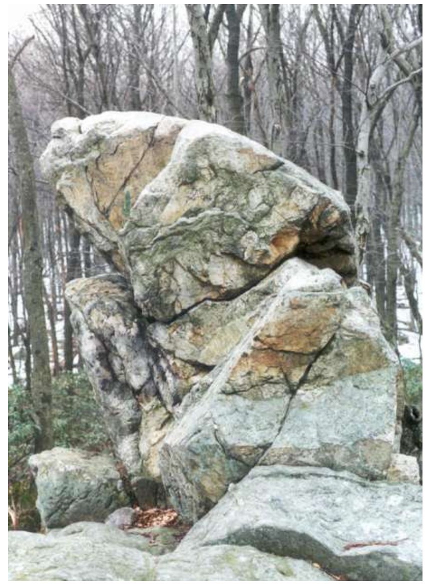

TimeWalk

A Journey through Time in Adams, Lancaster and York Counties, Pennsylvania

Written by Jeri L. Jones
Illustrations by Teanna L. Byerts

On the Front Cover:

Top Left – Columnar jointing in Catoctin Formation rhyolite at Carbaugh Reservoir, Adams County, Pa

Top Right – Chickies Quartzite exposure
Money Rocks County Park near Narvon,
Lancaster County, Pa

Lower Left – Funkhauser Quarry near
Delta, York County, Pa

Lower Right – Spheroidal weathering in diabase,
Governor's Stable near Falmouth,
Lancaster County, Pa

Back Cover Photographs:

Top Left: Jointing in the Harpers Phyllite
Codorus Furnace, York County

Top Right: Atreipus foot print on bridge
over Plum Run, Gettysburg National Military Park
Gettysburg, Adams County

Bottom: The "Serpentine Barrens",
Black Barrens, Lancaster County

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Written by Jeri L. Jones
Illustrations by Teanna L. Byerts

2008

Jones Geological Services, Spring Grove, Pennsylvania

ABOUT THE AUTHOR AND ILLUSTRATOR

Jeri L. Jones, a native of York, holds a B.A. in Geoarchaeology from Catawba College in Salisbury, N. C. He has studied the area's geology for 30 years. He enjoys researching geologic sites, mining history, groundwater and the geologic history of southeastern Pennsylvania. This is his fourth published book dealing with local geology as he loves to share his knowledge with those wishing to learn more about the fascinating science of geology. In 2006, Jeri was awarded the Digman Award for Teaching Excellence from the Northeastern Section of the National Geoscience Teachers Association. He owns and operates Jones Geological Services in Spring Grove, PA and also is employed by the York County Department of Parks and Recreation.

Teanna L. Byerts studied traditional art privately, and at York Academy of Arts in York PA, and was dragged kicking and screaming into the computer age by a cinematographer friend, where she discovered the wonders of Photoshop, and the Wacom graphics tablet (used extensively for the illustrations in this book). A fan of science fiction/fantasy, she nevertheless draws on real-world experience. Her illustrations and young adult stories are influenced by her own experiences training wild mustangs and her own (small) sled dog team, wrangling otters and raptors for wildlife rehabbers, crewing on a Viking longship (and other historical recreation), sea kayaking and decorating underwater Christmas trees. She volunteers with the York County Park System and finds it impossible to walk, paddle, or ride anywhere without returning with a pocketful of rocks.

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Preface

It is both exciting and adventurous to go to any rock outcrop and try to imagine how the rocks got there – what processes were involved in their formation, what they have experienced since their origin and the many years that have past. Every rock has a story to tell about their past, some having more chapters than others, depending upon their locations. Only if rocks could talk, what a story they would have to tell!!

The geologic sites included in this book will take you on a long journey back into geologic time. Remember though, that some of the geologic sites are on private lands and require permission from the property owners to view the outcrops. In some cases, the property owners know the value of their outcrops and may love to have “geologic interested” visitors on their property. In the cases of active quarries, all of these operations are quite dangerous and in most cases, the company will not allow visitors to the quarry. However, some quarries may host public open houses on occasion to allow residents to see the operation and see the geology.

All locations contain coordinates so they can be easily found with a GPS instrument. In many cases a reference has been included so you may read in more detail about the particular exposure or at least the area’s geology. Because of the constraints within this publication, I was not able to have every definition of a geologic term included. There are many good geologic reference books on the market or on the Internet to further explain a specific term.

I also encourage readers to communicate with me regarding the area’s geology. Should you have any comments or questions, please email me at JLJ276@aol.com.

INTRODUCTION

Geology is the study of the earth. From studying ancient rocks deposited in an ocean that no longer exists, to finding a foot print of one of the first dinosaurs that roamed the earth, to recognizing some geologic environmental hazards, there is a story to be told about our planet. When you think about our planet within such a vast solar system, we are just a grain of sand on a beach. However, as we look at just earth, a piece of the crust here in southeastern Pennsylvania is a very small part of what we call home.

Humans have been studying the earth for thousands of years. The first geologists were prehistoric people in search of the best stone to produce their stone tools. The oldest stone tools recognized in the United States are approximately 30,000 years old. Stone tools are known to have been traded or transported for several hundreds of miles for their quarrying location.

Many early "scientists" made observations of what they saw in the rocks around the world. Fossils on top of high mountains, similar fossils found on shorelines of two continents separated by a large ocean and igneous rocks formed from volcanoes that are no longer visible have baffled our minds. With the start of the geologic scientific age, James Hutton and Charles Lyell, among others, opened a new era of observations and understanding of how the earth system operates. Recognizing that various processes work on the planet day in and day out does change our surface. Our crust is not as solid as originally believed. The crust, like a skin of an apple, is broken into pieces of plates, which are moving at random in different speeds and directions. Mountains are pushed up as continents collide, new oceans are born when plates move apart and older crust is being destroyed as crustal plates are destroyed as they sink beneath other lighter plates.

In any case, the "TimeWalk" story will carry you through many millions of years of geologic history. As technology advances so does scientific thought. Scientific thought introduces new theories which are proven with observations and the recognition of these natural processes. Our story relies on one important theme – natural cycles. As you read the following chapters, a cycle of how our continent grew will become obvious fairly quickly.

"TimeWalk" was written as a result of furthering the thinking of geologic theories dealing with the evolution on the East Coast of the United States. In 1988, this author and Paul Chrastina published "Whispering Hills," the first ever publication on the geological history of York and Lancaster counties, Pennsylvania. This publication, now out of print, has been used by many as a teaching tool for local geology. When this author re-read "Whispering Hills" several years ago, much more has been learned about the geologic history of southeastern Pennsylvania. Some of the stages of development for our part of the country shown in "Whispering Hills" are now obsolete. The geologic story of southeastern Pennsylvania has to include a highland region in Adams, Franklin and Cumberland counties known as South Mountain. A new publication had to be written to bring the reader up to date on how our landscape in Adams, Lancaster and York counties evolved.

Now, enjoy "TimeWalk" and take that journey out to view the rocks. Each rock has a particular story to share to whoever wants to listen. Use the extensive reference list to read more about different topics. There is so much to understand and certainly more to learn……………………

CHAPTER 1.
LET'S GET DOWN TO EARTH

The Beginning

So you want to understand how our Earth's crust in southeastern Pennsylvania has developed. We need to start with the basics of understanding geology. After all, the same processes that are affecting earth today have affected our lovely planet for millions of years.

Geology is the study of our planet Earth. It involves the materials which make up the planet, the processes that shape it everyday, the organisms that have and are living on it, and the future development of the earth. So much like every science, a scientist must be familiar with other branches of science to understand the wider picture. For example, the rock types under a particular area often determine the type of plants that can grow there, which in turn may influence the species of animals living there.

So where did the earth come from? Several different ideas have evolved over the years concerning the origin and evolution of the vast universe and our solar system. About five billion years ago, a cloud of gas, dust and cosmic materials condensed to form what would become our solar system. As separate gaseous clouds condensed within the large oval mass, individual members of our solar system were born. Earth is believed to be 4.6 billion years old. From research on the moon and surrounding planets, we believe all of the members of the solar system are about the same age. The oldest rocks dated on our planet are about 3.8 billion years old.

As the earth and the other planets began to cool and condense, the young planets began to rotate and revolve around the centerpiece, the sun. Gravitational fields formed around this planet, moons and smaller bodies of the solar system. Sir Isaac Newton suggested the law of universal gravity, "where every body is affected by every other body."

As cooling continued, the foundation of the young earth formed our core, the center of the earth. This solid sphere composed of iron and nickel is what produces our magnetic field and on occasion, has a habit to fool compass users by reversing the magnetic pole.

Surrounding the core is a sphere of one-half liquid and one-half solid materials. This is known as the mantle. Its upper regions served as a source of magma for some of our volcanic activity.

The outer shell of our planet is known as the crust. This protective wrapping around the vital organs of the earth's active zones, formed as a result of magma cooling to form rock and cooling of the mantle rock. The crust underlying our massive continents is thicker than that underlying the spanning oceans. Another difference between continental and oceanic crusts is their composition. Continental crust is made up of granite while the oceanic crust is composed of basalt. Basalt is a denser rock than granite. When granite and basalt are face-to-face with each other, basalt will sink down below the granite. This difference in crustal rock types will play a role in the geologic history of southeastern Pennsylvania.

Over time, large amounts of water and gases were released from volcanic eruptions, forming the oceans and primitive atmosphere. As both the oceans and atmosphere developed further, primitive life began, starting a cycle which is continuing today.

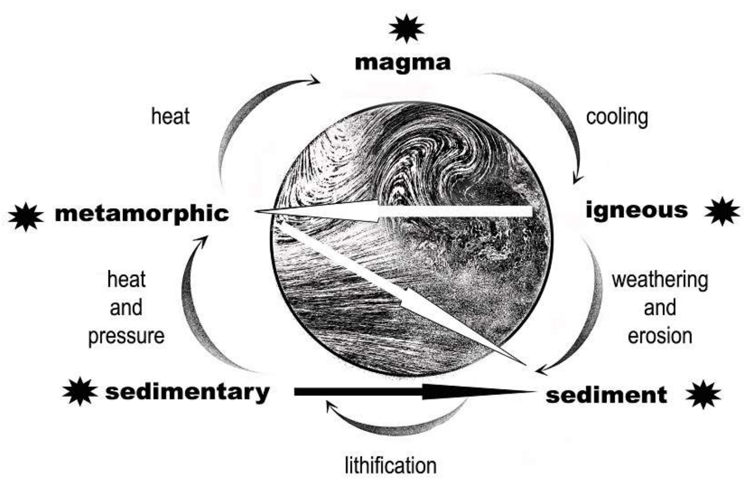
Reading the Rocks

The geologic history of an area is determined by the interpretation of researchers interpreting the rock types, their origins, their structure and changes over time. We have learned over the years that various processes have been affecting our earth for millions of years and are continuing to change the world. Although change is usually very slow, these processes are at work everywhere we look. Understanding how these processes function and what results are created help geologists decipher the geologic history. If the rocks could talk, they would have a magnificent story to tell.

A rock is simply an aggregate of one or more minerals naturally glued together. Based on their origin and/or changes, rocks can be classified into three classes: igneous, sedimentary and metamorphic. Just like so many natural objects, rocks are not stable. They can and do change due to the sometimes unpredictable natural changes or effects.

When I do programs involving rocks, I start my session by asking the students "Name me one thing in nature that does not operate in a cycle." I have yet to hear a correct answer!

Rocks are no exceptions. The rock cycle has been introduced to trace the life of a rock. As mentioned above, the foundation crust of continents and oceans are composed of igneous rocks. As the earth was being born, magma was the starting ingredient that would begin the process of forming our home. As magma cools, they form igneous (fire-derived) rocks. Magma extruded on the surface will turn to lava with the addition of atmospheric elements. This lava will cool quickly, forming microscopic crystals. This rock is an extrusive igneous rock. Magma trapped inside the earth will cool more slowly, forming larger crystals. A coarse-grained igneous rock is termed as intrusive.



Igneous rocks, when exposed to the atmosphere, will be affected by weathering and erosion. These two agents are like the movie characters Laurel and Hardy. When you see one, the other one is there! The igneous rocks break off of the bedrock into smaller pieces known as sediment. Sediment is transported by erosion, either down slope on the surface or downstream in a body of water. However, sometime and somewhere, sediment will gather and will eventually be glued together by natural processes using minerals.

Sedimentary rocks are the most common rock on the earth's surface. That is pretty understandable, knowing that weathering and erosion happens everywhere all of the time, for millions of years. Clastic sedimentary rocks are formed by the gluing together of sediment. The size of the sediment determines the rock type, which in turn reflects on the environment in which the sediment was deposited. Sometimes sedimentary rocks are formed by the precipitation of chemicals out of marine water or the buildup of minerals on the ocean bottom for organisms. These rocks are known as chemical sedimentary rocks.

As the ever-changing fractured crust of the earth shifts around, often igneous and sedimentary rocks suddenly (relatively speaking in geologic time) find themselves coming face to face with another piece of crust coming toward them. Collisions occur between two pieces of crust causing burial of rocks, heat and pressure. This is metamorphism, a process that will totally change either the mineral composition of the rock and/or the rock's texture. A rock undergoing these processes and forming a new distinct rock type is a metamorphic rock.

The type of metamorphic rock to be formed depends upon the original rock type and degree of heat, pressure and depth of burial. For example, take the sedimentary rock limestone. Placed under the agents of metamorphism, the small crystals of calcite in the limestone will be heated and weld themselves together to form a larger calcite crystal. This rock is then termed marble, a massive-looking rock known as a non-foliated rock.

At the other end of the scale is the sedimentary rock called shale. If shale is changed by tectonic events, the clay in the rock changes into mica. The mica fragments having perfect cleavage in one direction will align themselves perpendicular to the direction of the pressure presented. The rock formed could be called a phyllite, slate, schist or gneiss depending upon crystal size and degree of heat and pressure. These rocks take on a "layered" appearance which are known as foliation to a geologist. Gneiss forms under the greatest amount of metamorphic processes known. Not only does foliation occur, but the light and dark colored minerals separate themselves, giving the rock a banded appearance.

Because gneiss is the highest-grade metamorphic rock, any increase in heat and pressure would turn this rock back into magma, completing the rock cycle. Within the rock cycle are smaller cycles. Sedimentary and metamorphic rock can be eroded back into sediment. Metamorphic rocks can be put under processes again to make them another type of metamorphic rock.

Sedimentary rocks now found in our region will one day be weathered into sediment, transported by water, perhaps into the Chesapeake Bay or Atlantic Ocean, and glued together to make another sedimentary rock. Eventually, this rock may be deeply buried in the earth, re-melted into magma and the process would start all over.

STRATIGRAPHY

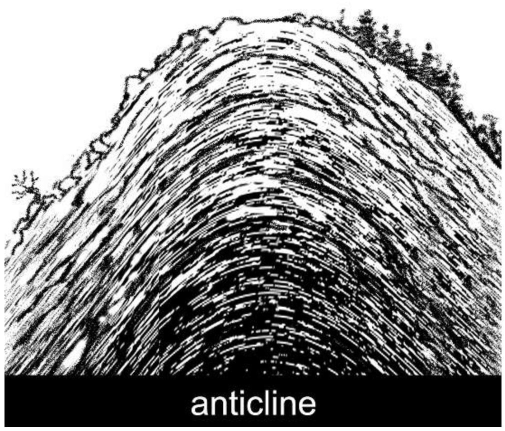
When rocks form, whether it be lava, sand or clay, are laid down in horizontal or near-horizontal layers. Although no actual age can be placed on layers without the aid of some ancient life form, we can use the principle of relative time. Relating one event to another event is very helpful in the interpretation of the origin of rocks.

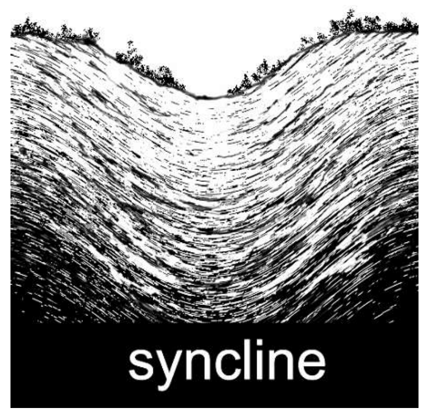
There are three rules to relative dating. The first was stated above as all rock layers are formed horizontal or near horizontal. If we see layers dipping into the Earth at a high angle, that tells a geologist that some type of force tilted these rocks. The second rule is that of superposition. The oldest layer is on the bottom and as you proceed upwards, the layers become younger. This makes sense if you think about it. Unless some tectonic forces are involved, the oldest layer is always on the bottom. The third rule is that of cross-cutting. Any rock that cuts through an existing rock has to be younger in age. Again, that makes sense when you think about it.

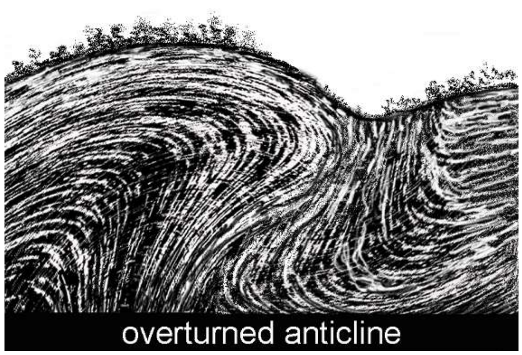
FOLDING

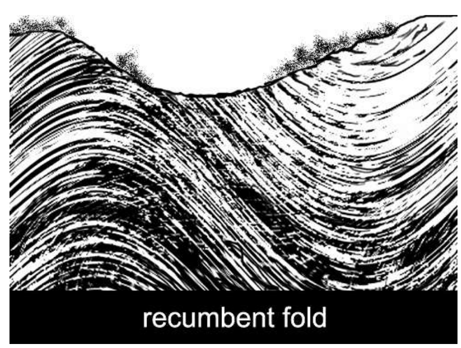
Up to this point, learning about rocks sounds simple. As long as you don't wander off of the rock cycle, there is no problem, right? After all, when you pick a rock up to identify it, it can only be one of three rock classes – what is so hard about that?

Well, here comes the complication, or at least several scenarios that could make understanding rocks more difficult. Constant tugging and pushing in the Earth's crust constantly creates pressure that shifts the rocks. On a regional view, large slabs of rocks known as formations can be put under pressure. Not only can metamorphism affect a large area, but rocks can be pushed together or folded. When the rock layers are pushed upwards into an arch, an anticline is formed. When the rock layers form a letter "U", the fold is known as a syncline. On a smaller scale, rocks can be bent and twisted by lesser pressure forming recumbent folding.


anticline


syncline


overturned anticline


recumbent fold

FAULTING

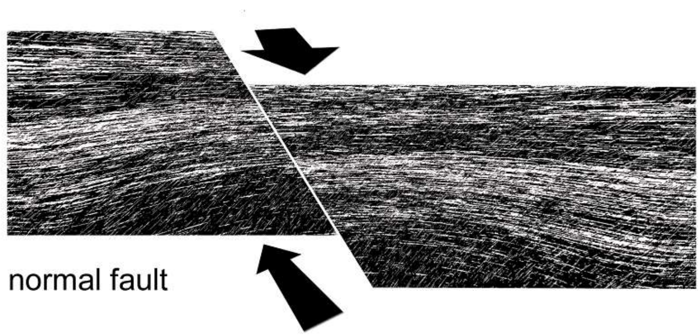
As the puzzle pieces of the earth's crust shift, some of these fragments grind together and other pieces come together. These forces can create breaks or fractures in the crust. A fault is a fracture where movement has taken place. Displacements in southeastern Pennsylvania range from several feet to tens of miles. A fracture showing no or very little movement is a joint. There are three different faults located in our region. Based on various factors with the rock type and amount and direction of pressure exerted is what determines the type of fault formed.

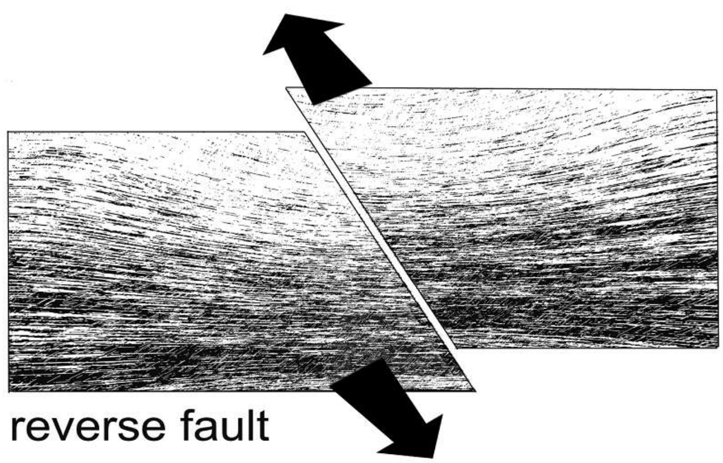
The fracture of a fault is known as the fault plane. Faults can be tilting into the earth at any angle, from nearly flat to vertical. The rock above the fault plane is known as the hanging wall. The rock below the fault is the foot wall. It depends on the relative movement of these two walls to determine the type of fault.

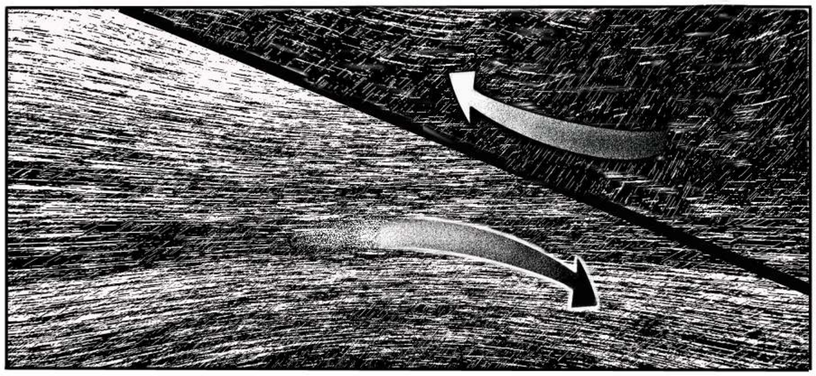
Faults where the hanging wall moves down compared to the footwall is a normal fault. These faults are created when tensional stress is involved. A fault where the hanging wall moves upwards is a reverse fault. Reverse faults are formed from compressional forces. A reverse fault that has a low-angle fault plane is a thrust fault, where one slab of rock has been pushed up and over another slab of crust.

All three types of faults are found in southeastern Pennsylvania, but thrust faults are the most wide spread.

You can now realize that rocks, when combined with folding and faulting, can be confusing to understand. If rock was totally exposed across the region, interpretation for a geologist would be very easy.







overthrust

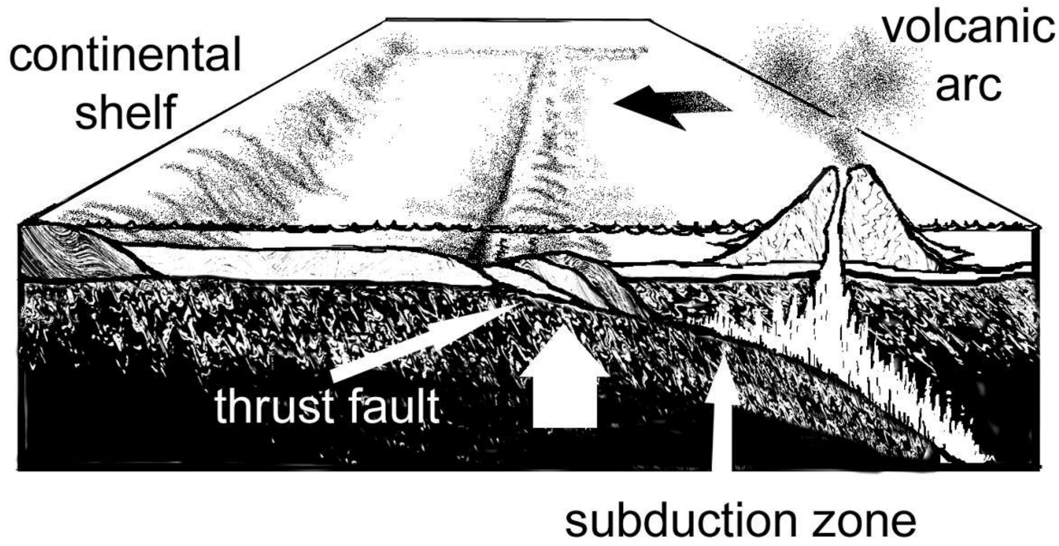
PLATE TECTONICS

For 200 years, scientists have recognized fossils on top of mountains, rocks that have been warped upwards to form large mountain ranges and even glacial deposits in the Sahara Desert. A world map shows a perfect fit between the continents in the Southern Hemisphere. These inquisitive investigators did a great job at recording their observations, but they could not explain how and why these processes occurred. In 1857 and 1858, respectively, Richard Owen and Antonio Snider clearly express the view that the Atlantic Ocean had opened by the separation of opposing continents. They believed this happened during a catastrophic event early in the earth's history. In 1882, Osmond Fisher proposed that the moon evolved from the Pacific Ocean, thus explaining the great depths of that massive ocean. From other research, we of course know that is not true.

In the early 1900's, geologists began to draw the conclusion that the earth was not rigid but was mobile. Scientists began to recognize that great folding and shortening of strata in alpine mountains had moved together. Geophysicists discovered that the continents weighed less compared to the oceanic crust and that all of the continents and oceans were floating. This led to the theory of isostasy.

In 1912, a German meteorologist, Alfred Wegener wrote his book "The Drifting Continents." Using fossil evidence on either side of the Atlantic Ocean, evidence of the South Pole once in Africa for his support. and the jig-saw fit between Africa and South America, Alfred attempted to convince the scientific community of his new theory. Although Alfred wrote four books between 1915 and 1928, his evidence was not supported by many people, particularly North American scientists. Sadly, Alfred died in 1930 without his works on continental drift being accepted by the science world. It was not until the early 1950's that his theory was being acknowledged. The symposium in continental drift sponsored by the British Royal Society in 1964 is considered to have launched this hypothesis on its modern course. Finally, the science world had a common theory to explain the observations that hundreds of researchers recorded, but could now explain.

Combining his works with other researchers, J. Tuzo Wilson recognized that ocean basins opened for a period of geologic time and later closed. Indeed, oceans do have a birth and a death over millions of years. Terms like convergent and divergent boundaries, subduction zones, island arcs and hot spots began to show up in the vocabulary. This theory is known as the Wilson cycle.



LET'S TALK ABOUT THE PRESENT

Take a moment and think about the landscape in Adams, Lancaster and York counties. We are so used to seeing our home area that we don't stop and appreciate our landforms. You drive from point "A" to point "B" every day, but do you really look at the surroundings? Our landscape is blessed with the famous Appalachian Mountains, elongated ridges, fertile valleys and historic streams and rivers. As viewed from the air, our landscape appears like a ribbon crossing southeastern Pennsylvania in a northeastern-southwestern direction. With topography, relief, geology and even vegetation, we can divide the region into physiographic provinces and sections. In our region, we have the Ridge and Valley Province, South Mountain Section and the Appalachian Piedmont Province which includes the Gettysburg-Newark Lowlands Section, Lowlands Section and the Uplands Section. (Numbers represent elevations in feet above sea level).

- Ridge and Valley Province
  South Mountain Section
  Adams County: Valleys - 800-1,000 feet; Ridges -1,400-2,100 feet
  York County: Valleys - 600-1,000 feet; Ridges -1,000-1,460 feet

The western portion and extreme northern York County is highlighted by the slopes of South Mountain, the northern extension of the Blue Ridge Mountains, which continues south to form the scenic mountains in Virginia, North Carolina and Tennessee. South Mountain comes to a impressive end near White Rocks, Monaghan Township, York County, about two miles north of Dillsburg. South Mountain is composed of parallel ridges of quartzite, phyllite and volcanic rocks of Proterozoic to Early Cambrian in age. Its narrow valleys are underlain by less resistant Cambrian limestones similar to the limestones of the Great Valley to the west.

