Observations of the Geology of the Hot Springs Window Region

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This scientific research paper is based on observations made in the Hot Springs Window Region of North Carolina of the Mesoproterozoic (1.6-1 Ma) through Cambrian age (541-485.4 Ma) rocks located there. The Appalachian Mountains has a geological window in the Hot Springs region, exposing different metamorphic sedimentary rock units to the surface of the Earth. The Hot Springs window exists due to the thrust faulting in the Appalachian Mountain area originating back to the Taconic (440 Ma) and Alleghenian progenies (299-251 Ma), in which the Appalachian Mountains were formed. The erosion of the rock units on the surface were likely caused by a body of moving water, evident in the Honaker formation's limestone deposits. Observations made at outcrops in a field book during a field trip to the Hot Springs Region, confirm that mylonite had been found in an outcrop near the Meadow Fork River (Fig.6). Mylonite is indicative of fault activity in the area since its appearance is created by the metamorphosing of rock during tectonic activity and is evident in some crystalline complex and Snowbird formation rocks. The outcrops studied during the research trip were either igneous metamorphic or sedimentary metamorphic in nature and most of them had specific evidential features of metamorphic rock such as crystalline structure or banded and foliated texture. The igneous metamorphic rocks of the outcrops had visible minerals such as k-feldspar, pyroxene, micas, epidote, chlorite, and quartz, with colors like pink, black, grey, and tan. The sedimentary metamorphic rocks were observed to have things like micas, quartz, fine-grained textures, flakiness, and tan to brown colors. Through these observations, hypotheses were made about which rock unit each outcrop belonged to. It is notable in appearance and mineralogy, that the rock units exposed at the Rocky Mount Window Region, are metamorphosed rock, dating back 1.2 billion years ago, placed there by the Taconic Orogeny (440 Ma), Alleghenian orogeny (299-251 Ma), and further faulting, in what is now the Appalachian Mountain area.

.Introduction

This scientific research paper is based on observations made in the Hot Springs Window Region of North Carolina of the Mesoproterozoic (1.6-1 Ma) through Cambrian age (541-485.4 Ma) rocks located there, during a weekend long research camping trip. A geologic window is an erosional hole in a sheet of older rock that has been pushed on top of younger rock in a thrust fault. A thrust fault is a break in the Earth's crust, in which older rock is pushed on top of younger rock. is The Hot Springs Window Region, the area studied for this report, is a 10.4-mile-long, 6.4-mile-wide window revealing older rock on top of younger rock that traveled there through extensive thrust faulting of four different thrust sheets. The rock near the thrust faults are monetized and fractured in a way that is indicative of fault activity in the rock. Mylonite is a metamorphic rock containing fine-grained bands resulting from the metamorphosing and recrystallization of the rock. The textural appearance of mylonite is extremely indicative of fault activity in the area since its appearance is created by faulting. Two of the thrust sheets are made of granitoids and are adjacent to each other. These thrust sheets include Paleozoic (541-251.9 Ma) carbonate rocks in which there are clastic, metamorphic, and granitic rocks underneath it. In the Hot Springs Window, different rock units that comprise the window region, are available to view and study, listed from oldest to youngest, including, the Basement Crystalline Complex, Snowbird Formation, Sand suck Formation, Unicoi Formation, Hampton Formation, Erwin Formation, Shady Dolomite, Rome Formation, and Honaker Limestone (Oriel 1951). The purpose of this research paper is to outline the topics of the geological window in the Hot Springs Window region, the singular rock units that exist within this window, the geologic history of the region based on personal observations made and the work of previous geologists focusing on tectonic activity and progenies, and regional Appalachian geological history.

Rock units

Basement Complex: The basement complex or Crystalline complex is Pre-Cambrian, formed 4.6 Ma, and characterized by granitoid that has been turned into sericite (sericitized) and hydrothermally introduced to epidote (epitomized), mylonite, and pegmatitic textured rocks. The Brushy Mountain thrust sheet is present in the pre-Cambrian crystalline rocks. Overlying the Brushy Mountain thrust sheet rocks, are pre-Cambrian crystalline rocks which are partly monetized, called the Meadow Fork thrust sheet. A thrust fault called the Rector Branch thrust fault goes through the Hot Springs region, this fault contains traces of the Meadow Fork thrust sheet, meaning the Rector Branch thrust fault may be on top of the Meadow Fork thrust sheet. Outcrops observed along U.S. Highway 25-70 in Oriel (1951), were interpreted to have pre-Cambrian Crystalline rocks overlying rocks from the Snowbird formation on a fault through much of the formations. The mylonite in the Hot Springs area was formed by the micro brecciation of the pre-Cambrian Crystalline complex and Snowbird formation rocks, and in most cases, it is difficult to distinguish whether it is mylonite from the pre-Cambrian Crystalline or Snowbird rocks (Oriel, 1951). Since mylonite is a large characteristic of the crystalline complex, it can be inferred that its deposition was based around the thrust faults that are in the rock unit. According to field notes taken during the observation of an outcrop of the pre-Cambrian Crystalline complex, the rock seemed to be metamorphic sedimentary with folding in the bedding and some sort of faulting present. The outside is pink but orange, black, tan, and blue on the inside, with obvious inclusions of biotite, quarts, and k-feldspar minerals.

