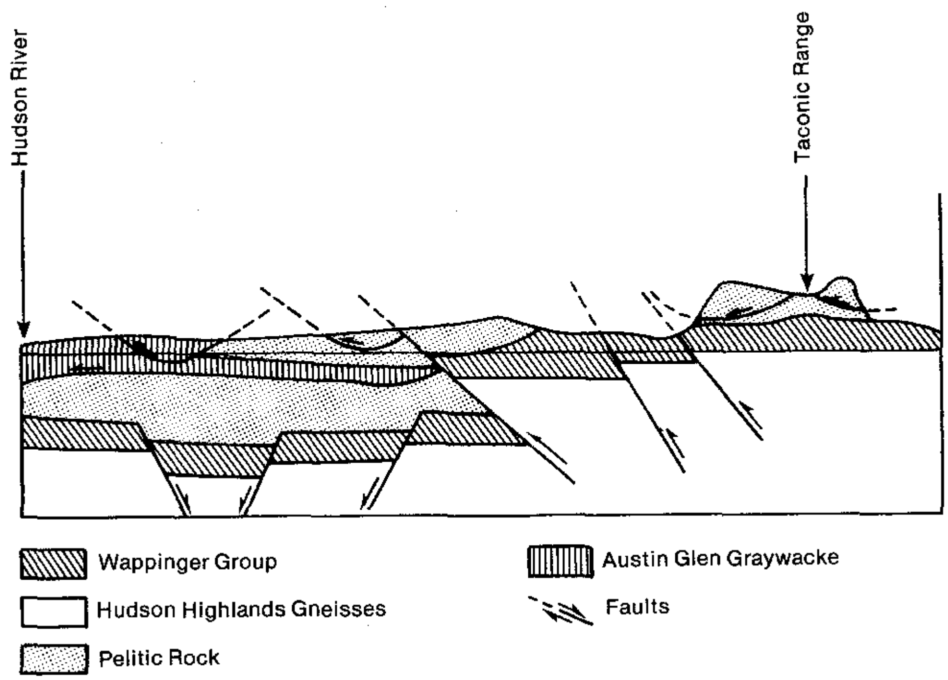
Most of the bedrock types are metamorphic or sedimentary rocks ranging in age from the Proterozoic Era (more than

1,100 million years ago) to the Ordovician Period of the Paleozoic Era (about 450 million years ago).

Metamorphic rocks are those that have been changed in texture and composition by heat, pressure, or chemically active solutions. Sedimentary rocks are stratified rocks composed of rock particles and other cementing materials deposited in water. The older Proterozoic rocks consist primarily of metamorphic rocks formed from granite, including the coarsely banded gneisses. The younger Paleozoic rocks are sedimentary and metamorphic and include quartzite, limestone, dolostone, marble, phyllite, shale, slate, and schist. Older rocks are generally found in southeastern Dutchess County, with a progression to younger rocks in the northwestern part of the county. A simplified view of bedrock in Dutchess County is shown in the Bedrock Map. The cross section diagram in Figure 2.1 illustrates how complex these bedrock patterns can actually be.

Bedrock Patterns:

