SENSITIVE

GEOLOGIC FEATURES

GREEN TOWNSHIP
SUSSEX COUNTY, NEW JERSEY

PREPARED BY

ECO SYSTEMS ENVIRONMENTAL CONSULTANTS

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Additional copies of this report and blueprints of the Bedrock Geology Map may be obtained at the Green Township Municipal Building.

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INTRODUCTION

This report was prepared with the aid of a Well Head / Aquifer Protection Grant from the New Jersey Department of Environmental Protection, Office of Environmental Services. The grant enabled the Green Township Environmental and Heritage Commission to undertake the study with matching funds provided by the Township Committee.

The project's purpose is to identify *Sensitive Geologic Areas* within Green Township. An awareness of these area's connection to our future potable water supply is crucial to assure proper planning and protection of the Township's groundwater resources. In Green Township, 100% of the residents currently rely on and will continue to rely on groundwater for their water supplies. The Township's two largest aquifers extend for more than 3,000 acres under the township's central limestone valleys.

The *Shale* to the west and the *Crystalline rock* to the east of this area are much poorer aquifers. The shale has no primary porosity or permeability except for some included sandstones. Almost all of its water is contained in fractures. The fractures in the Martinsburg Shale are considered to be very tight and generally create very poor aquifer conditions. Exceptions include areas that are faulted or tightly folded.

Precambrian Crystalline rocks form the Township's eastern boundary. Practically all groundwater in these formations occurs in joints and in fractures along faults. In areas where the joints are far apart, there is no distinct water table, each system of joints having its own flow system. Only where weathering has occurred at depths less than 150 feet and fractures are most abundant, can you find water in sufficient quantities for domestic use.

The importance of the Township's limestone aquifers cannot be understated. These are the areas that we can depend on for our future water supplies. However, the same process that makes the limestone our best aquifer, also makes it highly susceptible to contamination. Where the limestone is at a shallow depth, sinkholes, cracks, fissures and joints allow rapid flow of surface water into the system. The following maps and text detail areas that must be carefully protected from surface contamination. Only our prudent planning of cautious and considerate development, will insure the safety of our drinking water.

GEOLOGIC HISTORY

The geologic history of Green Township has its beginnings more than 1.5 billion years ago, during the Precambrian Era. The resistant bedrock that forms the Allamuchy Mountain consists of igneous and metamorphic rocks with a long and complex geologic history. These Precambrian rocks were once sandstones, shales, limestones and volcanic rocks, that became buried deep within the earth, and formed the roots of mountains as high as many of the earth's present great mountain ranges. As they were buried these ancestors to our present granitic rocks were subjected to immense heat and pressure. These extreme forces melted and altered the rocks, resulting in the present day granite and gneiss that make up Allamuchy Mountain. These crystalline rocks were later exposed during subsequent mountain building events, creating the ridge we see today.

The next period of geologic activity in the region resulted in the formation of a major ocean basin. The history of the ocean basin started with the formation of shallow, warm tropical seas in which limestone reefs and lagoon-like mudflats predominated. In other parts of this ocean basin, deep trenches formed in which large amounts of sediment rapidly accumulated.

This warm tropical sea was the origin of the rocks we now call the Kittatinny Limestone. A period of sea level lowering and uplifting of the sea floor marked the end of the formation of the Kittatinny. The exposed coral reefs and underlying limestone deposits were subjected to an interval of significant erosion. The emergence and erosion of the Kittatinny Limestone was then followed by the deposition of the Jacksonburg Limestone, during a reestablishment of the ocean basin. Deposition of the Martinsburg Shales tells of the subsequent rapid deepening of the ocean basin, when shallow conditions favorable to the continued formation of the limestones no longer prevailed in what is now New Jersey.

The immense thickness of the Martinsburg Shale, greater than 20,000 feet, records a period of rapid deposition in a deepening ocean. Near the end of this deposition, more than 400 million years ago, the ocean basin occupied a place where the great plates that make up segments of the earth's crust were beginning to converge. The wide ancient ocean basin, piled thick with the limestone of the Kittatinny and the shale of the Martinsburg, was caught up in the collision between the plates. The sediments that were formed in the ocean were then raised up above sea level.

This mountain building episode squeezed the thick accumulation of shale, limestone folding and lifting them. The folding process created weakened areas in the semi-brittle sediment, reflected in the joints and fractures we see today.

The region went through a second period of ocean basin formation, deepening, and closing, which ended about 225 million years ago. This last mountain-building episode further stressed the bedrock in the area, resulting in more folds, and faults. Some of the faults from the earliest mountain building period (such as the Federal Springs, Grass Pond, Springdale, and the Tranquility Fault) shown on the Bedrock Geology map, are significant. These major faults have important implications with regard to the occurrence of ground-water, radon gas, and earthquakes. In addition, many of the smaller faults formed at the time, serve as significant zones of ground-water circulation, and enhance the water-bearing capabilities of nearby rocks.

The most recent geologic episode that shaped the township was a period of glaciation. During the past two million years New Jersey has undergone three advances of glacial ice sheets. The last glacier to occupy New Jersey, the Wisconsin glacier, reached its maximum extent just 20,000 years ago (fig.1)

The advance and subsequent retreat of the Wisconsin glacier, left a variety of unconsolidated sediments over the landscape. These surficial deposits are shown on the Surficial Geology map. The physical properties of these glacial deposits are a function of how the sediments were released from the ice during its advancement and retreat.

At the end of the Wisconsin glaciation large glacial lakes were formed by glacial meltwater that became trapped behind ice dams and glacial debries. The remains of these glacial lakes consist of silt, clay and fine sand and are often found under the larger swamps in the area, such as Great Meadows and Bear Swamp.

Upland areas were draped with glacial till, an unsorted mixture of sand, clay and stones deposited directly from glacial ice. Valleys were filled with thick accumulations of sand and gravel released and sorted by streams flowing from the melting glacier. These sand and gravel outwash deposits when thick, form productive aquifers and serve as important recharge areas for underlying bedrock aquifers.

The various geologic processes described above left their mark on the landscape of Green Township. Mountain building and differences in the resistance of the bedrock to erosion have controlled the location of valleys, hills and mountains. Glacial advances have modified the contours on the bedrock surface, stripping it of soil in places and piling up thick accumulations of sediment in other places.

The various forces, that have broken and subsequently weathered the bedrock, control the movement of water through the rock formations and the availability of water to wells. The glacial processes have determined whether the unconsolidated overburden on top of the bedrock permits rapid infiltration of precipitation or retards infiltration. The resultant topography has shaped the network of streams and rivers that drain the landscape.

These geologic processes that formed the rocks have produced an environment with great variety, and shaped human habitation of the region. Deep, rich limestone soils; steep, rocky, cavernous limestone outcrops; cool springs and perennial swamps; and rolling, thinly veneered hills of shale are all the product of the township's unique geologic history. Each one of these environments presents it's own planning challenges and development limitations.

PHYSIOGRAPHIC PROVINCES

Green Township is host to a variety of geologic settings. Two Physiographic Provinces are represented: (1) the Reading Prong of the New England Province, which in New Jersey is called the New Jersey *Highlands*, and; (2) the Kittatinny Valley, which is part of the Appalachian *Ridge and Valley* Province. Each of the two provinces is characterized by particular geologic formations and geographic features (fig. 2).

Only a small part of the eastern portion of the township lies within the Highlands, and is represented by the Allamuchy Mountain. This ridge line is underlain by granitic rocks and is characterized by a rocky terrain, steep slopes, marshy depressions and generally poorly drained soils. Since soil formation is a function of the underlying parent rock, soil types associated with this granitic formations are not found elsewhere in the township.

This crystalline upland is a source of runoff for the Trout Brook watershed, and, therefore, the quality of the water draining from the mountain affects water quality within the south eastern part of the township. Surface and ground-water that originates in this granitic terrain is generally moderately soft, with a moderate pH (6-7), low dissolved solids and often moderate to high concentrations of iron and/or manganese.

The majority of the township lies within the Ridge and Valley Province. This Province is underlain by sedimentary rocks including limestone, sandstone, and shale. Geologic structures and the resistance of the various sedimentary rocks to weathering and erosion have formed a landscape in this Province consisting of alternating linear valleys and ridges. Those rocks that are more resistant to erosion, such as sandstone and shale form the ridges; while rocks more easily eroded, such as limestone and dolomite, occupy the valleys. Soil cover being a function of the topography, is usually thin on ridges and deeper in valleys.

Within Green Township two bedrock units make up the Ridge and Valley Province; these are the Kittatinny Limestone and the Martinsburg Shale. The limestone underlies the lower elevations while shale and sandstone, form the higher elevations.

BEDROCK GEOLOGY

Bedrock geology is important in terms of land use, as it controls where ground water occurs and determines the stability of the environment. There are many unstable features associated with the Kittatinny Limestone, such as sinkholes and caves, that are the result of chemical and physical weathering. Bedrock geology helps us plan where to locate wells for water supply and where to exercise caution in undertaking construction (fig. 5).

Kittatinny Limestone

The former Kittatinny Limestone is now subdivided into five separate formations, all of which are found in the township. The individual formations within the Kittatinny Group include the Leithsville, Allentown, Rickenbach, Epler and Ontelaunee Formations; these formations are described in the Bedrock Hydrology Section. Underlying,the Kittatinny are the resistant Precambrian crystalline rocks and Hardyston Sandstone, while on the top of the Kittatinny is another limestone, the Jacksonburg Limestone (formed during that second reef building period).

The Kittatinny Limestone formations consist mostly of dolomite, which is a more resistant form of limestone, containing magnesium as well as calcium carbonate. Even though this dolomitic limestone is harder and more resistant than pure limestone, it exhibits hydrogeologic traits found in areas underlain by limestone. Caverns, sinkholes, undrained depressions, disappearing streams and springs are common in the Kittatinny terrain.

Within the Kittatinny, formations that contain the coarsest dolomite grains have undergone the most severe weathering. The formations most susceptible to weathering include the Leithsville, the Allentown (lower part), and the Rickenbach Formations. These formations constitute the most prolific carbonate aquifers and have the greatest amount of caverns, sinkholes, springs, bedrock pinnacles and other "karst" features thereby making these limestone valleys a very sensitive environment (fig. 3).

The carbonate formations that are less susceptible to weathering include the upper Allentown, Epler, and Ontelaunee Formations. While sinkholes, caves and other karst features are found within these formations, environmental limitations associated with more resistant carbonate formations include steep slopes, small sinkholes, thin rocky soil and poor ground-water yields. Within the Kittatinny Valley the Leithsville, lower Allentown and Rickenbach Formations tend to underlie stream valleys, marshes and floodplains, while the upper Allentown, Epler, Onteluanee and Jacksonburg Formations make up the more elevated terrain.