- Piedmont Province

  Gettysburg-Newark Lowlands Section
  Adams County: Valleys - 450-600 feet; Ridges - 900 – 1,300 feet
  Lancaster County: Valleys - 400-600 feet; Ridges - 800-1160 feet
  York County: Valleys - 400-600 feet; Ridges - 800-1260 feet

  This section contains some famous man-made and natural landmarks in the area. Localities in Adams County include the Gettysburg National Military Park, Ski Liberty; in Lancaster County, Roundtop, Furnace Hills, Three Mile Island; and in York County, Ski Roundtop, Pinchot State Park and Conewago Mountain.

  Triassic sandstone, shale, conglomerate and limestone conglomerate are joined with diabase and isolated basalt flows of Jurassic age to make up the rock types in this area.

- Piedmont Province

  Lowlands Section
  Adams County: 400-600 feet
  Lancaster and York Counties: 350-550 feet

  The Lowlands Section is characterized with a broad valley with isolated rounded hills. The valley is locally known as the York-Hanover Valley (Adams and York counties) and Conestoga Valley (Lancaster County). To the east, the valley continues to become the Chester Valley. Traveling from west to east, you may follow Pa. Rte. 194 from Littlestown to Hanover and then Pa. Rte. 116 into West York and Rte. U.S. 30 through York and Lancaster counties. In Lancaster County, the Lowlands Section quickly expands to the north, but narrowing back down to a valley at the Chester County line, including much of East Hempfield Township and the U.S. Rte. 222 corridor north to Ephrata.

  This section is underlain by the soft rocks of limestone, dolomite, sandstone and shale ranging in age from Cambrian to Middle Ordovician.

- Piedmont Province

  Uplands Section
  Adams County: 700-800 feet
  Lancaster County: 300-950 feet
  York County: 600-1,200 feet

In the area, the Uplands Section is divided between several landforms. In Adams County, the section is only found in the southeastern corner east of Littlestown. The southern third of both Lancaster and York counties is composed on this section which is characterized by parallel ridges with narrow valleys. If you have ever driven south on Interstate Rte. 83 from Leader Heights or U.S. Rte. 222 south out of Willow Street, Lancaster County, you know there is very little flat area along the way. This area is composed of phyllites, slate, schists, metabasalts and serpentinite of probable Lower Paleozoic age.

Acting as a border between the Uplands Section and the Lowlands Section is a conspicuous ridge known in York County as Reservoir Hill. This ridge runs from Codorus State Park south of Hanover; northeastward to the Susquehanna River. Stoverstown, North Codorus Township; Reservoir

Hill above York College of Pennsylvania and Sam Lewis State Park in Lower Windsor Township all sit on this ridge. Sam Lewis State Park is the highest point on this ridge at an elevation of 840 feet.

In Lancaster County, Manor Hills is the eastern extension of Reservoir Hill Ridge. Manor Hills runs from Washington Boro on the Susquehanna River to a point south of Lancaster.

In York County, the Pigeon Hills between Abbottsotwn and Thomasville and the Hellam Hills between Pleasureville and the Susquehanna River west of York are included in the Uplands Section. The highest point in the Pigeon Hills is 1,196 feet at Pulpit Rock in Heidelberg Township. In the Hellam Hills, the highest elevation is 1,057 feet, located east of Tower Road in Hellam Township. These highlands consist of Late Proterozoic and Early Cambrian quartzite, conglomerate, phyllite with older metavolcanic rocks making up the core.

In Lancaster County, the eastern extension of the Hellam Hills is Chickies Ridge with a northern spur called Chestnut Ridge. Along the Susquehanna River at the Chickies Ridge gap is one of the most famous rock outcrops in the area, Chickies Rock. Here Proterozoic quartzite is exposed in an anticline. Within these ridges are the Late Proterozoic and Early Cambrian quartzites and phyllites.

In eastern Lancaster County, there are two other highlands to be mentioned. The Honeybrook Uplands extend from the Earl-East Earl/Salisbury Township confluence eastward into Chester County. This ridge is locally known as the Welsh Mountains. The highest point is 1,101 feet at a point east of Pa. Rte. 872 in East Earl Township near Money Rocks County Park.

Mine Ridge, a region of Proterozoic metavolcanic rock is sandwiched between the carbonate rocks of the Conestoga Valley. Mine Ridge extends from approximately two miles northeast of Quarryville, east-northeast into Chester County, where it runs into the Honeybrook Upland. The highest elevation is 827 feet, located east of Gap, Lancaster County.

Proterozoic metagabbro, serpentinite, granodiorite gneiss and granitic gneiss make up the core of these two regions. Late Proterozoic quartzites, quartz schists and phyllites surround the older metamorphic and igneous rocks.

DRAINAGE

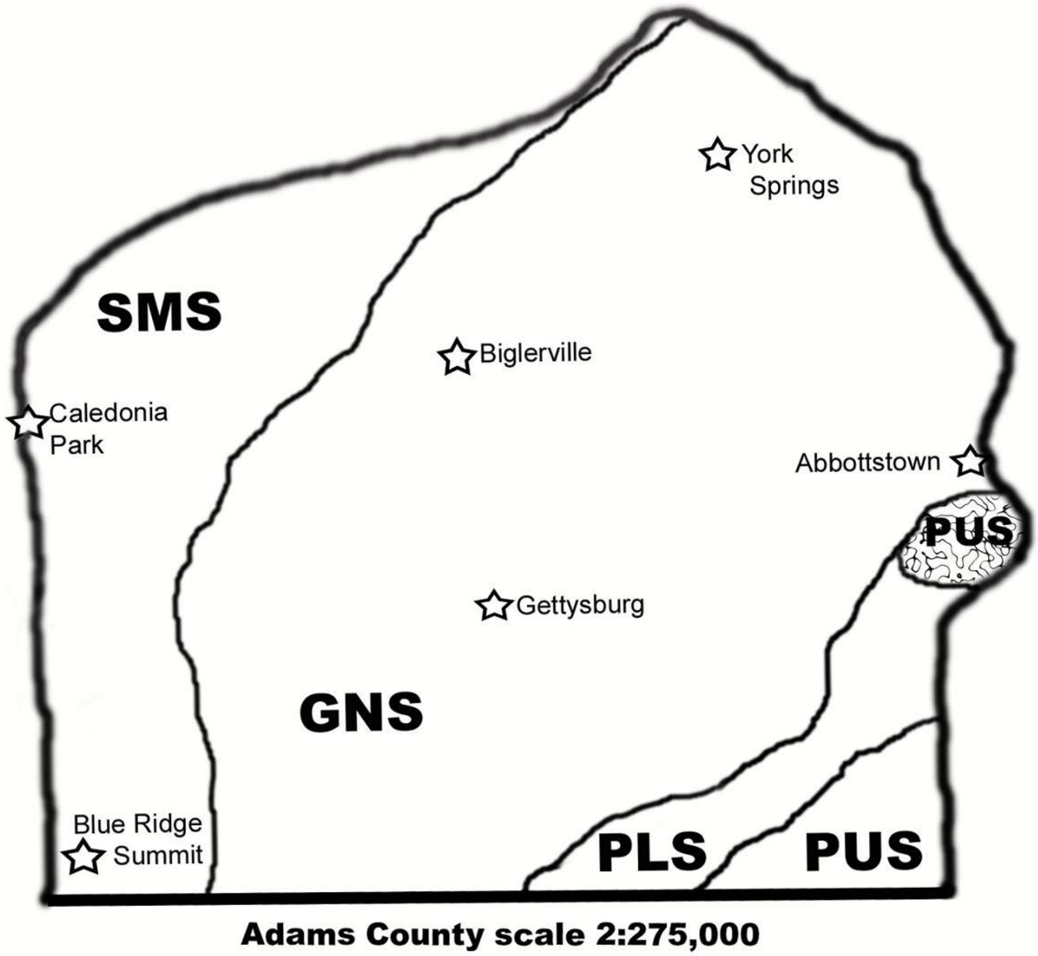
Two drainage basins are involved in Adams, Lancaster and York counties. Adams County contains a small version of a continental divide. All of the streams south and west of an imaginary line from Littlestown, Bonneauville, Biglerville, Aspers and northwest to the Adams-Cumberland County line eventually flow south into the Potomac River. Streams located to the north and east of the divide flow into the Susquehanna River. Major tributaries in Adams County flowing into the Potomac River include from west to east: Antietam Creek, Tom’s Creek, March Creek, Rock Creek and Alloway Creek.

All of the streams in York and Lancaster counties belong to the Susquehanna River Basin. Drainage direction is to the north and east in northern and central York County. In the southern portion of York County, drainage is into Muddy Creek. The three tributaries in central and northern York County include Conewago Creek, Codorus Creek and Yellow Breeches Creek.

All of the drainage in Lancaster County flows generally to the south. Major tributaries from north to south include: Conewago Creek, Donegal Creek, Chickies Creek, Pequea Creek, Muddy Run and Octoraro Creek.

SINCE YOU KNOW ALL THE BACKGROUND MATERIAL…………

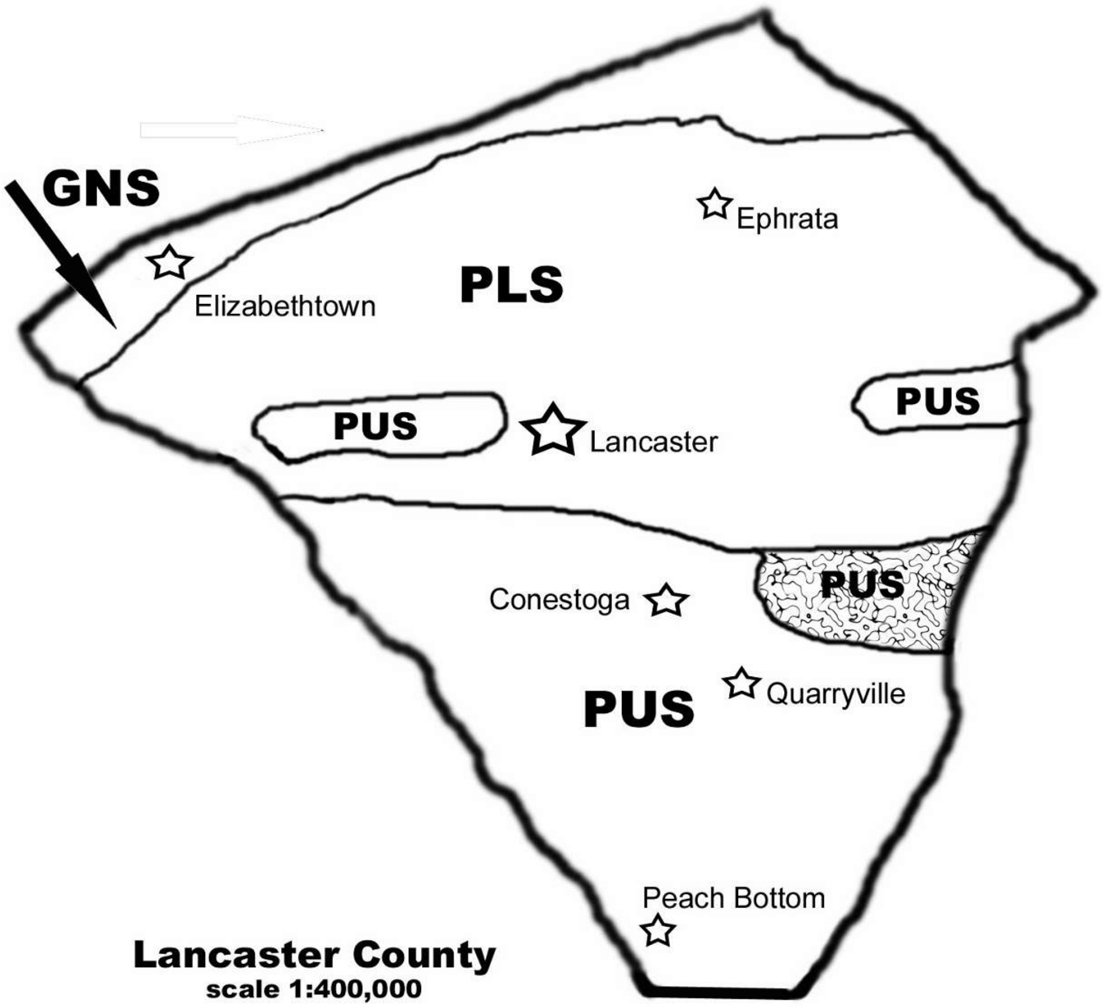
Now that you understand the basics of geology and an understanding of the topography in the region, it is now time to march ahead and get to the story of the area. Luckily, we will march through the geologic history faster than what it took to develop. Our story is going to start one billion years ago. Have a great TimeWalk!!!!!



North is toward top of page

SMS	South Mountain Section of the Ridge and Valley Province
GNS	Gettysburg-Newark Section of the Piedmont Province
PLS	Lowlands Section of the Piedmont Province
PUS	Uplands Section of the Piedmont Province

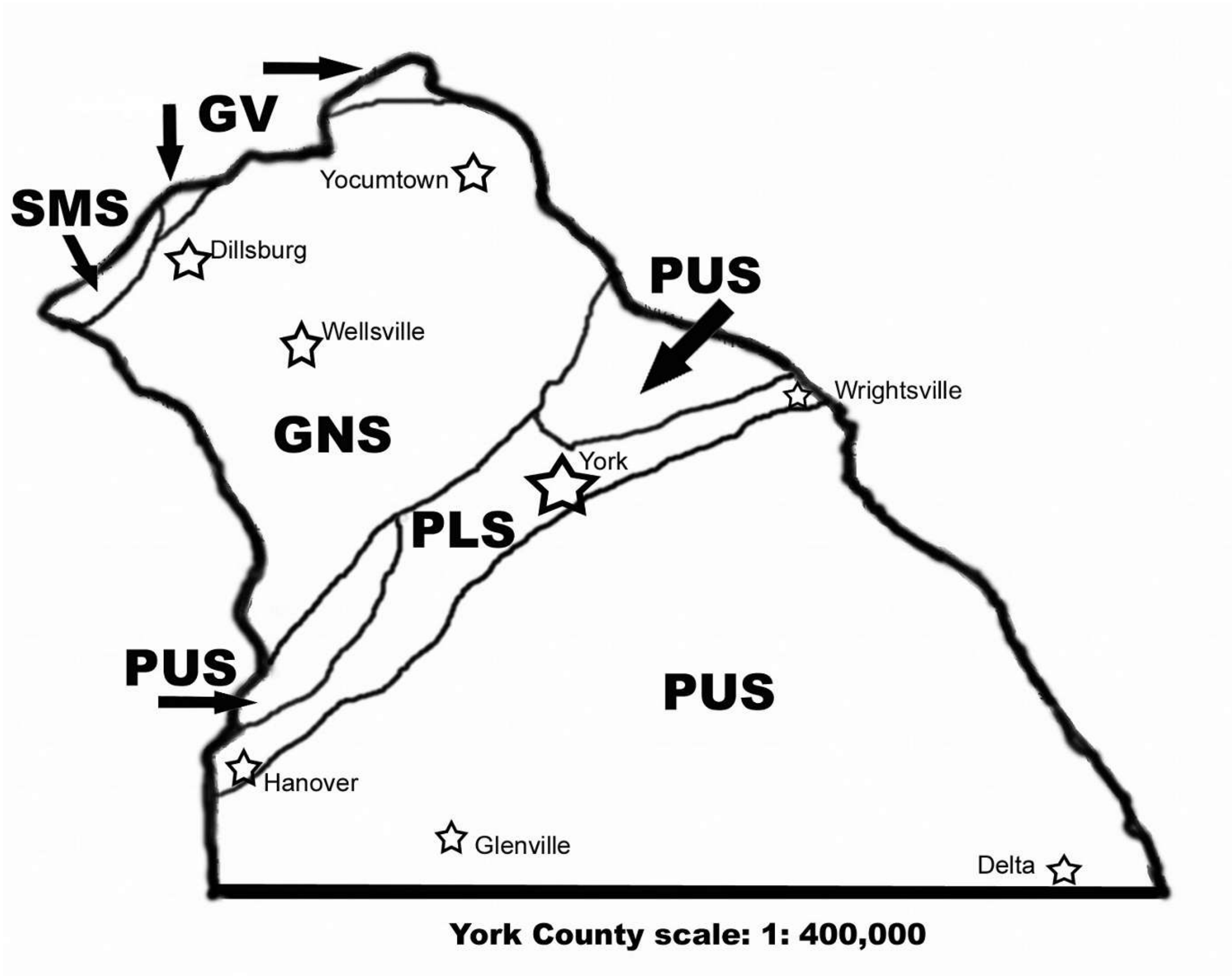
PUS (shaded) are the Pigeon Hills



North is toward top of page

GNS	Gettysburg-Newark Section of the Piedmont Province
PLS	Lowlands Section of the Piedmont Province
PUS	Uplands Section of the Piedmont Province

PUS (west of Lancaster) is Chickies and Chestnut Ridges
PUS (east of Lancaster) is Honeybrook Uplands
PUS (east of Quarryville) is Mine Ridge



North is toward top of page

GV	Great Valley Section of the Ridge and Valley Province
SMS	South Mountain Section of the Ridge and Valley Province
GNS	Gettysburg-Newark Section of the Piedmont Province
PUS	Uplands Section of the Piedmont Province
PLS	Lowlands Section of the Piedmont Province

PUS (north of Hanover) is the Pigeon Hills
PUS (north of York) is the Hellam Hills

Rock Formations In Adams, Lancaster and York Counties
(in alphabetic order)

Name	Rock Type(s)	Age	Approximate Thickness (feet)
Annville Fm.	Limestone	Ordovician	250
Antietam Fm.	Quartzite	Cambrian	300
Buffalo Springs Fm.	Limestone, Dolomite	Cambrian	1,000
Cardiff Fm.	Conglomerate, Quartzite	Ordovician?	200
Catoctin Fm.	Metarhyolite, Metabasalt	Proterozoic	?
Chickies Fm. Hellam Member	Conglomerate	Proterozoic	600
Chickies Fm. Quartzite Member	Quartzite	Proterozoic	400
Cocalico Fm.	Sandstone, Shale	Ordovician	2,000
Conestoga Fm.	Limestone	Cambro-Ordovician	300
Elbrook Fm.	Limestone, Dolomite	Cambrian	3,000
Epler Fm.	Limestone, Dolomite	Ordovician	1,000
Gettysburg Fm. Conglomerate Member	Conglomerate	Triassic	7,300
Gettysburg Fm. Heidlersburg Member	Sandstone Shale	Triassic	4,800
Gettysburg Fm.	Shale, Sandstone, Limestone	Triassic	16,000
Hammer Creek Fm.	Sandstone, Shale	Triassic	9,360
Harpers Fm.	Phyllite	Proterozoic	1,500
Hershey Fm.	Limestone	Ordovician	1,000
Kinzers Fm.	Shale, Limestone	Cambrian	150
Ledger Fm.	Dolomite	Cambrian	2,000
Loudoun Fm.	Phyllite, Conglomerate	Cambrian	200
Millbach Fm.	Limestone	Cambrian	500+
Myerstown Fm.	Limestone	Ordovician	220
New Oxford Fm.	Conglomerate, Sandstone, Shale	Triassic	4,000
Octoraro Fm.	Schist, Quartzite	Ordovician?	10,000?
Ontelaunee Fm.	Dolomite	Ordovician	800
Peach Bottom Fm.	Slate, Schist	Ordovician?	1,000
Peters Creek Fm.	Schist, Quartzite	Ordovician?	2,000?
Richland Fm.	Dolomite	Cambrian	750
Schaefferstown Fm.	Limestone	Cambrian	300
Snitz Creek Fm.	Dolomite	Cambrian	1300
Stockton Fm.	Sandstone,Shale	Triassic	5,000

Rock Formations In Adams, Lancaster and York Counties
(in alphabetic order)
continued

Stonehenge Fm.	Limestone	Ordovician	1500
Tomstown Fm.	Dolomite	Cambrian	1,000
Vintage Fm.	Dolomite, Limestone	Cambrian	650
Weverton Fm.	Quartzite, Phyllite	Cambrian	900
Zooks Corner Fm.	Limestone, Dolomite	Cambrian	1,600
Zullinger Fm.	Limestone, Dolomite	Cambrian	2,500
	Felsic Gneiss	Proterozoic	?
	Granodiorite and Gneiss	Proterozoic	?
	Grantic Gneiss	Proterozoic	?
	Gabbroic Gneiss, Gabbro	Proterozoic	?
	Hornblende Gneiss	Proterozoic	?
	Metagabbro	Proterozoic	?
	Pegmatite	Proterozoic	?
	Quartz Monzonite	Proterozoic	?
	Quartz Monzonite Gneiss	Proterozoic	?
	Serpentinite	Proterozoic	?

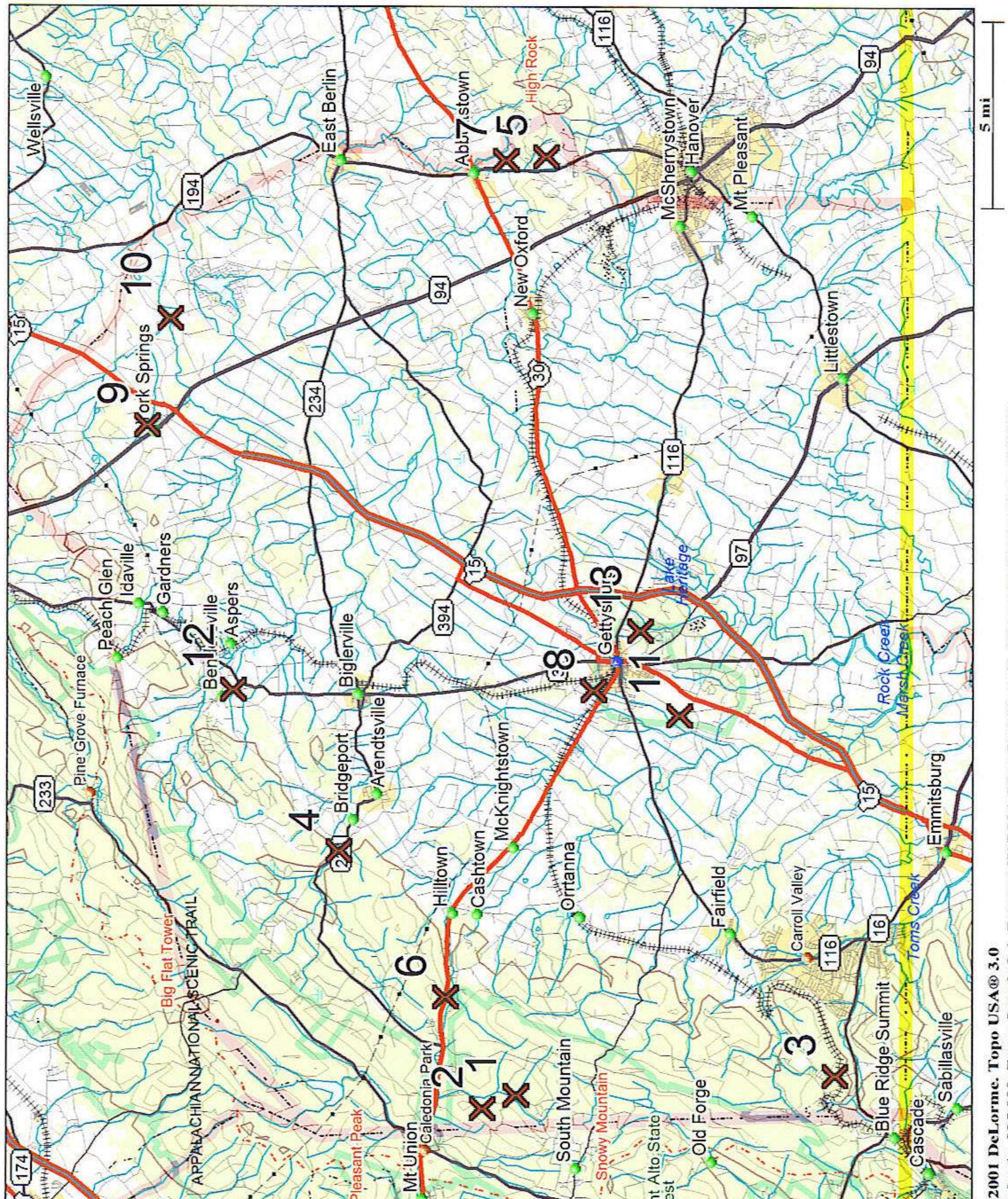
NOTES

Adams County TimeWalk Localities

#	Location Name	Formation(s) and General Description
1.	Carbaugh Reservoir	Columnar Jointing in Catoctin metarhyolite
2.	Carbaugh Run Rhyolite Quarry	Prehistoric Quarry in Catoctin Formation
3.	Jacks Mountain Tunnel	Folded and Faulted Weverton quartzite and Catoctin metabasalt
4.	The Narrows	Stream Erosion in Catoctin metarhyolite
5.	Beaver Creek Road South	Exposure of Catoctin metabasalt
6.	Carbaugh Run-Marsh Creek Fault	Gap through South Mountain
7.	Beaver Creek Road North	Exposure of New Oxford sandstone
8.	Gettysburg CSX Railroad Cut	Gettysburg sandstone and siltstone with diabase intrusion and hornfels
9.	York Springs Fossil Site	Gettysburg sandstone and siltstone with plant remains
10.	Trostle Quarry	Gettysburg Heidelsburg Member siltsotne and sandstone with mud cracks
11.	Devil’s Den	Exposure of diabase and weathering
12.	Aspers Roadcut	Rare glimpse of the Aspers Basalt
13.	Culp’s Hill	Panoramic view of regional landscape

NOTE:

- North on map is toward the top of the page
- Other map information found at the bottom of the map
- Localities are described in more detail under “Where Can I See Some Examples” at the end of the chapters
- Many of the sites are on private property. Please get permission before approaching the site.