Cross Section Across Northern Dutchess and Southern Columbia Counties

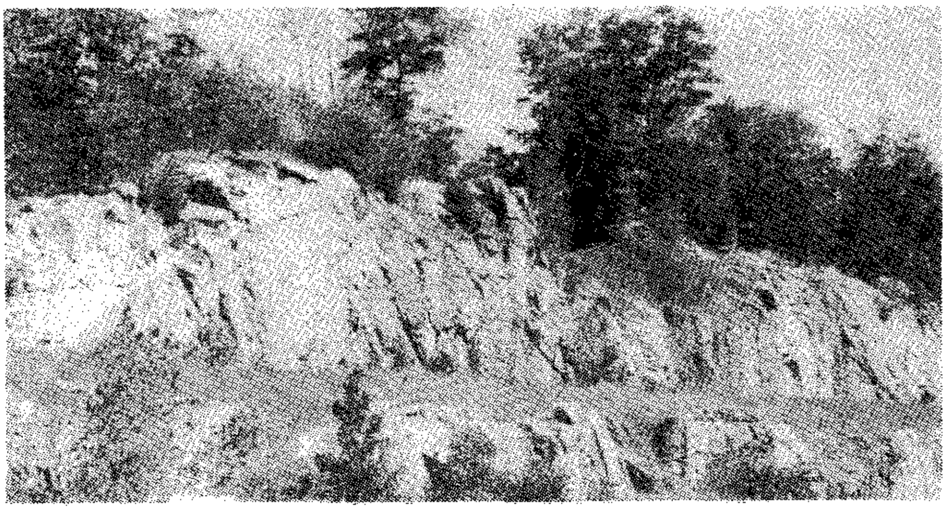


Adapted from Woodward-Clyde Consultants, 1979

Figure 2.1

Hudson and Housatonic Highlands Gneisses and Uprooted Blocks of Gneiss

The oldest rocks in Dutchess County are in the Hudson Highlands, an upland area composed primarily of various gneisses. These rocks, which were formed during



the Proterozoic era, are most common along the southern border of Dutchess County, between the Hudson River and the western border of the town of Pawling. The second largest occurrence of these rocks underlies a group of prominent hills, the Housatonic Highlands, east of Dover Plains. Isolated, uprooted blocks of gneiss crop out at Todd Hill in the town of LaGrange, Corbin Hill north of the village of Pawling, Stissing Mountain in the town of Pine Plains, and in a series of small fault slivers between the city of Beacon and the town of Fishkill. The orientation of this bedrock is northeast to southwest.

Most of the gneiss consists of light and dark colored minerals arranged in layers with a banded, streaky, or speckled appearance. Gneisses containing light colored minerals such as quartz, feldspar, and white mica or muscovite predominate. Various types of gneisses containing dark minerals such as hornblende, garnet, and black mica or biotite also occur.

Extensive outcrops of gneiss are generally more resistant to weathering than younger Paleozoic rocks. Gneiss outcrop areas are usually part of more rugged terrain and exist at higher elevations. Granite gneiss, which occurs at North Beacon Mountain, is the most durable of these types and is sometimes quarried for crushed stone and building stone. The weaker gneisses form the lower hills and tributary valleys to the Hudson River. They follow crushed areas along faults or softer carbonate belts. The yield of drilled wells tapping gneiss is usually small, averaging about 11 gallons per minute of soft water.

Poughquag Quartzite

A compact, hard quartzite with a quartz content greater than 90 percent occurs in a few areas in Dutchess

County. Poughquag quartzite rests on Proterozoic gneisses and form the flanks of the Hudson and Housatonic Highland and Stissing Mountain. Wells tapping this formation produce only a small amount of water, averaging 10 gallons per minute.

Wappinger Group

The Wappinger group, an elongated mass of carbonate rocks, occurs along the Wappinger Creek for which it was named. It also appears beneath the Fishkill Creek valley north of and adjacent to the Hudson Highlands, beneath the Harlem Valley along the Tenmile River and its tributaries, and in the north central parts of Dutchess County.

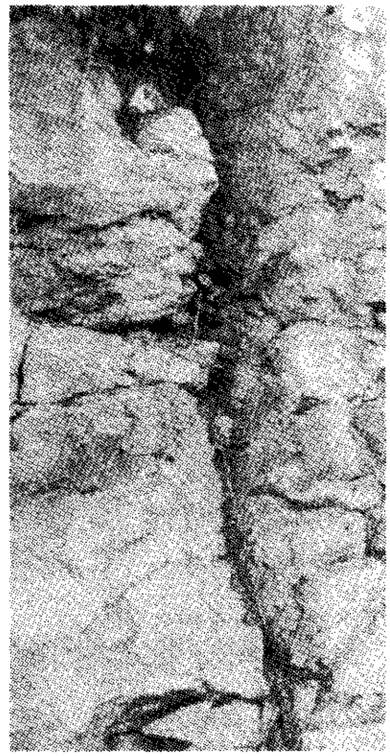
The carbonate rocks range from almost pure calcium carbonate (calcite) to almost pure calcium magnesium carbonate (dolomite) and include:

- Copake limestone,
- Rochdale limestone,
- Halcyon Lake calc-dolostone,
- Briarcliff dolostone,
- Pine Plains dolostone,
- Stissing dolostone, and
- Stockbridge limestone.

The chemical content of the Wappinger group and associated unconsolidated deposits is well suited to agriculture. The lime component also has economic value as crushed stone or agricultural limestone. One of the largest quarries in New York State is located south of Poughkeepsie at Clinton Point. The dolostone in this quarry has an average magnesium carbonate content of 38.16 percent. Stones of all sizes are produced, ranging from large rock fragments (riprap) and aggregate sizes used in construction, to stone sand used for fill and masonry work. The Wappinger group is also mined in the towns of Pleasant Valley, near the Wappinger Creek, and Dover, in the Lake Ellis area. The Lake Ellis bedrock has a high magnesium content that makes it valuable for agricultural uses. These economically important limestones and dolostones were mostly formed from direct precipitation of calcium and magnesium carbonate in sea water.

The metamorphism of the Wappinger group generally increases in intensity from the northwest to the southeast.

In the town of Milan and the valley of the Wappinger Creek, the original bedding is readily visible because the area is relatively undisturbed. Farther east, in the Harlem Valley, the formation has been metamorphosed into marble and the beds are severely folded. The marble in the southeastern part of the county has been deformed several times by plastic flow so that it appears to be wrapped around stronger rocks. South of Pawling, masses of schist have been folded and vaulted into the carbonate, appearing as inclusions.



It is difficult to determine the exact thickness of the carbonate rocks because of the amount of deformation and metamorphism that has occurred. These rocks are believed to be approximately 1,000 feet thick in most places in the county. A thickness of 2,800 feet has been measured in the north-central part of the County, near Stissing Mountain.

The Wappinger group is often overlain by a thin layers of Balmville limestone and conglomerate, particularly in the Harlem Valley and at Rochdale in the town of Poughkeepsie. The Balmville layer is known for its fossils.

Rocks in the Wappinger group weather readily and are commonly found deposited in valleys and lowland areas. Internal erosion occurs within this formation as the movement of groundwater dissolves the carbonate deposits. Solution channels and voids are consequently formed, providing storage cavities for groundwater supplies. This stored water can easily be polluted by contamination sources, such as septic tanks, where there are not enough unconsolidated deposits on top of the carbonate bedrock to filter the waste materials. Although cave-ins sometimes occur in carbonate rocks, they are rare in Dutchess County. Wells in the Wappinger group average 22 gallons per minute and the water is hard.

Austin Glen Graywacke and Shale

The Austin Glen formation was deposited on an ancient, unstable continental shelf. Few fossils can be found in the formation because its original environment was not hospitable to living things. It is a poorly sorted rock type that displays many of the features of a rapidly deposited sediment, including ripple marks and cross bedding. Geologists theorize that the material was originally deposited 60 miles to the east and carried westward during a period of rapid uplifting known as the Livingston Gravity Slide. The formation consists of thin- to medium-bedded, coarse, dark gray sandstone, or fine-grained conglomerate composed of firmly-cemented, rounded fragments.

Austin Glen graywacke and shale are found in a wide band along the Hudson River from Poughkeepsie to Columbia County, in the towns of Wappinger, Fishkill, and LaGrange, along the uplands between the Wappinger and Sprout Creeks, and along an arm extending from Poughkeepsie into the towns of Clinton and Milan. Wells in this formation produce approximately 16 gallons per minute of moderately hard water.