The topography, ground-water yield characteristics, and environmental limitations associated with the various carbonate formations within the township are outlined in the Bedrock Hydrology Section. These geologic traits help to understand the potential for development above these formations and associated risks to the environment.

Martinsburg Shale

The Martinsburg Shale is found predominantly in the northwestern parts of township. It forms the rolling, hilly terrain that divides the Bear Brook and Pequest watersheds. The Martinsburg terrain is characterized by moderate to steep slopes, frequent bedrock outcrops, thin soils and shallow, sometimes marshy valleys.

The Martinsburg Shale can be divided into two units, or members, known as the Bushkill and the Ramseyburg members. The Bushkill Member consists mainly of claystone slate, a shale-like rock. The Ramseyburg Member contains mostly siltstone and sandstone. The Ramseyburg is the more resistant of the two members and, therefore, occupies the highest elevations in the township.

The shale does not normally provide exceptional ground-water yields to wells, although there have been prolific wells finished in the Martinsburg where geologic structure has caused extensive fracturing of the rock, such as near faults and folds. However, due to recent requirements for longer well casings to protect wells from the possibility of contamination and due to modern well drilling methods; well yields for recently drilled wells may be lower than those reported several years ago. Deeper well casings prohibit water within the upper, weathered portions of the bedrock from entering the well. Current practice requires that water be obtained from fractures deeper within the rock aquifer; but fractures tend to decrease with depth (fig. 4). The topography and ground-water yields associated with the Martinsburg Shale are described in the Bedrock Hydrology Section.

SURFICIAL GEOLOGY

The bedrock surface of the township has been modified by glaciation, as described above. The Surficial Geology Map shows the various types of glacial deposits left by the advance and retreat of the last glacier to occupy New Jersey, the Wisconsin ice sheet.

Glacial deposits, are categorized by their dominant texture, which is a function of the processes that formed the deposits. Meltwater carrying rock particles from the retreating glacier deposited layers of coarse and fine sediments, known as stratified drift. In high-energy environments such as streams and deltas, coarse sediments were deposited. In low-energy environments such as lakes, ponds and swamps, fine-grained sediments were laid down. Deposits laid down directly by the ice in the absence of meltwater are well mixed (heterogeneous) and are labeled glacial till.

Stratified drift deposits are well-sorted, tend to lack clay and silt, and are well-drained. These deposits form prolific aquifers where they are sufficiently thick. Stratified drift permits good infiltration of water and serves to store ground water, often contributing large volumes of high-quality recharge to underlying bedrock aquifers. The well-drained soils in the township are found on top of stratified drift deposits. The water table is often moderately deep in these deposits. The most significant deposits of stratified drift are found in the Pequest River watershed, in the central part of the township, where they overlie limestone bedrock.

Poorly drained glacial deposits include glacial lake-beds, glacial till and swamp deposits. Glacial lake-bed sediments are deposited downstream of melting ice, in low-energy environments where fine silt and clay are settled out. These fine lake-bed sediments often underlie better-drained stratified drift deposits, which causes springs to form at the base of the sand and gravel deposits. Fine sediments also underlie the larger swamps in the region. Although thick in places, glacial lake-bed deposits are not prolific aquifers but can supply water to some wells. Ground water in these sediments is often of objectionable quality due to a high content of organic material as well as high iron and sulfur concentrations in lake-bed sediments.

Glacial till is material deposited by gravity from the glacier as debris. Till deposits in the township are thin, although in places till may reach 25 feet in thickness. Till generally has a high clay content and a high percentage of gravel. The high clay content and poor grain size sorting within the till reduce its permeability, which causes poor internal drainage and a shallow seasonal water table within a few feet of ground surface.

Other important surficial deposits within the township include post-glacial or recent stream alluvium and swamp deposits. The alluvial deposits are sediments laid down in modern stream valleys. Alluvium has a variable composition depending on the terrain being drained by the stream. Alluvium can have a high silt content or a high percentage of organic material - both of which reduce the permeability of the alluvial deposit. These deposits are usually thin and the water table occurs at shallow depths within the alluvium.

Swamps are formed by underlying glacial lake-bed sediments and/or impervious bedrock that trap surface drainage. Swamp deposits contain a very high percentage of organic material and the water table is at or near the surface most of the year.

In Green Township several geologic sites have been mined in the past and are a part of our cultural landscape. The area abounds in old lime kilns and gravel pits. Such areas should be given consideration and development planned without their possible loss to future generations.

Where thin surficial deposits overlie the township's less resistant limestone bedrock, careful planning must be used to assure that our water supplies are not inadvertently contaminated. These areas are susceptible to unfiltered recharge from surface runoff and pollution from incompatible land use. Only sound land use planning of these vulnerable areas can prevent the pollution of our ground water supplies.

BEDROCK HYDROLOGY

Martinsburg Shale

Omb

Occurrence/Topography

Upper (Ramseyburg) member forms prominent ridges, with abundant rocks ledges, thin, coluviated soil cover, with isolated pockets of glacial drift. Valleys are usually long and narrow. Member forms smooth, rolling hills and underlies poorly drained valleys. Soil cover thin (less than 15 feet) to absent, with local deposits of glacial drift up to 50 feet thick.

Hydrologic Characteristics

Well yields generally prove to be adequate for domestic needs, with most wells exceeding 3 gpm. Yields often improve with proper well development or stimulation. Some very good well yields with poor drainage. Lower (Bushkill) near faults and near fold axes; yields of 100 gpm have been reported. Thick overburden may help contribute to good sustained yields. Most water-bearing seams shallower than 200 feet, with some seams up to 400 feet deep.

Jacksonburg Formation

Oj

Occurrence/Topography

Forms subdued topography between rock Kittatinny terrain and smooth, rolling Martinsburg terrain. Infrequent outcrops, but soil cover may be thin. May receive significant runoff from adjacent units. Locally thick deposits of drift up to 30 feet thick may occur. Sinkholes occur and can be large, several large caves have been identified.

Hydrologic Characteristics

Yields generally poor to moderate, 5 to 20 gpm, but generally adequate for domestic supplies; most wells exceed 10 gpm. Yields tend to be higher in lower part, with occasional yields of 100 gpm.

Ontelaunee Formation

Oo

Occurrence/Topography

Forms an irregular, hummocky to rocky, terrain with bedrock exposures. Soil cover generally thin to absent, but thicker in depressions.

Hydrologic Characteristics

Yields poor to moderate, with better yields in lower member. Frequent dry holes and very marginal wells in upper (Harmonyvale) member. Yields may range from poor to fair (3 to 20 gpm) in lower.

Epler Formation

Oe

Occurrence/Topography

Forms a steep, elevated rocky terrain with many bedrock exposures. Typical limestone "pinnacle-and-trough" topography, with thin soil in shallow depressions and intervening rocky pinnacles.

Hydrologic Characteristics

Yields range from poor to fair, 1 to 20 gpm. Yields improve near top and bottom of formation, or where blue limestone facies is present. Yields particularly poor where strata are steeply inclined.

Rickenbach Formation

Or

Occurrence/Topography

Forms a subdued topography that increases in relief toward overlying Epler Formation. Chert blocks in upper (Hope) member form rocky pinnacles. Many sinkholes, marshes and undrained depressions and springs in upper member; largest sinkholes in state occur in this unit. Lower (Lower Rickenbach) member is subdued with frequent, small rock exposures and thin to moderately deep soil cover. Sinkholes somewhat common, springs may occur.

Hydrologic Characteristics

Yields range from poor to good. Yields better in upper (Hope) member, with most wells yielding 10 to 50 gpm, but highly variable. Yields in lower member poor to fair, 3 to 20 gpm, with occasional good yields near upper member. Locally yields reported as high as 200 gpm.

Allentown Formation

OCa

Occurrence/Topography

Highly variable topography. Upper (Upper Allentown) member forms irregular, steep, rocky terrain with bedrock pinnacles and shallow soil cover in intervening depressions. Numerous small sinkholes may occur. Lower (Limeport) member forms benched topography, with lowest units underlying stream valleys or wetlands, and middle and upper units forming rocky terraces with shallow to moderate soil cover and subdued rocky exposures. Numerous large springs and sinkholes occur in lower member, with largest springs in state occurring here.

Hydrologic Characteristics

Yields highly variable. Yields in upper member poor to fair, 3 to 25 gpm, with occasional dry holes; most wells barely adequate for domestic needs. Yields in lower member good to prime, with most wells yielding between 10 and 50 gpm. Frequent wells in lower member in excess of 100 gpm, with some yields exceeding 500 gpm.

Leithsville Formation

Cl

Occurrence/Topography

Variable topography. Upper (Walkill) member underlies stream valleys and marshes. Soil cover shallow to deep, usually with shallow water table. Middle (Hamburg) member forms topographic high separating lower and upper members. Hamburg terrain often a prominent ridge, sometimes steep, with shaley rock exposures or thin soil cover on dip slope. Lower (Califon) member rarely exposed, forms shallow depression with moderate to deep soil cover. Many sinkholes in lower unit.

Hydrologic Characteristics

Well yields range from moderate to prime, depending on unit encountered. Yields in lower and upper members good to prime, with typical yields from 10 to over 1000 gpm. Yields in middle member tend to be significantly lower, with some good yields of 50 gpm where conditions are favorable.

Hardyston Sandstone

Ch

Occurrence/Topography

Forms smooth topographic bench at base of granitic uplands. Soil cover thin to moderate.

Hydrologic Characteristics

Well yields tend to be poor, with few wells finished in this unit.

Precambrian granitoid gneiss

Pc

Occurrence/Topography

Forms prominent ridges with rocky prominences. Soil cover thin, often containing significant boulders. Colluvium is often thick on mountain flanks.

Hydrologic Characteristics

Well yields vary, depending on geologic unit encountered and geologic structure. Layered gneisses often more prolific than massive granitic units. Proximity to brittle faults may affect yield greatly.

GEOLOGIC NOMENCLATURE

The following section details the sequence of geologic names and geologists who have built the currently well described stratigraphy of the Kittatinny supergroup.

Stratigraphy of the Kittatinny Supergroup

Until 1965 the Cambrian and Ordovician carbonate rocks below the Beekmantown erosion surface in New Jersey were grouped under the name Kittatinny Limestone (Weller, 1900). In 1909 a three-fold subdivision of rocks equivalent to the Kittatinny was introduced in Pennsylvania by Wherry; this classification included the Leithsville, Allentown and Coplay Formations (Wherry, 1909). Later, B.L. Miller and others introduced the term Beekmantown as a substitute for Coplay (Miller, et al, 1939). This three-fold grouping was revised by Hobson to include the Stonehenge, Rickenbach, Epler and Ontelaunee Formations in place of the Beekmantown; the Beekmantown was thereby elevated to the level of group (Hobson, 1957).

