A BRIEF GEOLOGICAL GUIDE TO CAMPBELL'S PEACEFUL VALLEY

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INTRODUCTION

Campbell's Peaceful Valley is underlain by rocks that record an important part of the last 400 million years of the geological history of North America. Careful examination reveals evidence of an ancient beach that bounded the eastern coast of North America 420 million years ago. We can see how these beach deposits were deformed into a Himalayan-scale mountain range when a small continent collided with North America 380 million years ago. We can see the effects of Africa colliding with North America 300 million years ago. In many of the boulders along the trails we see samples of lava that erupted from a fracture located three miles to the west of the area. This eruption occurred 200 million years ago when Africa pulled away from North America to form the present Atlantic Ocean, which is still widening at approximately two inches a year. The present topography in the area is largely the result of sculpting by glaciers that covered the area during the last ice age, which ended about 15,000 years ago.

Before describing the geology of Campbell's Peaceful Valley, it is important to appreciate where the area is located with respect to major geological divisions in Connecticut, which are shown on the map and cross section in Figure 1. A good place to view these divisions in the field is from the crest of the sharp hill in the northern part of the area. From here it is possible, when there are no leaves on the trees, to see a great distance. To the west, lies a low region known as the Hartford Basin. The Connecticut River flows through the center of this region, but the basin itself is much older than the river. The basin formed ~200 million years ago when Africa began to pull away from North America. The basin would have resembled Death Valley today, with sediments washing into it from high mountains in the vicinity of Campbell's Peaceful Valley. These sediments form the red sandstone that occurs in the vicinity of Buckland Hills Mall. As Africa pulled away from North America, the Hartford Basin could have become the Atlantic Ocean had another basin not formed off Cape Cod that eventually did become the Atlantic Ocean. The Hartford Basin is bounded on its eastern side by a major fault, which has at least 3 miles of vertical displacement on it. Just to the east of this fault is a major fracture from which lava erupted to form one of the thickest lava flows in the world, which can be seen forming the western horizon.

Between the eastern border fault and Campbell's Peaceful Valley and to the east of this area to the Rhode Island border, much older rocks are exposed that were formed in an ancient ocean between North America and a small continent named Avalon (now Rhode Island) that splintered off from Africa and collided with North America. Recently, Africa has done the same thing as it first shed India and then the Arabian peninsula, both of which are now colliding with Asia to form the Himalayan Mountains (Fig. 2). Approximately 450 million years ago, an arc of volcanic islands between North America and the Avalon continent collided with North America to form the oldest part of the Appalachian Mountains (Fig 3). The sediment eroded from these mountains formed deposits along the eastern shore of North America. It is these sediments that form the rocks underlying Campbell's Peaceful Valley. Approximately 380 million years ago, the Avalon continent collided with North America and the beach sediments were deformed into a Himalayan-scale mountain chain (Fig. 3). The heat and pressure associated with burial below these mountains turned the sediments into the metamorphic rocks seen in the area today. Just as India is being thrust beneath Tibet today (Fig. 2), the Avalon continent was thrust beneath North America (Fig. 3), which accounts for the westward dip of all the rocks in the Campbell's Peaceful Valley area. Approximately 300 million years ago, Africa collided with North America. This produced intense deformation in southern Connecticut, but in the Campbell's Peaceful Valley area only minor folds are evident. Following this continental collision, all of the continents on Earth were assembled into a single landmass, known as Pangea. Connecticut, which was located near the center of this landmass, was near the equator at the time. It was this landmass that began to pull apart to form the Hartford Basin 200 million years ago.