Pelitic Rocks

The most extensive bedrock formations in Dutchess County are included among the pelitic rocks. These formations are listed below, from oldest to youngest:

- Everett schist, quartzite;
- Elizaville argillite, quartzite;
- Nassau shale, quartzite;
- Germantown shale, limestone, congolomerate;
- Stuyvesant Falls shale, quartzite, chert;
- Indian River and Mount Merino shales and cherts;
- Snake Hill shale with areas of Poughkeepsie melange; and,
- Snake Hill shale with Walloomsac slate.

All of the pelitic units have low porosity and low permeability. They extend from the Hudson River to the Connecticut state line, with metamorphism--from shales to slates to phyllites to schists--increasing in intensity from the northwest to the southeast. Phyllite is chiefly found between the headwaters of the Fishkill Creek and the Wappinger Creek valley. A garnet-bearing schist predominates between the Fishkill Creek and the Harlem Valley farther to the southeast. Gneissic schist is found east of Pawling. Only a few relatively narrow limestone belts are intermixed with these formations. Glacial deposits of till and outwash cover the surfaces of the various units.

The mineral composition and structure of these bedrock units also change from the northwest to the southeast. Quartz and mica are found chiefly in the northwest and central parts of Dutchess County. Feldspar is an additional component in the southeast. Bedding plane openings that serve as channels for the storage and movement of groundwater are apparent between the Fishkill Creek and the Wappinger Creek valley. Also between the two creeks, slaty cleavage has resulted in numerous small, closely-spaced parallel joints within the rock. Such cleavage is absent and the rocks are more massive in the southeastern part of the county. The shales and clays north of the city of Beacon have been used in the past to make bricks. Few of the other materials from the formations are used commercially, except locally as fill. Pelitic rocks produce an average of 16 gallons per minute of soft water.

Geologic Faults

Faults are fractures in the earth's crust, often accompanied by movement of one side of the fracture relative to the other. They form a tight network covering the entire county and are often identifiable directly from ground-level topography or high-level aerial photographs.

As depicted in the Geologic Faults Map, fault lines generally run in a northeast to southwest direction, roughly parallel to the grain of the bedrock structures imposed on the region by the geologic deformation of the Paleozoic Era. A weaker trend towards the northwest is also evident, but fault lines favoring this direction tend to be short. Significant concentrations are found along a line running between Beacon and Pine Plains. A similar line of faults exists between Pawling and the northeast corner of Amenia.

Over 300 faults have been identified on NASA Skylab satellite photographs of the county. They range in length from a few hundred feet to many miles. Most are thrust faults formed where the earth is compressed or pushing together. Normal faults, where the earth's surface is pulling apart, predominate in the southern part of the county. Both types of faults are illustrated in Figure 2.2.

Types of Faults

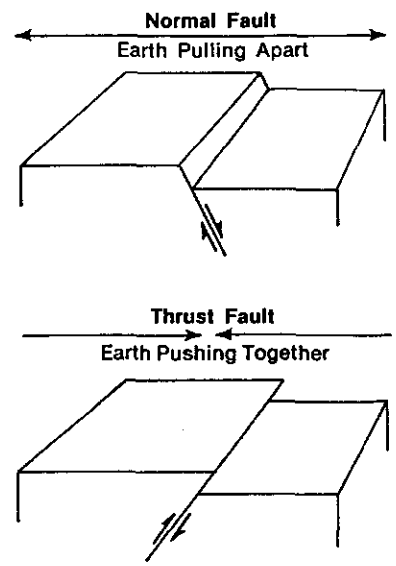


Figure 2.2

The quantity of groundwater found along these fault lines is difficult to determine due to a lack of field information. In general, however, the fracturing and crushing that occurs along fault lines forms channels that can carry large volumes of groundwater.