Snowbird Formation: On top of a presumed unconformity following the Basement complex material, the Snowbird formation is in a clastic group of unknown age and is about 1500-4600 feet thick. It is characterized by quartzites interbedded in pebble shapes, with vitreous luster, and felspathic minerals, the calcareous, micaceous, and arkose sandstones, shale rock, siltstone, slate, and mylonite. The Brushy Mountain thrust sheet is located partly in the Snowbird formation, and the Meadow Fork thrust sheet, which consists of primarily monetized pre-Cambrian crystalline rock, overlies the Snowbird formations thrust sheet. The Snowbird formation is found under the pre-Cambrian Crystalline complex rocks in certain areas where a fault is located, since Snowbird rocks are younger than the pre-Cambrian Crystalline rocks, the inferred deposition can be that a thrust fault caused the pre-Cambrian Crystalline rocks to be shoved on top of the Snowbird rocks during faulting. This is where the monetization happens and it becomes difficult to discern which rock unit the mylonite is from (Oriel, 1951). According to field notes taken during the observation of an outcrop of the Snowbird formation, the rock appeared to be metamorphic sedimentary rock that had been recrystallized into some sort of sandstone. It had a fine grain to varying grain size and flaky texture with an orange, black, grey, and white color. There were large bedding planes and indications of a fault between the pre-Cambrian crystalline complex and Snowbird formation. It is an ancient passive sediment deposit and therefore turbidites, or deposits from underwater landslides, may be visible in some areas.

Sand suck Formation: The Sand suck formation is of the clastic group of unknown age and has a thickness of about 700 feet. It is characterized by dark green to blue-green slate, shale, and siltstone with sandy grey bands and slaty black bands extending through the fine-grained rock, it contains conglomerates as well as limestone lenses, and cleavage seems to be developed the best in Sand suck formation rock compared to the other rock units. Inferred deposition includes a fault appearing to travel northwest to southwest goes through the Unicoi formation, with an identifiable presence in the contact between the northeast Unicoi conglomerate beds, and the Sand suck slate beds on the southwest side (Oriel, 1951). According to field notes taken during the observation of an outcrop of the Sand suck formation, the rock looked to be metamorphic sedimentary with a fine-grained and flaking texture. It had grey and orange colors with slaty cleavage that had been deformed in the fabric, along with veins of quartz running through the rock.

Unicoi Formation: Lying atop a presumed unconformity of the Sand suck formation rock, the Unicoi formation is in a clastic group of the lower Cambrian series in the Early Cambrian, 541-485.4 Ma, and is about 1400-2600 feet thick. It is characterized by quartzite with vitreous luster and the coarse-grained texture of feldspathic minerals, conglomerates with slate inclusions, slate itself, siltstone, and micaceous sandstones. Inferred deposition includes a fault ranging from northwest to southwest trails through the Unicoi formation, with an identifiable presence where the lower Unicoi conglomerate beds meet the Sand suck slate southwest of it (Oriel, 1951). According to field notes taken during the observation of an outcrop of the Unicoi formation, the rock was a poorly sorted, coarse-grained pebble conglomerate with 10 cm pebbles, and bands of larger pebbles of more medium sizes, all red, orange, and brown in color. The rock had vertical bedding and an angular unconformity with quartz veins throughout.

Hampton Formation: The Hampton formation is in the clastic group of the lower Cambrian series in the early Cambrian, 541-485.4 Ma, and has three specific layers of rock, often called "the Hampton sandwich." The oldest layer in the Hampton formation is lower shale at an approximate 210-380 feet in thickness, characterized with dark green siltstone, sandy and silty shale, and argillaceous shale, interbedded together. The middle part of the Hampton sandwich, is the middle quartzite layer at 500-750 feet thick, characterized by quartzite with medium to coarse grained felspathic minerals cross bedded with quartzite; vitreous in luster, and beds of pebble. The youngest and top layer of the Hampton formation is the upper shale layer that is about 200-300 feet thick. It is characterized by dark green siltstone, alternating with thin beds of quartzite and silty and sandy shale. A fault going northwest from the southwestern end of Deer Park Mountain is the inferred deposition considering the sudden offset of the Hampton formation, which is particularly identifiable in in the middle quartzite layer (Oriel, 1951). According to field notes taken during the observation of an outcrop of the Hampton formation, the rock seemed to have varying lithology with coarse sandstone and feldspar. It had vertical bedding in which skolions burrows, a common trace fossil ichnogenus, can be found, however it was not observed in the field notes.