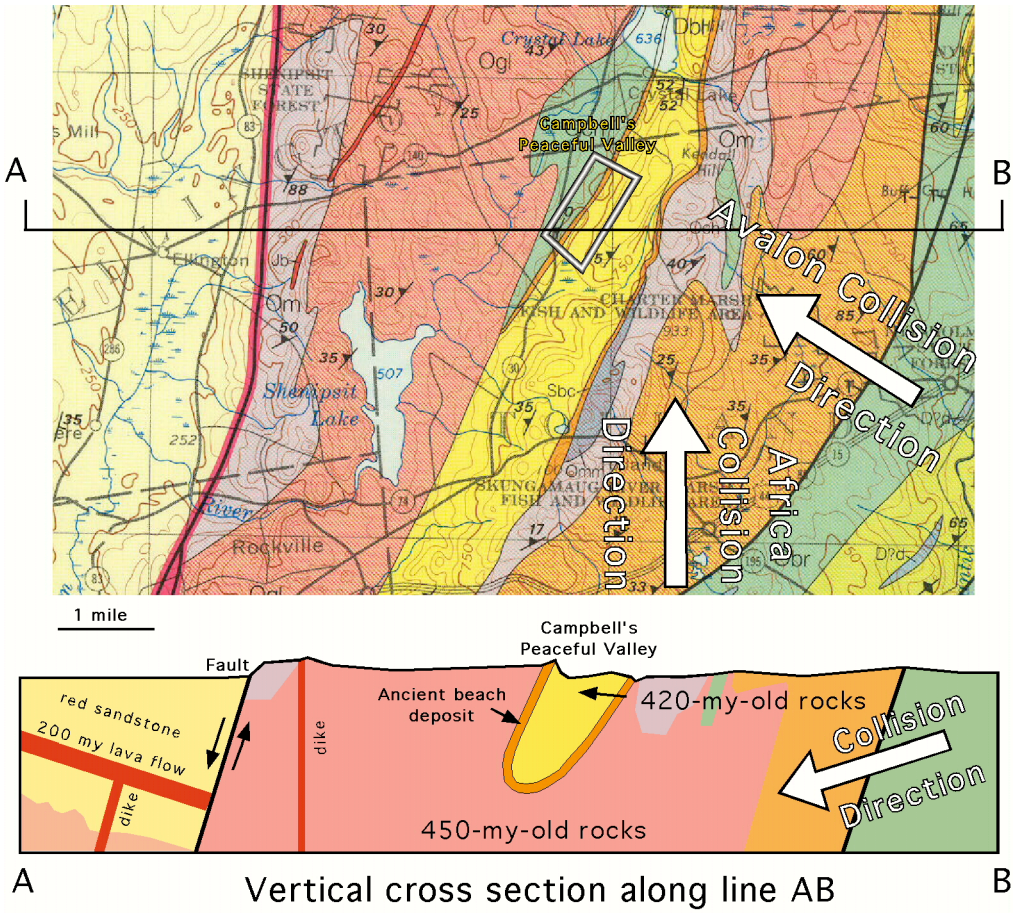

Figure 1. Part of the geological map of Connecticut and vertical cross section showing the location of Campbell's Peaceful Valley. The general north-northeasterly trend of the various rock types is controlled by the direction of collision of the Avalon continent (now Rhode Island) with North America 380 million years ago. A later collision (300 my ago) with the African continent from the south had only minor effects in this region. The large cream colored area in the west is underlain by sandstone deposited in a basin that formed 200 million years ago when dinosaurs roamed the area.

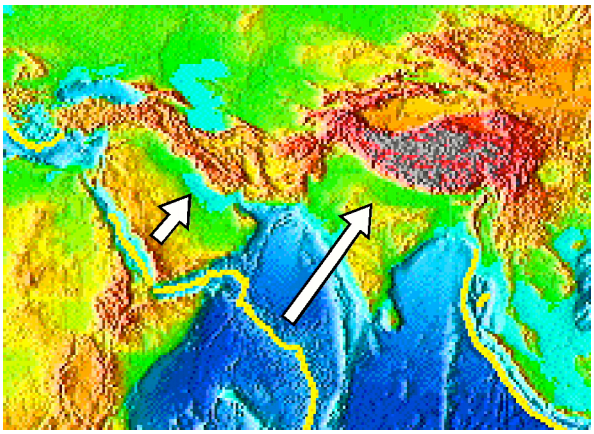

Figure 2. Map showing the Indian and Arabian tectonic plates that have recently (66 my ago) separated from Africa to collide with Asia to form the Himalayan Mountains. At a much earlier time, the Avalon plate separated from Africa and collided with North America 380 million years ago to form an equally high mountain chain in eastern Connecticut.