Glacial and Recent Sediment Deposits

During the last Pleistocene Glaciation, which occurred from 20 to 10 thousand years ago, Dutchess County was covered by a thick blanket of ice that stretched southward to the present site of New York City. Topographic variations resulted in local southeasterly and southwesterly advances, but on the whole, the glaciers moved in a southerly direction. During the course of their advances, the glaciers picked up soil and rock, smoothed down weak bedrock, abraded and polished hard bedrock and, at the same time, left widespread areas of thick sediments. Pre-existing valleys such as the Hudson were widened and deepened, while others were completely filled with these sediments.

Approximately 15 thousand years ago the melting of the glaciers accelerated and the ice blanket began to break up. In the process, layers of till consisting of clay, sand, pebbles, and boulders were left covering much of the bedrock. In some of the lowland areas south of the receding glaciers, clay deposits were formed in temporary meltwater lakes. As the ice continued its retreat and the weight of the great ice masses lessened, the land to the north began to rise an average of 2.25 feet per mile. This uplifting helped to renew and reshape the drainage pattern, and it brought about the further deposition of sands and gravels in low-lying areas.

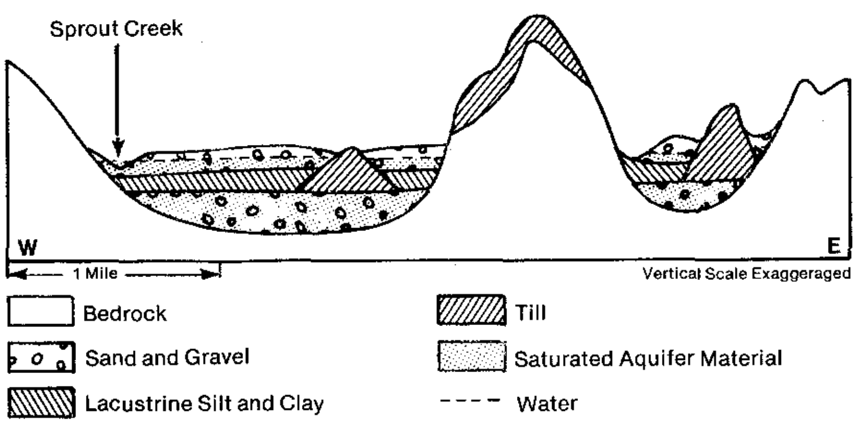
As indicated by the Glacial Deposits Map, unconsolidated material deposited by glaciers and glacial meltwater still overlies much of the bedrock in Dutchess County. These deposits are widespread and relatively thick in lowland areas. They are divided into three types:

- till, consisting of a heterogeneous mixture of poorly-sorted rock materials deposited directly by the glaciers, often having a high clay content;

- lacustrine deposits, consisting of silt and clay laid down in glacial lakes; and

Surficial Deposits

Cross Section of Sprout Creek Area, Town of East Fishkill



Redrawn from U.S. Geological Survey, Atlas of Eleven Selected Aquifers in New York, 1982.

Figure 2.3

- sand and gravel, left in lowlands by glacial meltwater.

These three units are not distinct entities in nature. Rather, there is usually a gradual horizontal and vertical transition from one unit to another. Sand and gravel deposits are often underlain by lacustrine silts and clays. Figure 2.3 is a simplified cross section of the many layers of surficial deposits typically found in the county.

Till

Till is a heterogeneous mixture of rock fragments ranging in size from microscopic clay particles to boulders several feet in diameter. It is the most widespread of the glacial deposits in Dutchess County and is predominant in uplands, where it was laid down by glaciers thick enough to pass over the county's highest peaks. Today, the cover of glacial debris in the highest areas is usually thin or absent because of erosion. In lowlands, where the eroded materials are deposited, the layers of till are relatively thick. Thicknesses over bedrock range from 0 to 20 feet on hilltops and from 20 to 40 feet on the slopes. In a few areas glaciers left till in the form of elliptical hills known as drumlins, as high as 100 feet or more. Osborne Hill, just north of the village of Fishkill, is a drumlin.

