Mine Hill lies in an exciting region of modern geologic research. The hard crystalline rocks that form the core of the hills and the softer rocks that underlie the valleys of western Connecticut have long puzzled geologists. It is only within the last decade that researchers have begun to understand the events which long ago formed the region. The key which is finally unlocking these geological mysteries is the theory of plate tectonics (or, as it was formerly called, continental drift).

The theory of plate tectonics suggests that the surface of the earth is comprised of a dozen or more independently moving pieces called plates (see Fig. 1). The interactions of these plates have shaped all the large scale features of the earth's surface. When they move past each other great tears in the earth are formed, such as the San Andreas Fault in California. These tears are known as transform faults. Places where plates move away from each other appear on the surface as submerged oceanic mountain chains called spreading ridges. When plates move under or over each other long trenches form; these trenches, the deepest places in the oceans, are called subduction zones. Unfortunately, plates do not move past each other easily. They bump and grind along their edges, making transform faults, spreading ridges, and subduction zones the sites of very intense and hazardous earthquake activity.

The other great force on the earth's surface is water. In either liquid or solid form, as a river or as a glacier, water is the master sculptor which shapes the ridges and valleys. Water is also the most important factor in the phenomenon of weathering. Weathering is the process that turns rocks into clay and, when combined with the carrying and carving capacity of rivers and glaciers, turns lofty mountains into low hills.

Plate tectonics and the action of water combine to create the three main types of rocks: igneous, metamorphic, and sedimentary (see Fig. 2). Igneous rocks (from the Latin word for fire) are rocks that were at some time in a hot molten state. This includes the lavas and ash falls that come out of a volcano (called extrusive igneous rocks) and the molten magma which feeds a volcano but never reaches the surface (called intrusive igneous rocks). The high heat and pressure of deep burial beneath the surface of the earth may cause rocks to take on a new texture or chemical composition; these changed rocks are called metamorphic (from the Greek and Latin for transformation). The third type of rocks, sedimentary rocks, are formed by the deposition and cementation of eroded material derived from igneous, metamorphic, or other sedimentary rock.
Igneous rocks are principally formed where plates move away from each other (spreading ridges), and metamorphic as well as igneous rocks form where plates move toward each other (subduction zones). Along spreading ridges, hot magma wells up from inside the earth to fill the space left by plates moving away from each other. When this magma cools, it solidifies into igneous rocks such as basalt and gabbro.

When new material is added along the ridges, a corresponding amount of old material must be consumed in subduction zones. Hence, the heavier portions of the subducted plates are incorporated into the earth's interior. The lighter portions rise up in huge molten blobs of magma and intrude into the overlying plate. When this magma cools and solidifies, it forms igneous rocks such as granite and diorite. If it reaches the surface, volcanoes are born and extrusive igneous rocks are deposited.

Subduction zones are also zones of very high pressure (because the plates are pushing towards each other). These pressures lead to the formation of metamorphic rocks. Subduction zones also lead to the formation of sedimentary rocks. The compressive forces and volcanism push up mountain belts which are eroded into the raw material needed for the formation of sedimentary rocks.
The Geologic History of Southern New England

Long ago, the present location of Mine Hill was probably deep ocean. The explanation of how southern New England was transformed from ocean to continent is a great achievement of plate tectonic theory. Although the interpretation of many pieces of the puzzle is still being debated, the overall history as shown in Figures 3a to 3f is now agreed upon by most geologists.

![Figure 3a: 500 million years ago](image)

Five hundred million years ago, southern New England probably resembled the Atlantic coast off North Carolina today. Along the shelf, shallow water marine sediments were deposited, forming limestones, sandstones, and sandy shales. These regions of shallow water shelf deposits are called *miogeosynclines*. Off the shelf on the continental rise deep water sediments such as black shales and silty shales were deposited in what is called a *eugeosyncline*. The transition zone along the shelf edge between the miogeosyncline and the eugeosyncline retained less sediment because of the steepness of the slope. The marine sediment from different depths and slopes can still be recognized in the metamorphic rocks of New England.

Although the coastline and continental shelf of 500 million years ago may have resembled those of today, other aspects of ancient geography were very different. For example, what is now the eastern coast of North America was then the southern coast. North America was also much closer to the equator and the climate was probably tropical. In addition, there was a small continent between North America and the Euroafrican land masses. This small continent is now known as Avalonia and, as we shall see below, can still be visited today.