Although the terminology used in Pennsylvania had been recognized informally in New Jersey by Johnson in field mapping during the 1950s, Drake of the United States Geological Survey first formally applied the above designations of the Cambro-Ordovician carbonates used in Pennsylvania in his geologic mapping in Warren and Hunterdon counties in New Jersey. He did not, however, recognize the existence of the Ontelaunee Formation in New Jersey (Drake, 1965). Markewicz of the New Jersey Geological Survey mapped the High Bridge Quadrangle utilizing the designations for the carbonate rocks used by Drake, including the Leithsville, Allentown, Rickenbach and Epler Formations (Markewicz, 1968).

Markewicz and Dalton (1970) of the New Jersey Survey subdivided the Leithsville Formation into three mappable members: Califon, Hamburg and Wallkill. They subdivided the Allentown into the Limeport and Upper Allentown members, using the latter as the equivalent of the Upper Allentown Formation of Howell and others (1950) and the Limeport as the equivalent of the Howell's Limeport Formation. Hobson's (1963) division of the Richenbach Formation into lower and upper member was formalized to include the Lower Richenbach and Hope members, and a distinct lithic facies, the Crooked Swamp Dolomite.

Initially, because of distinct lithic features, Markewicz and Dalton (1974) subdivided the Epler Formation into five units: the lower laminated, big red, upper laminated, black jack and Harmonyvale (Markewicz and Dalton, 1974). They later suggested the possible use of the term Ontelaunee Formation for the latter two units (Markewicz and Dalton, 1976). The black jack and Harmonyvale were later formally designated as the Beaver Run and Harmonyvale Members of the Ontelaunee Formation (Markewicz and Dalton, 1977). In the same year they established the names Branchville, Big Springs and Lafayette members to replace the lower laminated, big red and upper laminated units within the Epler Formation (Markewicz and Dalton, 1976).

Drake (1981) introduced the term Kittatinny Supergroup to include the Leithsville Formation, Allentown Dolomite and Beekmantown Group. In this elevation of the Kittatinny he suggested the existence of the Ontelaunee Formation in New Jersey and indicated that the Stonehenge Limestone was not known in New Jersey. In recent mapping in the eastern portions of the Portland and Belvidere Quadrangles (Drake, et al, 1985) and the Blairstown Quadrangle (Drake and Little, 1986) in Warren County, New Jersey, Drake introduced the use of Stonehenge as a mappable unit in New Jersey and reaffirmed the absence of rocks of Ontelaunee age. Further, he reassigned the age of the Allentown as Cambro-Ordovician ("Lowest Lower Ordovician") (fig.6).

TECHNICAL DESCRIPTION OF MAP UNITS

Cambro-Ordivician Sedimentary Rocks

Martinsburg Shale - Omb

The Martinsburg can be divided into two units. The upper unit is composed of Rhythmically-bedded, medium- to dark-gray claystone slate, alternating with light- to medium-gray, thin- to thick-bedded, fine- to medium-grained yellowish brown-weathering graywacke siltstone and gray weathering sandstone. Graywacke lenticular to uneven, in beds less than 1 inch to more than 4 feet thick, and comprises 20-30% of the member. Some fine conglomerate beds.

The lower member, a dark- to medium-gray claystone slate, containing very thin to thin beds of quartzose and graywacke siltstone and carbonaceous slate. Beds up to 3/4 inches thick, weathering medium- to very light-gray to yellowish brown, and displaying a very prominent slatey cleavage. Some 6 to 12 inch dolomite beds in lower part of section.

Jacksonburg Limestone - Oj

Upper member a dark-gray to nearly black, fine-grained, thin-bedded argillaceous limestone ("Cement Rock Facies"), with occasional beds of crystalline limestone. Lower member a light- to medium-gray, medium- to coarse-grained, largely well-bedded sandy limestone, and fine- to medium-grained high-calcium crystalline limestone ("Cement Limestone Facies"). Dolomite pebble-to-boulder conglomerate in lower part of formation.

Kittatinny Supergroup

Ontelaunee Formation - Oo

Upper member dense, fine-grained to cryptocrystalline, conchoidal-fracturing. Locally styolitic dolomite in beds 1 to 5 feet thick. Weathered surfaces light cream gray color. Lower member medium-bedded to massive, fine- to medium-grained, very light- to medium-gray, or black, sparkly, fetid silty weathering dolomite. Anastomosing to bedded chert common.

Epler Formation - Oe

Aphanitic to very fine-grained, light gray to black, highly laminated to massive-bedded dolomite. Weathers light gray, cream or buff, to orange-gray. Laminations stand out in relief on weathered surfaces. Knots and stringers of black chert common. Distinctive, red-weathering, light-gray, medium-grained dolomite with porous, siliceous laminations forms marker unit in middle member. Lenses of blue-gray, sandy limestone common.

Rickenbach Formation - Or

Thin- to massive bedded, light gray to black, fine-grained to coarsely crystalline dolomite and sandy dolomite. Fine-grained beds weather light gray, coarser beds weather dark gray. Two distinct black chert marker zones in upper unit, occurring in a dark gray, fine- to medium-grained, massive dolomite. Distinctive facies of fine to coarse, very light gray euhedral crystalline dolomite present throughout. Lower unit fine- to medium-grained, light- to dark-gray, thin- to thick-bedded dolomite and sandy dolomite; local sandy dolomite and quartzose beds contains some edgewise conglomerate.

Allentown Formation - OCa

Fine- to medium-grained, light- to dark-gray, tough dolomite in beds one to six feet thick. Upper unit weathers gray to reddish brown, with a distinct yellowish rind in some beds. Two distinct interbedded quartzites up to 20 feet thick occur in upper 100 feet. Lower unit a cream to gray weathering, fine- to coarse, cyclically bedded dolomite, in alternating light and dark beds. Oolites, stromatolites, ripple marks and mud cracks common. Thin beds or lenses, knots and stringers of chert common. Thin, ribbony shale and shaly dolomite occur throughout.

Leithsville and Hardyston Formation - Clh

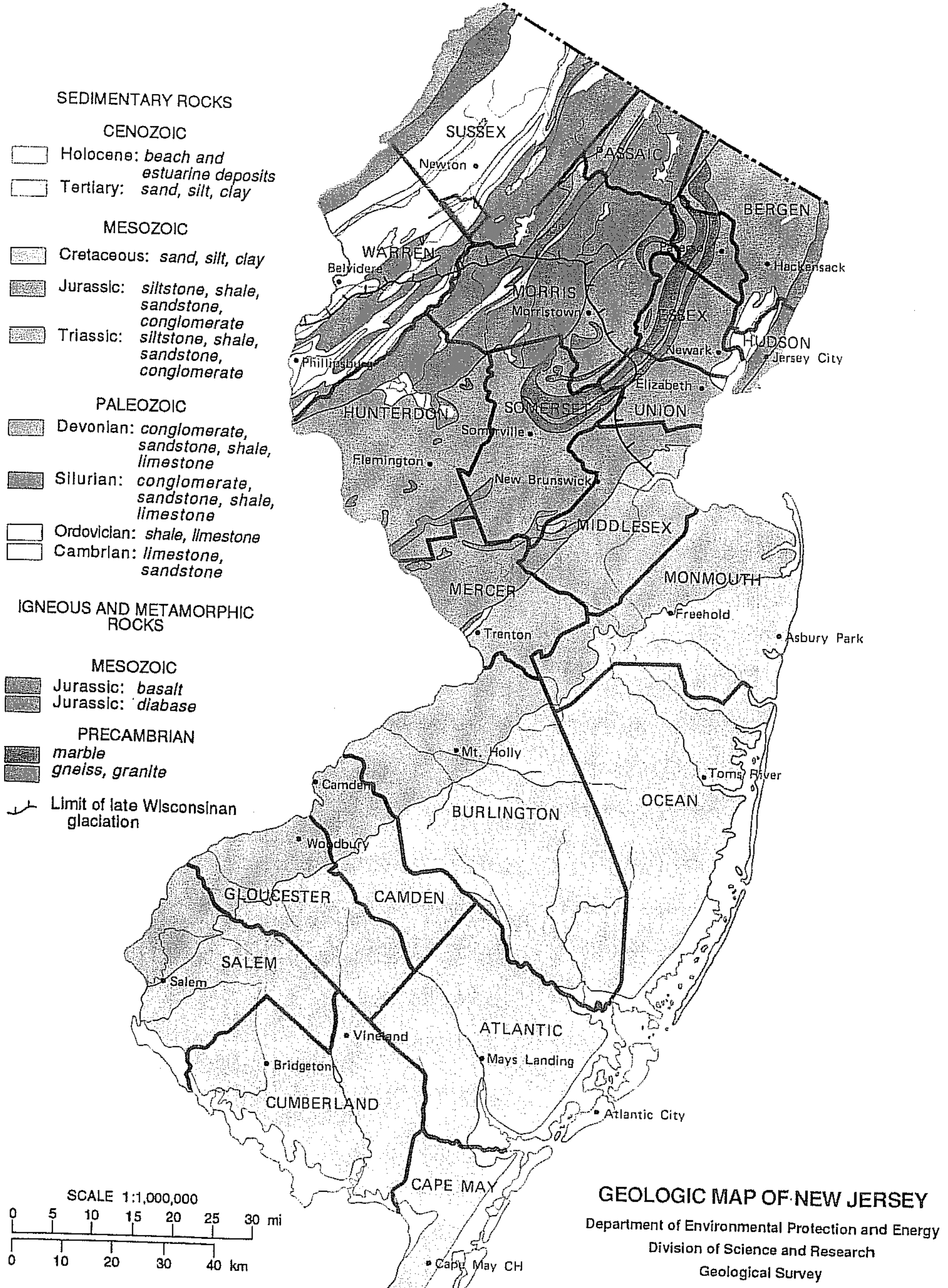
Thin- to medium-bedded, fine- to coarse-grained, light- to dark-gray, to black, silty weathering dolomite to sandy dolomite. Upper unit a ruditic, mottled, sparkly, medium-grained dolomite that weathers ashen gray; some algal-like structures, large oolites and pisolites in this zone. Middle unit light-gray to tan weathering, interbedded phyllite, sandy dolomite and quartzite, forming a distinct, tan-weathering, resistant, shaly marker horizon. Lower unit a thin- to medium-bedded, fine- to medium-grained, light- to dark-gray dolomite to sandy dolomite, with abundant stylolites and nodules of pyrite and chert. Underlain by steel-gray, tough orthoquartzite, quartz pebble conglomerate, to arkosic sandstone to calcareous silty shale. Weathers brown.