The rock fragments in till are primarily derived from local bedrock, but some are from areas many miles away. In places underlain by limestone, slate, and schist, the till consists of clay mixed with grains, pebbles, and cobbles of the parent material. Most of the till in the County is clayey. In some locations it has been cemented or compacted into a tough aggregate known as hardpan. Gneisses are generally overlain by sandy till containing an abundance of large boulders. Clean sand lenses are usually thin and cover only small areas.

Glacial till is usually only slowly permeable because of its high clay content. The movement of water into and through till deposits, to regenerate the groundwater supply or to dissipate septic tank wastes, is extremely slow. Most precipitation on areas underlain by till runs off the surface into drainage channels or is absorbed by plants. The average groundwater recharge capacity of till deposits is estimated to be 0.17 gallons per minute (gpm) per acre.

Water in usable quantities can be obtained only from large diameter wells that provide sufficient area for infiltration and storage. During dry periods such wells, which are necessarily shallow, often go dry or fail to yield the required supplies. Recorded yields from wells drilled into till deposits in Dutchess County range from 1 to 180 gpm with a mean of 22 gpm.

Lacustrine Deposits

Lacustrine deposits are stratified sediments that consist primarily of silt and clay deposited in glacial lakes. These glacial lakes were largely restricted to areas adjacent to the Hudson River. Consequently, lacustrine deposits predominate in western Dutchess County, especially north of Crum Elbow Creek, and are either absent or obscured in the eastern part of the county. Silt and deposits once underlay numerous small areas between Poughkeepsie and the Hudson Highlands in the southwest, but the brick industry has exhausted many of these locations. Lacustrine deposits are generally less than 50 feet thick, although depths of 125 feet border the Hudson River south of Rhinebeck. In some instances sand and gravel deltas overlie the silts and clays.

The permeability of clay and silt is extremely low. Wells that tap lacustrine deposits usually do not yield water in usable quantities. In areas where no other glacial deposits are present, groundwater supplies must be obtained from underlying bedrock. Such water supplies are not certain to yield an adequate supply.

On terraces adjacent to the Hudson River in northwestern Dutchess County, clay and silt layers retard or prevent the infiltration of groundwater into the bedrock. The clay and silt also retard the upward movement of water from underlying sources, sometimes causing natural underground water pressure to build up enough to force water to the surface without pumping. The average rate of groundwater recharge for lacustrine sediments in Dutchess County is 0.12 gallons per minute per acre. Estimates of well yields from these deposits are not available.

Sand and Gravel

Stratified sediments consisting principally of sand and gravel underlie extensive areas in the valleys of the county's major streams and tributaries. As shown in the Glacial Deposits Map, the most extensive beds are in the valleys drained by the Fishkill Creek, Sprout Creek, Swamp River, Tenmile River, and Wappinger Creek. The deposits range from layers of relatively clean sand to layers of mixed sand and gravel, and are usually underlain by thinner layers of silt and clay.

Stratified sand and gravel occurs in four principal forms in the county: kames, kame terraces, valley trains, and deltas. Kames are small conical hills found in southern Dutchess along the base of the Hudson Highlands, and in Wappinger and Fishkill between the Hudson River and Route 9. Kame terraces, relatively flat-topped deposits on the sides of valleys, are prominent in the Swamp River valley in Pawling and along the Hudson River in the town of Poughkeepsie, south of the city of Poughkeepsie. Valley trains are long, narrow deposits underlying stream valleys including those of the Wappinger, Fishkill, Crum Elbow, and Webatuck Creeks, as well as the Tenmile River. Delta deposits, laid down where streams once entered glacial lakes, have been mapped at New Hamburg near the mouth of Wappinger Creek, and in the lowlands near the Swamp River. Large deltas also exist at Rhinebeck and Red Hook.