Erwin Formation: The Erwin formation is a part of the clastic group of the lower Cambrian series in the early Cambrian, 541-485.4 Ma, and is at maximum, 1,975 feet thick. It is characterized by dark green siltstone, silty and sandy shale, quartzites of the white vitreous and purple ferruginous variety, topped off with calcareous siltstone. In the upper quartzites of the Erwin formation, evidence of a fault is present, acting as the top of the Hampton formation's fault that ranged from the southwest to the northwest part of the Deer Park Mountain and the inferred deposition of the Erwin formation. According to Oriel (1951), an area of upper Erwin strata is exposed on U.S. Highway 25-70, which has been observed as anticlinal, but may be an upside-down syncline if the rocks beds are overturned. However, across Spring Creek, Shady Dolomite rocks are present in a continuous string of outcrops along the steep shoreline slope of sediment, the bluffs of Spring Creek, which is indicative of a normal anticline, rather than an upside-down syncline, either of which would determine in which way they were formed and deposited (Oriel, 1951). According to field notes taken during the observation of an outcrop of the Erwin formation, the rock was located next to the French Broad River, down from Asheville, and was a wall of tan and black quartzite with vertical bedding. It's parent rock seems to have been metamorphic sandstone.

Shady Dolomite: Shady dolomite is part of the early Cambrian period, 541-485.4 Ma, and is about 1700-2100 feet thick. It is characterized by blue grey, light-grey, and white dolomite interbedded with limestone, under of which lies fine-grained and very fine-grained clastic rocks in some areas. Along the east bank of the French Broad River, there are exposures of Shady dolomite that show folds that may have been formed because of drag along the fault surface, which can be the inferred deposition (Oriel, 1951). According to field notes taken during the observation of an outcrop of Shady dolomite, "The Shady Formation," was located on River Road, along the French Broad River, the rock appeared to be a brown and grey color with vertical bedding.

Rome Formation: The Rome formation came to be at the end of the early Cambrian and continued into the beginning of the middle Cambrian period, 541-485.4 Ma. It is one of the more recent formations and so the thickness of this formation is unknown. It is characterized by red and brown siltstone and shale with interbedded green shale and light grey to blue grey dolomite. The Rome formation has a series of highly contorted and intricate bands with a plethora of different magnitudes ranging from just inches to over tens of feet. The way that the folds have resulted makes it difficult to determine the relation of them to the structural features of the surrounding area, however the bands are interbedded with Shady dolomite beds, this is all indicative of some sort of depositional folding with Shady dolomite and may be the way the Rome formation was deposited (Oriel, 1951). The Rome formation was not observed in the field notes on the camping trip to the Hot Springs region.

Honaker Formation: The Honaker formation is part of the middle Cambrian period, 541-485.4 Ma, and is the youngest unit that has been discovered, also with an unknown thickness as of today. It is characterized by white, grey, and blue-grey limestones with a thin layer of silt and shale that have banded chert nodules. The Hampton formation has horizontal rock beds in which there is an anticline in the beds. However, according to Oriel (1951), the beds in this anticline are upside down, making this anticline an upside-down syncline (Oriel 1951). The overturning of a fold can happen through the shortening and extension of tectonic plates, the inferred deposition of the Honaker formation is the extensive folding of layers during the middle Cambrian period. The Honaker formation was not observed in the field notes on the camping trip to the Hot Springs region.

Regional Geologic History

Around 1.2-1 billion years ago, the supercontinent Rodina formed because of the Grevilia Orogeny that occurred worldwide during the time. For about 300 My, Rodina stayed together until about 7.50 Ma when it began rifting apart in western and north-eastern North America. The rifting of Rodina along the southern-central Appalachian margin, occurring at about 565 Ma, had basins that deposited the Ocoee Supergroup. The Ocoee Supergroup is a group of Terrigenous clastic sedimentary rocks that are coarse textured and poorly sorted, this supergroup was deposited in Tennessee, North Carolina, Virginia, and Georgia. The Ocoee Supergroup has three groups. The Snowbird group, the Great Smoky group, and the Walden Creek group. The Snowbird group lies on top of the Grevilia basement with basal sandstones, quartz arenite and arkose sandstone laying on top as well as a politic unit. A politic unit is a clay dominated and fine-grained sedimentary protolith. The Great Smoky group is made up of deep-water greywacke, polite, cleaner sedimentary rocks, quartz conglomerate with sandstone, granite, shale, dolomite, and limestone. Most of the thickness of the supergroup is in the Great Smoky group and it is faulted on top of the Snowbird group. The Walden Creek group overlies the Great Smoky group and contains banded chlorite-sericite slate with limestone, shale, and sandstone. At about 73.5 Ma, a phenomenon called failed rifting occurred in the southern and central Appalachians. Failed rifts are the result of continental rifting that never rifted to the point of a full break-up. This failed rift caused the creation of a plutonic volcanic suite, different rocks in Grandfather Mountain and the Mount Rogers formation, and the Robertson River igneous complex in Virginia (Hatcher, 2005). Beginning 1.2-1 billion years ago, the deposition that occurred in North Carolina of the Ocoee Supergroup, deposited the beginnings of what is now the Hot Springs region in the Appalachian Mountains.