CONCLUSION

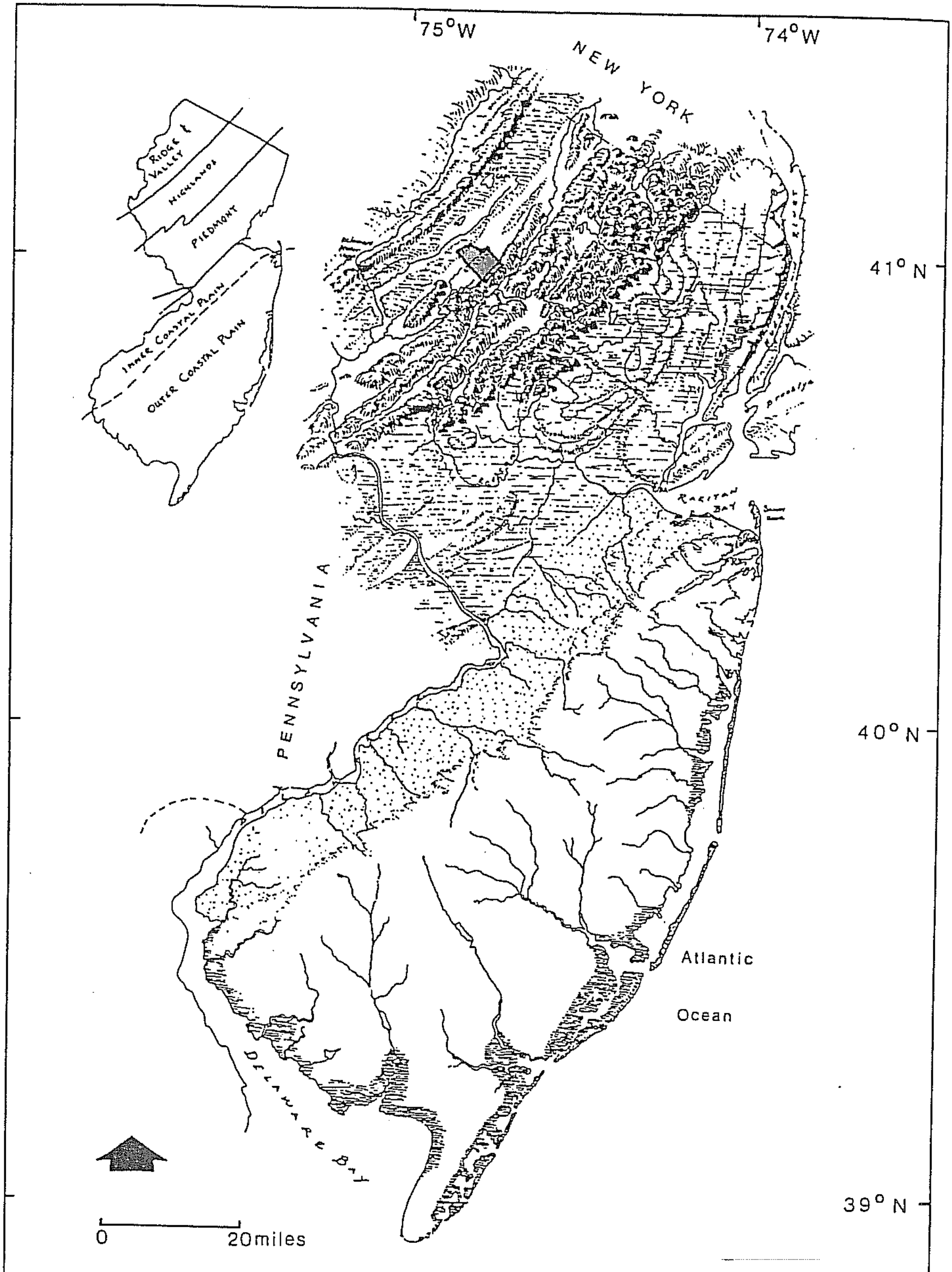
Areas within the township are underlain by carbonate bedrock (limestone and dolomite). The solution of this bedrock causes surface depressions, open drainage passages, and the development of irregular, sub-surface rock topography know as karst. These conditions make such areas unstable and susceptible to subsidence and surface collapse. As a result, the alteration of drainage patterns in these areas by the placement of impervious coverage, grade changes, or increased loads from site improvements promotes land subsidences and sinkholes.

Fractures or solution openings and fissures in the limestone rock lead to water supplies, making our limestone aquifers especially susceptible to groundwater contamination. Contamination of drinking water can occur from solid and liquid wastes, contaminated surface water, septic tank effluent, or other hazardous substances moving through fractures or solution openings and fissures within the rock.

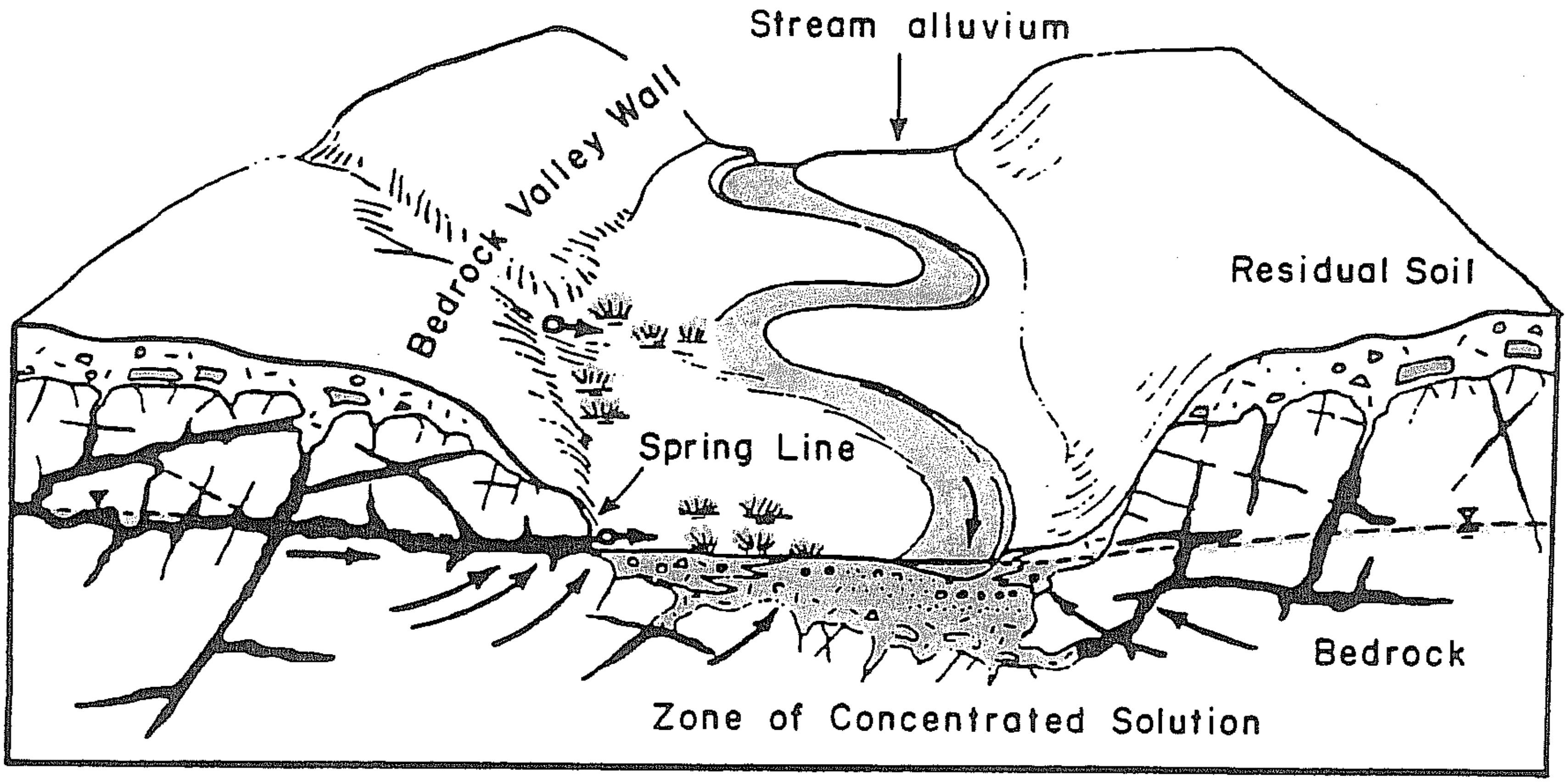
Carbonate aquifers are an important source of groundwater for Green Township. We must rely on a clean supply of subsurface water to foster and promote human health, welfare and economic and social development. Therefore, the purpose of adopting the addition of the Geology information to the township's EIS, is to protect, preserve and enhance a sensitive and valuable potable groundwater resource area and to reduce the frequency of structural damage to public and private improvements by sinkhole collapse or subsidence in areas of limestone geology, thus protecting the public health, safety and welfare and insuring orderly development within the municipality.



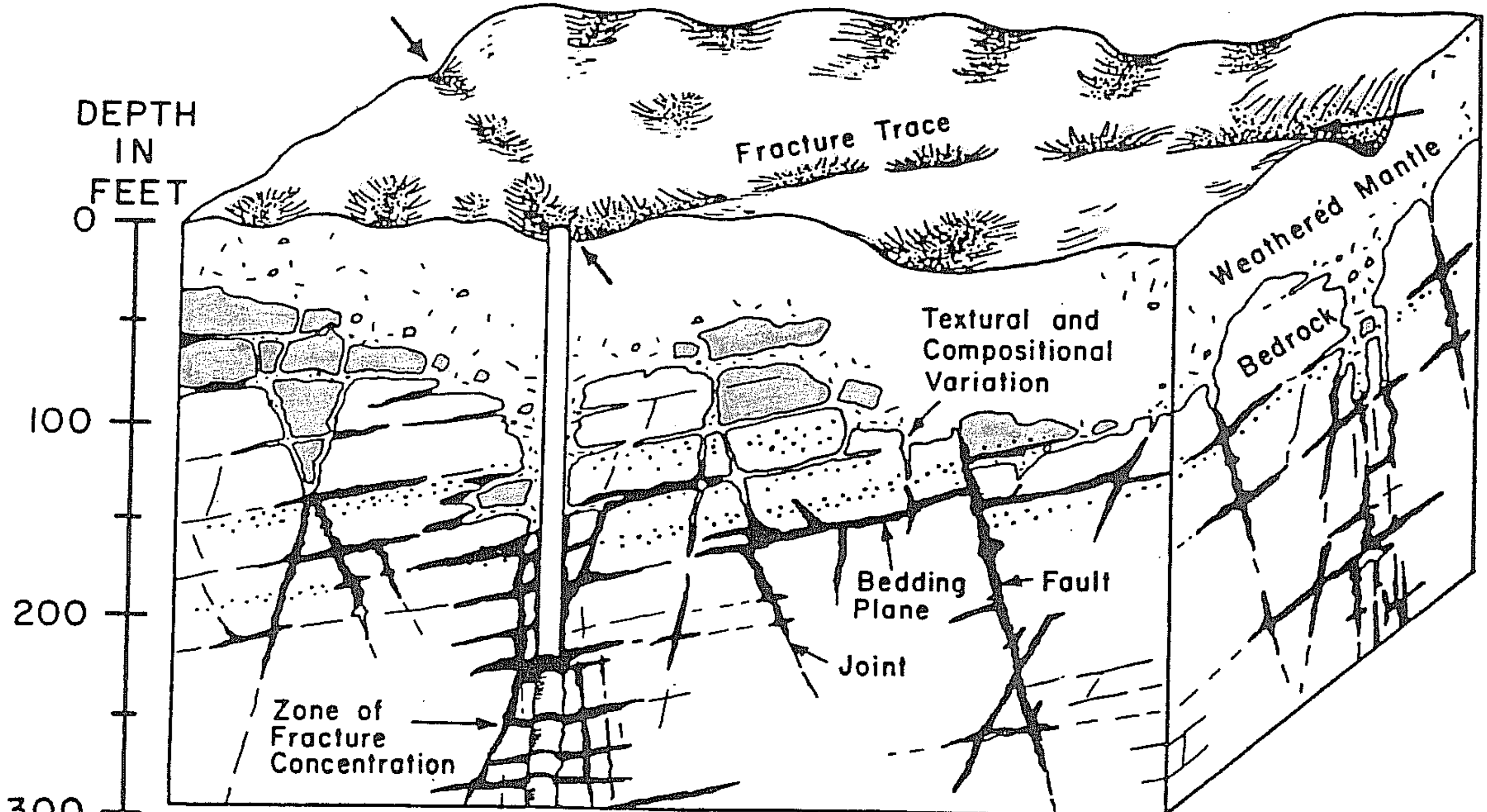
Wisconsin Glacier Map/Geologic (fig.1)