Silt and clay deposits underlie sand and gravel almost everywhere. Some wells have penetrated two or three distinct layers of sand and gravel interbedded with layers of silt and clay. The sand and gravel layers are generally less than 25 feet thick, although in some areas they are as thick as 50 feet. This sand/gravel and silt/clay layering is characteristic of terraces along the major stream valleys of the county. Such terraces can slip when the underlying clay layers become saturated with water, and slide away with their overburden of deltaic sand and gravel.

The sand and gravel mixture is by far the most productive water-bearing deposit in Dutchess County, and it is used extensively as a source of potable water.

Small-diameter driven wells with screened drive points generally yield sufficient water for farm, home, and commercial uses. Large diameter wells can usually furnish moderate-to-large quantities of water for municipal and industrial systems. The reported yields of wells tapping sand and gravel range from 2 to 1400 gpm, with a median of 20 and an average of 136. Largely due to their porosity, the average groundwater recharge capability of sand and gravel deposits is 0.74 to 0.93 gallons per minute per acre.

In addition to their water-bearing properties, sand and gravel deposits provide materials vital to the building and road construction industries. Sand and gravel mines, also called soil mines, are found in all areas of the County, with concentrations in southeastern Dutchess, the Harlem Valley, and along the Wappinger Creek. A 1982 map of sand and gravel operations is included in the appendix.

In 1976, almost 3,000 acres in Dutchess County were used by active sand and gravel mines and hard rock quarries. The towns with the largest mining acreages were Poughkeepsie, where the county's largest rock quarry is located, Dover, Beekman, Pleasant Valley, and Amenia. Fishkill, LaGrange, and Washington also support substantial mining operations.

Numerous inactive and abandoned mines dot the county. Many of these have been reclaimed and converted to municipal parks, lakes, or development sites. Many more, however, have never been restored to useful or attractive condition.

Soil mining can alter the recharge capability and potential yield of groundwater supplies by gradually reducing the size and thickness of sand and gravel deposits. In addition, many mining operations dig down below the water table, exposing the groundwater to surface runoff and silt that sometimes cause changes in water quality.

Resource Management Implications

Dutchess County is endowed with a complex array of bedrock types and glacial deposits, which are legacies of more than a billion years of geologic change. Drainage patterns, soil characteristics, microclimates, groundwater and surface water supplies, scenic areas, and patterns of vegetation all depend on the county's geologic features. These features give the county its physical shape and shape its land use as well. Consequently, the location, values, and limitations of various geologic resources have broad implications for land use planning and resource management.

Groundwater Resources

Bedrock formations that cannot be relied on for large, steady supplies of groundwater underlie most of Dutchess County. Developments that draw their water from these formations can exhaust the available groundwater supplies. The land use decision-making process should ensure that the types and densities of developments using bedrock wells do not exceed the carrying capacities of these limited resources.

Limestone bedrock tends to form solution channels as water flowing through the bedrock dissolves the rock material. This characteristic enables limestone to store and transmit large quantities of water, making it the most prolific bedrock water source in the county. However, this characteristic also allows pollutants to move quickly through these underground channels and contaminate the stored water supplies. To prevent such contamination, developments located atop limestone bedrock, particularly where surface deposits are thin, should either be connected to central sewer systems or built at densities low enough to protect groundwater quality. Facilities that handle or store hazardous or toxic substances should not be located over such formations. Similar precautions should be taken in fault zones, which are often capable of supporting uses with heavy water demands. The fissures and fractures in fault zones enable both groundwater and pollutants to travel quickly, making it particularly important to avoid land use practices that could threaten water quality.

Land use decisions should reflect the limiting characteristics of surficial deposits. The large expanses of lacustrine deposits along the Hudson River in the northwestern part of the county should not be developed for intensive uses without central water systems that tap outside water sources, such as the Hudson itself. Because lacustrine deposits have extremely slow permeability, central sewage treatment should also be required for intensive developments in these areas. Similar policies should be employed in areas covered by glacial till. In all areas, data about surficial geology should be considered in determining which land uses and utility systems are appropriate.