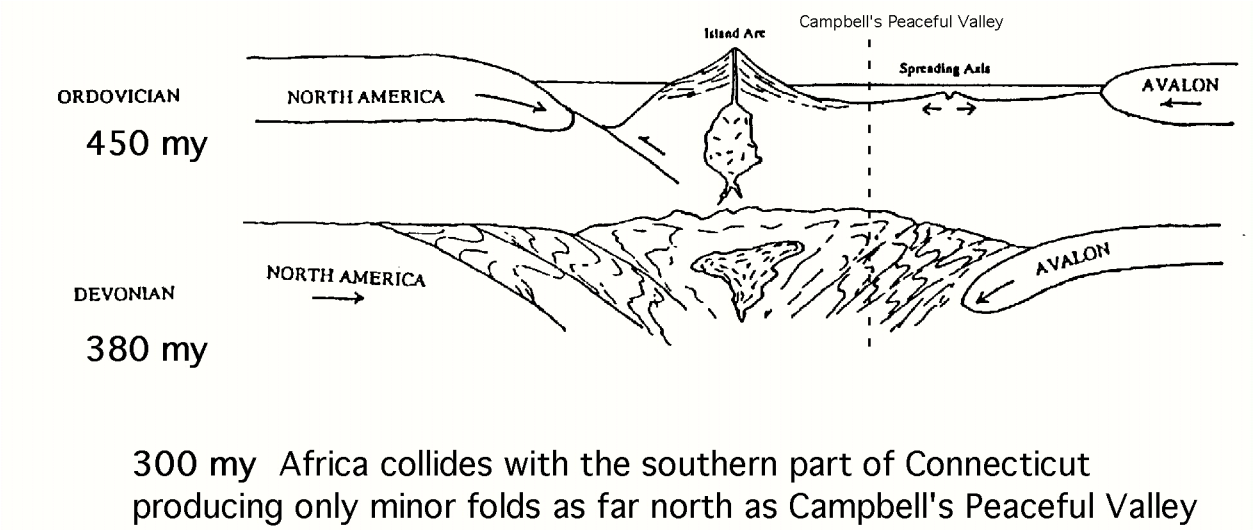

Figure 3. Collisions with North America of, first, a volcanic island arc (450 my), then the Avalon continent (380 my), which remains attached to North America as Rhode Island, and finally, the African continent, which caused considerable deformation of the rocks in southern Connecticut but only minor deformation as far north as Tolland.

GEOLOGICAL POINTS OF INTEREST IN CAMPBELL'S PEACEFUL VALLEY

The top of the hill in the northern part of the area is an ideal place to start a geological tour of the region. The white rock forming the crest of this hill is one of the most easily recognized rocks in New England, and as a result, it played an important role in producing the geological maps of New England. It is known as the *Clough quartzite* from its occurrence on Clough Mountain in New Hampshire. It is composed almost entirely of the mineral quartz, which explains its white color. Toward its base, it clearly contains what were originally pebbles of white quartz, which helps explain the origin of this rock. It was formed from beach sand deposited on the eastern shore of North America 420 million years ago.

To appreciate the sequence of rocks seen in the Peaceful Valley area, it is worth reminding ourselves of what a modern beach deposit consists. Figure 4 shows the typical types of sediment found in association with a beach. At the top of the beach, which waves reach only during storm activity, pebbles are commonly found. Lower down the beach where wave action continuously agitates the sediment, all fine particles are washed away leaving behind sand. The fine material is washed out into deeper, quieter water, where it settles to form mud. If wave action on a beach persists for a long time, most minerals other than quartz will be broken down into smaller particles and washed away into deeper water. As a result, mature beach sand consists predominantly of quartz. On burial, this sediment is turned into the rock known as *quartzite*, which underlies the crest of the northern hill at Campbell's Peaceful Valley and the prominent ridge along the western side of the property. Careful inspection around the crest of the northern hill will reveal pebbles in the quartzite, which record ancient storms lashing the eastern coast of North America.