The Appalachian Mountains formed because of the tectonic activity in the region, along the pre-Cambrian continental margin of eastern North America, following the breakup of the supercontinent Rodina. The tectonic events that occurred began in the Ordovician period (485.4-443.8 Ma) of the Paleozoic era and ended late into the Paleozoic era. These events created metamorphic rock from sedimentary rock during folding. Metamorphism of the rock in the Appalachian Mountains occurred 510-460 Ma during the Taconic orogeny. Metamorphic zones of the southern and central Appalachians can be demonstrated by a figure (Fig.5) cited from Hatcher (1987), representing spots of greenschist facies metamorphism, anchylose metamorphism, amphibolite facies metamorphism, and zones of Paleozoic facies metamorphism. The metamorphic rock present throughout the Appalachians is evident of extensive faulting and tectonic activity. The Alleghenian orogeny, a mountain-building event that occurred in the Permian Period (299-251 Ma), is what ultimately created the Appalachian Mountains that is seen today. The faults observed in the southern and central Appalachians are major tectonic boundaries that go through the crystalline complex rock. In the crystalline complex, deformation of the rock can be observed near the faults that run through it from the Blue Ridge and Inner Piedmont region into the distal flanks. Mylonite, evidence of fault activity based on the certitude that it is a metamorphic rock containing fine-grained bands resulting from the metamorphosing and recrystallization of the rock, is evident in the Brevard fault zone, resulting from the earlier metamorphosing events of the Southern Appalachians (Hatcher, 1987). Based on observations made in field notes taken during the field trip to the Hot Springs region of North Carolina, Mylonite is observed in an outcrop on the south side of Meadow Fork Road along the Meadow Fork River (Fig.6). Interpretations were made about the Runyon region during a hike in which outcrops were observed and strike and dip data were collected. These interpretations were turned into a hypothesis about where on a geological map (Fig.1.) and cross-sectional map (Fig.3) might the different rock units be located. The entire geological region of the Appalachian Mountains is a result of large-scale tectonic activity and metamorphism that began at least 1 billion years ago on the supercontinent Rodina.

Hot Springs Window Region Geologic History

The Hot Springs Window Region of North Carolina of the Mesoproterozoic (1.6-1 Ma) through Cambrian age (541-485.4 Ma), located in the Appalachian Mountains, spanning around 50 square miles, in western Madison County, North Carolina. Different rock units that comprise the window region, are listed from oldest to youngest; the Basement Crystalline Complex, Snowbird Formation, Sand suck Formation, Unicoi Formation, Hampton Formation, Erwin Formation, Shady Dolomite, Rome Formation, and Honaker Limestone (Fig.2). The Hot Springs window is one of the only exposures of southeastern Paleozoic carbonate rocks under which lies clastic, metamorphic rocks, and granitoids. The window is demonstrated by a cross sectional map (Fig.4) and is surrounded by four different thrust faults and thrust sheets, Oriel (1951), believes that the thrust sheet between the sedimentary and crystalline rocks is a thrust fault, which means there are two major structural units inside the window itself. One of the thrust sheets is called the Mine Ridge thrust fault, which is the best evident in the area, and separates the Snowbird Formation, Sand suck formation, and Unicoi formations outside of the window, from the younger rock units inside the Hot Springs window. Another thrust sheet is the Del Rio thrust sheet, in which Unicoi, Sand suck, and Snowbird rock units are found, as well as all units up to the Rome formation. Overlying the Del Rio sheet, the Brushy Mountain thrust sheet also frames the Hot Springs window, containing pre-Cambrian crystalline rocks and the Snowbird formation rocks. Small parts of the Meadow Fork thrust sheet are shown in the southern part of the Hot Springs window only, however, it consists of partly mylonized, pre-Cambrian crystalline rocks that overlie the Brushy Mountain thrust sheet and the Snowbird formation inside the window. The Rector Branch thrust fault goes for about a mile through the southern central part of the window in which pre-Cambrian crystalline rocks are lying above Snowbird rocks through most of the fault. The Rector Branch thrust sheet is the hanging wall of the thrust fault and is mostly pre-Cambrian crystalline rocks that stack on top of the Meadow Fork and Del Rio thrust sheets, and Snowbird rocks in the southernmost area of the Hot Springs window. Many of the structural features of the window are based on the thrusting that occurred in the area. There are mylonite planes parallel to the trends of the thrust surfaces, caused by those thrust surfaces moving, and cleavage planes also resulted from the forceful movements of the thrust faults. Mineralization is related to the presence of thrust faults, whether they are geographical or genetic. The deformation in the window is dated to have been created after the deposition of Honaker limestone or at least sometime after the middle Cambrian period (Oriel, 1951).

Thrusting in southern Appalachia is originated from the Alleghenian orogeny, a mountain-building event that created the Appalachian Mountains observed today, occurring in the Permian Period (299-251 Ma). Even though all these rock units originate over 1 billion years ago, the Crystalline complex is dated back to the pre-Cambrian and lies beneath the Snowbird and Sand suck formations with an unknown age. On top of the Sand suck formation is the Unicoi, Hampton, Erwin, and Shady formations of the early Cambrian. The youngest units, Honaker limestone, on top of the Rome formation, is of the middle Cambrian and has an unknown thickness because they are still being deposited and eroded. The Taconic orogeny created the original metamorphic properties in the rocks, along with the Alleghenian orogeny, that brought these formations together to create the Appalachian Mountains. The Appalachian Mountains now has a geological window in the Hot Springs region, exposing these rock units to Earth's surface. The Hot Springs window exists due to a thrust fault, however, the