Physiographic Provinces Map (fig.2)

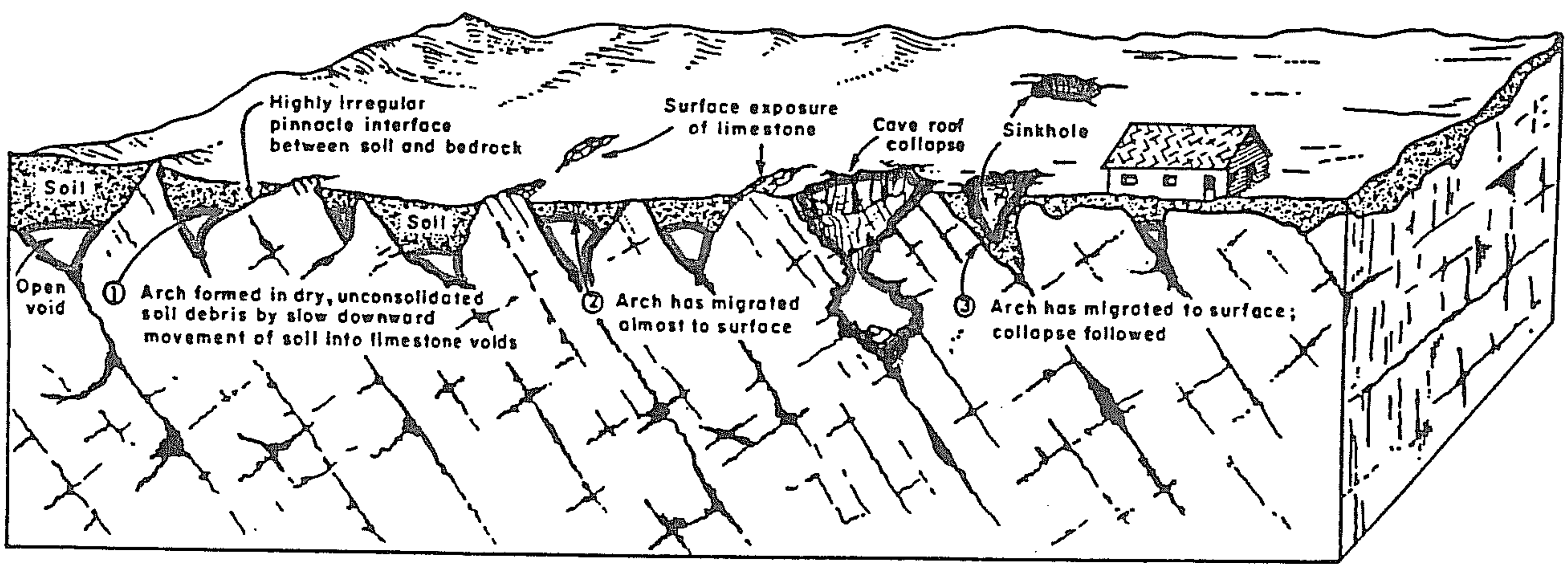


Hydrologic Features Diagram (fig.3) (Parizek, 1971.)



Karst Solution Channel Diagram (fig.4) (After Lattman and Parizek 1964)

Block Diagram showing geologic factors that may account for cavern distribution.



Sinkhole Formation Diagram (fig.5)

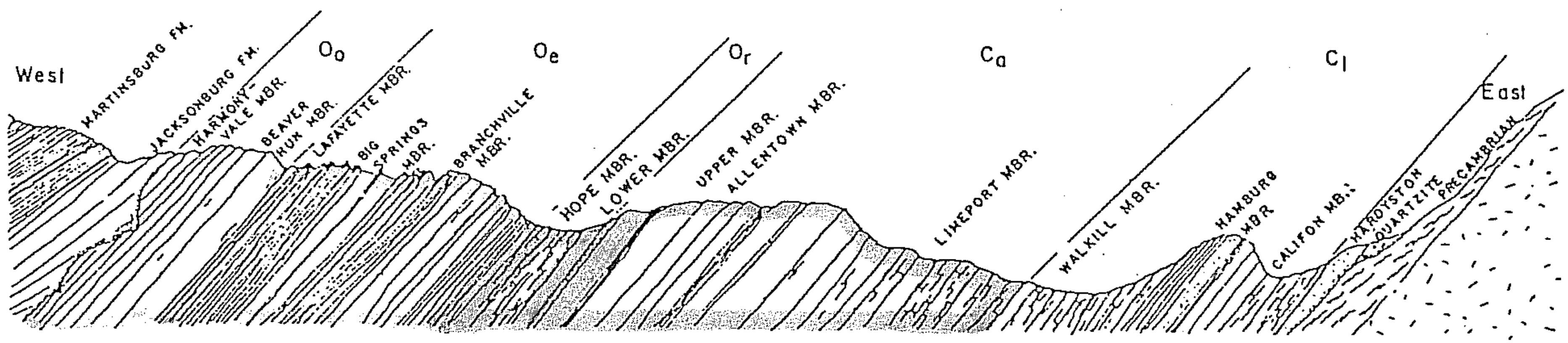
SUBDIVISION OF THE KITTATINNY LIMESTONE

	Formation Name used on N.J. Geol. Map	Formations recognized by H.B.Kummel & Others	Formations Recognized by A.A.Drake & F.J.Markewicz	Current Stratigraphy as used by F. J. Markewicz and R. F. Dalton		
LOWER ORDOVICIAN	KITTATINNY LIMESTONE	Beekmantown	Epler	Ontelaunee Formation	Harmonyville mbr.	
					Beaver Run mbr.	
				Epler Formation	Lafayette mbr.	
					Big Springs mbr.	
					Branchville mbr.	
			Rickenbach	Rickenbach Formation	Hope mbr.	Crooked Swamp Dolomite Facies
					Lower mbr.	
CAMBRIAN		Allentown	Allentown	Allentown Formation	Upper mbr.	
					Limeport mbr.	
		Tomstown	Leithsville	Leithsville Formation	Walkill mbr.	
					Hamburg mbr.	
					Califon mbr.	

The table indicates the present stratigraphy used in New Jersey and its correlation to those formational names used by earlier workers.

SOURCE: OFFICE OF THE STATE GEOLOGIST

Subdivision of Kittatinnay Chart (fig.6)



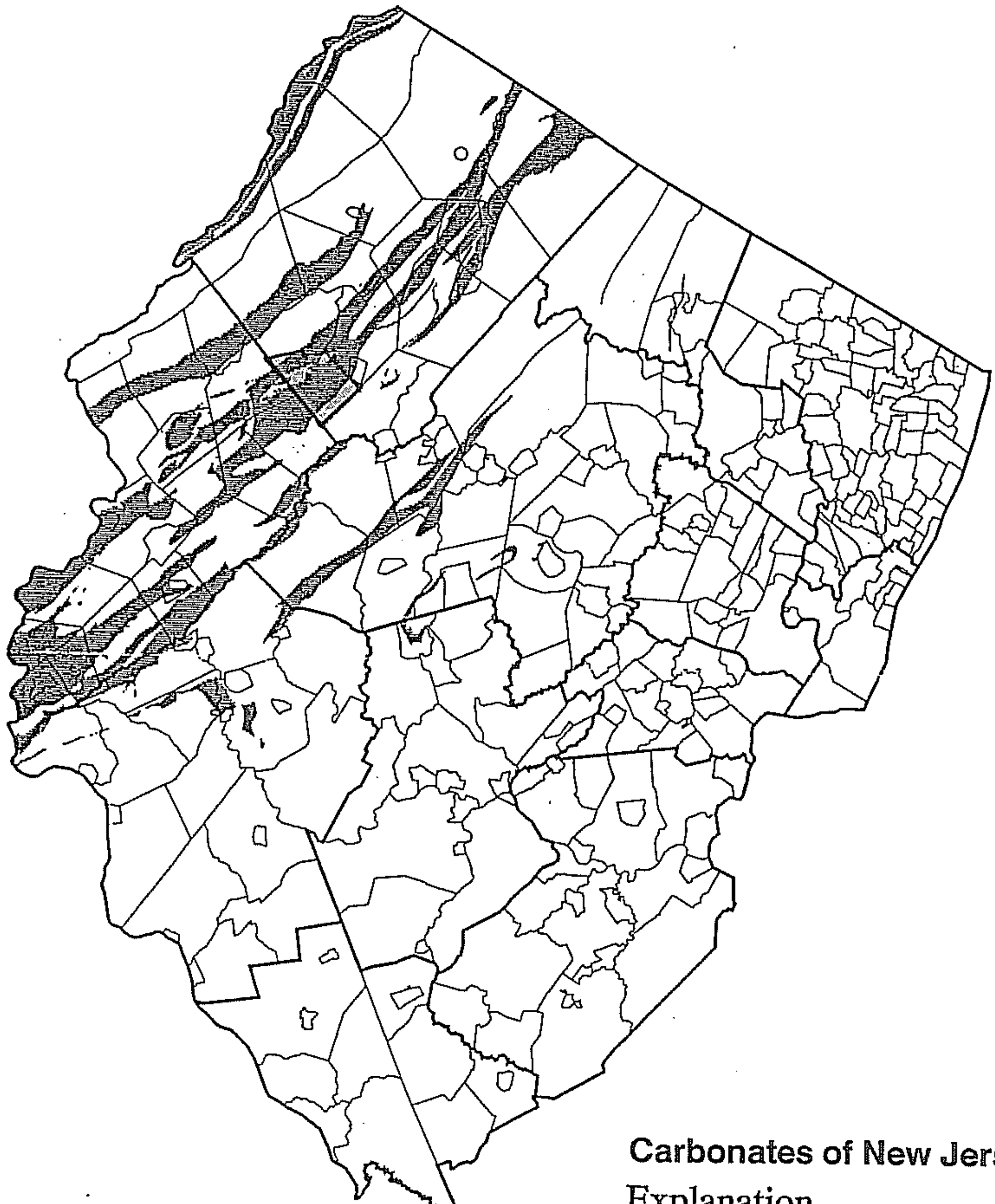
Idealized East-West Geologic Cross-Section of Cambro-Ordovician, "Kittatinny" Carbonate Rocks of New Jersey, Showing Relationship Between Topography and Member Subgroups of the Leithsville (C_l), Allentown (C_a), Rickenbach (O_r), Epler (O_e) and Ontelaunee (O_o) Formations.