In descending the steep eastern side of the hill, the white quartzite gives way to a gray shiny rock containing abundant deep red garnet crystals (the Connecticut State "stone"—actually a mineral) and an elongated dark mineral, staurolite. This is a metamorphic rock formed from the mud sediment deposited in deeper water off the coast where the white sand was washing back and forth on the beach. A little farther off the shore a coral reef provided calcium carbonate sediment, which on being metamorphosed turned into marble, a soft rock, that now occupies the low region down the center of Peaceful Valley. Thus in going from the crest of the northern hill to the bottom of Peaceful Valley we traverse a sequence of rocks formed from the various types of sediment formed along the coast of North America 420 million years ago.

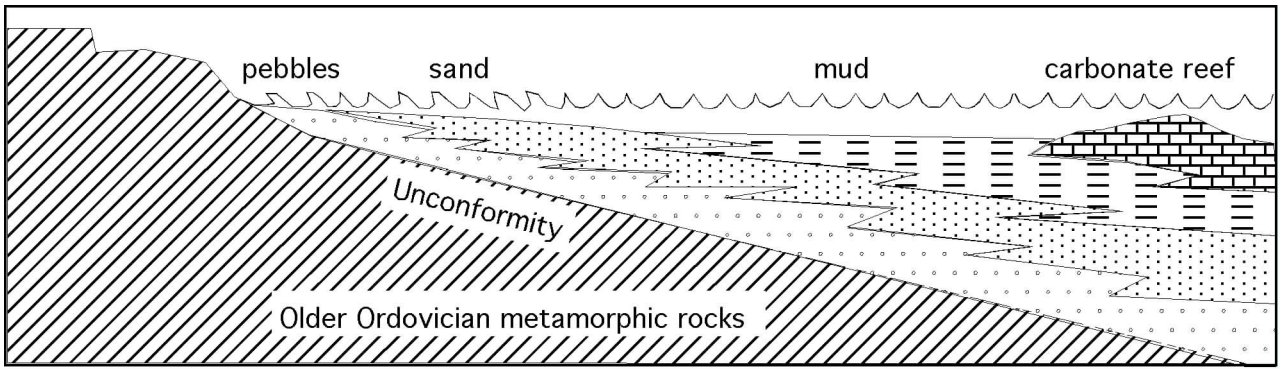

Figure 4. Schematic cross section through a beach showing how the composition and grain size varies from the top of the beach (pebbles), which is reached by waves only during storms, down through the surf zone (sand), and out into deeper water where mud is deposited. If the climate is warm enough, a coral reef may form, which on being broken up by waves produces sediment that consists of calcium carbonate. The sequence is shown for a shore that is slowly subsiding (e.g., Mississippi delta today) so that the deeper water sediment (mud) eventually overlies shallow surf-zone sediment (sand).

If a trench is dug in a beach, layers of sand can be seen sloping gently toward the sea. Such layers can be seen in the quartzite on the northern hill. Because the sequence of rocks found in going from the crest of this hill to the bottom of Peaceful Valley is as shown in Figure 4, the layering would be expected to slope gently to the east. However, the layers now slope steeply to the west. In fact, the entire sequence of metamorphosed sedimentary rocks has been turned completely upside down. This happened when the Avalon continent collided with, and was thrust beneath, the North American continent (Fig. 3). Such a collision, similar to that of India being thrust beneath Tibet today, involves enormous pressures and deformation. Evidence of this deformation is visible in the rocks on the northern hill. Quartz pebbles on a beach, after being tumbled by waves, gradually become almost spherical, and the pebbles in the ancient beach sand that now forms the rock on the northern hill would have been no exception. During the collision between North America and Avalon, these spherical pebbles were stretched into extremely elongate ellipses. From the elongation direction of the elliptical pebbles we have a measure of the direction of the collision between the continents.