© 2001 DeLorme. Topo USA® 3.0
Scale: 1 : 225,000 Zoom Level: 9-1 Datum: WGS84 Map Rotation: 0° Magnetic Declination: 10.9°W

Lancaster County TimeWalk Localities

#	Location Name	Formation(s) and General Description
1.	Fishing Creek East	Fishing Creek metabasalt
2.	Chickies Rock	Chickies quartzite and folding
3.	Money Rocks County Park	Chickies quartzite exposures
4.	Weaverland Quarry	Stonehenge limestone, folding and faulting
5.	Rohrer's Quarry	Epler limestone, folding and faulting
6.	Cherry Hill Roadcut	Peters Creek schist, Cardiff conglomerate, Peach Bottom slate and diabase
7.	Black Barrens Road	Serpentinite and barrens
8.	Rheems Quarry	Epler limestone, folding and faulting
9.	Shenk's Quarry	Peach Bottom slate folding
10.	Propsect Quarry	Millbach carbonates, folding and faulting
11.	Miller Road Roadcuts	2 stops with the New Oxford fanglomerate and sandstone and shale
12.	Eagle Rock	Hammer Creek sandstone
13.	Aberdeen Cut	Diabase intrusion
14.	Governour's Stable	Diabase intrusion and weathering
15.	Holtwood Dam	Overlook to the Susquehanna River
16.	Conewago Falls	Pothole development in diabase
17.	Kirk Farm	River terrace gravels
18.	Fishing Creek West	Peters Creek schist in Drumore Tectonite Zone

NOTE:

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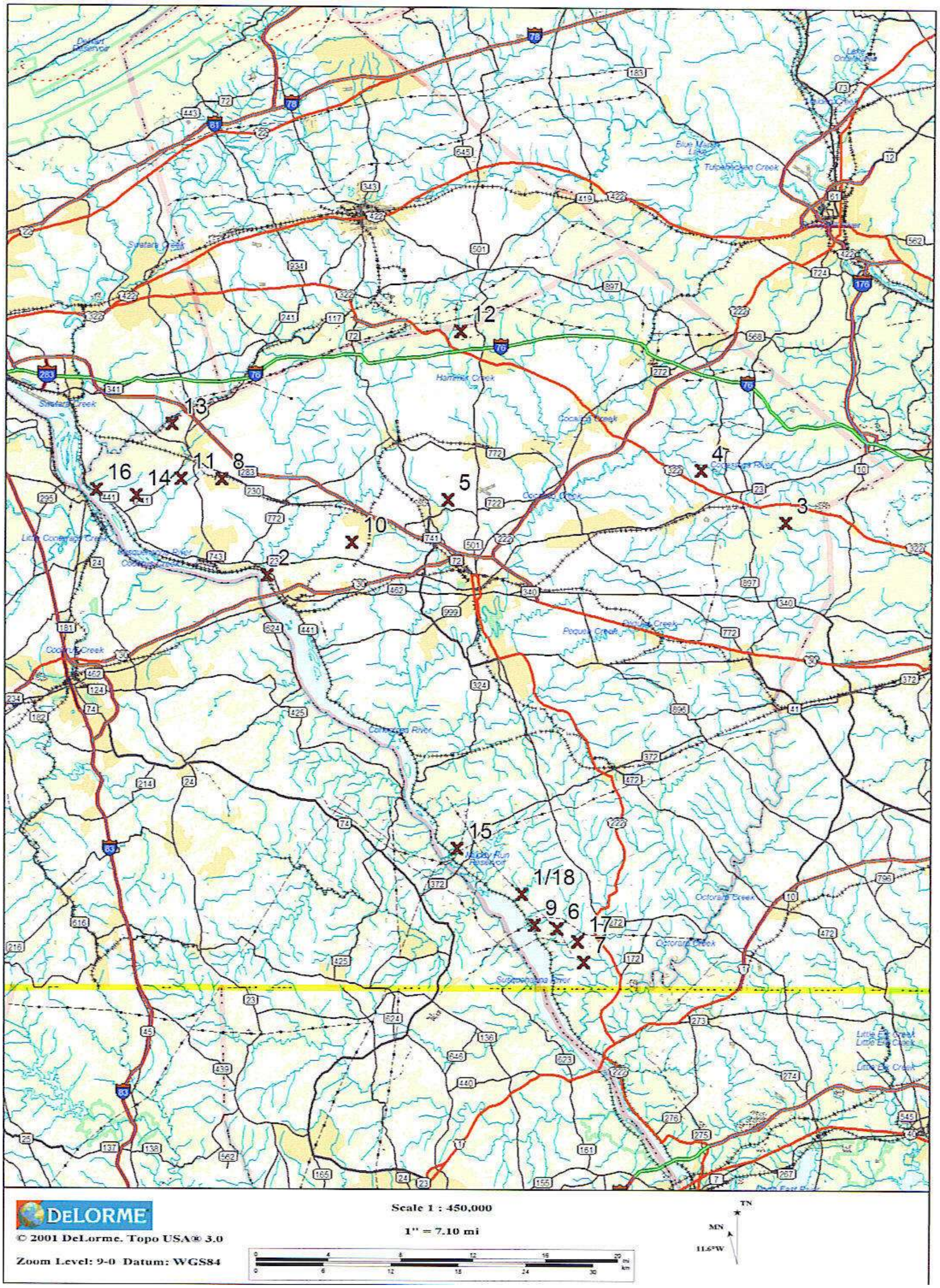
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Susquehanna River
Conestoga River
Octoraro Creek
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© 2001 DeLorme. Topo USA® 3.0
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York County TimeWalk Localities

#	Location Name	Formation(s) and General Description
1.	Accomac	Catoctin metabasalt
2.	Glen Rock South	Sam’s Creek metabasalt
3.	Holtwood Dam	Pillow structures in Holtwood metabasalt
4.	Rocky Ridge County Park	Chickies Hellam Member conglomerate
5.	Sam Lewis State Park	Susquehanna River overlook
6.	York Silica Quarry	Chickies quartzite
7.	LWB Quarry	Ledger carbonates and Kinzer limestone
8.	Locust Lane	Kinzer shale with trilobites
9.	Frogtown Road Exposure	Marburg schist
10.	Lock 12 Exposure	Octoraro schist
11.	Funkhauser Quarry	Peach Bottom slate
12.	Stoney Brook Railroad Cut	Diabase intruding Conestoga limestone
13.	Glen Rock North	Octoraro quartzite
14.	Seitzland Railroad Cut	Octoraro schist and folding
15.	Raab County Park	Harpers phyllite and historic mine
16.	County Line Quarry	Vintage dolomite with folding and faulting
17.	Pottery Hill Exposure	Gnatstown Overthrust
18.	Indian Rock	Chickies quartzite with an anticline
19.	Gut Road	New Oxford conglomerate
20.	Sheep Bridge Road Cut	New Oxford sandstone and shale
21.	Rossville Road Cut	Gettysburg hornfels with copper
22.	York Haven Quarry	Diabase
23.	Pinchot State Park	Diabase and weathering
24.	Shull’s Rock	Chickies Quartzite and Overlook
25.	Chimney Rock	Chickies Hellam Member conglomerate

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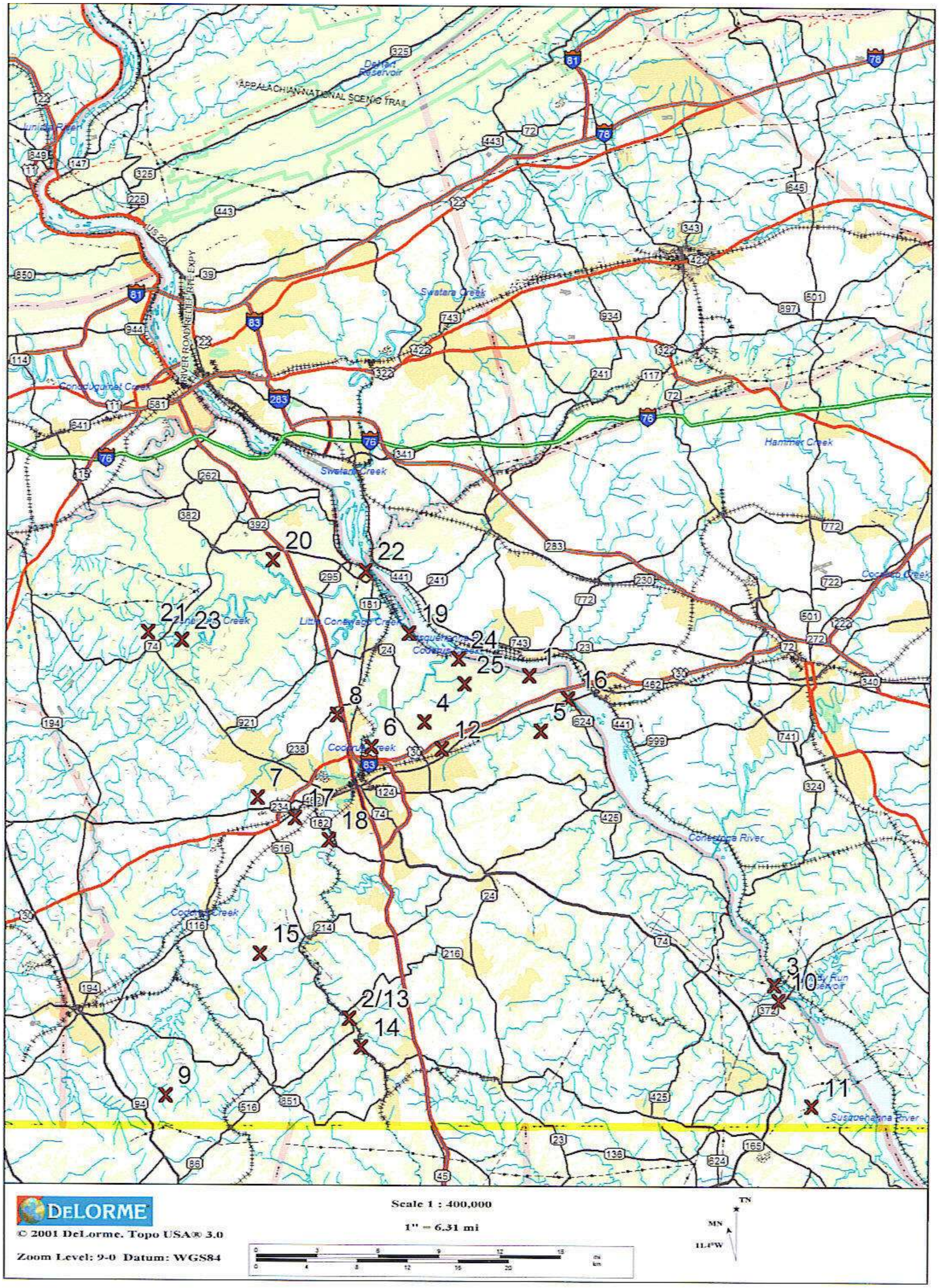
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Swatara Creek
Conodoguinet Creek
Little Conewago Creek
Codorus Creek
Hammer Creek
Conestoga River
Susquehanna River
APPALACHIAN NATIONAL SCENIC TRAIL
DeLorme
© 2001 DeLorme. Topo USA® 3.0
Zoom Level: 9-0 Datum: WGS84
Scale 1 : 400,000
1" = 6.31 mi
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CHAPTER 2.
THE FIRST SUPER CONTNIENT?

Before we start building our continent, we have to understand that all of the continents are made of a granitic crust. We also have known that each continent has a shield or craton, which was the original building block of a continent. The foundation of North America is known as the Canadian Shield which is located in the upper Midwestern United States and central Canada. Our shield rocks produce radiometric dates of over 3.0 billion years old (bya). In fact, the oldest rock in the world has been dated at 3. bya and was found in the Minnesota River Valley in Minnesota. It was the shield that the remaining parts of North America were added onto by plate collisions during geologic history. This shield was the creation of a continent that was known as Laurentia from the Late Proterozoic into the Permain Period, way before the name of North America came about.

So if you are ready to get started to investigate our geologic past, we always need a starting point. Should we start where Alfred Wegener began with his theory of continent drift and the formation of the super continent, Pangaea, during the Permian period? After all, that would be the most logical place to start, the building of a continent. In the 1960's, that would have been a good starting point but with today's research and technology, we know that there was another super continent similar to Pangaea about one billion year ago. This super continent is known as Rodinia and during its evolution, it is believed that this super landmass was located near the South Pole. Now you may ask "How do we know these facts since no one was around at this time?" Through the use of paleomagnetism, a rock's history of movement can be traced through the earth's history. For example, if magnetite is present in sediment or magma, before lithification or crystallization takes place, the magnetite will act like a compass needle, pointing toward the magnetic north. Geologists can carefully sample the rock, examine the magnetite in the sample and determine its location at the time the rock formed.

One also has to understand that the older the rock, the less evidence there is to develop a theory. This is similar to you walking in the snow right after a storm, leaving your footprints. After several days, additional people have followed the same route and possible later snow falls would destroy or damage your prints. Putting pieces together of Rodinia is difficult due to the various plate tectonic activities that have occurred since one billion years ago. This is what makes a geologist's occupation interesting - once you think you know all of the answers, you find out you don't!

It's difficult to imagine exactly what Rodinia looked like. Certainly, this super continent was not shaped like its cousin, Pangaea, some 700 million years later (mya) in time. What we do know is that it is possible that some of Rodinia's crust is found in Pennsylvania, including the southeastern portion. It is believed that Proterozoic rocks underlie all of Pennsylvania. These rocks have been metamorphosed one or more times and occur today as grandiorities, granitic gneisses, biotite-quartz gneiss, and biotite granite. We will refer to these oldest rocks as Grenville rocks. These rocks have been encountered in deep exploratory oil and gas wells in northwestern Pennsylvania, eastern Ohio, northern West Virginia and southern New York.

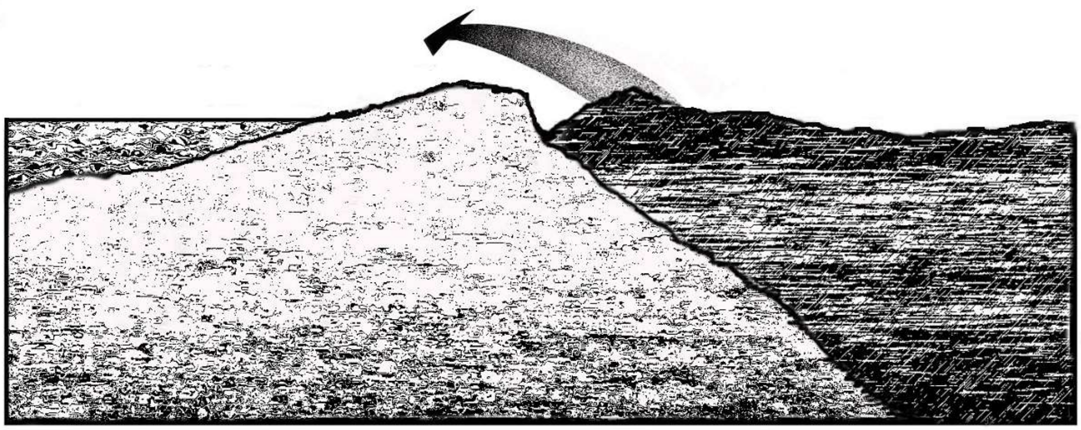
The gneisses indicate that the parent product was a granitic composition. It is believed that some of these rocks show evidence of several stages of crystallization from magma, recrystallization, replacement and deformation of the rock fabric. The rocks examined from the exploratory wells give radiometric date ranging from 900 mya to 1.1 bya. These are clearly the oldest rocks found in the state.

The granitic gneiss is exposed within the core of the Blue Ridge Mountains as far north as Maryland. Younger metavolcanic and metasedimentary rocks cover these rocks within the South

Mountain Section of the Ridge and Valley province in Pennsylvania. These Proterozoic rocks are only exposed within the Reading Prong in eastern Pennsylvania and the Piedmont Uplands.

Within the Piedmont Uplands, the Honey Brook Uplands and Mine Ridge play host to similar Grenvillian rocks. Both of these upland landforms contain a complex suite of granitic gneisses, gneisses, quartzites and ultramafic intrusions. These rocks provide a rare glimpse of the Rodinia landmass. With the tectonic movement that occurred since this ancient super continent, these two masses were separated and positioned at their present day location.

Through radiometric dating and chemical compositions, all of these Rodinia crustal rocks have been intensely metamorphosed approximately 1 bya during the Grenville Orogeny. This date would indicate that the original rock actually formed much earlier in geologic time.



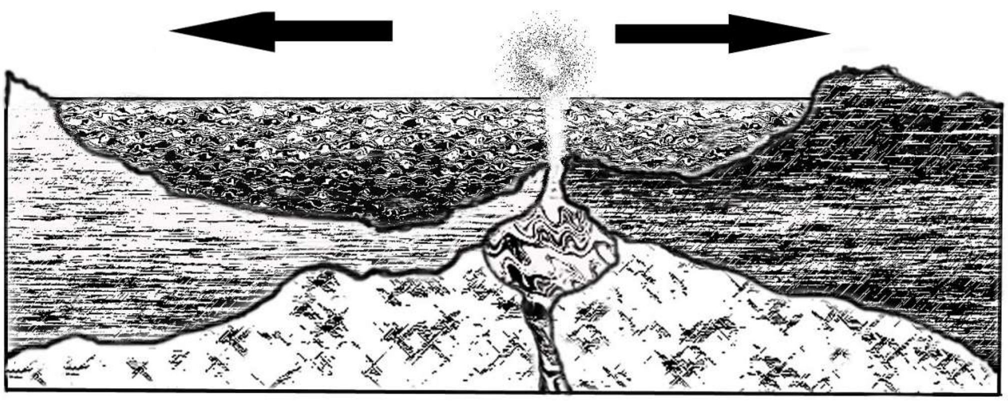
Building of Rodinia

An orogeny is usually named for an area that is most strongly influenced. In this case, Grenville is named from a township in Ontario, Canada. The Grenville rocks in Pennsylvania vary considerably in lithology and metamorphic grade. Some of the rocks have a chemistry similar to those of igneous rocks while others have the chemistry of sedimentary rocks. The metasedimentary rocks can be separated by their quartzitic, calcareous or aluminous compositions. The Grenville rocks of our state can be associated with similar rocks within the Grenville terranes of New York and Quebec.

What caused the Grenville Orogeny has been debated for years. Research conducted in the past twenty years, however, has enforced the thinking that a plate collision was involved. In the Adirondacks of New York, it appears that a continental collision and under-thrusting is the accepted model for that region. However, Baer (1981) suggests a plate “jostling” with infra-continental deformation. In any case, the Grenville rocks were deeply buried and heated to a point to recrystallize the rock to a high level of metamorphism. The continental collision was probably the result of convection currents bringing crustal fragments together to form the supercontinent, Rodinia.

About 750 mya, the convection currents within the asthenosphere reversed. (This is a procedure that occurs periodically throughout geologic time as you will see in the following chapters). Continental breakups were caused by stationary columns of magma that broke the crust into fragments. These columns are known as plumes or hotspots. Rodinia began to be split apart, separating into at least four blocks: Laurentia, Baltica, Gondwanaland (Africa, South Ameirca and Antarctica) and Siberia. As the convection currents continued to push apart these segments, the

IapetusOcean (Proto-Atlantic) was born.



plume

Faill (1999) does a nice job in reconstructing what this part of the country looked like during the Proterozoic and Paleozoic. He shows four rift valleys cutting through present-day Pennsylvania. The Rome Trough is found in western and northern Pennsylvania; the Catoctin Rift through the southeastern portion of the state; the Octoraro Sea off of the coast of present-day Delaware and further southeastward, the Iapetus Ocean.

The Catoctin Formation, named from the Catoctin Mountains of Maryland contains metamorphosed rhyolite and basalt. Catoctin Mountain is the southern extension of South Mountain in Pennsylvania. In geologic terms these rocks are known as metarhyolite and metabasalt. This is also where the Catoctin Rift is so-named. Radiometric dating within the Catoctin Formation rocks suggests a date of 820 mya in Virginia (Ranklin and others, 1969). Many geologists feel that this date is too old to fit the picture. Rankin himself has suggested a date of 700 mya for these rocks. Badger and Sinha (1988) dated the Catoctin in central Virginia as 570 mya.

The Catoctin Formation rocks have been metamorphosed to a greenschist stage Rhyolite, containing quartz and feldspar, classified in the granite class. The only difference is the size of the crystals or texture. Granite is an intrusive rock while rhyolite formed on the surface as lava. Rhyolites are associated with continental rifting while basalts form in oceanic environments. The age relationship between these two extrusive rocks is difficult to determine. Stose (1932) notes that rhyolitic fragments have been found within the coarse clastic material of the overlying Chillhowee Group, meaning that the rhyolite overlies the basalts. Also, Smith and others (1991) have determined that the lava producing the rhyolites extruded after the basaltic material. A good example of rhyloite exposures are found in Carbaugh Run Preseve of Michaux State Forest, along District road along the Adams-Franklin County line.

The Catoctin Formation is not limited to the South Mountain Section. The unit also exists in the Piedmont Uplands Section. Metabasalt is the oldest rock exposed in the Pigeon Hills, Berwick Township, Adams County, northeast of Hanover. Along Beaver Creek Road in the Pigeon Hills, metabasalt can be seen containing amydules (filled-in gas bubbles). Both metarhyolite and metabasalt are well exposed in the Hellam Hills at Accomac, Hellam Township, north of Wrightsville,York County. Here, quartz filled amygdules are seen. A small amount of native copper and malachite is also visible. Throughout southern York and Lancaster counties, there are also metabasalts associated with the metamorphic rocks of the Piedmont Uplands Section. In historic times, it was believed that these metabasalts were of the same age as the Catoctin Formation rocks, but today that thinking has changed thanks to more detailed mapping techniques and geochemical analyses.

Smith and others (1991) and Smith and Barnes (1994) have conducted detailed geochemistry on the metavolcanics located in both the South Mountain Section and the Piedmont Uplands. Based on their data compared to data taken from present-day known volcanic environments, these metabasalt environments can be established.

It is an acceptable theory among geologists that these volcanic rocks were associated with rifting of Rodinia and the opening of the Iapetus Ocean. In fact from the radiometric dates provided, there appears to be two different stages of rifting. The first event starting about 750 mya separating crustal fragments off of Rodinia and forming water-filled rift valleys. About 570 mya, another event further split the continent to begin the initial stage of the Iapetus Ocean.

The geochemical analyses indicate that all of the Catoctin metavolcanics are related to the rifting of Rodinia. However, Smith and Barnes (1994) research does take the rifting stages a bit further. Each metabasalt location does represent a particular stage of rifting, ranging from intra-plate initial rifting to fore-arc and back-arc locations. One metabasalt also indicates a sea-floor basalt during the drifting period. It is interesting to note that the Pigeon Hills metabasalt is labeled as ocean-bottom basalt, thus explaining why no rhyolite is located there. Metarhyolite is associated with the metabasalt in the Hellam Hills, which is labeled as within-plate rifting where rhyolite would be expected to be found. Metarhyolites are not associated with any of the metabasalts in the main section of the Uplands Section in southern York and Lancaster counties..

Smith and others (1991) have identified a host of volcanic features that support a land (subaerial) volcanism involving intra-plate rifting. These features include pillows, pipe vesicles, pyroclasts, ropy pahoehoe, pahoehoe toes, volcanic rock containing unsorted large clasts (agglomerates) and thin flows having chilled tops. Pillows and the chilled tops are good indications of submarine eruption. Similar occurrences today can be seen off the coast of Hawaii. Agglomerates are usually formed at a vent breccia or as debris in mudflow or lahar. Columnar jointing, indicative of lava flowing into water, has only been observed at one site in this region. This significant site is located at Carbaugh Reservoir, Franklin Township, Adams County.

It has also been suggested that the east-to-west trending faults through South Mountain may have originally formed in the Late Proterozoic or possibly in the Ordovician during the Taconic Orogeny. They also mentioned that the Gettysburg Basin (an active Mesozoic rift basin) could lie in the same location that the Rodinian rift valley is situated in. The trace of Catoctin Mountain in Maryland projected into southern Pennsylvania brings a compass bearing very cross to the trend of both the Pigeon Hills and Hellam Hills.

WHERE CAN I SEE SOME EXAMPLES?

Adams County:

1. Carbaugh Reservoir, Franklin Township
   39° 52’ 15.0’/77° 27’ 05.9”
   Intersection of Carbaugh Road and District Road
   Reference: Geyer and Bolles (1979)
   Columnar jointing in the metarhyolite

2. Carbaugh Rhyolite Quarry, Franklin Township
   39° 53' 00.5"/ 77° 27' 32.9"
   Park in the Carbaugh Run Natural Preserve parking area on District Road on the Adams-Franklin counties boundary
   Reference: Carr and others (2001)
   Metarhyolite outcrops and prehistoric quarry – no collecting permitted
3. Jacks Mountain CSX Tunnel, Hamiltonban Township
   39° 44' 40.67"/ 77° 26' 38.74"
   0.5 mile east of the intersection of Iron Springs Road and CSX railroad
   Reference: MacLachan (1993)
   Metabasalt exposures west of and west end of the tunnel
4. The Narrows, Pa. Rte. 234, Menallen Township
   39° 56' 38.4"/77° 20' 6.3"
   Located near the intersection with Nawakwa Road
   Reference: Geyer and Bolles (1979)
   Rhyolite boulders and outcrops along road and Conewago Creek
5. Pigeon Hills Metabasalt, Beaver Creek Road, Berwick Township
   39° 51' 50.3"/76° 58' 31.1"
   Located behind a private residence north of the intersection of High Rock Road
   Reference: Jones (2003b)
   Small outcrops along this road of road

York County:

6. Accomac Metabasalt, Hellam Township
   40° 02' 41.27"/ 76° 33' 50.15"
   Large road cut west of River Road
   Reference: Stose and Jonas (1939)
   One of the best such exposures of metabasalt in Uplands Section
7. Sam's Creek Metabasalt, York County Heritage Rail Trail, Glen Rock
   Located just south of Main Street at the south end of the first outcrop
   39° 47' 42.61"/ 76° 43' 51.3"
   Reference: Smith and Barnes (1994)
   Small outcrops between Glen Rock southward to New Freedom
8. Holtwood Metabasalt/ Holtwod Dam, Lower Chanceford Township
   39° 49' 32.29"/ 76° 20' 27.92"
   Located at the west side of the spillway east of River Road
   Reference: Smith and Barnes (1993)
   Good examples of pillow lava

Lancaster County:

9. Fishing Creek Metabasalt, Fishing Creek, Drumore Township
   39° 47' 58"/76° 15' 16.5"
   Near Fishing Creek Road in a large meander.
   Reference: Smith and Barnes (1993)
   A dense greenish rock only recognized in the early 1990's

CHAPTER 3.
ANYONE FOR THE BEACH?

About 570 mya, the headlines in a local paper may read "New ocean and islands form off the coast of Laurentia." Now before you get the wrong vision in your head, remember that geologic events take longer than overnight. Matter of fact, it is said "That the fastest anything can happen in geology is one million years." Although not really true in all cases, you get the point. From the previous chapter you will remember that it took some 200 million years for Rodinia to rift apart to start the Iapetus Ocean, our proto-Atlantic Ocean.

If we could see a world map of our Early Cambrian world, it would appear different from today. Using present-day Middle-Atlantic states as a reference the following would be seen. Southeast of the already introduced Catoctin Rift was a landmass, probably a portion of Rodina that was separated by the rift valley. To the southeast of this landmass was the Octoraro Sea. The Baltimore and Brandywine micro continents were next in line. These two micro continents were fragments of Rodinia that became isolated from the big continent. The Iapetus Ocean containing a magmatic arc was further to the southeast. At some distance past the arc was Gondwanaland, which will play a role in our geologic history later on.

Toward the end of the Proterozoic, the craton of Laurentia underwent a stage of uplift. This was to the west and northwest of South Mountain, perhaps in the area now currently occupied by a part of the Appalachian Mountains (east of the Rome Trough). Through weathering and erosion of this land area, material was washed into the Catoctin Rift and further east out onto the Laurentian landmass). Sediments eventually formed the basal clastic formations overlying the Catoctin metavolcanics and/or rocks of the Grenville terranes. In South Mountain, this includes the Loudoun, Weverton and the Mont Alto Member of the Harpers Formation, all considered Late Proterozoic or Early Cambrian in age. These formations are a part of what is termed the Chilhowee Group.

Within the Piedmont Uplands Section, the Chickies Formation is equivalent with the Loudoun Formation in South Mountain. The base of the Chickies Formation is the Hellam Conglomerate Member. This rock does not exist everywhere as the base of the Chickies Formation. The rock contains rounded quartz pebbles and an occasional metarhyolite fragment. This rock is well exposed in eastern York County on both sides of the York Valley at Rocky Ridge County Park and Sam Lewis State Park. The conglomerate is not exposed at its type locality of the Chickies Formation at Chickies Rock in Lancaster County.

It has been much debated over the years if an unconformity exists between the Catoctin Formation and the Chillhowee Group. An unconformity is where the period of deposition does not continue, leaving a gap in geologic time. The unconformity marks a period where the crust was positioned above sea level allowing no deposition of new material. Based on the radiometric dates provided for the Catoctin Formation (570-700 mya) and fossil evidence from the overlying Chillhowee Group (600 mya), there appears to be a time gap.