Cross Section of Kittatinnay Diagram (fig.7)

SOURCE: OFFICE OF THE STATE GEOLOGIST

Carbonate Rocks of New Jersey

Generalized from the New Jersey Atlas Sheet Series Geologic Overlays



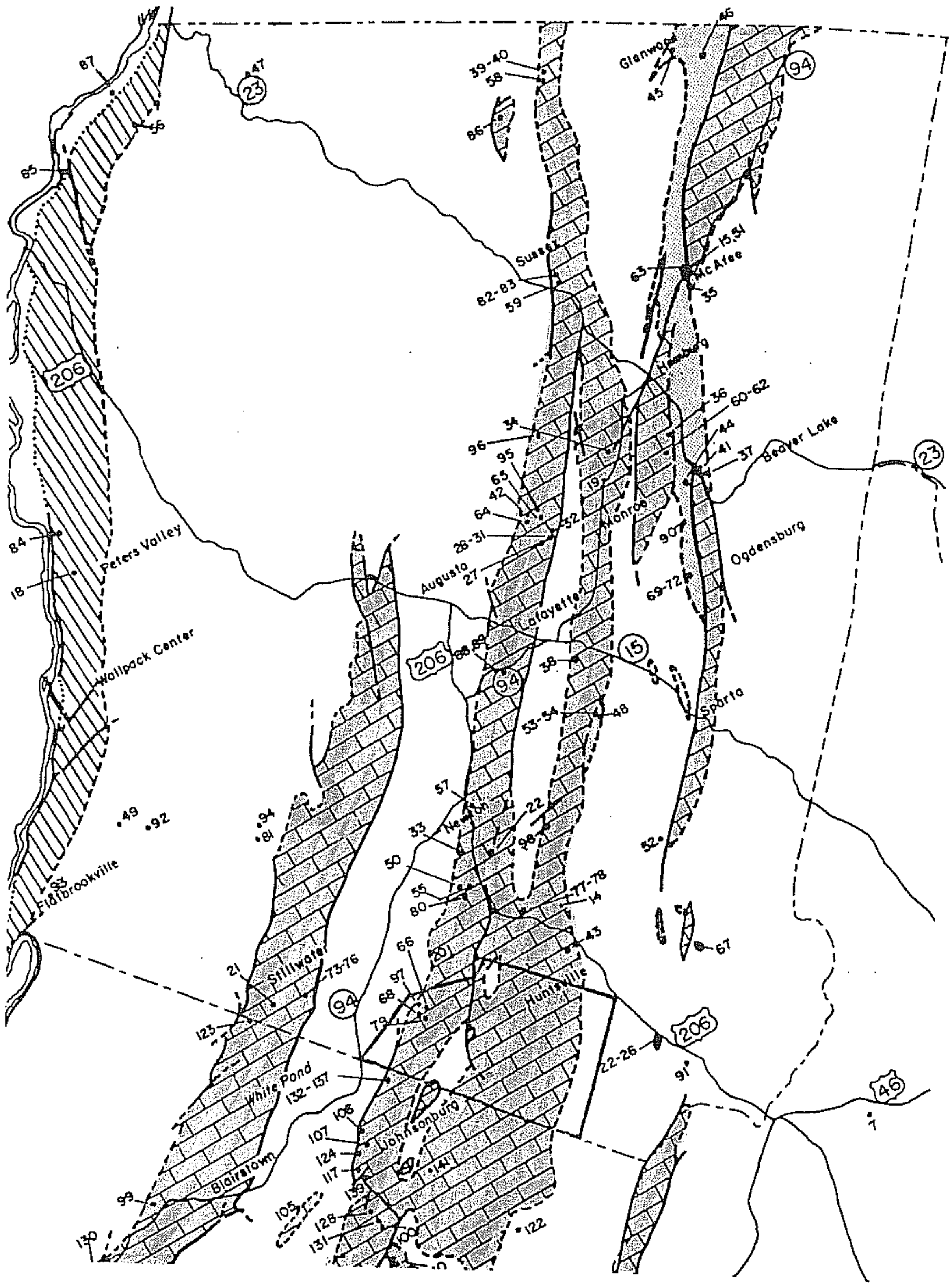
Carbonates of New Jersey Map

Explanation

- Carbonate rock formations
- County boundary
- Municipal boundary

New Jersey Geological Survey
June 1993

0 5 10 15 20 25 30



Limestone Cave Map

66. **Rocky Ledge Cave** *40°59.3'N;74°44.9'W, 620, Tranquility Quadrangle, PR, R. Shotwell*

Rocky Ledge Cave is on the farm of Ralph Shotwell, half a mile northeast of Swimming Pool Cave. The cave is three to four feet in width and 55 feet in length. Many interesting leads exist on the right side and at the back, but further progress is blocked by a large rock in the middle of the passage. Some flowstone can be found. The cave is a solution channel in the Rickenbach Formation, which follows the dip of the bedding; about 30° to the northwest.[13,27]

68. **Shotwell Cave** *40°59.7'N;74°49.7'W, 620, Tranquility Quadrangle, PR, R. Shotwell*

Shotwell Cave is located 100 yards north of Swimming Pool Cave, at the south end of a fifty-foot deep sinkhole next to the road. The cave, just above the water level of a large pool, is developed for about 40 feet in a fissure, parallel to the cliff face. It is formed in the Rickenbach Formation.[11,27]

79. **Swimming Pool Cave** *40°59.7'N;74°49.7'W, 600, Tranquility Quadrangle, Fl, PR, Mrs. Collins*

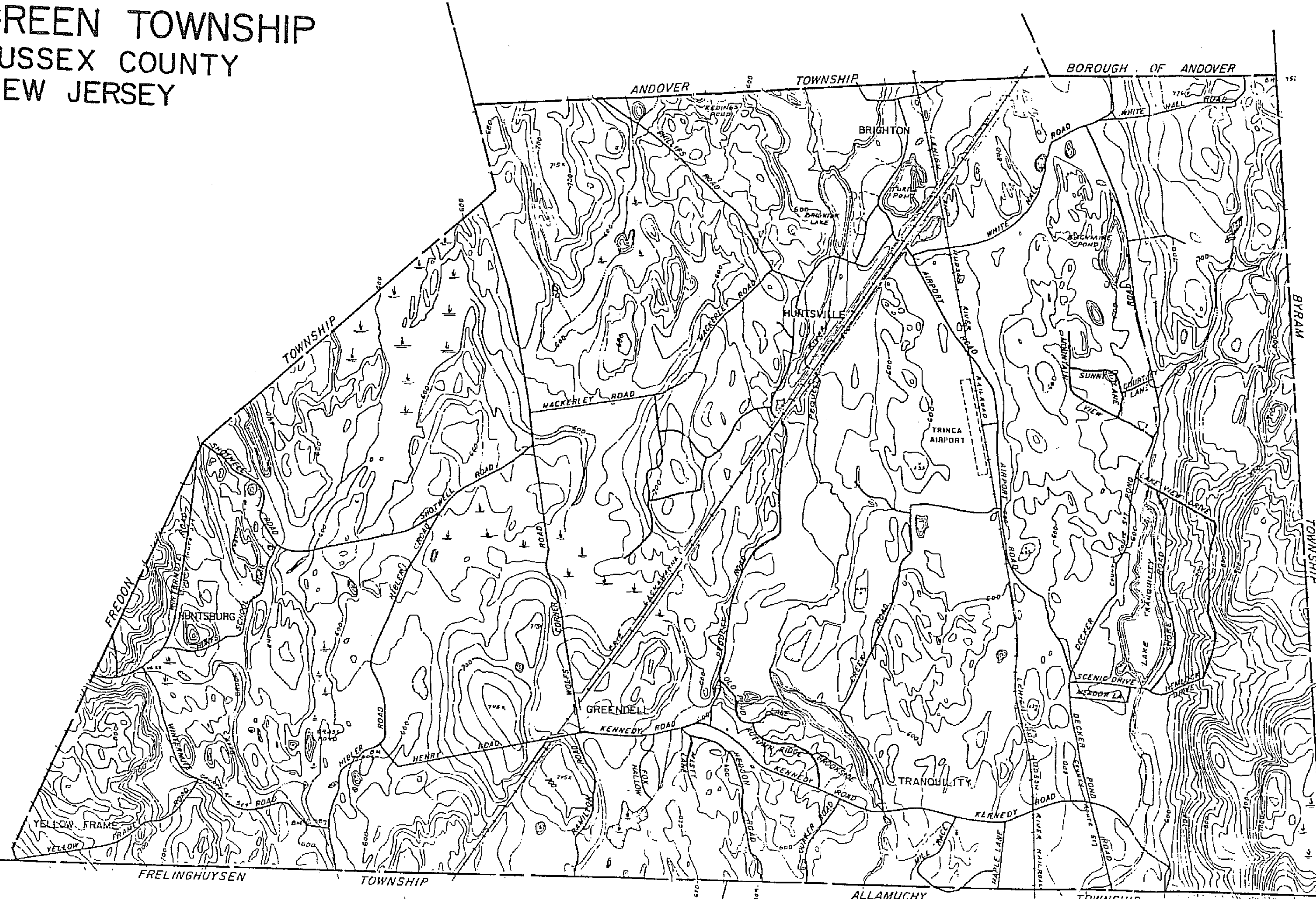
This cave (Plate 7) is located three miles northeast of Johnsonburg near Shotwell Cave. An artificial pond is directly below the entrance; the water completely floods the cave except during periods of exceptional drought (as in late Fall of 1957 and 1963). The cave is both geologically and biologically interesting. Quartz crystals were once found here in considerable numbers and the twilight zone of the cave has an exceptionally rich fauna – several species of salamanders, beetles, water striders, small crustaceans, frogs, spiders, and cave crickets. This cave, which is in the Rickenbach Formation, has 400 feet of passages.[25,27,59,65,67]

97. **Sinking Stream (Huntsburg)** *Newton West Quadrangle*

There is a stream on Route 519 which sinks under a ledge. There are several small openings nearby. The rock here is the Epler Formation.