French Broad River in which the outcrops were not far from, or some other type of fast-moving body of water may have caused the erosion. This is especially evidential in the Honaker formation's limestone deposits. Summary:

Evidence of extensive large-scale metamorphosing of rock units exists in the Hot Springs Window Region of North Carolina near Asheville. The Appalachian Mountains were formed by two progenies, the Taconic and Alleghenian, in of which occurred this extensive and large-scale metamorphosing. The tectonic activity in the area, consisting of multiple thrust faults, lead to the creation of the Hot Springs window where the Earth's surface was eroded by rivers and streams that trail through it. The erosion of the window exposed the following rock units listed from oldest to youngest, the Basement Crystalline Complex, Snowbird Formation, Sand suck Formation, Unicoi Formation, Hampton Formation, Erwin Formation, Shady Dolomite, Rome Formation, and Honaker Limestone. These formations can be viewed in outcrops along the French Broad River and other locations in the Hot Springs Window Region where the surface has been eroded. The recent deposition of limestone in the youngest unit, the Honaker formation, is indicative of erosion via quick-moving water across the Appalachians, which is why it makes sense that the eroded outcrops can be viewed somewhere next to a body of water. Mylonite is extremely indicative of fault activity in the area since its appearance is created by faulting and is evident in some crystalline complex and Snowbird formation rocks. The mylonite in the Hot Springs area was formed by the micro brecciation of the pre-Cambrian Crystalline complex and Snowbird formation rocks originating from the supercontinent Rodina, around 1 billion years ago. Observations made at outcrops in a field book during a field trip to the Hot Springs Region, confirm the theory, as mylonite had been found in an outcrop near the Meadow Fork River (Fig.6). The Honaker Formation had not been observed during this field trip, so the Honaker limestone deposit has not been confirmed. It is notable however in appearance and mineralogy, that the rock units exposed at the Rocky Mount Window Region, are metamorphosed rock, dating back to 1.2 billion years ago, placed there through a series of tectonic events and progenies in what is now the Appalachian Mountain area.