The best method to detect a unconformity is the "hands-on" approach in the field. Unfortunately, this is not as easy as it seems. Long, continuous rock exposures are not common in the Mid-Atlantic States due to our past and present climate. This makes the detection of a unconformity somewhat harder since no "clear-cut" contact exposures between the Catoctin and Chillhowee are known in southeastern Pennsylvania. I have mapped exposures of each of these formations within fifty feet of each other in the Accomac area, York County.

MacLachan (1994) and Drake (1999) and Faill (1999) agree that an unconformity does exist between the Catoctin and Chillhowee rocks. In his investigation within the Hellam Hills, Jones (2000) mapped an unconformity between these two units. Key (1991) provides a review of the ongoing debate about the unconformity.

By the Early Cambrian, Laurentia had drifted north due to the convection currents within the mantle. The east coast had now became a passive margin. It was like taking a dog off of a leash that Laurentia had broken loose from Rodinia and began its journey northward. Paleomagnetism tells us that we have rotated, so that the east coast was now facing south.

At the start of the Cambrian Period, the Iapetus Ocean began its long, westward, slow transgression across eastern Laurentia. Slow subsidence of the Laurentian craton allowed for this transgression. Sands were deposited near the shoreline, muds deposited in deeper water and muddy, limy waters were found offshore on a continental margin or slope with very little influence of other clastic material.

The oldest evidence of this migrating sea is the Antietam Formation. This formation consists mostly of sandstones. This is interpreted as a quartzitic, sandy beach, reaching western Pennsylvania by the late Middle Cambrian. Kauffman and Frey (1979) proposed that the Antietam Formation originated as barrier islands off of the coast. They compared the outcrops of the Antietam Formation to those of modern-day barrier islands along the east coast.

Evidence of ancient life within these formations is a great environment indicator. Fossils are known from the Chickies, Mont Alto Member of the Harpers and Antietam Formations. The Chickies and Mont Alto Member of the Harpers formations contain *Skolithos linearis*, a worm tube index fossil which dates the rock at 600 mya. The Antietam Formation is the youngest unit within the Chillhowee Group. *Skolithos linearis* and trilobite fragments belonging to *Olenellus* are found within the Antietam Formation. Geologists have assigned an age of 550-540 mya to the Antietam Formation. This then places the lower part of the Chilhowee Group as very Early Cambrian or even very Late Proterozoic.

Carbonate deposition was occurring to the east of this shoreline. As the shoreline migrated westward, the carbonate bank followed. The carbonates formed on a tidal flat. The dolomites formed on a tidal flat where most often the sediment was slightly underwater, but occasionally was exposed above the high-tide mark. The limy sediment commonly forms in deeper water below the low-tide line with rare periods where the sediment is exposed to the atmosphere. The continental shelf formed on the southeastern side of the Laurentia landmass along the western shore of the Octoraro Sea.

Rapid subsidence allowed for quick deposition of these sediments. Because the waters were warm due to the geographic location of Laurentia, geologists today compare these Paleozoic rocks to what is currently occurring within the Caribbean Sea.

This lengthy period of continental platform construction created a thick sequence of limestones and dolomites. Only for several short periods did a source area introduce mud onto the platform environment. The change from the clastic deposition into the carbonates is reflected within South Mountain. The Tomstown Formation conformably overlies the Antietam Formation (meaning there was no lapse of sedimentation as in an unconformity). In this area, the carbonate rocks make up a large portion of the Cumberland, Lebanon, and Lehigh valleys (known as the Great Valley Section of the Ridge and Valley province.

In the Piedmont, these carbonates are found within the York-Hanover and Conestoga valleys (Piedmont Lowlands Section). In ascending order, these formations include: Vintage, Kinzers, and Ledger. All of these formations are considered Early to Middle Cambrian based on stratigraphic position and fossil evidence. Both the Vintage and Ledger are predominantly composed of dolomites. The Antietam Formation underlies both the Tomstown and Vintage formations, making these two carbonate units equivalent in age.

The Conestoga Valley carbonates represent various stages on the building of a wide continental margin. This sequence described below is only one of two places in the entire length of the Appalachians where an Early Cambrian carbonate platform is preserved intact. The other location is the Shady Dolomite in southwestern Virginia (Taylor and Durika (1990).

A geologist can examine the rock and recognize features within the rock that would help in determining the environment the sediment was formed in. Similar to a private detective, they gather clues and finally conclude with a theory or idea. From the evidence gathered by numerous researchers within the Piedmont Lowlands, it was a quiet time as far as plate tectonics is concerned, but a time that an extensive continental shelf was constructed. Life within the marine waters was becoming more abundant as seen by the fossil evidence.

Within the Vintage Formation, the thin, wavy, siliceous layers indicate that an individual period of sedimentation was short-lived. A number of layers include rip-clasts, a feature formed where unconsolidated sediment slid down slope. Turbidity currents appeared to have been quite common in Vintage times. Also, submarine "landslides" may have occurred not only in Vintage times but through this sequence. Clasts up to seven inches across have been observed within the Codorus Stone and Supply Company quarry near Emigsville (Jones, 2003). Flute marks formed by turbidity currents within the Octoraro Sea are also found at the Codorus quarry. A slight change of sea level changed toward the end of Vintage times which is represented by the presence of limestone in the top half of the formation. Also, bedding is thicker in the upper half of the Vintage Formation suggesting longer periods of individual sedimentation.

The Kinzers Formation shows alternating sedimentation environments between clay and carbonate. There appears to be a slight time difference in the stratigraphy of this formation across the region (Taylor and Durika, 1990). The Kinzers Formation has been further divided into three subunits: Emigsville Member, York Member, and the Greenmount Member (Taylor and Durika, 1990). The lower member, Emigsville Member, is the first unit of this margin environment where fossils are found. Trilobites and other marine animals are preserved in the shale and limestone. Several of the trilobite species are world-renowned. A brachiopod, believed to have been found in the Kinzer Formation, was assigned the species name *Yorkia wanneri* in honor of York resident, educator and avid geologist, Atreus Wanner. Outstanding paleontologist and geologist, Charles Doolittle Walcott collected the specimen and named it in honor of his friend. The age of the Kinzers Formation is considered Lower Cambrian. Turbidity currents and an unstable continental slope continued into Kinzers time.

The Ledger Formation conformably overlies the Kinzers Formation. The Ledger rocks appear to have been deposited in shallower waters than the underlying carbonates. The Ledger Formation has been divided into three subunits within the West York area. They are: Lower Dolomite Member, the Willis Run Member, and the Upper Dolomite Member (Ganis and Hopkins, 1990). These subunits help to give us a more detailed look at the development of the continental margin. Until recently, fossils have been rather rare in the Ledger Formation. The only fossil find within the Ledger Formation has been unearthed at the LWB Refractories quarry in West York. Here, within the Willis Run Member, algal reefs have been described by deWet and Hopkins (2006). This reef structure was the most important paleontological find within the Conestoga Valley and one of the outstanding discoveries within Cambrian rocks in the country. The Ledger Formation has been assigned a Middle Cambrian age. Oolites found in this formation suggest a tropical environment.

The Conestoga Formation overlies the Ledger Formation. In earlier days, the Conestoga-Ledger contact was thought to have been an unconformity. Geologists established a Middle Ordovician age for this unit. Today the contact is considered conformable. Ganis and Hopkins (1990) using poorly preserved fossils and stratigraphic relationships established a Middle Cambrian to Early Ordovician (Cambro-Ordovician) age.

It appears that a change in water depth accompanied the start of the Conestoga Formation. Faill (1999) suggests that this formation is a combination between debris off of the continental margin mixing with clastic material from the Octoraro Sea, forming on the continental slope. Taylor and Durika (1990) suggest a toe-of-slope location for some of these rocks. deWet and Hopkins (2006) show the Conestoga Formation as forming at the base of a continental slope. From evidence of the large clasts in the rock (some measuring over seven feet across), the Conestoga rocks formed as a result of submarine landslides. At the Stony Brook dike exposure in Springettysburg Township, York County, I identified mud crack in the limestone of the Conestoga Formation meaning that at times, the sediment was exposed to the air.

The Conestoga Formation does not overlie the Ledger Formation throughout the entire area. In northern Lancaster County, where the Piedmont Lowlands contains the largest square miles underlying any of the area, the Zooks Corner Formation conformably overlies the Ledger Formation. Silty-to-sandy dolomite with thin shaly beds dominate this unit. This formation is considered Middle Cambrian in age. The Zooks Corner Formation appears to be associated with the inner margin of the Ledger bank margin facies. Because this unit interfingers with the Ledger Formation, this may represent the transition from the bank margin to shelf.

As one travels north on Pa. Rte. 222 from Lancaster, the predominant carbonates are becoming younger. The Coococheague Group contains the following formations: Middle Cambrian Buffalo Springs, the Upper Cambrian Snitz Creek and the Millbach and Richland units. The Buffalo Springs unit was formed in a subtidal, shelf deposit that received abundant sedimentation from Laurentia. The remaining formations within this group are predominantly limestones and dolomites, perhaps with lesser influence of Laurentian sedimentation (slightly deeper water).

Conformably overlying the Conococheague Group are three formations belonging to the Beekmantown Group: Stonehenge, Epler and Ontelaunee, all containing a high percentage of dolomite and limestone. The Stonehenge and Epler units are considered Early Ordovician in age. The Ontelaunee unit is Middle Ordovician in age. Echinoderm stem plates have been found within Stonehenge and Epler formations. Coiled gastropods have been collected from the Epler Formation. During this time, life diversity began to grow.

Let’s Go Further East

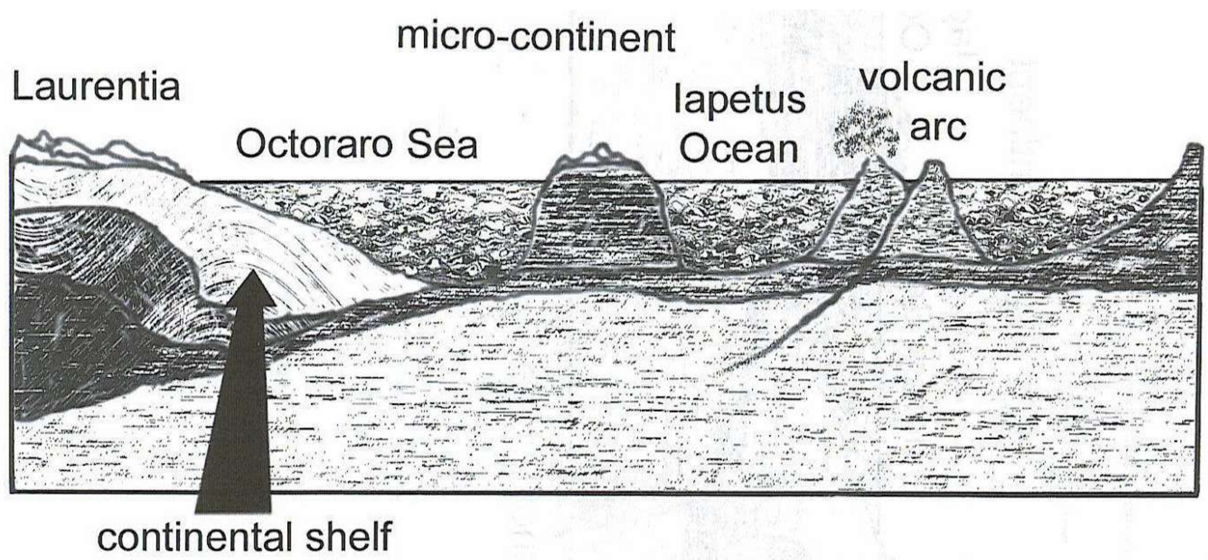
Located to the east of the Octoraro Sea was the Iapetus Ocean. Within the Iapetus Ocean were micro-continents Brandywine and Baltimore. Remember these two fragments contain Grenvillian-aged rocks originating from the breakup of Rodinia. The Iapetus Ocean is believed to have been another rift basin during the Rodinia breakup.

Sediment was being washed into the Octoraro Sea from both Laurentia and the micro-continents. The sediments that made up the bottom of the Octoraro Sea are now mapped as the Peters Creek Formation, located in southern York and Lancaster counties (Valentino and Gates, 1994). The overlying Octoraro Formation was also deposited in the Octoraro Sea. Wiswall and others, (2004) suggest that the Peters Creek Formation and Octoraro Schist can be divided into five lithologies based on structural fabrics. Geochemical analyses indicate that the two rock units were formed at the same time as a sedimentary unit. The Peters Creek Formation contains rocks that originated in a submarine canyon as turbidite fans. Valentino and Gates (1994) suggest that the Peters Creek Formation formed

93 – 124 miles to the east.

Baltimore and Brandywine micro continents were also developing a continental margin. In many regards, the development of these margins started similarly to the Laurentian margin, with clastic material forming, followed by carbonate deposition. The Setters Formation and the Cockeysville Marble formed on these margins (Faill, 1999). These two formations are latest Proterozoic to very Early Cambrian in age. Both units are found in Chester County and Maryland and are the lower two units of a thick sequence of metamorphic rocks known as the Glenarm Series. Blackmer and Srogi, (2004) while working with the Setters Formation in Maryland, suggest that the depositional setting was less stable than transgression onto a passive margin.

Sometime in the Early-to-Middle Cambrian, convection currents within the plates reversed themselves. This action ceased the expansion of the Iapetus Ocean. An eastward-dipping subduction zone occurred within the Iapetus Ocean. The subduction zone was perhaps created as another micro continent, Avalonia, drifted northwards. Avalonia had broken away from Gondwanaland, but its exact origin is not known. In this case, the Iapetan oceanic crust went down under the continental crust. Melted rock from the oceanic crust formed volcanic islands on the seaward side. Rocks mapped today as the Wilmington Complex, Baltimore Complex and the James Run Formation located in Delaware, Maryland and extreme southern Pennsylvania were formed by the subduction. The Wilmington Complex and James Run Formation are composed on rocks that originated as a volcanic island arc. The Baltimore Complex is made up of ultramafic rocks that stoled magma from the upper mantle and



formed rocks that stole magma from the upper mantle and formed ultramafic rocks such as serpentinite. The Wilmington Complex and James Run Formation have been dated as Late Proterozoic and Lower Cambrian. Some of the ash fell into the Octoraro Sea and is found today in some of the carbonate rocks of eastern and central Pennsylvania. The closest occurrence to our study area is in the Bethlehem Steel Steelton Quarry in Dauphin County. Here, three inch thick bentonite layers are found with carbonate rocks. These volcanoes have been dated as Middle Ordovician. Eroded remnants of the intrusive bodies are found within the Wilmington Complex. A belt of Early Paleozoic volcanic rocks can be traced from the subsurface of Florida northward into Newfoundland (Jones, 1977; Ansley, 2000). These volcanic islands eventually collided with Laurentia, but not all at the same time. The upcoming Taconic Orogeny reflects these collisions.

Within the extreme southern portion of York and Lancaster counties, ultramafic rocks occur. These rocks are serpentinite, dunite, peridotite and pyroxenite. The origin of these rocks comes from the upper mantle of the Earth. These ultramafics are without doubt, the deepest "seeded" igneous rocks we know of from this area. The ultramafics have been dated 490 ± 20 mya. This places the protolith crystallization at the beginning of the Taconic Orogeny and probably emplaced beneath a volcanic arc.

The parent material for these rocks represents what is left behind after the differentiation process separated out basaltic magma at spreading centers. Exactly where these ultramafic rocks underlie southern Lancaster County is marked by an area known as the "Barrens." The Barrens are so-named for the lack of abundant vegetation. Only scrubs, oak, pine, cedar, grasses and some unique and rare wildflowers grow on this rocky, unfertile soil. There are only three such "barren" occurrences known in North America. It is estimated that less than 1% of the United States is underlain by these rocks. Small lenticular exposures of serpentinite are found in southern York County, north and west of Delta in Peach Bottom Township. We can see similar rocks forming today along the Mid-Atlantic Ridge, some of which contain valuable hydrothermal deposits.

WHERE CAN I SEE SOME EXAMPLES?

Lancaster County:

1. Chickies Rock, West Hempfield Township
   40° 03' 3.29"/76° 31' 31.17"
   Parking Available along Pa. Rte. 441 near Chickies Creek and walk about 0.25 mile following trail to base of rock
   Reference: Wise and Ganis (2006)
   See quartzite, *Scolithus* tubes and ripple marks preserved
2. Money Rocks County Park, Carenarvon, Salisbury and East Earl Townships
   40° 56' 43.6"/75° 58' 54.5"
   Parking lot located on Narvon Road south of Red Hill Road. Walk trail to west to examine rocks
   Reference: Schlegel (2002)
   Quartzite, *Scolithus* tubes, cock-comb weathering
3. Weaverland Quarry, East Earl Township
   40° 08' 12.0"/76° 03' 22.1"
   Located at the intersection of Quarry Road and Martindale Road
   Reference: Martin Limestone, Inc. (2002)
   Limestone, ripple marks and fossils
4. Rohrer's Quarry, Penn Township
   40° 07' 55.29/76° 20' 9.53"
   Located at the intersection of Erb's Quarry road and Lititz Road
   Reference: Jones (2001b)
   Limestone, bedding, folding and faulting

5. Cherry Hill Roadcut, Fulton Township
   39° 46’ 41.8”/76° 13’ 3.0”
   Large outcrop located just south of Tanning Yard Hollow Road
   Reference: Jones and others (2006)
   Peach Bottom, Cardiff and Peters Creek formations
6. Black Barren Road Road Cut, Fulton Township
   39° 44’ 30.75”/76° 10’ 52.82”
   Located on the north side of road about 0.3 mile west of Happy Hollow Road
   Reference: Jones and others (2006)
   Serpentinite and vegetation change between rock types

York County:

7. Rocky Ridge County Park, Springettsbury Township
   40° 0.0’ 46.64”/76° 39’ 15.75”
   Park in the Tall Oaks Parking Area and walk 700 feet northwest to North Overlook
   Reference: Kreiger and Jones (1994)
   Chickies conglomerate and scenic overlooks
8. Sam Lewis State Park, Lower Windsor Township
   39° 59’ 46.61”/76° 32’ 54.62”
   Located off of Mt. Pisgah Road about 0.25 mile west of Cool Creek Road
   Reference: Inners (1983)
   Chickies conglomerate and scenic overlook
9. York Silica Sand Company Pit, Springettsbury Township
   39° 59’ 35.84”/76° 43’ 14.47”
   A large sand quarry at the end of Sand Bank Road, off of Eden Road
   Reference: Stose and Jonas (1939)
   Chickies quartzite, *Scolithus* tubes, cross-bedding
10. LWB Quarry, West Manchester Township
    39° 56’ 36.3”/76° 48’ 57.1”
    Located at the end of Baker Road, 0.25 mile north of U.S. Rte. 30
    Reference: deWet and Hopkins (2006)
    Ledger dolomite, microbial reefs, oolites
11. Locust Lane Trilobite Site, Manchester Township
    40° 00’ 21.5”/76° 44’ 21.0”
    A small outcrop just west of Interstate 83
    Reference: Jones (1998)
    Kinzer shale, trilobites
12. Frogtown Road Metamorphic Road Cut, West Manheim Township
    39° 44’ 54.52”/76° 54’ 51.85”
    Small outcrop at the intersection with Musselman Road.
    Reference: Low and others (2005)
    Marburg schist

13.. Lock 12 Recreational Park Metamorphic Outcrop, Lower Chanceford
39° 48’ 45.7”/76° 19’ 50.3”
Parking Area is located about 0.25 mile north of Pa. Rte. 372 on River Road.
Outcrops on hill to west and in stream gorge.
Reference: Thompson (1987)
Octoraro Schist

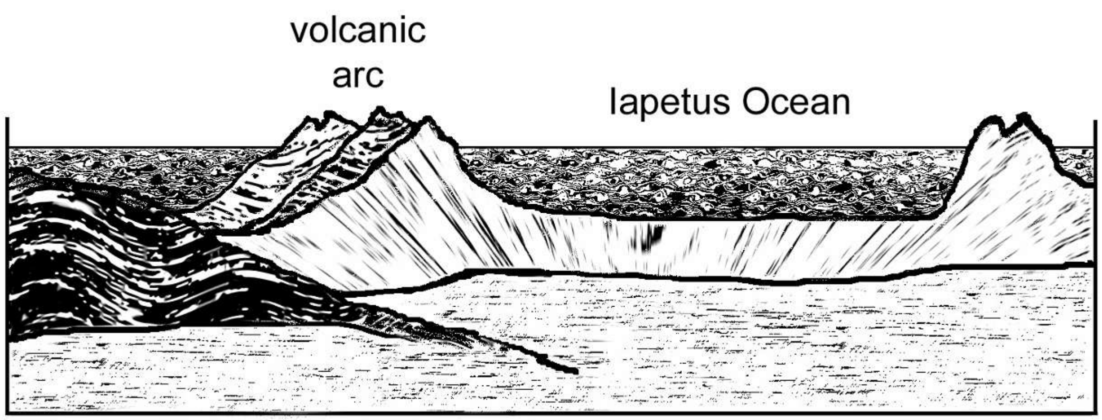
14. Funkhauser Slate Quarry, Peach Bottom Township
39° 44’ 5.2”/76° 18’ 4.1”
On private property about 0.13 mile south of Atom Road and 0.40 mile east of Pikes Pike Road
Reference: Jones and others (2006)
Peach Bottom slate

15. Stony Brook Diabase Dike with Conestoga Formation
39° 59’ 10.50”/76° 38’ 54.82”
Park at end of access road to the west of the Roadhouse Restaurant and walk railroad tracks east for about 0.1 mile
Reference: Stose and Jonas (1939)
Conestoga Formation limestone with mud cracks

16. Glen Rock Octoraro Formation Quartzite
39º 47’ 42.3”/76º 44’ 1.3”
Located directly across from the York County Heritage Rail Trail Glen Rock Parking area, 0.07 mile northwest of Water Street.
Reference: Stose and Jonas (1939)
Rare exposure of thin, well-jointed quartzite from this formation

CHAPTER 4.
TACONIC OROGENY – THE FIRST COLLISON
GET THE HARD HATS!

The last 150 million years or so have been a quiet time on the East Coast. The only tectonic activity was occurring in the Iapetus Ocean (or perhaps along its eastern edge) associated with a subduction zone. An extensive continental platform was being constructed off of the coast of Laurentia, as well as smaller margins associated with micro-continents. Sediment was being washed into the Octoraro Sea and Iapteus Ocean. Like the saying goes if you were in Florida, "If you don't like the weather now, just wait a bit." Well, the same can be said about the Laurentian east coast. "If you don't like the boring passive margin, just wait several hundreds of millions of years and things will change."



Change they did as both the volcanic arcs and Avalonia continued their march toward Laurentia. The Iapetus Sea narrowed, starting to push up its sediment onto the continental slope. Finally, the Baltimore and Brandywine micro continents and the volcanic arc with their individual continental shelves collided with Laurentia. If you have been reading ahead, you might see a prediction - an orogeny may be upon us. Yes, you are right, the start of the second orogeny in our journey occurs during the Middle and Late Ordovician. Welcome to the Taconic Orogeny!

Early geologic works in the area believed that the Taconic Orogeny only slightly affected the rocks in southeastern Pennsylvania. A later event known as the Alleghanian (or Appalachian) Orogeny was thought to have deformed the rocks. As the picture of the geologic past started to unfold with a better understanding of plate tectonics and technological developments, it is now understood that this mountain-building event played a major role in our crust.

The Taconic Orogeny started in maritime Canada and continued toward the south. Various geologic data obtained concerning this mountain-builder shows us earlier dates in the north compared to the southern region of our country. This orogeny lasted from 470-440 mya in the Mid-Atlantic States. The peak of the metamorphism was 444 mya. This date was obtained from detailed geochemical analyses from the Wilmington Complex in Delaware. Evidence of these incredible stresses that occurred during this stage can still be seen along the New York-Connecticut border.

Prior to the Taconic Orogeny, the coastline of Laurentia ran from a line starting in the Hudson River Valley, southward through Philadelphia and to Washington extending into western South Carolina. Geologists have determined that the east coast of Laurentia was not a smooth line drawn on a map. After the rifting of Rodinia, the coastline was a zig-zag outline. What this meant during the Taconic is that the pressures from the collisions were not equally felt across the region. For example, southeastern Pennsylvania was protruding eastward more than the coastline in Virginia, thus the Mid-Atlantic States were hit harder than Virginia.

The Baltimore and Brandywine micro continents arrived to the subduction zone probably in the Middle Ordovician. A subduction zone can be thought of a ramp, allowing an approaching crustal plate to travel up onto other slabs. The crushing of the volcanic arcs against these two plates changed the character of the continental margin.

Two different factors influenced the continental margin. The sediment from the Octoraro Sea and the Grenville crustal fragments were thrusted over the carbonate margin. Secondly, due to the weight on the shelf deposit, the shelf started to subside. Since the collision came from the southeast, weathering and erosion from the volcanic arcs began to wash sediment onto the shelf toward the northwest. This was the start of the Appalachian Basin. These sediments are now reflected within formations now found in the Great Valley and Appalachian Mountain sections of the Ridge and Valley province.

Associated with the thrusting of large slabs of crust came klippes and nappes. It is believed that a group of eight or more blocks and slices of various lithologic sequences slid onto older rocks in southeastern Pennsylvania. These nappes are believed to have moved across older crust in the manner that bulldozer tracks move. One such structure is known as the Hamburg klippe which developed in the Lebanon Valley nappe (Faill, 1999). Evidence for the Lebanon Valley nappe is found in the Middle-to-Late Ordovician carbonate rocks of northern Lancaster County. Other large nappes are found within the Reading Prong in eastern Pennsylvania and New Jersey.

Recently, Wise and others (2007) released new data on the Taconic Orogeny in Lancaster County. Using galena from the Pequea Silver Mine , Pequea Township, their results indicate that by 450 mya, the shelf deposits were already buried approximately 6 miles under a mature mountain range. They also determined that the Taconic Orogeny only lasted approximately 15 million years in this area.

Within South Mountain, several faults have been connected to the Taconic Orogeny. Two faults that run in an east-to-west direction are at least Taconic in age and perhaps as old as Proterozoic. These two faults are the Shippensburg Fault and Carbaugh-Marsh Creek Fault. The Shippensburg Fault extends into South Mountain at Pine Grove Furnace. The Carbaugh-Marsh Creek Fault runs from the Great Valley near Chambersburg eastward through South Mountain (basically where U.S. Rte. 30 runs through the mountains) and terminates on the east side. A satellite photograph shows the definite offset of South Mountain along this fault. Displacement is measured at about three miles (north side moving westward relative to the south side). These two faults are believed to be a part of a large, major fracture known as the Transylvania Fault, which extends deep into the continental crust.

It is possible that these two faults originated in the Late Proterozoic with the rifting of Rodinia and were reactivated in the Ordovician Period during the Taconic event. Reactivation of older faults seems to be a somewhat common procedure within southeastern Pennsylvania. After all, these old faults are still considered zones of weakness during younger geologic episodes.

In southeastern Pennsylvania, we can detect similar nappes. If you were a real estate agent during this time, you would have liked the Taconic Orogeny. Every time you would have turned around, there would have been a new piece of crust added on to Laurentia. First, as the convergence continued, additional slabs broke off the Brandywine micro continent and were carried northwestward onto the shelf. Secondly, fragments of Octoraro Sea oceanic crust were pushed in the same manner. Then, rocks of the Glenarm Series found today in Maryland were pushed up and over the rocks derived from the Octoraro Sea. Finally, the rocks of the volcanic arc were thrusted up and over the Baltimore and Brandywine micro continents.