GREEN TOWNSHIP
SUSSEX COUNTY
NEW JERSEY

BASE MAP



MAP SOURCE : UNITED STATES GEOLOGICAL SURVEY
1954 PHOTO REVISED 1971
CONTOUR INTERVAL 20 FEET
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GEOLOGY BY : NEW JERSEY GEOLOGICAL SURVEY, 1994

NOTES:

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SCALE:

1000' 0 1000' 2000' 3000' 4000' 5000' 6000' 7000'

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Environmental Consultants

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for the
GREEN TOWNSHIP
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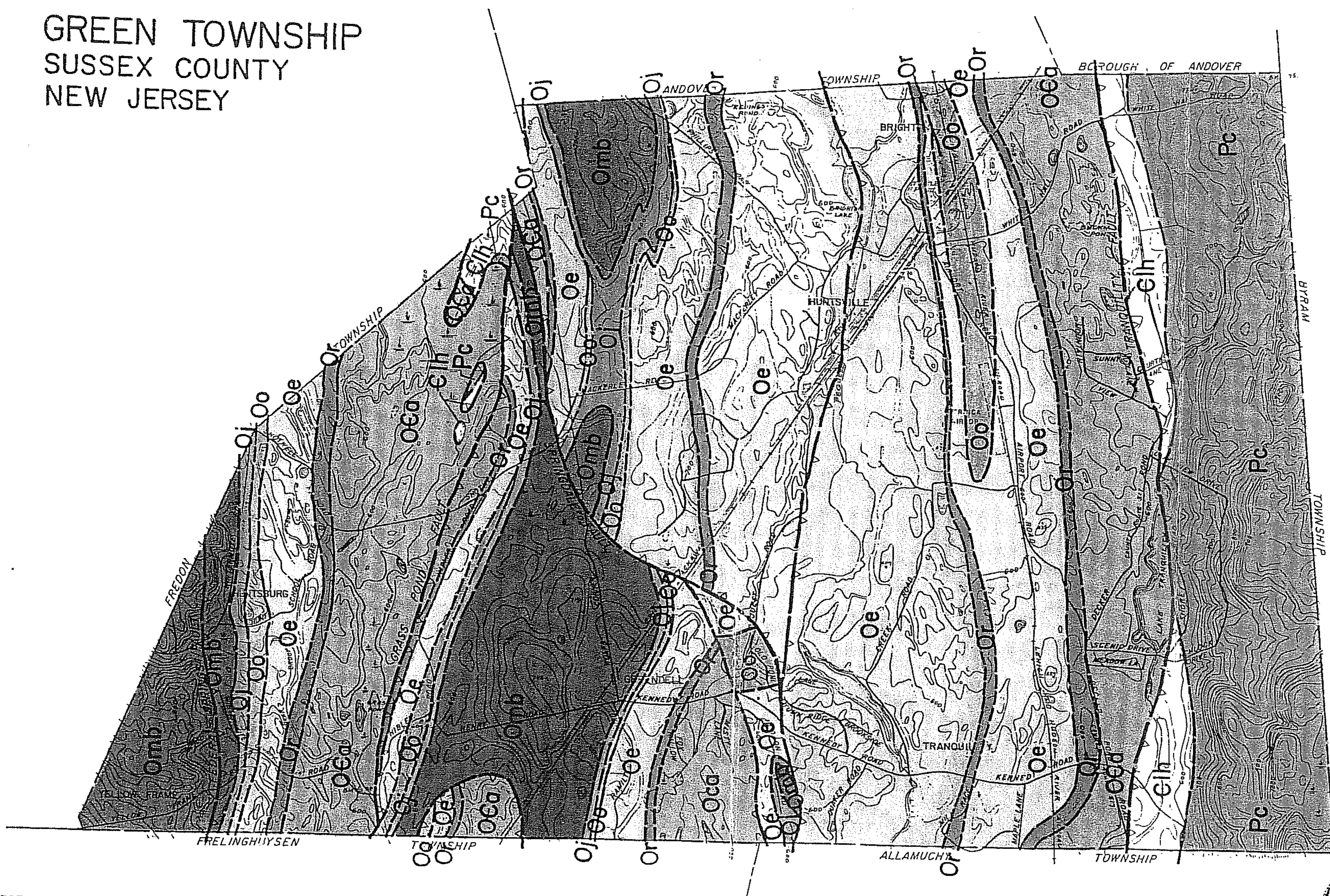

BEDROCK GEOLOGY

Cambro-Ordovician Sedimentary Rocks

- Omb Martinsburg Shale
- Oj Jacksonburg Limestone

Kittatinny Supergroup

- Oo Ontelaunee Formation
- Oe Epler Formation
- Or Rickenbach Formation
- OЄa Allentown Formation
- Єlh Leithsville and Hardyston Formation
- Pc Undifferentiated gneisses and granitic rocks

Fault

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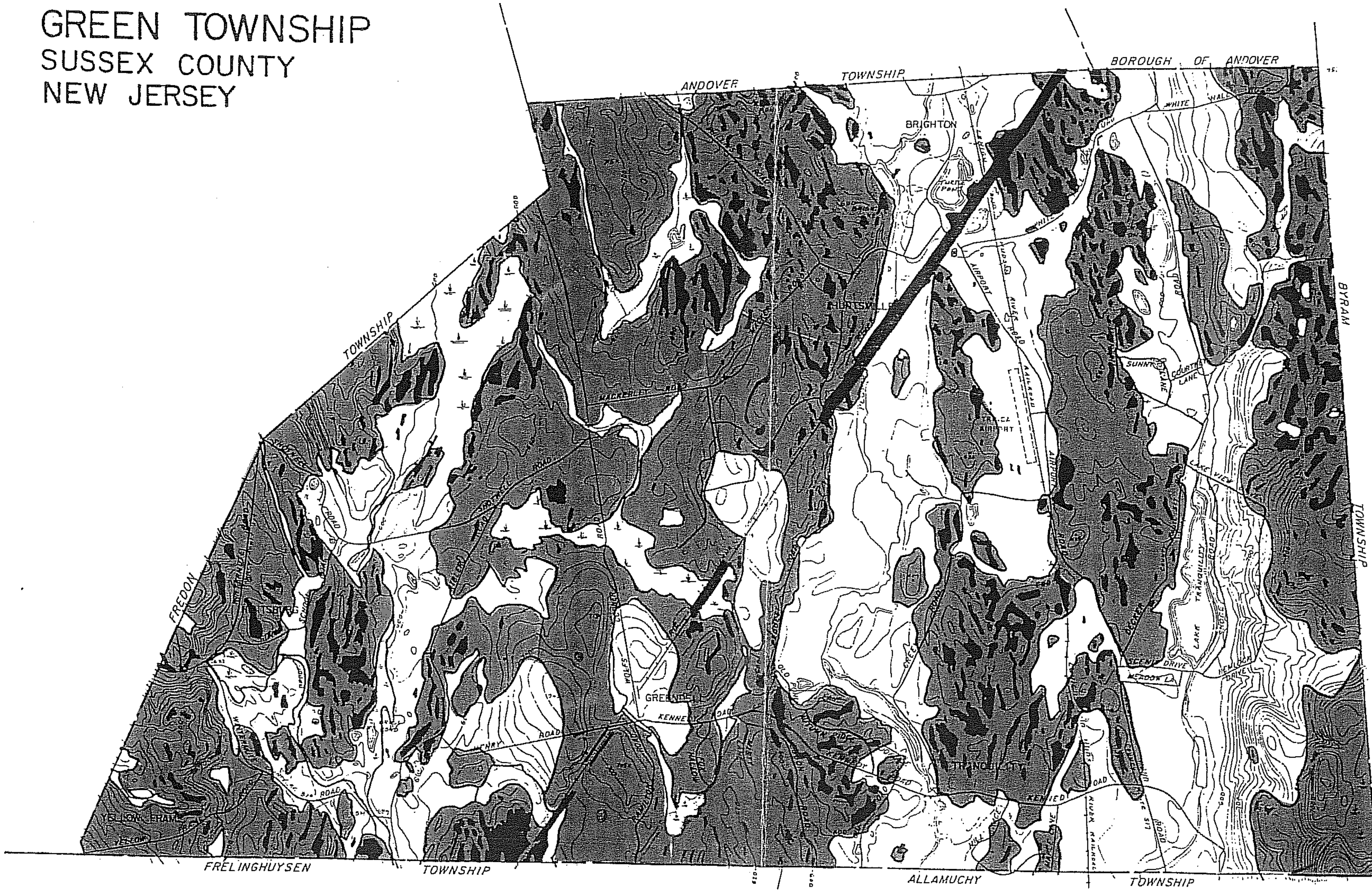