All of the rocks in Campbell's Peaceful Valley have layers with a steep slope to the west and are all upside down. However, just to the east of the hill on the east side of Hunter Road, which bounds the eastern side of Campbell's Peaceful Valley property, the same sequence of rocks can be found, but in their correct position; that is, they are not overturned. Thus, extending in a north-south direction approximately beneath Hunter Road is a large fold known as a *syncline* (see cross section in Fig. 1). Such folds are common in mountain chains and in part explain the thickening of the crust to form the mountains.

The rocks in Campbell's Peaceful Valley were buried beneath these mountains and some of the minerals that grew at that time provide a record of how high the mountains were. One aluminum silicate mineral (Al_2SiO_5) has the ability to grow with three different crystal forms depending on the temperature and pressure under which it grows. Such minerals are known as *polymorphs* (many forms). Diamond and graphite, for example, are polymorphs of carbon, diamond being the high-pressure form. The three polymorphs of Al_2SiO_5 are *andalusite*, *kyanite*, and *sillimanite*. The pressure and temperature under which each of these minerals is stable has been determined by experiment and thermodynamic calculation (Fig. 5). The polymorph in Campbell's Peaceful Valley rocks is *kyanite*, the high-pressure variety, whereas just to the south around Storrs, the higher-temperature *sillimanite* is the stable polymorph. *Kyanite* forms bladed crystals, which in the Peaceful Valley rocks are

commonly dark gray due to inclusions of graphite, but large pale blue, inclusion-free crystals occur in some quartz veins. The presence of this mineral and certain other minerals, indicate that they formed at a temperature of 500°C under a pressure of 4000 atmospheres (**X** in Fig. 5), which corresponds to a depth of 9 miles or 50,000 feet at the time of growth. This does not mean that 50,000-foot-high mountains covered this area. It is likely that the mountains were not much different from the present Himalayan Mountains (<30,000 feet), but the rocks that we see at the surface today were buried much deeper at the time of their metamorphism. The rocks making up mountain ranges have lower density than the rock beneath them and as a result a mountain stands high because it is floating in the denser plastic rock beneath. As the tops of mountains are eroded away, the rocks at depth slowly float upward toward the surface. The process is similar to what would happen to a large block of wood floating in water if pieces were slowly shaved from its upper surface; it would keep floating upward until the block was completely shaved away. The rocks now found on the surface in Campbell's Peaceful valley were initially much deeper in the earth in addition to having the mountains on top of them.

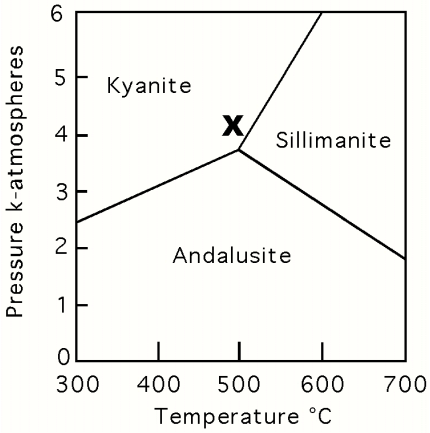

Figure 5. Pressure-temperature stability fields of the minerals andalusite, kyanite, and sillimanite, and the conditions in the Peaceful Valley rocks at time of metamorphism.

The mineral kyanite and many of the others in the rocks in Peaceful Valley, such as garnet and staurolite, were formed from clay that was deposited as mud off the coast of North America 420 million years ago. Clay contains considerable water, which for example, is released when clay pottery is fired in a kiln. Similarly, when the mud was heated during the collision of North America with the Avalon continent to form kyanite, garnet, and staurolite, water, or more accurately super heated steam, was released from the rock, escaping along fractures. The same reactions that produced the kyanite, garnet, and staurolite released silica, which was transported in solution by the steam escaping from the rock. As the steam rose toward the surface into cooler rocks it deposited its dissolved silica to form veins of quartz. These veins are seen throughout the Peaceful Valley area forming pure white rock, some of which may have rusty stains due to the weathering of small amounts of fools gold (pyrite) that is commonly present. Because these veins formed in fractures in the rock, they would have initially been straight planar features, but by the end of the Avalon collision and the later African collision they became deformed. They now commonly pinch and swell and resemble a string of sausages, which is why geologists refer to this structure as *boudinage*, a boudin being the French word for a sausage.