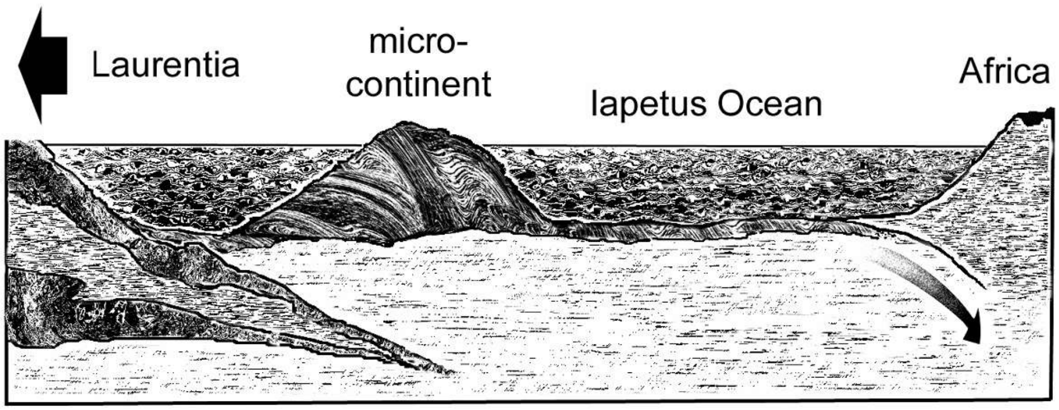
With all of the pushing of crustal slabs over adjoining slabs in a chain reaction, thrust faults developed across the Piedmont. One structure is known as the Martic Line which runs through Chester, Lancaster and York counties and continues southward into Maryland. Older researchers referred to this structure as the Martic Overthrust or Martic Fault (Stose and Jonas, 1939; Stose and Stose, 1944). Because this structure is not completely understood, recent researchers labeled it as the Martic Line. Some researchers believe it does not represent a fault at all, but only a transition between highly metamorphic rocks to the southeast and lesser metamorphic-grade rocks on the northwest side. With its unclear status, this is why "Martic Line" best describes this structure. Some researches, particularly the earlier works, believed that the Martic Line was the suture between Africa and North America in the building of Pangaea during the Permian Period.

There is evidence to support a fault. Other than separating the metamorphic class abruptly as indicated on a geologic map, an aeromagnetic map shows a strong anomaly along its distance.

In the mid-1980's, a new shear zone was detected in the Lancaster County Uplands Section when David Valentino conducted detailed mapping. He called this zone the Pleasant Grove-Huntington Valley shear zone (Valentino, 1999). This zone is correlated with the Cream Valley Fault in Chester County. Krol and others (1999) describe that the Pleasant Grove shear zone originated as a thrust fault in Taconic times, but was reactivated during the later Alleghanian Orogeny.

Another feature uncovered during Valentino's research in the Piedmont was the Drumore Tectonite Zone. This zone is an southern extension of the Pleasant Grove-Huntington Valley shear zone toward the Susquehanna River. This zone is exposed along the East Branch of the Octoraro Creek and in the scenic Fishing Creek valley closer to the Susquehanna River. At the later, the Fishing Creek metabasalt outcrops within the Drumore Tectonite Zone. It has also been suggested that the regional combination of the Fishing Creek metabasalt, the adjoining schists and serpentinites may represent a subduction zone assemblage. Other similar, but lesser known faults occur in the area that formed during the Taconic Orogeny.

Associated with the faulting and folding in the Piedmont was burial of rock, which was widespread, creating low-to-medium grade metamorphism. Some rock was believed to have been buried as deep as two miles. Lapham and Bassett (1964) using K-Ar dating of the Piedmont Uplands metamorphic rocks have determined that it appears that metamorphism occurred between 320-395 mya. You can imagine that with all of the thrusting of nappes within the Piedmont, considerable heat was produced in the rocks. Temperatures could have exceeded 600° C. (Faill, 1999). Heat probably remained in these rocks for more than fifty million years, before another small orogeny (if there was such an event) occurred.



To The West, A Basin Forms

With the attachment of the micro continents and magmatic arcs, the real estate of Laurentia would now increase. The mountains formed by the Taconic Orogeny were now located right in our backyards. The Taconic Mountains were to our east in the Baltimore-Wilmington-Philadelphia area. The last period of deposition from the Iapetus Ocean in this area occurred in the Late Ordovician. Thus, an unconformity exists between the last marine rocks and the sedimentary rocks deposited not until 200 million years later. Finally by the end of the Silurian Period, the Iapetus Ocean was now closing with the nearing of Avalonia. A basin began to form to the west of the highlands.

The Appalachian Basin began to form in central Pennsylvania during the Late Ordovician. The basin formed as a result of the new mountains to the east and north and additional subsidence of the crust due to the events of the Taconic Orogeny. This basin eventually formed the mighty Appalachian Mountains that run from New York southward into Alabama. The older literature referred to this basin as the Appalachian geosyncline, since the cross section view of the basin was like a syncline (Emmons and others, 1932; Stose and Jonas, 1939). However, plate tectonics was not a part of the scientific thinking at that point, particularly, the concept that various micro-continents attached themselves onto an ancient North America.

The high Taconic Mountains in New England, formed as a result of the orogeny for which they are named, also donated sediment to the basin. A large delta formed on the basin's edge known as the Queenston Delta. This fan-shaped structure was built in a similar way as the Mississippi River is carrying sediment into the Gulf of Mexico today.

Another mountain-builder, the Acadian Orogeny, occurred in the Devonian Period, starting 430-425 mya and lasting 40 million years. This orogeny was caused by Laurentia colliding with Avalonia which in turn collided with Baltica. Avalonia was a probable fragment of Gondwanaland. These collisions affected the structure of the crust through the entire distance of the Appalachian Piedmont. It appears, at best, that only low metamorphism occurred within the Mid-Atlantic Piedmont from the Acadian Orogeny. If there were stronger signs of its presence, the younger Alleghanian deformation "overprinted" that evidence.

By now the Taconic Mountains were eroding down to hills. A new mountain range has now appeared along the coast of Laurentia to the east of Pennsylvania. Folding, faulting and metamorphism once again affected the rocks that made up the former volcanic island arc, micro-continents and Octoraro Sea sediment. Radiometric dating states that the Acadian Orogeny started in the maritime Canada and New England and continued south, very similar to the Taconic Orogeny.

With the addition of a mountain range to our east, this once again introduced sediment into the Appalachian Basin. The largest such body in the country was beginning to form - the Catskill Delta. As an incredible amount of sediment was added to the basin, two different procedures took place: 1) The weight of the sediment continued to sink the crust downward under the basin, allowing for more sediment to be washed in and, 2) As sediment was being washed into the basin, the alluvial plain continued to move westward. This migration, in turn, forced the water to continue to move westward. Sedimentation into the basin and westward migration of the ocean continued into Early Carboniferous time. Rivers continued to carry material into the basin.

By the end of the Carboniferous, the basin was very deep, probably containing 26,000 feet of sediment, some of which was derived from our backyard highlands. By this time the ocean was near the Ohio border, almost depriving Pennsylvania of any marine waters and deposition.

By this time, Laurentia was moving closer to its current location. Rotation was underway, turning the continent in a north-south orientation that we are familiar with. Southeastern Pennsylvania was just south of the equator, still in a tropical environment. In the southern hemisphere, Africa, South America, India, Australia and Antarctica were joined, known as Gondwana. Eventually, Gondwana and the enlarged Laurentia will soon meet to cause one of the largest continental "wrecks" we know of.

WHERE CAN I SEE SOME EXAMPLES?

Adams County:

1. Carbaugh Run-Marsh Creek Fault on U.S. Rte. 30, Franklin Township
   39° 53' 43.6"/77° 21' 47.8"
   A series of exposures between Short Cut Road extending west into Franklin County
   Reference: Fauth (1973)
   The fault lies within this gap which has offset the ridge east-to-west

Lancaster County:

2. Chickies Rock, West Hempfield Township
   40° 03' 3.29"/76° 31' 31.17"
   Parking Available along Pa. Rte. 441 near Chickies Creek and walk about 0.25 mile following trail to base of rock
   Reference: Wise and Ganis (2006)
   A classic example of an anticline and many other structural features
3. Rheems Quarry, Rheems
   40° 07' 46.3"/76° 34' 4.5"
   Active quarry along Heisey Quarry Road, west of Anchor Road
   Reference: Wise and Ganis (2006)
   Examples of recumbent folding and boudinage in the Epler Formation

4. Weaverland Quarry, East Earl Township
   40° 08’ 12.0”/76° 03’ 22.1”
   Located at the intersection of Quarry Road and Martindale Road
   Reference: Martin Limestone Inc. (2002)
   Overturned folds and faults in the Stonehenge Formation
5. Shenk’s Slate quarry, Peach Bottom Township
   39° 46’ 10.8”/76º 14’ 20.2”
   At the north side of an abandoned quarry 0.23 mile west of Slate Hill Road
   Reference: Behre (1933)
   Folding in the Peach Bottom Formation

York County:

6. Seitzland Exposure, York County Heritage Rail Trail, Shrewsbury Township
   39° 46’ 34.7”/76° 43’ 23.7”
   On the west side of trail about 0.1 mile south of the Pa. Rte. 616 underepass
   Reference: Stose and Jonas (1939)
   Great example of isoclinal folding in the Octorara Formation
7. Raab County Park, aka York Iron Company Mine, North Codorus Township
   39° 50’ 32.75”/76° 48’ 56.99”
   Parking area located on the west side of Hoff Road, 0.3 mile south of Ziegler’s Church Road. Follow trail #1 into ravine
   Reference: Geyer and others (1976)
   Harpers phyllite that has been deformed in a large shear zone forming quartz/hematite quartz veins

CHAPTER 5.
THE BUILDING OF PANGAEA
NOT ANOTHER WRECK?

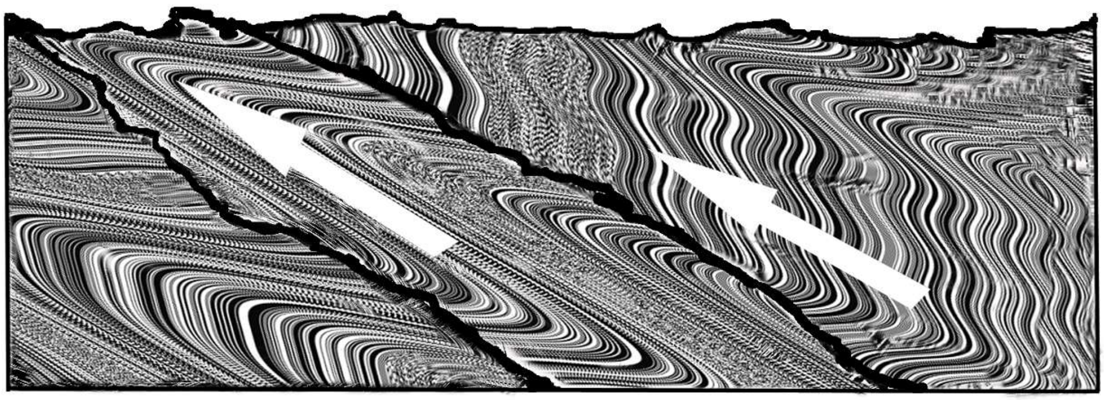
The main event is now upon us. An event larger than the three preceding orogenies - Grenville, Taconic and the Acadian began to unfold (or maybe we should say, fold) at the start of the Permian Period, about 290 mya. Africa collided with Laurentia to form a portion of what Alfred Wegener termed Pangaea. Wow, this is where Alfred's original continent drift theory started, but you can see that we have learned much more about plate tectonics and the evolution of our East Coast.

It is easy to say that simply Africa collided with Laurentia. Before other orogenies were well known to scientists, this event was called the Appalachian Orogeny, because, as you already know, formed the famous Appalachian Mountains. Again, looking back into earlier literature, the Appalachian Mountains were then associated with the Piedmont and the Blue Ridge Mountains. Today, the Piedmont and the Appalachain Mountains contain different suites of rocks, but in origin, they are all tied together.

Some modern-day researchers now term the Appalachian Orogeny as including the Grenville, Taconic, Acadian and the Alleghanian mountain-building events. If you have been paying attention to the timing of these events, there has been only a short time span separating the orogenies. The Alleghanian Orogeny is a term that has replaced "Appalachian" in literature.

The most widespread tectonic event to occur on the East Coast lasted from 356-290 mya. During the Alleghanian Orogeny, the Piedmont had large sheets of rock thrusted onto the eastern margin of the continent. Similar thrust faults are found in the subsurface of the Appalachian Mountain Section and the Appalachian Plateau. This procedure, similar to what occurred during the Taconic and Acadian orogenies, stacked or telescoped crustal sheets over other sheets. The Alleghanian event pushed slabs of rock over structure constructed by the Taconic Orogeny. So what a mess we have now! Stacking or telescoping slabs is like the example of a piece of wood drifting downstream during a flood. The wood would get caught onto another object, like a bridge. Other debris coming down behind the wood would get caught on the wood on the upstream side. Each piece proceeding down the stream would telescope itself onto an earlier piece of debris.

Some faults that were born during the Taconic Orogeny or earlier events were reactivated during this major mountain-building period. This "stacks upon stacks" principal is found throughout southeastern Pennsylvania. Several thrust faults (or perhaps high-angle faults depending upon whose interpretations you like), run across York and Lancaster counties in a southwest-to northeast direction. This would indicate that the pressure to cause the thrusting (or stacking) came from the southeast. Examples of these thrust faults would include the Yellow Breeches Thrust in northern York County, the Stoner Thrust running through central York County, and, the Chickies-Oregon Thrust in central Lancaster County. Other Alleghanian faults exist that were either formed during earlier events, were reactivated or were new faults formed during the Permian.



Thrust Faulting with Telescoping Slabs

Associated with the telescoping, the rocks also became folded. The Appalachian Mountains were formed as a result of the Alleghanian Orogeny. The Alleghanian Orogeny with predominant thrust faulting, built a mountain range 150 miles wide, 750 miles long and at least 2.5 miles high. The Hercynian Mountains in the United Kingdom correlate with our Appalachians. This correlation helps geologists to connect the various parts of Pangaea. Which jigsaw piece goes where?

The rocks forming the crest of Blue Mountain between Harrisburg and Chamersburg were situated at least fifty miles farther east prior to folding (Barnes and Sevon, 2002). There have been reports elsewhere within the Appalachians that measure lateral movement up to 150 miles.

The Piedmont contains numerous anticlines and synclines, along with smaller-scaled structures known as recumbent folding. Chickies Rock, north of Columbia, is a classical example of an anticline. The rock serves as a great teaching tool to geology students. It is a good chance that every geologist that conducted research on the East Coast has visited this fascinating rock. Chickies Rock is a laboratory for geology students. With the presence of cross-bedding, *Scolithus* burrows and the great structural geology examples, one can trace the geologic history from the Cambrian-Proterozoic Era boundary up through the Alleghanian Orogeny.

Combining faulting and folding across a region makes the geologic interpretation extremely difficult. Lash and others (1984) proposed that the majority of thrust faulting within the Piedmont appears to be Taconic; in the Great Valley Section as combined Taconic and Alleghanian; and, in the Valley and Ridge, entirely Alleghanian. Add in the metamorphism of the rocks (particularly in the Uplands Section) over-printing older tectonic events and you have yourself a big problem to reconstruct.

South Mountain is a classic example of how the crust can become distorted by the forces of the earth's movement. The Shippensburg and Carbaugh-Marsh Creek faults were reactivated during the Alleghanian Orogeny. Another system of faults found within South Mountain trend parallel to the mountains. One of these faults, the Tunnel Hill-Jacks Mountain fault system, is the northern limit of what Smith and others (1991) term the Catoctin plate. This is one of four thrust plates they identified in South Mountain using structural geology. The Catoctin plate appears to be covered on the east side of South Mountain by the younger Mesozoic rocks in Adams County. Projecting this line further northeast, this line comes close to the Pigeon Hills and Accomac (Hellam Hills) in Adams and York counties respectfully. In attempting to correlate the basalts (remember the breakup of Rodinia) between South Mountain, Pigeon Hills and Accomac, the areromagnetic map suggests that such a fault exists. As discussed in the Rodinia rifting chapter, the basalts in the Catoctin plate and Pigeon Hills are similar. Those samples tested at Accomac however, have a different chemical composition and probable different stage of origin. It is possible that a Pigeon Hills-type basalt may occur in the subsurface at Accomac. If this is the case, the Pigeon Hills and the Hellam Hills broke away from South Mountain during the Alleghanian Orogeny.

South Mountain structurally formed as a result of the African-Laurentian collision. South Mountain is classified as an anticlinorium (a large arch-shaped fold that contains synclines and anticlines). Not only did this mass of rock get pushed upwards, but it also got pushed enough that the axis of the fold went over the center point. This is known as an overturned fold. In this case, the fold appears to be falling over toward the northwest, the direction in which the rock was being pushed. As the crust was being pushed, the crust stopped moving, maybe because of hitting another slab of crust. The pressure continued to push South Mountain, causing the axis to go over-center.

The low-angle thrust faulting in the area is believed to have been the last event occurring during the Alleghanian. At the end of the orogeny about 270 mya, long parallel mountains existed in the foreland and a more irregular topography in the Piedmont on the stacked and over thrust nappes. It is also believed that the Appalachian Basin continued to accept sediment west of the newly formed mountains.

So we have been talking about a great continent-to-continent collision here. From our building of our landscape, you might by now realize that orogenies do not just come and go. They last at least several tens of millions of years - a very slow process - a method that Mother Nature is superb in pulling off every day of our lives.

When you picture a continental collision, you may think of a head-on encounter. For many years, the general thinking of Africa attacking from the southeast relative to Laurentia was acceptable. After all, the southwest-to-northeast-trending reverse faults represent convergence. But as times have changed so has the thinking of how some processes work. When Avalonia collided with Laurentia during the Taconic Orogeny, it has been theorized that the landmass made contact with maritime Canada and New England first. Slowly, Avalonia rotated using the contact point as a hinge point and attached itself on to Laurentia. Perhaps that is why the Acadian Orogeny did not leave much evidence in southeastern Pennsylvania!

Hatcher (2002) proposed that a similar collision occurred during the Alleghanian Orogeny (why not since we know everything here works in cycles). Gondwanaland collided with Laurentia first in New England. Using what Hatcher defines as “zipper tectonics”, the African-portion of Gondwana pivoted around and attached itself to Laurentia’s east coast. As it pivoted, it did strike Laurentia in a “head-on” type collision.

Hatcher‘s model includes a three stage development: 1) Early stage of thrusting of the clastic onto the margin; 2) A middle phase of early thrust faults producing the first elements of the Piedmont-Blue Ridge mega sheets; and finally, 3) A main event which produced major transport on the Piedmont-Blue Ridge mega thrust sheet and drove foreland thrust belt (Valley and Ridge and Plateau) ahead of it, producing the famous Appalachian Mountains. Similar to the Acadian Orogeny (and probably the Taconic episode), the eastern coastline of Laurentia was not a straight line, but very irregular. This irregularity of the coastline prevented the African collision to be felt the same along the East Coast.

This type of collision has also been termed the “scissors affect.” Slowly, a small part of the larger Rheic Sea was trapped between the west coast of Africa and the east coast of Laurentia.

With the final closing of the Rheic Sea by the end of the Permian Period, the formation of Pangaea was completed. All of the pieces were now in place for Alfred Wegener to write his continental drift theory.

Within southeastern Pennsylvania, you may ask which faults belong to which tectonic event? As indicated earlier, faults have been found to be reactivated over geologic time. As a general rule (which means that there is always an exception to the rule), the faults (thrust or high-angle reverse) that are crossing our landscape in a southeast-to-northeast direction were active in at least the Alleghanian Orogeny and perhaps during Acadian, Taconic or even Grenvillian times.

So how high were the Appalachian Mountains originally at the end of the Alleghanian Orogeny? Slingerland and Furlong (1989) concluded that the mountain system had an average relief of 11,500 to 15,000 feet and was developed on a 155-to-185 mile-wide accreationary wedge superposed on Laurentian crust. The toe of the wedge was near the Allegheny Front and the proximal end lay in the upper Chesapeake Bay region. The suture between Laurentia, Avalonia and Africa may lay within this region. Some researchers have mentioned the Martic Line in the Uplands Section as the possible suture.

Another fascinating fact is the amount of overburden that has been added to our crust through all of the faulting and folding. Geologists have attempted to come up with those answers. During the Ordovician, the tectonic overburden in southeastern Pennsylvania was at least twenty miles above the West Chester Prong. Between the Taconic and Alleghanian times, about twelve miles of soil and rock were removed. This leaves about eight miles of erosion removed from the end of the Alleghanian times to the present (Faill, 1999).

An important factor was also occurring during this time. The Acadian Mountains were now being eroded down and by the end of the Permian Period, sedimentation into the Appalachian Basin ceased. Thus, the youngest rocks found within the Appalachian area are Permian in age, found in the southwestern corner of Pennsylvania. The famous coal fields throughout the Appalachian Mountain Section were already formed, waiting for the first miner.

During the Permian Period, Pennsylvania was still near the equator, but the climate became much drier. With the convection currents working, all of the continents came together to form Pangaea. Pennsylvania was suddenly now located in the middle of the super continent with no oceans nearby. What a change that was after sitting along the east coast for millions of years, being an eye witness to various tectonic events. The swamps that eventually formed our rich coal deposits in northern and western Pennsylvania dried up.

Another factor occurred with the formation of Pangaea. With all of the continents now joined together, shallow ocean basins were very limited. Continental margins had been greatly reduced. Deep oceans now surrounded Pangaea. With this change in the environment, some marine life became extinct, including the trilobites. At the end of the Permian, a major extinction of marine animals occurred. Like most extinctions, the theory of an asteroid impact caused the loss of life.

Recently, another theory has surfaced, although the idea lies deep beneath our oceans. Kunzig (2004) states that scientists have discovered that nearly a third of all the life on this planet consists of microbes living under the ocean floor, in a dark world without oxygen. Many of these microbes make so much methane gas that if even a small proportion of it is released, huge tsunamis, runaway global warming and extinctions can occur. In the spring of 2000, scientists discovered cracks and potholes associated with this methane accumulation at the edge of the continental shelf near Cape Hatteras, North Carolina.   Evidence points toward previous methane explosions which may have flooded the Mid-Atlantic shoreline with a tsunami and massive submarine slides.

At the end of the Permian Period, so much methane had accumulated that when it erupted, it set the planet on fire. When such eruptions took place and, may take place in the future, the methane took all of the oxygen out of the atmosphere, killing all life.

On the other side of the coin, land creatures and plants were beginning to flourish, which leads us into one of the final chapters of our continent-building story.

WHERE CAN I SEE SOME EXAMPLES?

Adams County:

1. Jacks Mountain CSX Tunnel Exposure, Hamiltonban Township
   39° 44’ 40.67”/77° 26’ 38.74”
   0.5 mile east of the intersection of Iron Springs Road and CSX Railroad
   Reference: MacLachan (1993)
   Folding in the Loudoun Formation and faulting with the Catoctin Formation
2. Carbaugh Run-March Creek Fault on U.S. Rte. 30, Franklin Township
   39° 53’ 43.6”/77° 21’ 47.8”
   A series of exposures from Short Cut Road west into Franklin County
   Reference: Fauth (1968)
   This fault lies in this historic gap and has offset the ridge east-to-west

Lancaster County:

3. Chickies Rock, West Hempfield Township
   40° 03’ 3.29”/76° 31’ 31.17”
   Parking Available along Pa. Rte. 441 near Chickies Creek and walk about 0.25 mile following trail to base of rock
   Reference: Wise and Ganis (2006)
   A classic example of an anticline and related strucrural features
4. Prospect Quarry, West Hempfield Township
   40° 05’ 23.5”/76° 26’ 54.6”
   Active quarry located at the intersection of Prospect Road and Quarry Road
   Reference: Wise and Ganis (2006)
   Chickies-Oregon Thrust in the Millbach Formation
5. Fishing Creek Drumore Tectonite Zone, Drumore Township
   39° 47’ 55.7”/76° 15’ 21.9”
   Outcrop on east side of Fernglen Road, 0.23 mile northwest of Fishing Creek Road
   Reference: Stop 11, Faill and Sevon (1994)
   Peters Creek schist showing good folding in the Drumore Tectonite Zone

York County:

5. County Line Quarry, Lower Windsor Township
   40° 01’ 4.3”/76° 31’ 38.3”
   On east side of Pa. Rte. 624 south of Kreitz Creek
   Reference: Stose and Stose, 1944
   Stoner Thrust exposure within the Antietam-Harpers and Vintage formations
6. Pottery Hill Stoner Thrust, West Manchester Township
   39° 56’ 34.5”/76° 47’ 18.4”
   Small abandoned quarry on south side of Pa. Rte. 462 about 0.3 mile east of U. S. Route 30
   Reference: Stose and Stose (1944)
   Stoner Thrust where faulting has disrupted the rock sequence
7. Indian Rock, York Township
   39º 55’ 25.1”/76º 45’ 3.9”
   Just north of Indian Rock Dam spillway on the east side of the Codorus Creek
   Reference: Stose and Jonas (1939)
   Isolated Chickies Formation quartzite comprising of the core of an anticline

CHAPTER 6.
A TIME TO REST IN THE SWAMP

It is hard to imagine that our part of the country has been exposed to all of these tectonics events. Thus far we have seen building of Rodinia and Pangaea, the rifting apart of Rodinia and three episodes of accretions to our East Coast. What a geologist's paradise! Remember the Wilson Cycle? Well, guess what? We have one more chapter involving plate tectonics for you to read. This one involves the rifting apart of Pangaea. Sometime in Early Triassic times, the convection currents within the asthenosphere reversed themselves (yes, again). Instead of driving plates together, rifting is about to happen. This process eventually leads us to the world we know today.

Africa and North America (yes, we can finally say North America after millions of years as Laurentia, is no longer present) began to separate due to the convection currents. A divergent boundary was set up along the boundaries between these two continents. New rocks developed on the ocean floor in the form of basalt. This is what is termed seafloor spreading. A hot spot or also known as a plume developed near Manhattan, New York. As the magma approached the surface, the Earth's crust split into three rifts. As the continents divided, long, fault-bounded troughs, called rift basins, formed parallel to the margin of the continents.

The rift valley affecting us passed through New Jersey, Pennsylvania and northern Maryland. Today this area is termed the Gettysburg-Newark Section of the Piedmont Province. This section has also been termed a Triassic Basin, since its general topography was lower than the surrounding area. The rocks found here are referred to as the Newark Supergroup. By definition, the Gettysburg Basin runs from near Frederick, Maryland northward into Lebanon County. The Newark Basin continues from this point eastward into New Jersey. Near the Lancaster-Lebanon county boundary, the Triassic rift basin narrows significantly compared to the other locations. The reason for this narrowing may be related to tectonic stresses during the rift period.

Based on physical features found within the Triassic rocks and paleomagnetism, geologists have determined that we were located near the equator in Early Triassic times. Witte and Kent (1989) have established the paleo pole for eastern Pennsylvania at 3.8° N. latitude about 225 mya. Our landscape was warm, but did alternate between periods of dryness and heavy rainfall. Numerous meandering streams were passing through the basin. Oxbow lakes and meander scars appeared. Swamps containing abundant vegetation, including ferns and trees filled the landscape. Finally, some of the earliest dinosaurs and reptiles were wandering through these wetlands.