The county's most critical groundwater resources are its thick sand and gravel deposits. These areas can yield large volumes of water and can support a variety of uses; they are also vulnerable to contamination, if they are improperly developed or overused. The importance of these deposits should be recognized by local and county governments, and steps should be taken to ensure they are managed wisely. At a minimum, detailed protection strategies and appropriate aquifer protection regulations should be developed by each municipality for those aquifers being tapped or considered for use as municipal water supplies.

Mining

In many cases, different uses of geologic features may conflict. For example, the demand for sand and gravel for construction projects may ultimately conflict with the need to protect the integrity of the county's most productive groundwater storage areas. A balance must be struck between the use and preservation of these geologic resources. To resolve conflicts, the following issues should be addressed at local and county levels:

1. how much mining should be allowed, and where;

2. how mines should be reclaimed so that they become community assets when they are no longer active;

3. how mines should be designed and shielded so as not to detract from the visual quality of their surroundings;

4. how mines should be located and controlled so that their impacts on groundwater and surface water supplies are minimized; and,

5. how state and local mining laws should be better enforced so that violators are caught, while conscientious mine operators are rewarded for their environmental concern.

The answers to these questions are critical to the safe, economical use of the county's bedrock and surficial deposits.

The economic value and land use impacts of limestone bedrock quarries should be recognized. Hardrock quarries provide jobs and materials that contribute to the county's economic well-being. Quarries can also, however, produce large-scale changes in the landscape and can adversely affect adjacent neighborhoods; this has been particularly evident in the town of Poughkeepsie. Intensive development, in turn, can block access to extractable resources, requiring local users of bedrock products to depend more heavily on expensive non-local sources. Such trade-offs and conflicts raise significant questions about how mineable land should be managed.

Faults

Numerous faults run through Dutchess County. Although major earthquakes are not expected in the fault zones, smaller tremors and shifts in the earth's crust are not unlikely. Accordingly, facilities that must maintain their structural integrity at all times, or which require absolutely stable foundations, should not be constructed on top of faults. Such facilities include power plants, chemical storage areas, landfills, fuel tank field, dams, reservoirs, and high-rise buildings.

Scenic Values and Community Identity

Bedrock and surficial deposits play an important role in visually defining, and even isolating, communities. For example, many people in the Harlem Valley feel separated from the rest of Dutchess County, at least partly because of the high bedrock ridges that form the valley's western wall. Bedrock characteristics are also responsible for the scenic landmark qualities of the Hudson Highlands, Stissing Mountain, the eastern wall of the Harlem Valley, and the Hudson River bluffs. Stissing Mountain, in particular, is unique because it is an

ancient rock "floating" on a younger formation. Its natural beauty and geological significance merit careful preservation.

Many of Dutchess County's significant geologic features are upland areas with shallow, highly erodible soils and steep slopes. They support fragile ecological communities that are easily scarred by erosion, clear-cutting, excavation, earthmoving activities, and careless or inappropriate development techniques. To preserve these scenic resources, greater use of selective clearing, erosion controls, careful grading, viewshed analysis, and strict development density limits should be encouraged.

Development Constraints

Bedrock and surface geology affect the location, development, maintenance, and cost of public services such as sewers, water supply sytems, and roads. Geological features should, therefore, be considered in all comprehensive plans and capital projects, particularly those using public funds.

The presence of bedrock once limited construction activities. Modern technology, however, in the form of large, powerful earthmoving equipment, has made it possible to develop almost any piece of land. This ability has important implications for the visual environment. It makes it feasible to obliterate the natural variability of of the terrain, at a social and environmental cost that is often incalculable. In areas with sensitive or valuable geological features, landscape changes should be limited to what is absolutely necessary for particular development projects, and should be undertaken in ways that minimize environmental harm.