The north-northeasterly trend and steep westward dip of the rocks in the Peaceful Valley area are the result of the collision of North America with Avalon. Throughout the region a number of folds are present that rotate the north-northeasterly trending layers into an almost east-west orientation with a vertical dip. These folds are particularly common along the valley that separates the northern hill from the ridge in the southern part of the area. Here these folds produced a zone of weakness that has given rise to this cross valley. All of the cross folds were formed when Africa collided with North America along the southern coast of Connecticut. Cross folds of this type become more abundant and eventually become the predominant type south of a line that passes through Norwich, Connecticut. This line can be thought of as the collision boundary between North America and Africa. Campbell's Peaceful Valley is far enough north of this line to have suffered only minor ripples.

By 300 million years ago all of the continents were assembled into the single landmass known as Pangea. The mountains that had been formed in Connecticut were part of the Appalachian Mountains that crossed this super continent. All of the tectonic plates that had been assembled to form Pangea remained together for 100 million years. Then 200 million years ago, Pangea began to stretch and come apart approximately along the line where it had sutured together to form the Appalachian Mountains. At first, the stretching resulted in deep basins

forming with internal drainage. Sediment being eroded from the surrounding high mountains cascaded down into the basin forming huge alluvial fans similar to those seen along the sides of Death Valley today. Buckland Hills Mall is built on one of these alluvial fans. Examination of the red sandstone seen in the vicinity of the Mall reveals the presence in some layers of boulder-sized blocks of white vein quartz, which would have been washed down into the basin during thunderstorms. The only dinosaur skeleton ever found in Connecticut was of a victim who was buried rapidly by such a storm deposit on the west side of the Mall.

As Pangea stretched and the basins deepened, the hot mantle beneath the basins began to rise, and with the decrease in pressure, melting took place. Because the melt was less dense than the surrounding rock, it migrated toward the surface and erupted as basaltic lava flows that form the ridge to the west of Hartford. The thickest of the three flows, the Holyoke basalt, was erupted from a long fracture that is located only three miles to the west of Campbell's Peaceful Valley. Large blocks of this extremely hard massive rock can be found as brown smooth boulders throughout the area. They are particularly common on trails where the soil has been removed by pedestrian traffic. They were brought from the fracture to this area by the movement of glacial ice during the last continental glaciation, which peaked 22,000 years ago. Evidence of the direction of ice movement can be seen near the summit on the west side of the northern hill where the white quartzite was scratched by boulders embedded in the base of the glacial ice.

One of the most important evolutionary steps in the earth's history was the migration of plants and animals from the sea onto dry land. This step happened rather late in earth history, but it occurred during the time interval when the sediments were being deposited that form the rocks on the northern hill in Campbell's Peaceful Valley. Unfortunately the fossils needed to document this event were destroyed by the deformation that occurred during the continental collisions. Nonetheless, it is still thought provoking to stand on the top of the northern hill and look down at the valley below and contemplate the significance of this event. At the time the rocks on the top of the hill were deposited on the eastern coast of North America no plants or animals lived on land anywhere in the world; everything lived in the sea. The land surface would have been totally barren, and any soil that was formed would have been rapidly washed off the continents into the ocean. If you look down from the top of the hill, the rocks you see at the base of the cliff (remember the rocks have all been overturned so you are looking down at younger rocks) were formed at a time when first, plants, and then animals, migrated out of the sea onto dry land. Although these early plants and animals were very different from modern ones, the surface of the earth would at least have begun to resemble what we are familiar with today.

ACKNOWLEDGMENTS

I would like to thank Mr. Campbell who for many years allowed the University of Connecticut geology field class to investigate the rocks on his property. He always had a cheery word for the students as they trudged off laden down with survey equipment. I would also like to thank him for keeping the woods in such pristine condition. I am pleased that the Tolland Conservation Commission will now take over that stewardship and preserve the area for future generations.