About 220 mya, the rift valley began to form. Perhaps the Gettysburg-Newark basin was located where a Rodinia rift once occurred some 500 million years earlier. Do you remember the discussion during the Taconic Orogeny concerning the Jack's Mountain Fault being covered by the Triassic rocks? As a result of subsidence, drainage was directed into the basin. The Piedmont Lowlands Section was higher in elevation to the south and east. Of course, the newly formed Appalachian Mountains were located just to the west and north. Much weathering was occurring from both directions into the basin. Not only was subsidence occurring, but also the rift valley was acting like a hinge with the fixed point along the southeastern side. As sediment was added to the basin, the basin tilted more toward the northwest.

All of the sedimentary rocks within the Gettysburg Basin are considered Late Triassic in age. The first episode of sedimentation during this period came from the south and east of the basin. In Adams, York and Lancaster counties this first period of sediment is now preserved in rocks belonging to the New Oxford Formation. This is the basal (oldest) member of the Newark Supergroup. The sedimentary rocks of this unit are known as “arkosic”, which are rocks containing quartz and at least 25% feldspar. The significance of feldspar in the rock through geologist’s eyes is that the sediment was not transported for a long distance - the source was nearby. Most of the sediment derived for this sediment originated from rocks directly to the east or south of the basin. That would include the Uplands Section and Lowlands Section of the Piedmont province.

The Gettysburg Formation in Adams, York and Lancaster counties conformably overlies the New Oxford Formation. As a review of relative time, remember if the formation is lying over another formation, the top rock unit is younger in rock. This concept is accurate unless tectonic movement has been involved. It appears that the contact between the two formations is gradual, meaning that a sudden change of sediment origin did not occur. The Gettysburg sedimentary rocks, however, contain red shales and soft red sandstones compared to the New Oxford unit. Origin of this sediment was again nearby, but from the west and north of the rift basin. Sediment from South Mountain, the Great Valley and Appalachian Mountains greatly contributed to the Gettysburg Formation.

In York County, within the Gettysburg Formation is the Conewago Conglomerate Member. This subunit is found in the Conewago Mountain which runs between just south of Wellsville northeast to Strinestown. This rock contains poorly sorted pebbles to cobble size sandstone and conglomerate clasts in a red matrix. MacLachlan (1999) believes the conglomerate was deposited in the ancestral Susquehanna River. A middle member of the Gettysburg Formation is the Heidlersberg Member. This is also a conglomerate unit, but contains black shale and sandstone. Along the western border of the basin there are isolated occurrences of quartzitic conglomerate and limestone fanglomerate. These isolated pods represent former alluvial fans coming off of the highlands to the west and north.

Within the narrow portion of the basin in Lancaster County, a middle formation has been identified. Known as the Hammer Creek Formation, this rock unit gradually grades both upwards into the Gettysburg Formation and downward into the New Oxford Formation.

The Triassic rocks have not been through any regional metamorphism events to the present. This makes the interpretation of the geologic history of the Triassic Period mush easier, compared to the previous events discussed earlier. Fossils are always an important indicator of what the environment was like. Fossils have been found within the New Oxford and Gettysburg formations that tremendously assist in determining the environment during Late Triassic times. Petrified wood and fern fossils are known from numerous sites from the New Oxford Formation throughout the region. Carbonized plant fragments are associated with thin bituminous coal layers within the New Oxford. Petrified wood is also reported from the lower beds of the Gettysburg Formation.

The author and Mary Ann Schlegel have recovered fresh-water phyllopod, *Esthria ovata* from an abandoned clay pit in Royalton, Lancaster County. Stose and Jonas (1933) identified the same species from this locality. *Estheria ovata* are also known from several other sites in York and Lancaster counties. Also at this site an yet unidentified ostracod species has been found. Dr. Roger Cuffey of Pennsylvania State University has joined this research project. The presence of ostracods in the Gettysburg Formation strongly suggests a fresh-water environment.

Both of these formations have yielded numerous foot track sites of dinosaurs and reptiles. As urban development continues, more opportunities to finding additional foot tracks are very possible with some effort and luck. Some skeletal material of the roaming reptiles has been recovered in York and Lancaster counties. Fish fossils have also been reported from the area. Details on these sites and species are discussed under the “Fossil” chapter.

In addition to the fossils, primary sedimentary structures also help a geologist determine the environment of deposition. Because we understand how structures like ripple marks, mud cracks, cross-bedding, rain prints and flute casts are produced, geologists are able to interpret the environment that the sediments were laid down in. All of these sedimentary structures are found within the New Oxford, Gettysburg and Hammer Creek formations. These findings suggest shallow, fresh-water swamps, lakes or braided streams. Wet areas are occasionally exposed to the atmosphere and dry out. Even raindrop impressions are found in some of these rocks.

Structurally, the western border of the rift basin is marked by the "Border Fault." Similar to the subsidence of the Appalachian Basin during the Paleozoic, the rift basin also subsided with additional sediment. Do you remember hearing the word "isostasy"? Most of the Triassic rocks are dipping into the earth 15-30° toward the northwest to north. This is exactly how the sediment lithified into a rock, set on a gradual subsiding rift valley floor. The "Border Fault" has been a center of seismic activity in Pennsylvania during historic times, particularly in the Sinking Springs-Wyomissing area of Berks County.

The southern or eastern border has been a topic of discussion over the years. Some researchers feel that the border is faulted while other researchers believe it is simply an unconformity (where 220 million year old rocks are lying directly on rocks at least 450 million years old). The contact between the Triassic rift basin and older Paleozoic rocks is rarely observed. Although not a true contact, Triassic breccia has been found in the LWB Quarry in West York It is believed this exposure of breccia originated as clay-filled caves during Triassic times.

The process of sea floor spreading continued into Jurassic times. This movement caused magma buried deep within the Earth to approach the surface. However, before the magma could reach the surface in most cases, the magma cooled and crystallized into an intrusive igneous rock known as diabase. Some researchers believe that the diabase came only within about one mile of the surface prior to forming a rock. There are isolated occurrences of basaltic flows in the Triassic basins. One small lava flow is known as the Aspers Basalt and is poorly exposed in a road cut south of Bendersville, Adams County.

Much research has been conducted on the origin and chemistry of the diabase. In his classical report on diabases in Pennsylvania, Smith and others (1975) identified the different types based on chemical composition and mineralogy. They are from oldest to youngest: Quarryville, York Haven and Rossville. They concluded that the three different diabases had different magma sources and originated at different depths in the earth (lower crust or mantle).

The Gettysburg Sheet (or sill) is composed of one-third Rossville and two-thirds York Haven diabase. The Rossville type occurs in the western part of the basin in Adams and York counties. The York Haven type runs along the regional trend from the Mason Dixon Line near Greenmount northeast to Pinchot State Park, near Rossville, York County. Within the rift basin Lancaster County, all of the diabase is York Haven with several exposures listed as undetermined. The Quarryville diabase occurs as a dike swarm, extending from west of Wakefield, Lancaster County north-northeast into Berks County where it truncates across the southern border of the rift basin.

When examining a thick diabase sheet such as the one south of Gettysburg, Adams County, one can see the difference in speed of cooling. Near the margin of the sheet, the diabase has a fine-grained texture. This indicates quicker cooling compared to the magma in the middle of the sheet where heat was retained longer, slowing the process. The diabase in the middle of the sheet is coarser-grained. The same differentiated crystallization can be observed in the diabase sheet in eastern Lancaster County near Governour's Stable, east of Falmouth.

All of the diabase in Pennsylvania is now considered Jurassic in age. Older works in the area considered the diabase to be both Late Triassic and Early Jurassic. The Triassic-Jurassic border was revised in the early 1990's, pushing all of the diabase dates into the Jurassic. These intrusions were the last episode of the breaking up of Pangaea. The magma filled in open areas created by the divergent boundary. The magma also used cracks and faults to migrate upwards toward the surface. Diabase dikes, mostly running in a general north-to-south direction, are also found in the surrounding Paleozoic rocks. The Quarryville diabase is not found in the rift basins. It is only within the Late Proterozoic and Paleozoic rocks of the Lancaster County piedmont.

Where magma cut through the Late Triassic rocks, a chemical reaction occurred. Along these borders, contact metamorphism occurred. Contact metamorphism is produced by heat only, where the surrounding rock was heated and changed into a new distinct rock type. In places that once contained, for example, a sandstone, the rock is now a dark, dense rock known as a hornfel. Based on the chemistry of the country rock and the magma, possible economic mineral deposits were formed. In Adams County, these included the Hunterstown copper deposit; in York County, the Dillsburg magnetite deposit; and in Lancaster County, the Gap Nickel Mine.

As you may realize after reading this far into "TimeWalk", not everything is certain in geology. One example of this is found in Fairfield, Adams County, at the Valley Quarries - Fairfield plant. Fairfield lies within the Gettysburg-Newark Section so you would expect to find the formations described above. Within the quarry, a limestone breccia is exposed. The limestone fragments within the rock are up to eleven inches across (Jones and Bowling, 2002). This rock does not match any of the known Triassic units in color, typology or structure. In fact, the rock is stratigraphically similar to rocks found within the Great Valley section south of Chambersburg.

We know that an incredible amount of the Triassic sedimentary rocks have been weathered and eroded. Recent thinking is that the location of the Fairfield quarry is what a geologist calls a "window." All of the Triassic rocks have been removed, allowing scientists to look beneath the rift basin (or the strata that the basin is situated upon). This is the kind of puzzle that continues to make geology interesting. Once you think you know most of the answers, you find out you don't!

The Jurassic Period began a long duration of weathering and erosion to our landscape. That procedure even continues today, as we live on a passive margin. As the convection currents carried North America and Africa further apart, the Atlantic Ocean was born and widened. That process is still ongoing today as the Atlantic Ocean widens by about two inches per year. The Mid-Atlantic Ridge, near the center of the Atlantic Ocean, continues to bring basaltic magma to the surface, forming new ocean crust in the empty voids.

WHERE CAN I SEE SOME EXAMPLES?

Adams County:

1. Beaver Creek Road Exposure
   39º 51’ 53.9”/76º 58’ 33.9”
   Southeast corner of the intersection with Maple Grove Road
   Reference: Stose (1932)
   Nice exposure of New Oxford sandstone and conglomerate
2. CSX Railroad Cut, Cumberland Township
   39° 50’ 03.8”/77° 14’ 31.5”
   About 0.1 mile east of U.S. Rte 30 and south of Doubleday Ave.
   Reference: Jones and Bowling (2002b)
   Excellent exposure of Gettysburg Formation rocks and Rossville diabase
3. York Springs Fossil Site, York Springs
   40° 00’ 27.4”/77° 06’ 21.6”
   Behind the office of Wolf Bus Company east of Harrisburg Road
   Reference: Stose and Jonas (1939)
   Gettysburg Formation with plant roots and mud cracks
4. Trostle Quarry Foot Track Locality
   39° 51’ 54.6”/76° 59’ 01.9”
   0.2 mile east of the intersection of Latimore Valley Road and Quaker Church Road
   Reference: Cleaves (1937)
   Historical foot track location with Gettysburg Formation including mud cracks
5. Devil’s Den – Gettysburg Military National Park, Cumberland Township
   39° 47’ 21.6” /77° 14’ 21.2”
   Intersection of Crawford Ave. and Warren Ave.
   Reference: Cuffey and others (2006)
   Type site for diabase exhibiting spheroidal weathering and cooling cracks
8. Aspers Basalt
   39º 58’ 33.3”/77º 14’ 46.0”
   Road cut 0.36 mile north of Pa. Rte. 34 on South Main Street
   Reference: Stose (1932)
   Small outcrop of the only Jurassic volcanic flow in southeastern Pennsylvania

Lancaster County:

7. Miller Road Fanglomerate Road Cut, West Donegal Township
   40° 06’ 49.8”/76° 37’ 41.8”
   On west side of Miller Road about 0.3 mile south of Ridge Road.
   Reference: Mowery (1983)
   A small exposure of New Oxford fanglomerate
8. Miller Rock Triassic Road Cuts, West Donegal Township
   40° 06’ 57.9”/76° 37’ 45.0”
   On east side of Miller Road, about 0.1 to 0.2 mile south of Ridge Road
   Reference: Stose and Jonas (1933)
   Several exposures showing New Oxford Formation sandstone and shales

9. Eagle Rock, Elizabeth Township
   40° 14' 35.4"/76° 18' 53.9"
   On the Horseshoe Trail, about 1.1 miles west of Pa. Route 501
   Reference: Geyer and Bolles (1979)
   Hammer Creek Formation quartz conglomerate that resembles an eagle
10. Aberdeen Diabase Exposure, Conewago Recreation Trail, Mt. Joy Township
   40° 10' 43.3"/76° 37' 15.5"
   Located about 0.2 mile east of Mill Road and south of Conewago Creek
   Reference: Stose and Jonas (1930)
   Diabase sill exposed and surrounding rock removed through erosion
11. Governor's Stable Diabase Exposure, Conoy Township
   40° 0.7' 43.4"/76° 41' 53.1"
   About 0.2 mile west of Governors Stable Road about 0.35 mile south of Turnpike Road
   Reference: Bolles (1978)
   Large outcrops with spheroidal weathering, cooling cracks and rock shelters

York County:

12. Gut Road New Oxford Formation Conglomerate Exposure
   40° 04' 32.8"/76° 40' 53.0"
   On the west side of the road about 0.6 mile south of Wago Road
   Reference: Stose and Jonas (1933)
   Large exposure of conglomerate with quartz pebbles
13. Sheep Bridge Road Triassic Exposure, Newberrytown Township
   40° 06' 42.2"/76° 47' 54.5"
   Located on west side of road about 0.1 mile north of Conewago Creek
   References: Stose and Jonas (1939)
   Long exposure of Gettysburg Formation sandstone and shale
14 . Rossvile Hornfels Road Cut, Warrington Township
   40° 04' 19.15"/76° 55' 26.39"
   Located on east side of Old York Road about 0.5 mile north of Pa. Rte. 74
   Reference: Geyer and others (1976)
   Gettysburg Formation hornfels containing azurite, malachite and zeolites
15. York Haven Diabase Quarry, Newberrytown Township
   40° 06' 57.55/76° 42' 59.22"
   Located on west side of the railroad about 0.3 mile north of York Haven
   Reference: Jones (1995b)
   Large abandoned quarry with diabase, physical weathering and stilbite
16. Pinchot State Park Diabase Toboggan Slide, Warrington Township
   40°03' 58.5"/76°53' 24.8"
   Park in main parking area of Conewago Day Use Area and walk west on Oak trail
   Reference: Hoskins (1978)
   Outstanding outcrop of diabase with cooling cracks, joints and weathering

17. Stony Brook Diabase Dike, Springettbury Township
39° 59’ 10.50”/76° 38’ 54.82”
Park at end of access road to the west of the Roadhouse Restaurant and walk tracks east for about 0.1 mile
Reference: Stose and Stose (1944)
Classic example of a dike cutting through the Conestoga Formation

CHAPTER 7.
THE CENOZOIC ERA
DO YOU HAVE THAT WORN DOWN FEELING?

We now near the end of our one billion year journey through geologic time. The North American continent has now been released from Pangaea and we are becoming our own identity. You may breath easily now. There will be no further collisions, ripping or mountain building in our journey. Weathering, erosion and an ice migration is all that remains. By Cretaceous times, Pennsylvania had moved to about 30° N. latitude. By the beginning of the Paleocene Epoch during the Cenozoic, Pennsylvania would lay at N. latitude 33° N. latitude.

At the end of the Mesozoic period, all drainage was flowing into the Mesozoic rift basins. From the Paleocene into the Miocene Epochs (65-20 mya), Pennsylvania had deep chemical weathering of the bedrock with saprolites developing. A rain forest ecosystem evolved in the coastal region of eastern North America. Surface erosion was held at a minimum. Streams were probably not yet entrenched into the landscape. The obvious curvilinear ridges within the Appalachian Mountains and South Mountain were not as prominent since weathering and erosion was only beginning to shape today‘s landscape.

A major event occurred 35.7 mya when a bolide left an impact crater in the southern portion of the Chesapeake Bay. The impact crater is about 57 miles in diameter and is about 1,000 deep on the west side and 1,640 feet deep on the east side. There is a 25 mile wide peak ring in the center. Inside the peak there is an inner basin which measures about 1.2 miles deep. The rebound peak towers at least 0.65 miles above the basin floor (Poag, 2004; Harvey and Burbey, 2004). What did this do to our climate? Speculation is that the cosmic collision placed much dust into the atmosphere, limiting the sunlight that reached the surface. Limited sunlight did not furnish enough food for plants to survive, causing a small extinction.

By the middle of the Miocene (~16mya), things changed. Lower temperatures set in due to the further northern migration of North America. Lesser amounts of rainfall were recorded as a humid, subtropical climate now existed. Intense physical erosion accompanied the climate change. The final sculpturing of our landscape was now underway. Much sediment was washed down the Susquehanna, Potomac and Delaware rivers. Evidence of previous Susquehanna River elevations are found today as terrace deposits. Perhaps the landscape has been lowered by at least four miles in the last 16 million years. The relief increased as weathering and erosion took place more quickly in softer rocks. The ridges and hills supported by more resistant rock wore down more slowly.

During this time streams were becoming longer as they continued to erode upwards at their headwaters. Some streams combined with others (stream piracy). Streams and rivers began to develop good channels, cutting downward into the landscape.

Although the landscape was lowering due to intense erosion and weathering, the crust was reacting by what geologists call isostatic uplift. As weight is taken off the landscape, the crust (floating on top of the liquid layer known as the asthenosphere at the top of the mantle) would raise. This counter-move resulted in very little surface elevation change relative to sea level.

The Pleistocene Epoch set in. Beginning about 800,000 years ago (yes, that is thousands, not millions), the Laurentide continental ice sheet moved into northern Pennsylvania. Three periods of glaciation occurred during this time with the last advancement starting about 25,000 years ago. The closest that the mile-high wall of ice came to York County was about 50 miles to our north. Although not ever covered by ice, our climate did change. During the advancing periods of the glaciers, we were exposed to a cold climate, similar to Hudson Bay area today. During the periglacial periods, the weather was very similar to our weather today.

As a result, our landscape had another severe effect with erosion and deposition. Freeze-thaw broke up rock creating talus on slopes, particularly in the Appalachian Mountains and South Mountain. The ridge crests of the Appalachian Mountains were probably lowered many tens of feet through freeze-thaw. During this time, boulder fields, like those at Hickory Run State Park in the Poconos and Ringing Rocks in Bucks County, Pennsylvania formed. Large exposures of bedrock are rare within South Mountain due to this period of physical weathering.

You may remember that the Susquehanna River is believed to be responsible for the Conewago Conglomerate Member of the Gettysburg Formation during Late Triassic times. Of course, that would indicate that the river has been a factor in our landscape for millions of years. Some historians and scientists believe that the Susquehanna River may have been present during the Appalachian Basin days during the Paleozoic. If that was the case, the river was flowing in the opposite direction, since the newly formed mountains created by the Taconic and Acadian orogenies were to the east.
The Susquehanna River is nationally known for its water gaps, particularly through the Appalachian Mountains. Earlier researchers presented evidence that the Appalachians were eroded down to a flat plain (peneplain) and further erosion downcut into bedrock. Today, recent research conducted within several of the water gaps north of Harrisburg show that the gaps may be tectonic-controlled by fracturing and faulting.

Within the Piedmont region in which the Susquehanna River flows, faults have influenced the river's channel. For example, at Chickies Rock, Lancaster County, the river makes a conspicuous turn to the south. This marks the location of the Chickies Thrust. Rocks within a fault are highly fractured, allowing water to easily incise its channel. Further research is needed in the southern reaches of the river to verify if the gaps are tectonic-related or not.

Also, due to the rapid down cutting and once-higher velocity, the Susquehanna River has created numerous potholes, channel-cutting and bedrock island development both within and along the river. During lower water levels, a human can stand in one such pothole near Conewago Falls near Falmouth, Lancaster County. Classic examples of features formed by the Susquehanna River are found just south of Holtwood Dam in southern Lancaster County. There was also a study conducted in 1929 where a scientist concluded that a river as large as the Susquehanna River flowed nearly perpendicular beneath the present river. His research included the insertion of dye into a deep pothole near Holtwood. The dye appeared in a cavern in Virginia about four days later.

Within the Piedmont Province of York and Lancaster counties along the Susquehanna River, researchers have determined previous elevations of the river. With the tremendous outflow of melt water from the glaciers, the Susquehanna River had periods of rapid down cutting. Within the river hills, six different terraces have been mapped: They are at the following elevations (above sea level): 740-720, 620-600, 520-500, 440-400, 380-340, and 340-300. The gravels found in these terraces are believed to be between 57mya and 2 mya. Well-rounded pebbles of many compositions representing an ancient location of the Susquehanna River can be found in many areas, all located within 1.3 miles of the river. These pebbles are known locally as "potato stones."

Other evidence for rapid down-cutting is found when you view the cross sections of tributaries flowing into the Susquehanna River. One would accept that a tributary would have a concave profile, meaning the tributary would become flatter as it neared the river. Actually the tributaries have a convex profile, meaning the closer the stream gets to the river, the steeper it becomes. It appears that the tributaries could not keep up with the faster down-cutting of the Susquehanna River.

The Susquehanna River and many area streams have been used for transportation purposes. Examine a map of the area and notice how the towns are laid out. They are found either along major drainage systems or where the railroad could be installed. In the 1800's, the canals or railroad were the primary export methods. Ice creams, iron ore, textiles, lumber and manufactured goods were popular exports. Come to think about it, even before any human transport was used on the water, these streams and the river transported sediment. These bodies of water have transported something for thousands of years, if not millions of years.

Evidence that the Susquehanna River was used for transportation early in history is shown by the numerous petroglyphs carved into large boulders in the river. The nicest display of these carvings is situated on Big Indian and Little Indian rocks south of Safe Harbor Dam. Local archaeologist, Paul Nevin, has spent many years studying these petroglyphs and has clear evidence that some of the carvings represent either the start of a season or a directional marking (Paul Nevin, personal communication, 2003).

Today, after years of weathering and erosion, we are blessed with a magnificent landscape. It is difficult to comprehend that southeastern Pennsylvania was involved in numerous tectonic events in the last one billion years. With these natural processes still wearing down our land, many beautiful natural areas are now available for our enjoyment. Tucquan Glen and Shank's Ferry in Lancaster County, Otter Creek and Codorus Creek gorge in York County, and Pole Steeple and Chimney Rocks in South Mountain are just a few examples of these locations.

Last, but not least, two events worth noting are the documentations of two meteorites in the area. This is rather exciting, unfortunately true dates of their occurrences cannot be documented

In mid-November, 1887, a meteorite was found in Mt. Joy Township, Adams County. So named for where it was found, the Mt. Joy meteorite was found by Jacob Snyder about a foot beneath the surface near his house while planting an apple tree about five miles to the southeast of Gettysburg. It was thought that the discovery signified a possible iron deposit. After prospecting was done, no such ore turned up. The sample was placed on a timber near the farmhouse until 1891, when a visitor to the properly identified its true origin. The meteorite was identified as a breccia hexahedrite

In 1907, another meteorite was found in the area. Known as the Shrewsbury meteorite, the six-inch, 24 pound sample was discovered about 7 miles north of Shrewsbury, York County. Several other samples weighing a total of three pounds were also found in the vicinity. It was discovered by being struck by a plow while planting. Its unusual weight was puzzling. Again, the sample was thought to be a lump of pure iron ore. The meteorite was an iron-nickel rich type.

Specimens of both meteorites have been distributed to various institutions around the world. Locally, the Academy of Natural Science in Philadelphia, Pennsylvania and the Museum of Natural History, Smithsonian Institute have specimens.

WHERE CAN I SEE SOME EXAMPLES?

Adams County:

1. Devils Den, Gettysburg Nation Military Park, Cumberland Township
   39° 47' 21.6"/77° 14' 21.2" W.
   Intersection of Warren Ave. and Crawford Ave.
   Reference: Cuffey and others (2006)
   Classic examples of spheroidal weathering, jointing and rock piling

2. Culp's Hill Tower, Gettysburg Nation Military Park, Cumberland Township
   39° 49' 11.91"/77° 13' 14.62"
   On Slocum Ave. on Culp's Hill
   Reference: Cuffey and others (2006)
   See topographical changes due to erosion and weathering

Lancaster County:

3. Holtwood Dam Overlook, Martic Township
   39° 49' 39.5"/76° 19' 37.8"
   Off of Old Holtwood Road – following signs to "Overlook"
   Reference: Pazzaglia and Gardner (1994)
   Classic examples of river erosion including bedrock islands and channeling
4. Governor's Stable, Conoy Township
   40° 0.7' 43.4"/76° 41' 53.1"
   About 0.2 mile west of Governors Stable Road about 0.35 mile south of Turnpike Road
   Reference: Bolles (1978)
   Large outcrops of diabase showing physical weathering
5. Conewago Falls Potholes, Conoy Township
   40° 07' 39.6"/76° 43' 4.9"
   Along the Susquehanna River about 500 feet north of Falmouth Boat Launch Parking area
   Reference: Mowery (1983)
   Classic examples of potholes seen during times of low water levels
6. Kirk Farm River Gravels, Fulton Township
   39° 44' 32.4"/76° 11' 50.7"
   In field on east side of Cherry Hill Road about 0.5 mile south of Rigby Road
   Reference: Pazzaglia and others (2006)
   Quartz potato stones representing a former Susquehanna River elevation

York County:

7. Shull's Rock, Hellam Township
   40° 03' 25.8"/76° 38' 15.1"
   On private property on bluff about 0.4 mile south of the Codorus Creek
   Reference: Stose and Jonas (1933)
   Erosional mass of Chickies quartzite overlooking the Susquehanna River
8. Indian Rock, North Codorus Township
   39° 55' 26.9"/76° 45' 4.3"
   About 400 feet west of Pa. Rte. 182 just south of the Codorus Creke
   Reference: Stose and Jonas (1939)
   Erosional remnant of an anticline in the Chickies Formation
9. Chimney Rock, Hellam Township
   39° 44' 32.4"/76° 36' 13.7"
   East of Chimney Rock Road at end of Wilde Lane on private property
   Reference: Stose and Jonas (1939)
   Classic erosional remnant of the Hellam Conglomerate

10. Talus Field, Camp Tuckahoe Boy Scout Camp, South Middleton Township
    40° 06’ 17.3”/7° 05’ 55.0”
    On top of ridge north of Memory Lake
    Reference: Jones (2000c)
    Large talus field where bedrock broke down due to frost-thaw action

CHAPTER 8.
FOSSILS FOREVER

The Proterozoic

Face it, fossils are just down-right cool! It doesn't matter how many specimens you find. It's always thrilling to break that rock open and BAM - there it is, some kind of evidence of past life. You are the first person to have ever observed that particular animal. Fossils are a very important tool for geologists. They indicate to the scientist what the environment was like when these organisms lived. Some relatives of these fossils still exist today in conditions similar to what their ancestors lived in. For example, take the marine worm that lives today. They are relatives to a fossil, *Skolithos,* the oldest fossil found today in Pennsylvania.

Skolithos was first identified from Chickies Rock, Lancaster County. Mr Haldeman, who resided at the base of the "rock" was a professed naturalist. Mr. Haldeman found a specimen containing a cylindrical impression. As he wasn't sure what it represented, Mr. Haldemam sent a sample to Charles Darwin. In his response letter Charles Darwin indicated it was *Skolithos linearis,* a very ancient burrowing worm. Because worms are entirely soft-bodied, they do not fossilize well, but decay away. Geologists have never seen the actual animal that produced these burrows.

Since that communication with Darwin, it is now known that *Skolithos* is an index fossil. This means that they only lived several millions years in geologic time. When you find a rock containing *Skolithos,* that rock is automatically 600 million years old. That dates back into the Late Proterozoic time, a period before abundant marine life lived. By studying present day marine worms and by other evidence supplied by the rock, we know that the worm lived in very shallow marine water, i.e. a beach deposit. At Chickies Rock, *Skolithos* is found in the Chickies Formation associated with ripple marks. Because the worm dug its burrow downward into the sand, the tubes are found today, perpendicular to the bedding of the rock. This alignment helps a geologist to determine bedding where the layers are not evident. At Chickies Rock, because of folding, the orientation of the worm burrows shows the direction of the folding.   *Skolithos* can also be found in other areas of Lancaster County where the Chickies Formation outcrops. Money Rocks County Park in the eastern part of the county contains these organisms.