References

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Figures

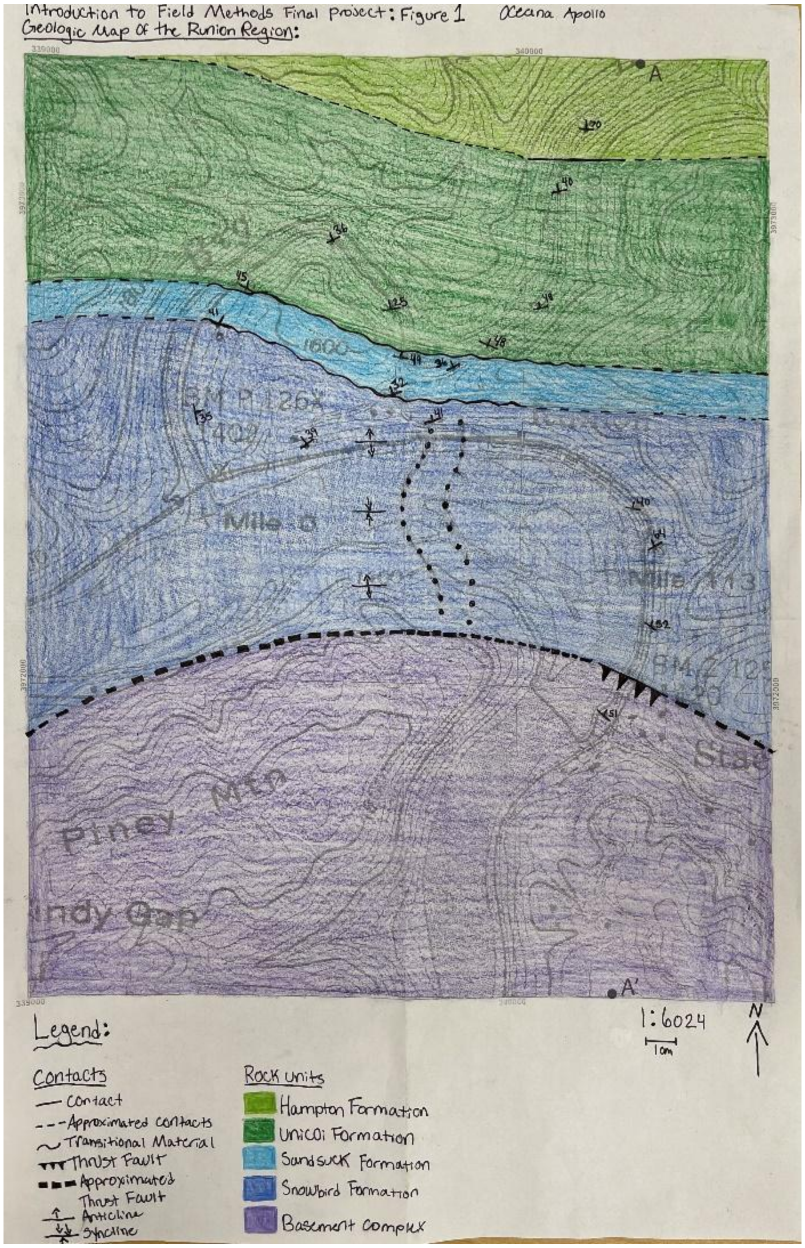

Figure 1. Geologic Map of the Runyon Region: *This geologic map is a bird's eye view of the Runion Region of the Appalachian Mountains, based on field observations made during the field trip to the Hot Springs Window Region, demonstrating the rock units; the Basement complex (pre-Cambrian crystalline complex), the Snowbird formation, the Sandsuck formation, the Unicoi formation, and the Hampton formation. Confirmed and approximated contacts as well as transitional material, thrust faults, anticlines, and synclines can be located on the map as well as strike and dip data collected at each outcrop observed in the Runion Region on this map.*

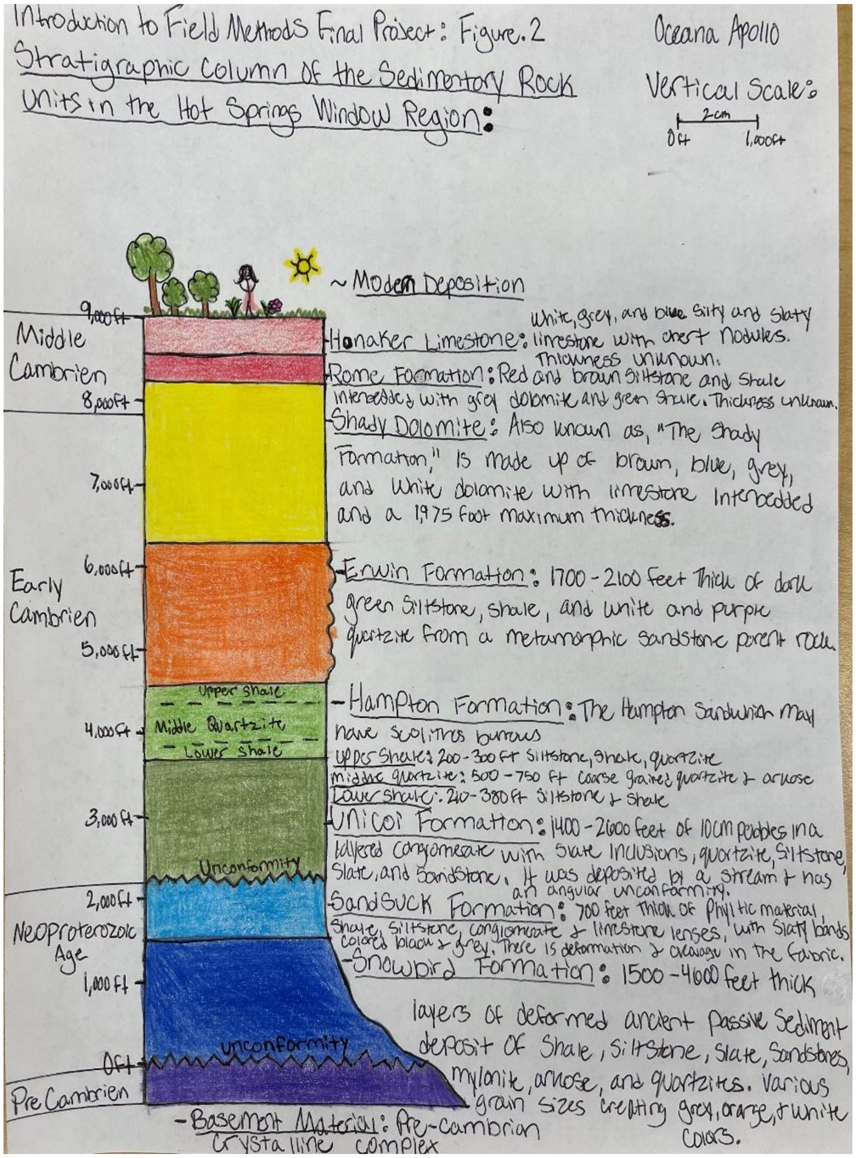

Figure 2. Stratigraphic Column of the Sedimentary Rock Units in the Hot Springs Window Region: *This stratigraphic column is a side view of the rock units; the Basement complex (pre-Cambrian crystalline complex), Snowbird formation, Sand suck formation, Unicoi formation, Hampton formation (Includes: lower shale, middle quartzite, and upper shale), Erwin formation, Shady dolomite, Rome formation, and Honaker limestone.*