![Figure 3b: 475 million years ago](image)

About 475 million years ago, the ocean between North America and Avalonia began to close. The ocean floor may have been subducted under Avalonia but researchers have not yet found conclusive evidence.

Geologists have named this ocean the Iapetos Ocean after the mythical father of Atlas, for whom the Atlantic Ocean is named.
By 450 million years ago, a process known as oduction had begun. Oduction occurs when the ocean floor is pushed over instead of under a continent, thrusting huge kilometers-wide chunks of rock great distances landward. As a result, the transition zone was squeezed out and the eugeosyncline shoved on top of the miogeosyncline along a thrust fault known today as Cameron’s Line. The enormous pressures created by the oduction process then began folding and metamorphosing all of the rocks along the continental margin. This period of thrusting, folding, and metamorphism is called the Taconian Orogeny and was the first stage in the building of the Appalachian Mountain Belt.

Around 360 million years ago, the Appalachian Mountain Belt experienced another period of intense folding and metamorphism called the Acadian Orogeny. Folds from the Taconian Orogeny were refolded, metamorphosed rocks were remetamorphosed, and granitic masses were intruded (including the Mine Hill Granite Gneiss), greatly complicating the geology of southern New England. This phase of mountain building appears to have been caused by the collision of North America and Avalonia and completed the closing of the Iapetus Ocean.

Following the Acadian Orogeny came the first of three periods of rifting when continental blocks that were colliding tried instead to pull apart. This led to the formation of the Boston and Narragansett Basins, broad, flat valleys that filled with sediments eroded from the surrounding hills. Beginning about 260 million years ago, rifting ceased and was replaced by the final period of mountain building in the Appalachians. This period, known as the Allegheny Orogeny, was caused by the collision of Africa with North America. The collision caused yet another phase of folding and metamorphism, this time mostly to the east in Rhode Island and eastern Connecticut; there is little evidence of the collision in western Connecticut. This last mountain building event was part of the great gathering together of all the continents into the super-continent of Pangea.
Figure 3f: Southern New England today

About 225 million years ago, the second period of rifting started as a new ocean began growing between North America and Avalonia. But this ocean was not to be and rifting stopped, leaving behind the sediment-filled Connecticut Valley. The third and final period of rifting began 180 million years ago as a new ocean tried once again to grow, this time between Africa and Avalonia, leaving Avalonia welded onto North America. This attempt proved successful and eventually formed the Atlantic Ocean which is continuing to grow wider today at a rate of about 2 centimeters every year. Avalonia has remained a part of North America and now includes all of Rhode Island, the eastern strip of Connecticut, and southeastern Massachusetts. The rocks of the miogeosyncline and the eugeosyncline between ancient Avalonia and the Housatonic Highlands are all that remains of the Iapetus Ocean. Although it has been severely folded, Cameron’s Line is still an important feature in Connecticut’s geology because it marks the precise junction between the miogeosyncline and the eugeosyncline. It also indicates the approximate location of the continental shelf edge during the geologic past when east was south and the Atlantic was the Iapetus.

The Geology of Mine Hill

Mine Hill is located just east of Cameron’s Line in the strongly metamorphosed deep-water eugeosynclinal sediments of the Iapetus Ocean (Figs. 3f and 4). Most of the preserve is underlain by the Mine Hill Granite Gneiss, a 360 million year old rock containing feldspar, quartz, and mica. Because the mica and other minerals are all aligned in the same direction, the rock is called a granite gneiss instead of a granite. Although it clearly had an igneous origin, the aligned (or gneissic) character of the rock indicates that at the time of intrusion the whole region was still under strong pressure, forcing the minerals to grow parallel to each other. In a way, the Mine Hill Granite Gneiss is both an igneous and a metamorphic rock.

The only other rocks within the preserve are part of the Hartland Formation (see Geology Map). Hartland Formation rocks are primarily extremely metamorphosed sediments from the eugeosyncline and show a wide variety of compositions and appearances. They range from a mica-rich quartzite (metamorphosed sandy shale) that looks very similar to the Mine Hill Granite Gneiss to a schist (metamorphosed black shale) that crumbles easily in one’s hand.