In York County, the worm tubes can be found in the Hellam Hills. In the now abandoned York Silica Sand quarry behind the Harley Davidson plant in Springettsbury Township, *Skolithos* is quite abundant. Within South Mountain, the worm is also found within the Antietam Formation which is correlated with the Chickies Formation. One location is near Stone Head, on the property of Camp Tuckahoe Boy Scout Camp, Franklin Township.

The Early Paleozoic

During Early Cambrian times, if you were to go swimming in the Iapetus Ocean, you were probably fairly safe from many marine animals. First of all, marine life was just beginning to thrive with limited species. You would maybe have to watch though if you went too far out into the waters where the ocean bottom was muddy. This is where trilobites were swimming close to the bottom. Trilobites were bottom-feeders and sought out food as they disturbed the mud. Worms were probably the most-sought food by the trilobites. The *Olenellus* species also had extended limbs to grab their prey. Why do we think trilobites liked worms for a meal? One piece of evidence found in a rock shows a trilobite track stopping at a worm burrow. Trilobites were the “king” of the sea as far as predators were concerned.

Trilobites and remnants of other marine life (brachiopods) have been found within the Lower Cambrian Antietam Formation. These fossils are mostly incomplete and poorly preserved. These animals may have died and got washed on the Laurentia margin, similar to how shells get washed up toward shore today. This results in what I call “cemetery rock.” Stose and Jonas (1939) and Stose and Stose (1944) have listed numerous Antietam sites. One such site is just northwest of the Codorus Stone & Supply Company quarry where the Antietam Formation underlies the ridge.

Trilobites were interesting characters. Not only were they the first complex type of life we see in the fossil record, but the trilobites are also credited for having the first eyesight of any animal. Some trilobites species were blind while other species had compound vision.

The Kinzers Formation is known in southeastern Pennsylvania as one of the best rock units for Early Cambrian fossils. The fossils are mostly in the shale, but they have also been collected in limestone. Only several species of trilobites are known during the Early Cambrian. They include *Olenellus*, *Paedeumias*, *Wanneria*, and *Welleraspis*. The first two are the most common and had very similar heads. Within the mud there also lived conical-shaped extinct animals, *Hyolithes* and a brachiopod known as *Obolella.* Little is known about the *Hyolithes*, other than they had their pointed end stuck in the mud.

Several good trilobite sites were known in York County during the late 1800’s into the early 1900’s. They included Gas Alley in York; North George Street between U.S. Rte 30 and Interstate 83 (Manchester Township); along Bull Road north of U.S. Rte. 30 (Manchester Township); and, a road cut near the intersection of Carlisle Road and Loucks Road (West Manchester Township). The Carlisle Road site is one of importance. Some of the best trilobites from York County were collected at this site. During the construction of the Holiday Inn immediately to the east of the road cut, similar fossils were collected, including what is thought to be one of the world’s earliest known echinoderms. This specimen is now in the collection of Harvard University. Rare fossils can be found today in a small road cut along Haviland Road, just to the west of the Holiday Inn.

In the last ten years, new trilobites sites have been found with the assistance of urban development and road improvements. New sites include Locust Lane near Interstate 83; an apartment complex on the west side of the Susquehanna Trail north of Lightner Road; and, behind the Round the Clock dinner on U.S. Rte. 30.

The Kinzer Formation appears to be more fossiliferous in Lancaster County. Older sites were more common including the Getz quarry off Rohrerstown Road near the base of Chickies Ridge; Fruitville quarry located south of Delp Road and west of Fruitville Pike in the middle of a housing development (quarry owned by Franklin and Marshall College in Lancaster and is used for educational purposes only - no collecting allowed); and in a field north of Miller Road and east of the Manheim Pike in East Hempfield Township.

Urban development and road improvements have located new Kinzer Formation sites in the last twenty years. They include: the south side of the east-bound exit ramp to the Harrisburg Pike of off U.S. Rte. 30 (Manheim Township) and near the intersection of the Harrisburg Pike and Rohrerstown Road (East Hempfield Township). During the construction of the Montesorri School on Weaver road in Manheim Township, excellent trilobites were collected. Today, the school has a showcase full of specimens found on their property. Several species of Early Cambrian trilobites have their type sites located in Lancaster County, as only several other localities in the world are known.

As mentioned in the geologic history section, micro-algal reef structures have been recently identified from the overlying Ledger Formation. Up until this find, fossils were not known from the

Ledger Formation. The micro-algal structure found at the LWB Refractories quarry in West York assisted geologists in assigning a more definite age for the formation. It also helps to define the environment that the rock was formed in. Just think, this first-of-a-kind find occurred right in York County.

Stromatolites are known from the Ledger Formation. Although they are not a “true” fossil, it does indicate that organic activity existed during the time of deposition. Formed in warm waters, these mound structures were built by cyanobacteria.

The age of the overlying Conestoga Formation has been debated for many years. George Stose and Anna (later became Jonas Stose) completed the first detailed geologic survey of the area in 1939 and 1944 respectively. They proposed an unconformity between the Ledger and Conestoga formations. These might show that a time of non-deposition and erosion took place during this time. They also placed a possible Ordovician age on the Conestoga Formation. With the lack of fossils from this unit in those days, their speculation was only based on stratigraphic position and structural geology.

It wasn’t until 1990 that poorly preserved casts of trilobite parts and brachiopods were identified from the Delta Carbonate quarry (now known as the Westgate Quarry of York Building Products; West Manchester Township) (Taylor and Durika, 1990). The fossils collected all indicate a Middle Cambrian age of the Ledger Formation, with or without an unconformity. Thus, the Conestoga Formation is now considered Cambro-Ordovician (Cambrian into the Ordovician) in age.

The carbonate rocks in northern Lancaster County do contain some fossils of Middle Cambrian to Ordovician in age, although no “museum specimens” are known. Stromatolites and algal mats are known from the Buffalo Springs Formation.

Moving into the Ordovician Period, the Stonehenge and Epler formations have yielded echinoderm plates. Coiled gastropods are also known from the Epler Formation. Brachiopods have also been seen along bedding planes in the Epler Formation.

From the geologic history, you may remember from the Late Ordovician up until the end of the Permian Period, no deposition occurred in the area. Although the Appalachian Basin was flourishing with abundant marine life during the Devonian Period, no rocks were being formed during this time. Fossils including brachiopods, pelecypods, coral, crinoids, bryzoan, gastropods, and trilobite are common within the Appalachian Mountains.

The Triassic Period

Jumping ahead into the Early Triassic is our next opportunity to unearth any fossils. You may remember that between the Late Ordovician and Triassic times, there was a switch from marine to terrestrial deposition. Of course, this also involved the birth of Pangaea with the Alleghanian Orogeny.

If you resided here during Triassic times, you had your choice of where to spend a “quiet” day. You could pull up a log beside a stream flowing from the highlands which was carrying abundant sediment. You could put up a chair on the beach of a lake or swampy area toward the center of the Gettysburg-Newark Basin. Apparently, it did not matter where you relaxed, you were surrounded with abundant vegetation (and shade) and roaming reptiles and dinosaurs. But the good news was, there were fish in the lake!!

Fern fossils and petrified wood can be found throughout the Triassic Basin. The New Oxford and Gettysburg formations have yielded nice specimens in York and Lancaster counties. Few plant remains are known from the Triassic in Gettysburg. Stose (1932) described unidentified plant segments and animal trails from both the New Oxford and Gettysburg formations. Fresh-water crustaceans have been identified from the New Oxford Formation throughout the region.

In York County, petrified wood and fern fossils have been collected for many years from the Gettysburg Formation near York Haven. Several sites have been destroyed by urban development in the Manchester-York Haven area (Newberry and East Manchester townships). Petrified wood had been observed along the banks of the Little Conewago River in the same area. Fern fossils were also found north of Zion View (Conewago Township) from the same unit (Dale Singer, personal communication, 1986). Further west, petrified wood has been collected from a farm on the north side of Conewago Mountain along Rohrer's Church Road, Dover Township). This is also mapped as the Gettysburg Formation.

In a new development near Palamino Road, Dover Township, petrified wood is associated with malchite stainings within the sandstone of the New Oxford Formation.

In Lancaster County, plant material is found associated with the thin bituminous coal seams near Hopeland (Clay Township). Here a small amount of Triassic coal was mined in the early 1900's. Of course, since organic material is needed to produce the coal, plant material is associated with other Triassic coal seams in York and Lancaster counties. One of the best exposures exhibiting thin coal seams with fern remnants is along in a small exposure north of Race Track Road, Berwick Township, Adams County.

Petrified wood has been reported from the vicinity of West Ridge Road in West Donegal Township and along the AmTrak Railroad in Elizabethtown (both sites in Lancaster County). Along the abandoned railroad north of Mt. Hope and the Pa. Turnpike petrified wood is found associated with the Gettysburg Formation conglomerate.

Collecting trilobites from the Lower Cambrian is exciting, but nothing is more trilling than finding a foot track of a Triassic roamer. Evidence of both dinosaurs and reptiles have been recovered from all three counties. The first Triassic foot tracks were found on the East Coast. In 1802, twelve-year-old Pliney Moody was plowing a field on his father's farm in South Hadley, Massachusetts, when he noticed some strange markings in one of the rocks. The richest source of dinosaur tracks in the world is still considered to be the Connecticut Valley. Foot tracks have been discovered as far south as North Carolina.

The earliest known documented find in Pennsylvania occurred in 1878 at the LeCron's Copper Mine (Manchester Township) near Emigsville, York County. Edward Cope described bones belonging to the *Galtonia gibbidens.* Teeth and bone material were also described by Wanner (1898).

Another site in York County that has been significant is the Zions View site (Manchester Township). Dr. Robert Stahle discovered bone specimens from here in 1909 and continued his work here from 1910 into 1912. In 1972, the Pennsylvania State Museum, under the watchful eye of paleotonology curator, Donald Hoff, made many finds that are now considered some of the most important Triassic research in Pennsylvania.

At Zions View, numerous skeletal material and skulls were found of a phytosaur, *Rutiodon*. The phytosaur 1s an extinct group pf crocodile-like reptiles that were up to about 18-feet in length. Also found here was a skull and bone material of *Buettneria,* which belonged to the Metopasur family. The metopasaurs were one of the last families of an extinct group of ancient amphibians. The *Buetternia* resembled a salamander, only it was up to 6-feet long. They were probably fish eaters. Other fossils found at the Late Triassic Zions View site were clam shrimp, unionid bivalves, primitive fish bones and vertebrate coprolites. Specimens from Zions View are now in the collections at the Academy of Natural Science in Philadelphia, Princeton University, Yale Peabody Museum, New Haven, Connecticut and at the Pennsylvania State Museum. The Zions View site is located within the

New Oxford Formation. How would you feel if you saw one of these walk past you as you sat on the lake shore?

A *Rutiodon* tooth was discovered during house construction on Arthurus Circle in West Manchester Township in 2002 (Michael Szania, personal communications).

Wanner (1921) described several sites along the Little Conewago and Conewago Creek where he found teeth and scales. North of Zions View, near Yocumtown, several foot tracks were discovered from a small quarry which is now covered by a housing development. Hickok and Willard (1933) described these tracks, but there is an interesting story attached to this site. These tracks were discovered in the summer of 1932 by J. Carroll Hayes who informed Dr. George H. Ashley, State Geologist of the tracks. Hickok, who was investigating the Triassic rocks of the New Cumberland area, independently discovered these tracks several weeks later in the course of his fieldwork. Later, the tracks discovered by Hickok were found to be those previously found by Hayes. Some of these tracks were on display at the January, 1933 State Farm Show in Harrisburg. Examples of the Yocumtown tracks can be seen at the Pennsylvania State Museum and in the collection of Pennsylvania State University in State College

As a result of a road widening project of Pa. Rte. 111 near New Cumberland (Fairview Township), Bradford Willard is credited for a track find in 1934. A single dinosaur track was found on a slab of red shale along with mud cracks, raindrop impressions, and the print of plant stems.

A small quarry excavated into a hillside between Goldsboro and Yocumtown (Newberry Township) yielded several foot tracks in 1889. Another foot track was recently found here (Kochanov, 2002).

Moving west into Adams County, one site became famous in July, 1937. Trostle's Quarry, located along the Bermudian Creek south of York Springs, was quarrying a thinly-laminated siltstone and shale belonging to the Gettysburg Formation. Elmer R. Haile, Jr. is credited for exposing about 50 foot tracks from the quarry. Several of these tracks are now in the collections at the Pennsylvania State Museum in Harrisburg and Pennsylvania State University in State College. The Adams County Historical Society also has a specimen on display in Gettysburg. The Weisser Farm (and Orchard) located on Old Harrisburg Road near U.S. Rte. 15 has several foot tracks in their sidewalk taken from Trostle's Quarry.

In May, 1998, Dr. Roger Cuffey and this author visited Trostle's Quarry. During their visit, Dr. Cuffey unearthed an unidentified foot track.

Another interesting story about a dinosaur find revolves around Trostle's Quarry. The rock being removed from the quarry was being used in building stone. The beautiful arch bridge over the Bermudian Creek just upstream from the quarry was constructed of rock taken from Trostle's. The rock was also used in the construction of bridges on the Gettysburg National Military Park. The bridge over Plum Run on East Confederate Ave near Big Roundtop shows several specimens of foot tracks. These are often overlooked by park visitors.

All of the foot tracks described above are three or four-toed animals. The *Grallator* tends to be a more common foot track in the fossil record in the area. This dinosaur is believed to have been about 8-feet long and was bipedal, sometimes walking on his hands. Another dinosaur, *Atreipus*, has also been found in these Triassic rocks. *Atreipus* was a quadruped animal. At Trostle's Quarry, two other quadruped dinosaurs have been identified. They are *Brachychirotherium* and *Rhynchosauroides*. Because only foot tracks have been recovered, what we can learn about these creatures is all based on stride length, size of prints and depth of impression. The only skeletal material discovered from the Triassic was at the Zions View, York County and the Lancaster County *Buttneria* sites.

In November, 2007 *Gettysburg Times* reporter found fossilized bone material of *Buettneria* in the Borough of Gettysburg. In December of 2007, geologists visited the site and recovered a 5-inch long jaw bone with ten teeth sockets and a possible rib section, both belonging to this ancestor of salamanders.

Later in time, during the Pleistocene Period, several specialty sites have been discovered. The first is known as the Bootlegger's Sink, which is on the property of the York County Firemen's Training Center in Emigsville (Manchester Township), York County. Lying with the Lowlands Section, a sinkhole had developed within the Kinzers Formation at least 8,000 years ago. It apparently was active into the recent times. What makes the Bootlegger's Sink so intriguing is that animals moved too close to the sink, fell in, got covered over with water carrying dissolved calcium carbonate, which later turned into calcite. For over 20 years in the 1960's into the 1980's, the York Grotto would spend selected Sunday afternoons excavating these fossils. The material was sent to Carnegie Institute in Pittsburgh for identification. Clearly, the fossils indicated glacial and interglacial periods during the "Ice Age." Many of the fossils represent those animals that live today in the Hudson Bay area, while others represent those living as far south as North Carolina.

By the way, how did this sinkhole receive its name? In the 1940's state police chased a bank robber past the uncovered sinkhole. After capturing the criminal, the state police returned back to the sinkhole as curiosity overtook them. They found, at the bottom of the 40-foot deep sinkhole, a whiskey still. The owner of the still, as the story goes, was never caught. Thus, the name Bootlegger's Sink."

About this time, there was another visitor to the area. Mastodons enjoyed living in the cold temperatures of the "Ice Age" including York and Adams counties. A discovery in the early 1970's in the Bethlehem Steel Company quarry (now known as the Vulcan Materials quarry) in Oxford Township received scientist's attention. This quarry was also located within the Piedmont Lowlands Section with abundant limestones and dolomites. The Ledger and Kinzers formations are exposed in the quarry. During quarrying on the north wall, a clay-filled sink hole was unearthed. Within the clay some bone material of the Mastodon was discovered. Specimens of the Mastodon have been studied by the Carnegie Institute in Pittsburgh. The quarry office has also retained numerous specimens. Mastodon bones are occasionally recovered from clay-filled sinks at the quarry even today.

Fossil Sites Included in Text Above

Proterozoic and Cambrian Localities

Lancaster County:

Chickies Rock	40° 03' 3.29"/76° 31' 31.17"
Money Rocks County Parks	40° 56' 43.6"/75° 58' 54.5"
Fruitville Quarry	40° 04' 56"/76° 20' 1.1"
Miller Road	40° 05' 38.6"/76° 20' 44.9"
U.S. Rte. 30 Exit Ramp	40° 03' 46"/76° 20' 25"
Montesorri School	40° 05' 18.5"/76° 19' 5.3"
Weaverland Quarry	40° 08' 12.0"/76° 03' 22.1"

York County:

York Silica Sand Company	39° 59’ 35.84”/76° 43’ 14.47”
Camp Tuckahoe Boy Scout Camp	40° 05’ 21.5”/77° 05’ 38.9”
Codours Stone & Supply Company Ridge	40° 01’ 29.5”/76° 43’ 4.1”
North George Street	39° 59’ 15.4”/76° 44’ 10.0”
Bull Road	39° 58’ 58”/76° 45’ 57.5”
Shiloh	39° 58’ 9.0”/76° 46’ 48.3”
Haviland Road	39° 58’ 5.2”/76° 46’ 35.9”
Susquehanna Trail Apartments	39° 59’ 48.1”/76° 44’ 49.3”
Round The Clock Diner	39° 59’ 4.6”/76° 43’ 41.8”
LWB Refractories Quarry	39° 56’ 36.3”/76° 48’ 57.1”
York Building Products –Westgate Quarry	39° 58’ 11.4”/76° 45’ 39.1”
Locust Lane	40° 00’ 21.5”/76° 44’ 21.0”

Triassic Localities:

Adams County:

Trostle Quarry	40° 00’ 03.74”/77° 03’ 26.95”
Plum Run Bridge	40° 01’ 29.5”/76° 43’ 4.1”
York Springs	40° 00’ 27.4”/77° 06’ 21.6”

Lancaster County:

Hopeland	40° 14’ 39.5”/76° 15’ 26.7”
Mt. Hope	40° 13’ 51.4”/76° 25’ 27.4”
Elizabethtown	40° 08’ 40.6”/76° 36’ 18.8”
West Ridge Road	40° 07’ 11.4”/76° 37’ 7.2”

York County:

Conewago Creek	40° 04’ 52.5”/76° 42’ 16.7”
Zions View Ferns	40° 04’ 8.0”/76° 46’ 20.5”
Rohrer’s Church Road	40° 04’ 19.5”/76° 51’ 5.1”
Race Track Road	39° 52’ 25.2”/76° 59’ 12.2”
Palomini Road	40° 0.0’ 14.2”/76° 50’ 2.8”
LeCron’s Copper Mine	40° 01’ 8.0”/76° 46’ 10.7”
Goldsboro Quarry	40° 10’ 30”/76° 45’ 48.6”
Pa. Rte. 111	40° 11’ 43.5”/76° 50’ 39”

Pleistocene Locality:

Adams County:

Vulcan Materials Quarry	39° 50’ 6.6”/77° 01’ 49.5”

York County:

Bootleggers Sink	40° 00’ 56.06”/76° 43’ 15.74”

CHAPTER 9.
MINERAL AND ORES – WHAT WOULD WE DO WITHOUT THEM?

This section looks at the mineral resources removed from the area and minerals collected by both professional geologists and amateur "rockhounders." Mineral resources are natural materials removed from the earth that are used in producing products that are advantageous to us. Examples of mineral resources include iron, carbonate rock (limestone and dolomite), coal, oil and gas and gold. Like the fossil section, this is not meant to be a detailed analyses of minerals, but only an overview. Various references have been included in the "References" to broaden your interests.

The earliest known geologist was prehistoric man. These people relied on various lithic material to produce their tools. Certain rock types are ideal for tool production while other types just don't work. Unfortunately, in southeastern Pennsylvania, a high percentage of the rock is not good for stone tool manufacturing. Imagine yourself living in this period – relying on a rock to survive. They could not hunt, cut, scrap or drill holes without this material.

The oldest known stone tool that shows definite chipping was found at the Laetoli site in Tanzania. The tool is dated at 3.5 mya. In North America, the oldest culture were the Clovis people. Their trademark on the projectile points is fluted bases and date to about 11,000 years old.

The metarhyolites of the Catoctin Formation have been quarried by prehistoric man. Many such sites where they removed large pieces of rhyolite from the ground within South Mountain are known. These were called quarry sites. It has been recognized by researchers that often prehistoric people transported large pieces of this raw material across the state of Pennsylvania to use in their villages or even trade for better quality rock.

The best-known site which has been researched by archaeologists is the Carbaugh Run Site in Franklin County, Pennsylvania (Carr and others, 2001). Since this site is within Michaux State Forest, collecting of artifacts is not permitted. Near Accomac, York County where the Catoctin Formation metarhyolite is exposed, there is a possibility that the rock may have been quarried during prehistoric times. Although some of the metarhyolites are highly metamorphosed, there are some rhyolites exposed that can be worked by people. A fine-grained rhyolite would work better than a coarse-grained rock or a rhyolite that has been fractured by tectonic activity. Rhyolite is a very common lithic material found in archaeological sites across the state, thus having a regional application. Rhyolite was also mined for ornamental stone in the early 20th century from near Highmount in the Hellam Hills.

Quartz is commonly found in archaeological sites. Crystal quartz, vein quartz and rose quartz are commonly found. Although quartz "quarries" are difficult to identify, there are a number of quartz veins in which lithic material could be gathered. Diabase has been used as banner stones and mortar and pestals.

Another rock that has been quarried during prehistoric times is the serpentinite found in southern York and Lancaster counties. The serpentinite occupies a larger area in Lancaster County than York County, so the resources would be more plentiful on the east side of the river. The serpentinite was used for soapstone bowls, pipes, and game pieces. Later in time, from the mid 1920's to about 1984, the rock was mined and marketed under the name of "Cardiff Marble." The quarry was located in Cardiff, Maryland, just south of the Mason Dixon Line. In Lancaster County, the now-abandoned Cedar Hill Quarry and its active neighboring operation, Penn-Maryland Material Company is situated within the serpentinite area of southern Lancaster County. Cedar Hill Quarry was noted for many fine "serpentine family" mineral species, including several species that are considered rare worldwide.

Iron was removed from the area as far back as the historical contact with the Indians. Nearly every region of Adams, Lancaster and York counties contained iron deposits, some richer and some poorer than others. In York County, a total of 175 iron mines worked between 1780 through 1910 (Jones, 1993). Goethite deposits are found in South Mountain and throughout the Piedmont Lowlands and Uplands sections. Most of these mines were open-pit operations.

Within the Gettysburg-Newark Section, magnetite deposits are commonly associated with the diabase bodies. A chemical reaction occurred between the magma and surrounding rock, possibly creating a profitable magnetite deposit. This is a type of contact metamorphism. These mineral resources are known as Cornwall-type deposits, since their geology is similar to their type site at Cornwall, Lebanon County, Pennsylvania. The Cornwall Iron Mine was the longest running iron mine east of the Mississippi River, operating from about 1750 until 1972. Examples of the Cornwall-type deposits in the area include: Comfort Mine, near Cashtown, Adams County, and the region within a triangle between Dillsburg, Wellsville and Grantham, York County. No Cornwall-type deposits are known in Lancaster County.

Associated with the iron deposits came furnaces. A furnace needed three resources to operate: 1) iron ore, 2) limestone for flux, and 3) wood to produce charcoal. All three natural resources were available throughout the area. It is said that most of the timber in the area has been cut at least once during the late 1700's and 1800's for use in the furnaces. The larger furnaces in the area include: Maria Furnace (Adams County); Caledonia Furnace (Franklin County); Pine Grove Furnace (Cumberland County); Codorus Furnace (York County); and, Chickies Furnace (Lancaster County).

Another early mineral resource is the Peach Bottom Formation slate in extreme southeastern York County, extending across the Susquehanna River into southwestern Lancaster County. The discovery of this slate occurred in the late 1700's and was listed as the best building slate in the world at the 1850 World Exposition in London, England. The Welsh had learned of the rich slate deposits and moved into the area in the late 1840's. The Welsh, using their experience of mining slate deep in the Earth from a platform, was introduced to the residents in 1848. About twenty different quarries worked on Slate Ridge in York County and northern Harford County, Maryland. About twelve quarries operated in Lancaster County. The industry continued at various rates until the early 1940's. The rich heritage of the slate industry in the Delta, York County area is well preserved through the efforts of some of its citizens.

Sometime in the mid 1700's, residents learned that some of the soils in the area were beneficial in growing crops. They also learned that the addition of limestone or dolomite enhanced the chemistry of the soil (especially in an acid-rich environment such as the metamorphic rocks). If a farmer had limestone underlying their farm, the farmer had their own quarry to remove the carbonate rock. For those not living in, for example, the Lowlands Section, they would purchase lime from those that were lucky to have the right rock. This was the start of the limestone industry in southeastern Pennsylvania.

Both limestone and dolomite is removed from the earth for many uses. The quarries are found within the Piedmont Lowland Section within the Piedmont. Their uses include agricultural, road construction, building materials, fillers, and flux. One special operation is that of LWB Refractories in West York, York County. Here they are mining the nearly pure dolomite of the Ledger Formation for refractories. This is one of only four such operations in the world. About 20% of their products are exported from the United States.

The Valley Quarry - Gettysburg plant removes hornfels of the Gettysburg Formation. The stone is used for road construction and aggregate. At Silver Hill, Lancaster County, hornefels are being produced for railroad ballast and filler.

Clay and sand is another commodity that benefits our area. Clay is used for bricks, filler, landfill applications, and landscaping uses. The Glen-Gery Brick Company operates several operations in York Township, York County and near New Oxford in Adams County. Abandoned pits once used by Glen-Gery are also located east of Dover, York County. The Pzaltzcraft Company, the maker of fine pottery, used clay from near Pinchot State Park in York County for their first products. Within South Mountain, several white clay operations are still active. Clay was also removed from South Mountain at Toland and near White Rocks in Cumberland County and southwest of Dillsburg, York County, now in the vicinity of Camp Tuckahoe Boy Scout Camp.

Sand, formed by the weathering of sandstone or quartzite, was quarried in various locations. The Antietam Formation is a producer of sand in South Mountain and in the Uplands Section of Piedmont. Cydonia Sand, a member of Valley Quarries, Inc. is located south of Caledonia within South Mountain and is one of the largest active operations. In York and Lancaster counties, the Chickies Formation has been worked for sand products.

Diabase is no longer quarried locally, but was once quarried in several locations in Adams, York and Lancaster counties. In the Gettysburg area, the diabase was quarried for ornamental stone. Locally it was known as "Gettysburg Granite." In York County, a diabase quarry was located north of York Haven along the Susquehanna River. Here, the rock was removed to build the foundation and dam at the York Haven Hydroelectric Plant, the nation's oldest such operation. Diabase was also shipped to build tunnel portals and bridges throughout the region. In Lancaster County, diabase quarries operated along the Susquehanna River south of Falmouth.

The sandstone of the New Oxford and Gettysburg formations were quarried as building stone. Throughout the region, "brownstone" houses and barns still stand. In York County, several different operations removed the sandstone on Conewago Mountain. The Dauphin County Courthouse has pillars that were formed from the Gettysburg Formation. Other smaller operations can still be found several miles north of Wellsville. Conglomerate belonging to the Gettysburg Formation was also quarried for millstones in northern Lancaster County. The finished product was known as "Cocalico Stone."