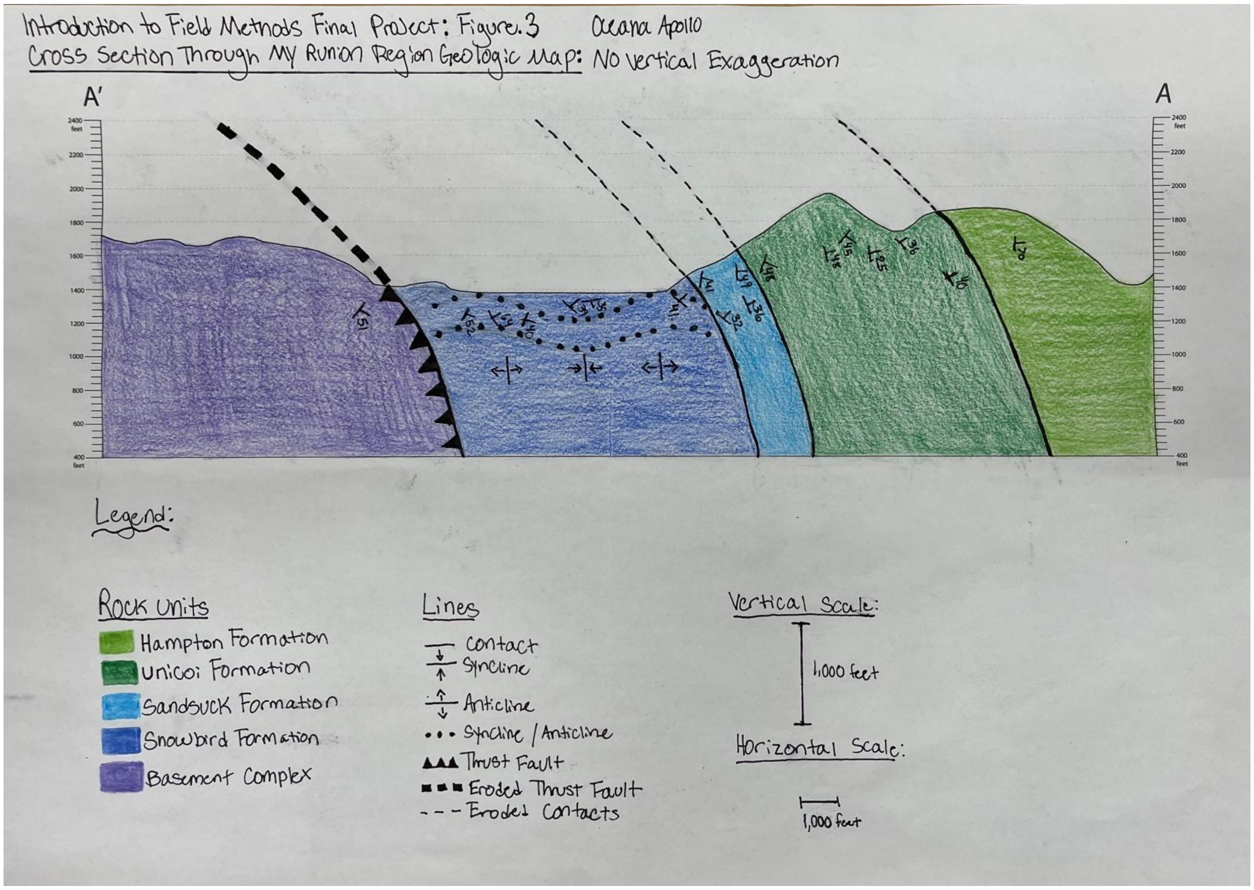

Figure 3. Cross Section Through My Runion Region Geologic Map: *This cross section is a side view of what the rock units in the Geologic Map of the Runion Region (Fig.1) from A-A' might look like, based on field observations made during the field trip to the Hot Springs Window Region. The cross section shows rock units; the Basement complex (pre-Cambrian crystalline complex), the Snowbird formation, the Sandsuck formation, the Unicoi formation, and the Hampton formation. Confirmed and approximated contacts as well as, thrust faults, anticlines, and synclines can be located on the map as well as strike and dip data collected at each outcrop observed in the Runion Region on this map.*