SURFICIAL GEOLOGY

ROCK

Thin Discontinous Deposits

- Bedrock Outcrop
- Thin Surficial Cover less than 10 feet thick

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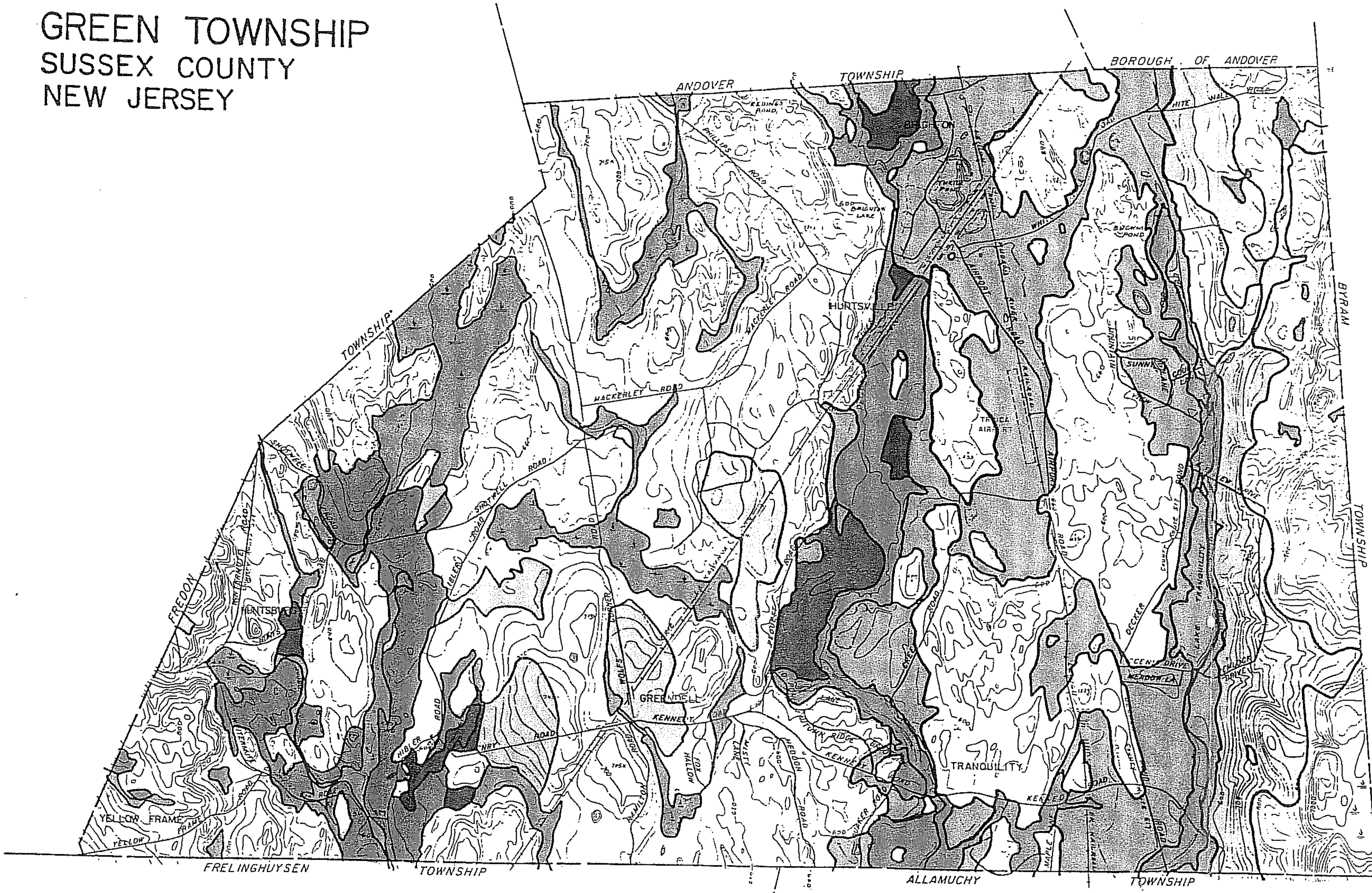

SURFICIAL GEOLOGY

DEPOSITS

Post Glacial

- Alluvium Stream

Glacial Deposits

- Till
- Meltwater
- Lake - Bear Creek
- Lake - Upper Pequest Valley

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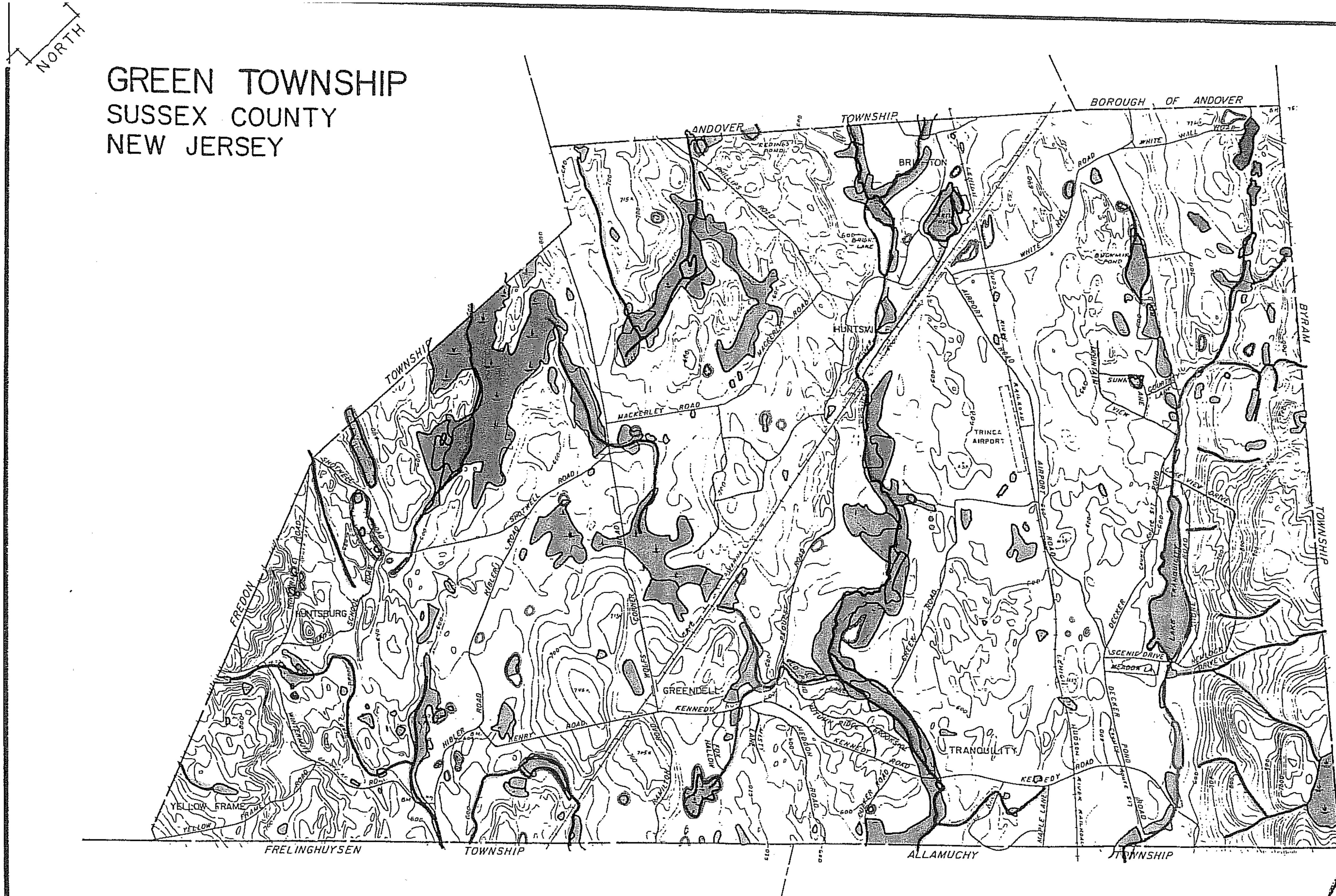
SURFICIAL HYDROLOGY



Surface Water

Wetlands

Sinks

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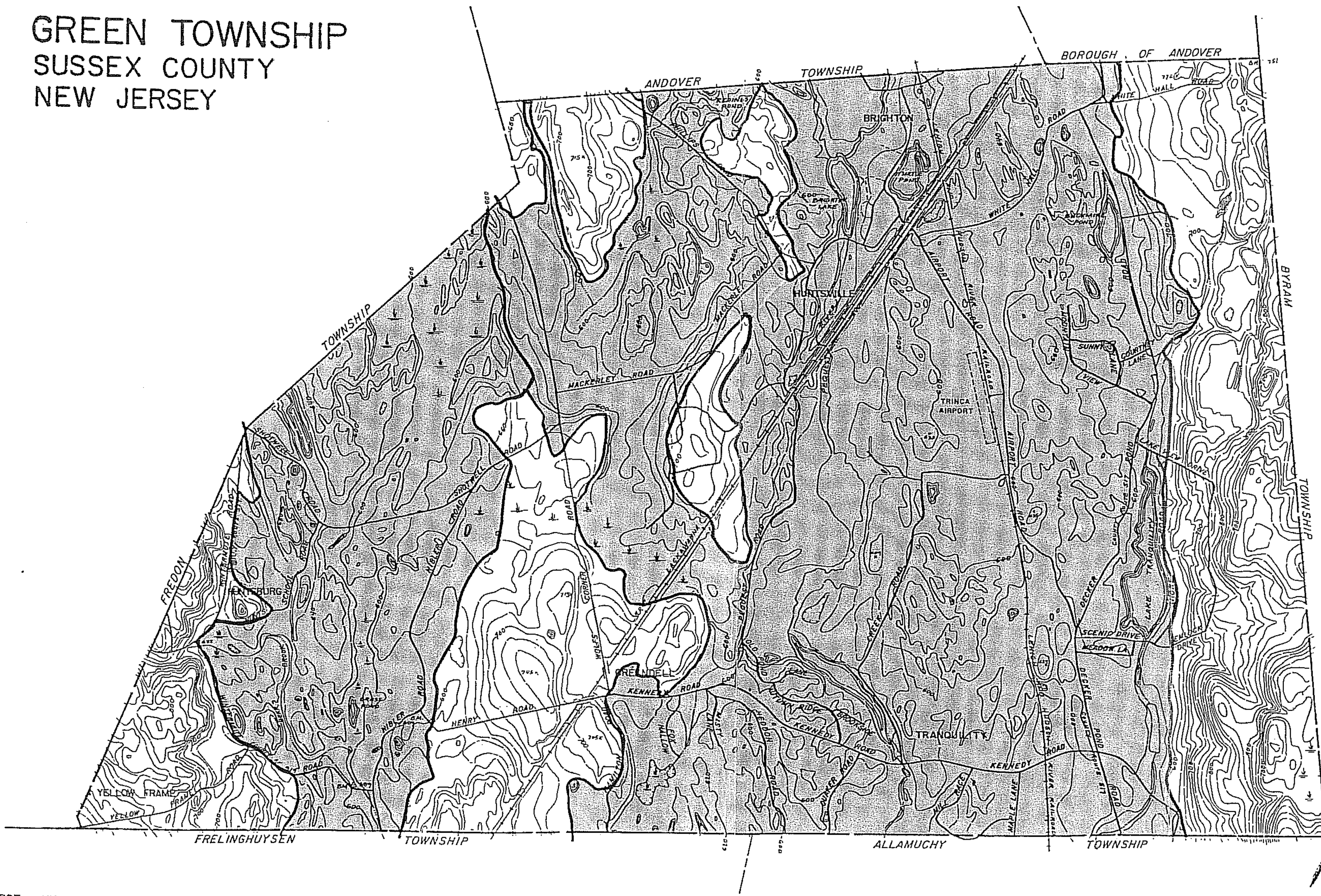

SENSITIVE GEOLOGIC DISTRICT

Area Underlain by Less Resistant Limestone

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