The Quartz-Siderite Veins

Striking northwest/southwest across Mine Hill in the granite gneiss are the well-known quartz-siderite veins. These veins are famous for the wide variety of minerals they contain and for the beautiful specimens that have been collected from them. The best known of these minerals, siderite (iron carbonate), was the object of the mid-19th century iron mining efforts. Galena (lead sulphide) was also mined from the veins for its lead and for the small quantity of silver it sometimes contains. Some of the other minerals that are commonly found are quartz (silica oxide), pyrite (iron sulphide), goethite (hydrous iron oxide), and limonite (weakly crystalline goethite). Rarely, the minerals malachite (hydrous copper carbonate), loellingite (nickel iron arsenide), and bismuthite (bismuth carbonate) are also collected. In all, a total of 32 different minerals have been reported from these veins.

Over the last 200 years at least 7 different quartz-siderite veins have been identified on Mine Hill. Tunnels have been cut on three of these veins. The most extensive mining and tunnelling was done on the largest known vein, where three horizontal tunnels (adits) and numerous vertical shafts (stopes) were put
in (see Tunnel Map). A short tunnel, the North Adit, was excavated in a vein located north of the main mining operations and another, the South Adit, was dug in a vein south of the Mine Hill Preserve. Numerous shallow test pits and trenches were dug to check for the presence of quartz and siderite, and these may be found all over Mine Hill. Outcrops of several veins can be seen in the upper and lower quarries.

Near the openings of the adits and shafts are ore dumps and rubble piles which contain beautiful mineral specimens from the veins. Siderite is the most prominent mineral in these piles and ranges in color from cream to a shining copper kettle brown. Black sphalerite with tiny hints of red is found alone and in association with silvery-blue galena all embedded in siderite. Many single large pyrites in the intriguing crystal shapes called pyritohedrons and octohedrons have been found but are becoming rare. Perhaps the most attractive specimens are masses of siderite sprinkled with gleaming yellow pyrites.

All of the quartz-siderite veins were intruded along minor faults trending northwest/southeast at about 120° and dipping steeply to the southwest at 75° to 90°. The pattern of the intrusion is well exposed in the tunnels in the old vein. Close inspection reveals not one but several vein members of different compositions running parallel to each other so that as a group they appear to be a single vein varying in width from 1/2 to 3 meters.

Any one vein member may range in composition from pure quartz to nearly pure siderite to a mixture of both and may run for only a few meters or more than 100 meters. In several places, one or more vein members split off from the main vein to form a branch or a parallel vein. This pattern is best observed in the lowest adit where the tunnel intersects three side veins to the main vein.

The origin and formation of the quartz-siderite veins is not yet certain and no explanations have yet been published. However, it is probably not a coincidence that the igneous veins of Mine Hill are so close to the sedimentary iron deposits found near Salisbury, Connecticut. One possible explanation is that thermal activity associated with the intense metamorphism of the Acadian Orogeny may have caused a buried deposit similar to the Salisbury ores to be remobilized and injected above as veins. This process would be possible if deformation of Cameron’s Line had, through recumbent folding or thrusting, placed a portion of the Stockbridge-Inwood marble belt with a sedimentary iron carbonate member beneath the Hartland Formation. This explanation, is however, extremely speculative and there is little geologic evidence on Mine Hill to support or deny it. The only piece of evidence that can be established with certainty at the present time is that since the veins intrude the Mine Hill Granite Gneiss, they must be younger than it.

![Regional geology](image)

Figure 4: Regional geology
Plan of the Tunnels

with three-dimensional relationships indicated
The Quartz Veins

Five veins of almost pure quartz were also mined on the hill, three of which are on the preserve's property (see Geology Map). Unfortunately, there are no known historical records of this episode of Mine Hill's mining history. Most likely, the quartz was used in glassmaking, ceramics, and paint manufacture.

Four of the quartz veins trend at about 205° and the fifth, associated with the north adit, trends at 235°. Their geologic origin may be related to the origin of the quartz-siderite veins. However, because they seem to be cut off by quartz-siderite veins in two places (near shaft S and in the North Adit), the quartz veins probably formed in an earlier geologic time.

The Granite Gneiss Quarries

In addition to harboring the famous quartz-siderite veins and the lesser known quartz veins, the Mine Hill Granite Gneiss has also had economic importance as a building stone. Seven separate quarries have been excavated on the Mine Hill Preserve (see Geology Map), and at least one other has been dug in the granite gneiss off the preserve. Two of these quarries are still active but only on a limited basis with an annual production of about 1500 tons. Although it once saw use primarily as "dimension stone" for bridges and buildings, it is now sold as facing stone, flag stone, mantel pieces, and wall stone.