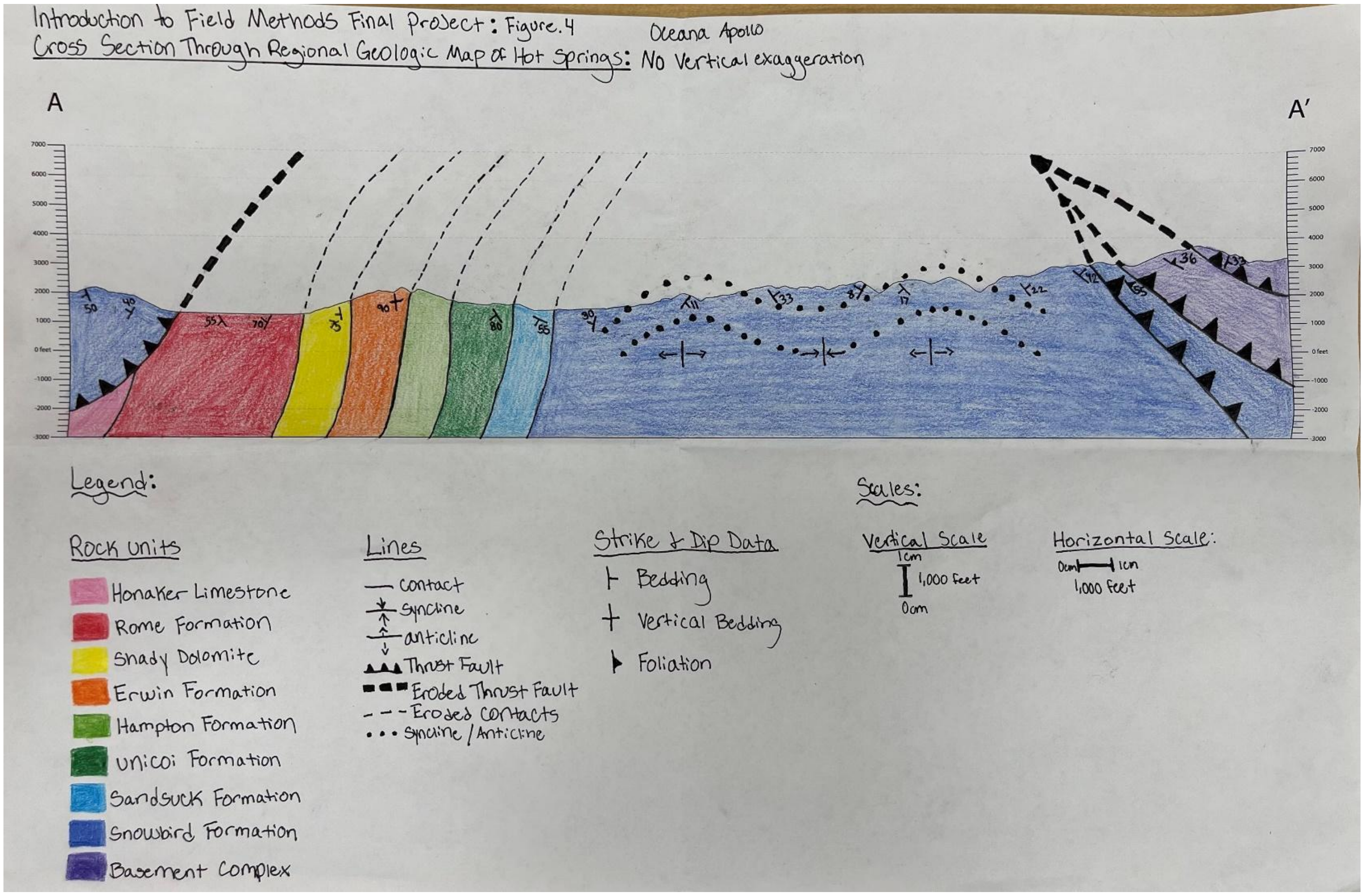

Figure 4. Cross Section Through Regional Geologic Map of Hot Springs

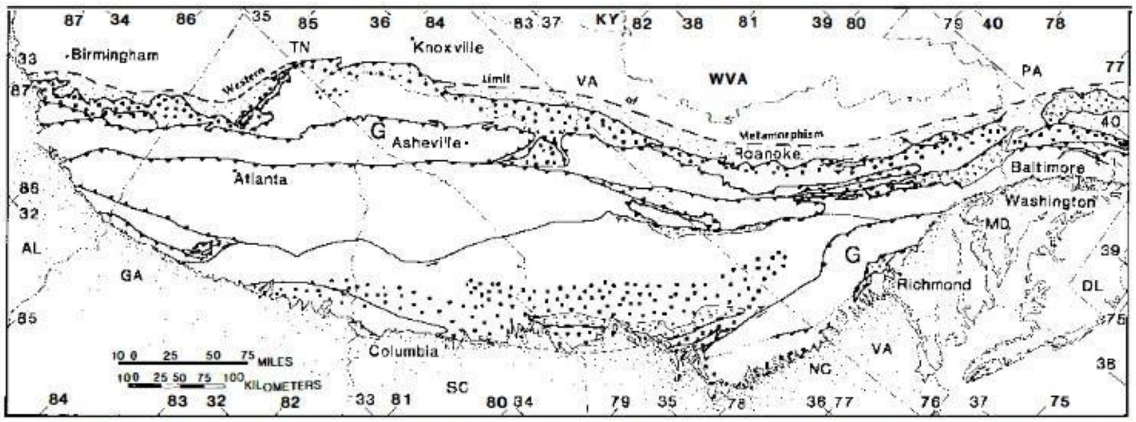

Figure 3b Metamorphic zones of southern and central Appalachians. Large-dot pattern represents greenschist facies metamorphism. Small-dot pattern is anchizone metamorphism along the western edge of the internides. Unpatterned areas in the central and eastern internides are zones of amphibolite facies metamorphism, with the G indicating local zones of Paleozoic granulite facies metamorphism. Other patterns defined in Figure 2. Modified from Glover et al (1983) and other published sources.

Figure 5. Metamorphic Zones of southern and central Appalachians: *Shows locations of spots of greenschist facies metamorphism, anchizone metamorphism, amphibolite facies metamorphism, and zones of Paleozoic facies metamorphism.*

Figure 6. *Based on observations made in field notes taken during the field trip to the Hot Springs region of North Carolina, Mylonite is observed in an outcrop on the south side of Meadow Fork Road along the Meadow Fork River.*