The desirability of the Mine Hill Granite Gneiss is largely due to its attractive uniform blue-grey color and its workability. The gneissic character of the rock gives it a pronounced "rift," which allows the rock to be split into any required size. Along the rift, the granite can be split with two or three well-placed blows from a sledge hammer. Perpendicular to the rift, however, is what quarrymen call the "hardway," which must be drilled if it is to be split. The normal technique for handling the hardway is to drill a series of short holes 10 to 12 centimeters apart, fill each hole with a wedge and two "feathers," and carefully tap each wedge once down and back along the line of drill holes until the rock cracks.

Another reason that the Mine Hill Granite Gneiss was so popular in the past is the enormous pieces that can be quarried from it. The limiting factor in the size of quarried stone is the distance between the thin cracks, called joints, that run through all bedrock. Joints form in two principal ways; either as minute faults caused by the pressures of mountain building events or from the release of pressures due to the removal of overlying rock by erosion and glaciation (joints due to removal of overlying rock are given the special name sheeting joints). According to a local story, the joints are so far apart in the Mine Hill Granite Gneiss that a piece was once removed so large that it took two weeks to load on the train and two railroad cars to transport it.
The History of Glaciation

The climate of the earth is strongly affected by the shape, size, and position of continents, and the height and position of mountain ranges. Thus, as North America grew larger, constructed mountain ranges along its edges, moved north, and turned counterclockwise during the last 500 million years, the climate changed with it. The steady tropical climate of the past is now a temperate one which experiences alternating warm and cold periods on an approximately 100,000 year cycle. Cold periods cause great ice sheets to advance and warm periods (such as the present) force the ice to retreat once again.

The explanation of the periodicity of glacial advances was worked out in the late 1800s by James Croll, a Scotsman, and in the early 1900s by Milutin Milankovitch, a Yugoslavian. However, this theory became generally accepted only in the past four or five years. Milankovitch and Croll suggested that the slight variations in the earth’s orbit around the sun and the slight wobble in the spin of the axis cause enough change in the amount of solar radiation received to touch off a glacial advance. Recent investigations in all the oceans of the world have found conclusive evidence of these glacial cycles and have shown that glaciation began in North America over 5 million years ago. The size of glacial advances increased around 3 million years ago and since that time there have probably been 25 to 30 major glaciations of North America.

Glaciation on Mine Hill

The only ice sheet of which there is a record in southern New England retreated around 14,000 years ago. It is impossible to say how many other ice sheets have reached here because the eroding power of a glacier usually wipes clean any evidence of earlier glaciations. But there is abundant evidence of the Wisconsin Ice Sheet, as the most recent glacial advance is called. Like a great white bulldozer it plowed through New England, pushing a long mound of debris in front of it. When the Wisconsin Ice melted back from its maximum extent, this mound was left to form a low sand ridge called a terminal moraine, part of which we know today as Long Island. In addition to the debris it pushed in front, the glacier also carried crushed sand and rock inside the ice. This material, called drift, was dumped all over New England when the ice melted.

The Mine Hill Preserve is covered by thick drift in three places: on top of the hill, along Mine Hill Road, and on a small area just south of the lower quarry. The drift on top of the hill is part of a streamlined elongate mound, called a drumlin, that probably formed at the bottom of the Wisconsin Ice Sheet while it was advancing. This drift and the glacial sediment along Mine Hill Road are both examples of till, an unsorted assortment of rocks and pebbles of all sizes. The drift south of the lower quarry is an example of ice contact stratified drift that was deposited by water flowing along the contact of the hill and the ice while the glacier was melting.

Most of the rest of the preserve is blanketed by shallow discontinuous patches of till and loose pieces of frost-cracked blocks of Mine Hill Granite Gneiss and Hartland Formation metamorphics. These pieces were probably broken off the bedrock during the first few thousand years after the glacial retreat when permafrost conditions prevailed in southern New England. The rounded edges and weathered surfaces of these tabular rocks distinguish them from the fresh appearance of rubble left over from mining and quarrying on the hill.

Mine Hill is currently undergoing very little geologic change. No significant erosion or earthquake activity is occurring now. Probably the next geologic event to have an important effect on Mine Hill will be the return of an ice sheet about 25,000 years in the future.