Siltstone of the Gettysburg Formation was quarried at Trostle's Quarry south of York Springs, a location as stated earlier was better known for its discovery of over fifty dinosaur foot tracks. Remember, the rock was used in the construction of the stone bridges on the Gettysburg National Military Park.

The Gettysburg Formation fanglomerate was quarried in the 1960's - 1980's on the Aungst Farm south of Elizabethtown. The rock was removed from a small exposure and transported to an off-site saw shop, where colorful decorative slabs for coffee table and counter tops were produced.

With the exception of iron listed above, all other descriptions are considered non-metal resources. In addition to iron, there were several other metal resources found in the area.

Copper was mined extensively in South Mountain in the vicinity of Charmain, and Mt. Hope, Adams County. These deposits were collected and mined from the late 1700's into the early 1900's. Most of the mines were underground operations and supplied a large tonnage of native copper to the country. ISP Minerals operates a quarry nearby at Chairmain. This mine removes the Catoctin metabasalt and processes the rock into roofing granules. Occasionally, ISP Minerals finds specimens of native copper during mining.

Copper is also known from the Triassic rocks, particularly in York County. The LeCron's copper prospect was located north of Roundtown, Manchester Township. A small amount of copper staining (malachite) was removed from a shallow shaft. Along Bull Road on the south side of Fox Run, Conewago Township, was another small copper prospect. Also in Dover township, the Livingstone farm south of Davidsburg Road has yielded malachite in hornfels. A nearby diabase dike was responsible for this small copper occurrence.

In Adams County, just north of Hunterstown, the Reliance Mining and Milling Company opened a small copper deposit. This operation turned into "the mine that was never a mine" as no production ever took place from here in the early 20th century. Gold was associated with the copper ore here. Beaverdam Creek, just to the west of the prospect is proclaimed as the first location where gold was found in modern times in southeastern Pennsylvania (Jones and Schmerling, 2002). Small occurrences of copper on Triassic rocks are located on the property of the East Berlin Fish & Game Club (Adams County); Old York Road roadcut near Rossville; along Fox Run west of Bull Road and on the Livingstone Farm near Admire (York County).

A unique mineral resource was once exploited in Lancaster County. As the name indicates, the Gap Nickel Mine once supplied most of the nickel to the United States during most of the 1800's. Copper was actually the first element discovered here as early as 1718. An attempt to mine copper around 1842 failed. In 1852, nickel was discovered on the site. Between 1863 and 1893, about seven million dollars worth of nickel was mined from shafts.

Likewise, along the Mason Dixon Line in southern Lancaster, another rare element, chrome, was taken out of the earth. The largest of these mines was known as the Wood's Mine. Between 1828 and 1880, about 96,000 tons of chromite were removed and shipped around the country. Prior to the Civil War, the Wood's Chrome Mine supplied nearly 100% of chrome to the United States. Chromite prospects were common in the serpentinite district in Lancaster and Chester counties, Pennsylvania and northern Maryland.

Silver was produced from galena at the Pequea Silver Mine near Burnt Mills, Pequea Township, Lancaster County. The mining was mostly conducted through shafts. From archaeological evidence found at sites in Washington Boro, Lancaster county, it is believed that lead was mined as early as the mid 1700's at Pequea. Zinc and lead were mined in Lancaster County near Bamford, East Hempfield Township. The Bamford zinc mine consisted of two shafts and operated during the second half of the 19th century. The mine is now located on the property of the Kellogg's Cereal plant.

Outstanding Minerals

In any particular area, there is bound to be a variety of minerals found by observant collectors. Of course, this variation would flex based on the geology of a region. As you already know by reading the geologic history, our region is very complex. Thus a large variety of minerals have been identified, some not so cool and some that really "set the world on fire"!

This section is not designed to provide all of the information about all of the minerals found, but will introduce some of the better-known discoveries to the reader. Plenty of resources are listed in the "Reference" section for further reading.

Listed below are some of the key mineral localities in the area. As a reminder, collecting at these locations is by permission of the owners. Often times, in the case of active quarries, mineral "finds" have a tendency to come and go as extraction of the rock continues.

Adams County:

Comfort Mine, Franklin Township
39° 53' 17.4"/77° 19' 55.5"
On the northwest corner of Flohr's Church Road and Hilltown Road
Reference: Frazer (1876)
Comments: Cornwall-type deposit with magnetite and garnet on dumps.

Valley Quarry – Gettysburg Plant, Freedom Township
39° 47' 59.3"/77° 12' 44.8"
Active quarry on south side of Pa. Rte. 97 and east of Rock Creek
Reference: Jones and Eisenberger (2006)
Comments: Zeolites, copper minerals and garnets found in Gettysburg Formation hornfels. Diabase seen at the northeastern corner of the quarry.

Reliance Copper mine, Hunterstown, Straban Township
39° 53' 15.1"/7° 09' 31.8"
On the east side of Red Bridge Road, about 0.4 mile north of Pa. Rte. 394
Reference: Stose (1932)
Comments: Malachite found on small dumps around covered-up shaft

Charmain-Mt. Hope Copper District, Hamiltonban Township
Major mines Include:

Snively	39° 48' 24.9"	77° 25' 44.62"
Culp Hill	39° 47' 56.10"	77° 25' 33.52"
Russell	39° 47' 16.00"	77° 25' 46.14"
Reed Hill	39° 46' 18.6"	77° 26' 23.3"
Bingham	39° 45' 45.6"	77° 26' 27.0"

Located in the vicinity of Copper Run with Gladhill on the south and Mount Hope on the north
Reference: Stose (1910)
Comments: Famous locality for native copper specimens.

Piedmontite Locality - P. H. Glateflter Tree Farm #1
39° 46' 57.1"/77° 25'35"
Located near Tree Farm Lane, east of Copper Run
Reference: Fauth (1978)
Comments: One of several locations in South Mountain where this rare epidote-family mineral can be found.

Vulcan Quarry, Oxford Township
39° 50’ 6.6”/77° 01’ 49.5”
On the west side of the intersection with Pa. Rte. 94 and Hanover Road
Reference: Stose (1932)
Comments: Minerals found here include nice calcite crystals, hematite and dolomite

Lancaster County:

Binkley and Ober Quarry, East Hempfield Township
40°06’ 45”/76° 21’ 46”
Active quarry on the west side of Pa. Rte. 72 just north of East Petersburg
Reference: Stose and Jonas (1930)
Comments: Nice saddle-shaped dolomite crystals and other minerals

Cedar Hill Quarry, Fulton Township
39° 43’ 36”/76° 08’ 28”
Abandoned quarry on south side of Quarry Road, south of the intersection with Cedar Hill Road
Reference: Geyer and others (1976)
Comments: Large variety of serpentine minerals found, including the type site for desautelsite, first identified in 1979.

Woods Chrome Mine, Little Britain Township
39° 43’ 52.09”/76° 09’ 56.4”
Located in a meander of the Octoraro Creek south of the end of Hollow Wood Lane
Reference: Lapham (1958)
Comments: Chromite and other minerals can still be found with some digging

Pequea Silver Mine, Pequea Township
39°56’ 45.2”/76° 18’ 51.6”
On the east side of Silver Mine Road on the north side of Silver Mine Run
Reference: Smith (1977)
Comments: Galena, anglesite and quartz can still be found with some digging

Burnt Mill Shaft, Pequea Township
39°56’ 27”/76° 18’ 29.2”
Located about 0.2 mile west of Pa. Rte. 324 and about 100 yards south of Pequea Creek
Reference: Smith (1977)
Comments: Open adit still visible. Small dumps in area with little mineral production

Gap Nickel Mine, Bart Township
39°57’ 25.5”/76°05’ 21.6”
Located about 0.2 mile south of White Oak Road and 0.2 west of Mine Road
Reference: Geyer and others (1976)

York County:

Old Castle Corporation, Jackson Township
39°55’ 26.9”/76°51’ 28.5”
Active quarry on the south side of the intersection of U.S. Route 30 and Biesecker Road
Reference: Stose and Stose (1944)
Comments: Some of the Pennsylvania’s best calcite was collected here in the 1960’s sand 1970’s. Formerly known as Thomasville Stone & Lime Company quarry.

Codorus Stone & Supply Company Quarry, East Manchester Township
40°01’ 16.4”/76° 42’ 59.4”
Active quarry locatec north of Mundis Race Road and west of Dellinger Road
Reference: Jones (2006)
Comments: Best known for its fluorite but a host of mineral identified including pyrite, dolomite, sphalerite and quartz

Logan Iron Mine, Carroll Township
40° 06’ 44.6/77° 00’ 52.6”
On the east side of Ore Bank Road about 0.4 mile south of Mumper Lane
Reference: Jones and Goodman (1980)
Comments: This is the best location within the Dillsburg magnetite district to mineral collect a variety of minerals including magnetite, pyrite, hematite, chlorite, datolite and orthoclase.

Yocumtown (Frogtown) Garnet Locality, Fairview Township
40°11’ 00”/76° 48’ 07”
Along Big Spring Road in the vicinity of Willis Lane
Reference: Stose and Glass (1938)
Comments: Andradite garnet and specular hematite fill cavities in the Gettysburg Formation conglomerate

Rossville Copper Road Cut, Warrington Township
40° 04’ 19.15”/76° 55’ 26.39”
On the east side of Old York Road about 0.5 mile north of Rossville.
Reference: Geyer and others (1976)
Comments: Azurite and malachite commonly found but keep your eyes open for zelolites in the road cut to the south of this location. Opal also found at these sites.

Constitution Rutile Locatality, Fawn Township
39° 43’ 20”/76° 24’ 59.4”
Along the Mason-Dixon Line on Pa. Rte. 851
Reference: Lininger (1997)
Comments: Rutile crystals occur in the cultivate fields here.

York Building Products – Westgate Quarry, West Manchester Township
39°58' 11.4"/76° 45' 39.1"
South of U.S. Rte. 30 and west of Roosevelt Ave
Reference: Smith (1977)
Comments: Excellent calcite crystals are known from here in recent years along with a variety of other minerals.

CHAPTER 10. THOSE WHO LEFT FOOTPRINTS HERE

We know that early Greek, Roman and Chinese philosophers were some of the first to take notes on observing the earth. It was not until between the 15^{th} and 18^{th} centuries that modern geology was starting to be born. Leonardo da Vinci, Rene´Descartes and Robert Hooke were just some of the individuals making strides in not only taking notes but comparing their notes. The work of James Hutton (1726-1797) of Edinburgh, Scotland, made him the "father" of geology. He developed the classification of rocks and showed evidence that the earth was very old by looking at the thick layers of rocks comprising the crust.

In the early 19^{th} century, William Smith, an English surveyor, provided the ability to place rock sequences in chronological order. This new area became known as stratigraphy, which made possible the mapping and correlation in a regional aspect.

The first geologic map of the eastern United States was developed by Philadelphia merchant, William McClure who was familiar with the new geological thinking in Europe. As the United States grew in both population and geographically, the State and Federal governments began researching potentially important natural resources. These geologists were engaged in mapping the Appalachian region in the 1830's.

The First Geologic Survey of Pennsylvania was started in the late 1830's and headed by Henry Rogers. Henry interpreted the stratigraphy in the folded layers of the Appalachian Mountains.

In the early 1840's, the Second Geologic Survey of Pennsylvania was formed. The chief of the department was J. Peter Lesley who investigated the geology of most of the state, on a county-by-county basis.

Lesley's chief assistant geologist was Persifor Frazer, Jr., who initiated research in Adams, York, Lancaster and Chester counties. Between 1874 and 1890, Persifor covered nearly every square foot of the region, mapped every exposure and sampled at every opportunity. Persifor used his patience and scientific knowledge to carefully map the region. Frazer's maps were redrawn by Lesley and published in color in 1879 and 1880 respectively by the state. These colorful maps were the most detailed maps designed at that time

In the late 1800's, Atreus Wanner, a York educator and self taught geologist collected a large collection of fossils from the Lowlands Section and Triassic region of York County. Mr. Wanner assembled specimens of trilobites, plant impressions and dinosaur footprints, adding much value to the understanding of the regional geology. A federal geologist, Charles Doolittle Walcott, came to York to visit Mr. Wanner and his collection and a friendship was formed. As stated earlier, Mr. Walcott identified a new species of brachiod that Atreus discovered in the Cambrian rocks of York County. In honor of Mr. Wanner's dedication to paleontology, Mr. Walcott named the fossil *Yorkia wanneri.*

Atreus traded the favor back to Charles Walcott. Atreus discovered a new species of the subgeneus *Holmia.* In Wanner's words, "I take great pleasure in naming it after Mr. Walcott in recogniztion of his work on the Cambrian fauna." Atreus named it *Olenellus* (Holmia) *walcottanus*.

Atreus has other fossils named after him. Not until 1986 were footprints of a dinosaur Mr. Wanner discovered named *Atreipus* which means "Atreus's foot."

In the field of mineralogy, York chemist Edgar Fahs Smith and Frederick Ehrenfeld of the University of Pennsylvania teamed up and collected numerous mineral species from the same area that Atreus Wanner studied, the Lowlands and Gettysburg-Newark sections. Oddly enough Mr. Smith had a York City middle school named after him, in which this writer attended as a young man.

In the early 1900's, the Piedmont metamorphic rocks (Uplands Section) became the mecca for research. Thanks to Bryn Mawr College's Florence Bascom, her colleagues and students began the long and still on-going research on this complex region. Maria and William Crawford followed suit from the same university in adding data to the research of the Piedmont around the Philadelphia area.

Without doubt, one team of geologists that laid the foundation for research in Adams, Lancaster and York counties was George Stose and Anna Jonas. George was employed by the United States Geologic Survey and Anna was employed by the Pennsylvania Geologic Survey. Their love for the Earth expanded for the love of each other, eventually marrying and doing work as Stose and Stose. Their work covered South Mountain, Adams County, York County and western Lancaster County. George and Anna seemed to have been ahead of their time, using aerial reconnaissance, chemical and microscopic examination and structural interpretation to complete a geologic map.

George and Anna were also responsible for naming many of the rock formations in the area. The New Oxford and Gettysburg formations of Triassic age; the Chickies, Harpers, Antietam, Vintage, Kinzers, Ledger, Conestoga, Elbrook and Conocoheague formations; and the Peters Creek formation were all named for type localities described in over sixty reports and articles which they published, together and separately, from 1903 to 1944.

The detailed mapping that George Stose and Anna Jonas Stose did using the tools of their time among the complex folded and faulted rocks of the Piedmont is remarkably accurate. Also, remember that plate tectonics (or continental drift as it was known in the early days) was not accepted into the science world until 1954. In addition, Stose and Stose worked off of limited exposures as mining, quarrying and urban development was not what it is today. They summed their work up by saying "…the Paleozoic and underlying pre-Cambrian rocks of York County were folded and compressed at the same time as those of the Appalachian region in general, during the epoch of mountain making, which is called the Appalachian Revolution."

In the 1950's, reconsideration of the continental drift theory became a household name. The recognition of rifting occurring at the Mid-Atlantic Ridge, paleomagnetism measurements and radiometric dating became well established. Combining these three principles, it became obvious to scientists that the crustal pieces of the earth known as plates have been and are currently shifting. Evidence even showed that over long periods of time, the North and South poles on Earth swap. It appears that the magnetic North Pole becomes weaker and eventually switches polarity. We are currently seeing a decrease in magnetism, possibly leading to such a swap of poles.

Research has continued within the entire region. Much of the research is contributed to the Pennsylvania Geological Survey and the United States Geological Survey. Work on the igneous rocks of South Mountain and the Uplands Section, the structural geology of the Uplands Section and ground water have been some of the leading research themes in the past twenty years.

For those that continue research in southeastern Pennsylvania, more discoveries will be made and ideas will be advanced. With better technology, more details about the origin of rocks will be unraveled. As I have told audiences, with today's technology, we are able to view the makeup of a rock in microns, no longer in centimeters.

CHAPTER 11.
EVERYONE CAN BE AWARE OF OUR SURROUNDINGS

Sinkholes and Caves

Now since you have read this far into the book, you are either totally lost with the subject; interested but unclear on many thoughts; enjoying the information; or you just want to read and get it completed (don't read the last page to see how it comes out).

This last section involves a topic of geologic hazards and conservation. You may not think that geology affects you. Sit back for a moment and think "Does it really affect me?" Time, is up, get back to reading!! Yes, geology does affect you. Let's take a look at some of the geologic topics that occur in southeastern Pennsylvania that might interest you.

Areas having the rather soft rocks like limestone and dolomite are good candidates for sinkholes, disappearing streams and caves. Limestone and dolomite composed of calcium carbonate and magnesium carbonate respectively, are easily weathered by groundwater and our rainfall (acid rain). With some of the richest soils in the area comprising the Piedmont Lowlands Section, there are hidden secrets beneath the regolith. All of the rocks within the Lowlands have been folded and faulted, creating fractures. As rain follows these fractures, the cracks get wider and eventually will create a void, which in turn evolves into a sinkhole. Because the mineral dolomite is slightly more resistant to weathering compared to calcite in limestone, sinkholes are prone more for the limestone areas. There have been some classical cases in Adams, York and Lancaster counties.

In Adams County, sinkholes are very common in the area of Bittinger, Oxford Township, near the location of Vulcan Materials Quarry. A number of sinks are common around the entire area, but are noticeable on the north side of Hanover Street between Pa. Rte. 94 and Red Hill Road. There is even a road sign saying "Sinkholes – Drive at your own risk." A large sinkhole is found on the east side of Pa. Rte. 94 (York County) just to the north of Municipal Road. The Bittinger area sinkholes are found within the Kinzer and Ledger formations.

In York County, Pa. Rte. 116 from Hanover to U.S. Rte. 30 follows the carbonate rock. This area is underlain with a dolomitic rock belonging to the Vintage formation, not as prone to sinkhole development. The Ledger and Kinzer formation reappear on the map at Thomasville and follow U.S. Rte 30 eastward in to Lancaster County. Similar to Bittinger Station, sinkholes are common within these two rock units. Sinkholes can be regularly seen in the fields surrounding the York Airport west of Thomasville and in the area of the West Manchester Mall between the parking lot and U.S. Rte 30. One sinkhole in particular near the highway contains limestone bedrock that resembles a mummy. Also, in recent years, U.S. Rte. 30 westbound has had lane closures due to a sinkhole under the highway.

A northern extension of the Lowlands Section containing the Vintage Formation passes east of Emigsville to Saginaw at the Susquehanna River. Again, being the Vintage Formation, sinkholes are not as common. However, this is the belt in which the Bootlegger's Sink discussed in the Cenozoic Era is located.

Also, in 1984, an unusual type of sinkhole occurred at John Rudy County Park in Easter Manchester Township. On a particular Sunday afternoon, a gentleman was riding his horse through the fields of the undeveloped park. His horse's hoof fell into what appeared to be a groundhog hole. The horse fell nearly straight down and when his weight hit the ground, the soil gave way, creating a sinkhole about eight feet deep and twelve feet in diameter. The Parks maintenance crew responded with a bulldozer and safely removed the horse. Both the horse and rider were not injured. When I did an inspection of the depression the following day, the rock on the walls was that of the Antietam sandstone, which underlies the ridge to the north of the park. It was concluded that a subsurface sinkhole had formed earlier in time in the underlying Vintage dolomite and left a bridge of Antietam sandstone over the hidden depression. With the weight of the horse, the arch collapsed.

In Rohrerstown, Lancaster County, sinkholes have been associated with the Ledger and Kinzer formations. A large industrial facility here had to undergo major renovations due to sinkhole development. Better planning could have avoided this from occurring. Several houses were destroyed by a sinkhole in the early 1980's in Columbia caused by a broken water main pipe.

Caves are associated with sinkholes. Everyone has to accept the fact that the earth under our feet is not always solid bedrock, but contains these little secrets, some of which are as beautiful as commercial caves elsewhere in Pennsylvania. As in sinks, the Kinzer and Ledger formations tend to contain the larger caves, containing thousands of feet of passages and exotic calcium carbonate cave formations. Many caves have been mapped within the Thomasville, West York, North York and East York regions. Quarry operations also discover caves on occasion. A cave within the Vintage Formation near Saginaw has been said to be one of the longest caves in Pennsylvania.

Caves have been known to occur under the West Manchester Mall in West Manchester Township. Also in the City of York, Emmanuel United Church of Christ at the corner of North Sherman Street and East Market Street discovered a small cave during construction.

Rohrer's Cave in Rohrerstown, Lancaster County has a unique setting. Located under what was once the Rohrer's Hardware store, the basement of the building had a door built in to access the cave. Within this subsurface void, the cave formations were stained with iron, allowing the stalagmites, stalactites, flowstone and columns to be discolored reddish and yellowish-brown.

Radon

Radon is a colorless, odorless radioactive gas that is produced through the breakdown of the uranium isotope U238 in soil and bedrock. Radon can accumulate in homes and other buildings lacking adequate ventilation. Radon has a half-life of 3.8 days, decaying through the loss of alpha particles which are capable of causing damage to living tissue. Radon is also one of the leading causes of lung cancer.

In Adams, Lancaster and York counties, radon tests have shown moderate to high levels. The Pennsylvania Environmental Protection Agency recommends that all homes be tested for radon. A home or building showing a high reading can be fixed rather easily by sealing the foundation or the installation of vents to keep the radon concentration at acceptable levels.

Earthquakes Hazards

Examining an earthquake potential map of the eastern United States, southeastern Pennsylvania is not at high risk for seismic activity. The existence of many old faults cutting the Paleozoic and Mesozoic rocks, however testify to powerful earthquakes which shook the area long ago, as continents collided and rifted in vast tectonic events. These faults for the most part are inactive today, with the notable exception of the Martic Line-Fruitville Fault intersection in south Lancaster County. The “Easter Earthquake” of 1984 reached a magnitude of 4.1, shaking furniture and rattling windows in York and Lancaster counties, but causing little or no property damage in the area.

One effect was noticed by the earthquake. On the rocky bluffs of the Susquehanna River south of Pequea is Wind Cave. This cave is the largest tectonic, or fault, cave in the eastern United States. The walls of Wind Cave, composed of schists, were pulled apart in the distant past in response to tectonic processes. A section of ceiling collapsed in one of the chambers. Southern Lancaster County, with limestone bedrock, is said to have seen an increase in sinkhole occurrence, possibly due to the added “rock and roll” caused by the earthquake.

Another notable seismic event occurred within the Newark-Gettysburg Lowlands Section just east of Franklintown, York County in June 1997. Actually, at least three earthquakes occurred within nearly a 24-hour period. The largest of the events was measured at magnitude 2.3. Over 75 area residents were interviewed and reported no damage. This was the first documented earthquake in southeastern Pennsylvania west of the Susquehanna River. As a result of this earthquake, further fieldwork showed evidence of a nearly north-south running fault that was not mapped previously.

Other smaller earthquakes have occurred and are believed to be associated with the Fruitville Fault in Lancaster. Also, one earthquake was reported in Adams County east of Biglerville. In this case, the epicenter was at the contact with the Gettysburg Formation and diabase, possibly a zone of weakness.

Groundwater

Although not a geologic hazard, groundwater is a precious treasure of the earth. As far as we know, the earth is not producing water. Water was formed very early in the geologic history of the earth. For millions of decades, this water has flowed, both within the Earth and on the surface.

We always have taken drinking water for granted. “It is and will also be here” is an opinion that many of us have. We always have water flowing when we call for it. Our water either comes from springs that possibly flow into reservoirs or from wells extracted from the complex groundwater system. Hydrogeologists conduct various tests and measurements on water from wells to determine the size and personality of an aquifer. By mapping various aquifers and producing a water-table map, we can estimate the amount of water available within the ground. This is only a prediction, since a geologist cannot view groundwater in place.

Various rocks have a wide range of properties that allow water to flow or not to flow through them. Some rocks have the ability to store water among their crystals and grains, while other rocks do not have any available storage space for water. Rocks that cannot transmit or store groundwater based on their properties must rely on tectonic fractures, bedding planes, or foliation to act as channels for water movement.

Generally speaking, sedimentary rocks have the best aquifers. Rocks like sandstone, limestone and shale have pore space between sediment grains that allows easy transmission of water. Igneous rocks, consisting of crystals interwoven together do not allow good permeability or porosity. Most metamorphic rocks are similar to igneous rocks since these rocks were changed into new distinct rock types using heat and/or pressure.

Now using your knowledge from “TimeWalk”, guess what areas might be best in which to drill a well. The Piedmont Lowlands Section and sedimentary rocks of the Gettysburg-Newark Lowlands Section would be the best candidates. The diabase associated with these Meozoic aged rocks are poor aquifers. The Uplands Section, particularly the schists are very unpredictable. Schists rely on foliation and fractures in the rock to transmit water. Predicting water yields for a new well in metamorphic rocks is difficult. Well yields can vary greatly only within a few feet on the ground.

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APPENDIX 1

The following pages contain photographs of the “Where Can I See” locations described in the text.

Black Barren Road, Lancaster County
Serpentinite with a serpentine vein

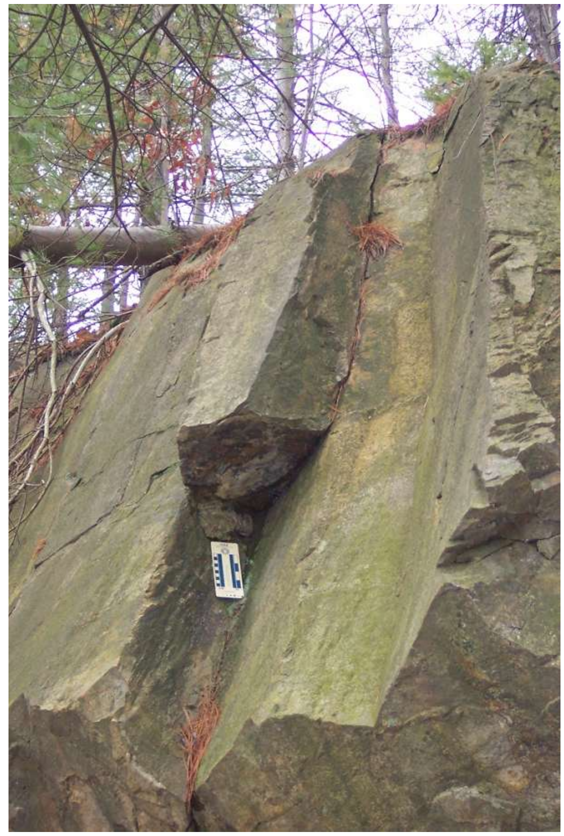
Aberdeen, Lancaster County
A group of students examine the diabase dike.

Codorus Stone & Supply Company, York County looking east

Aspers, Adams County
Vesicular sample of the Aspers basalt

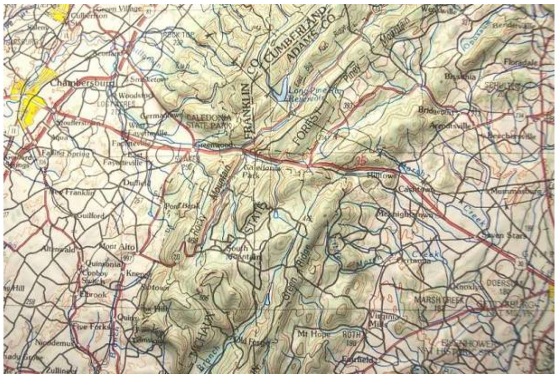
CSX Railroad Cut, Gettysburg, Adams County
From left to right: sedimentary rocks (red), hornfels (gray) and diabase dike now covered by gabion.

Camp Tuckahoe, York County
Large areas of talus on top of ridge

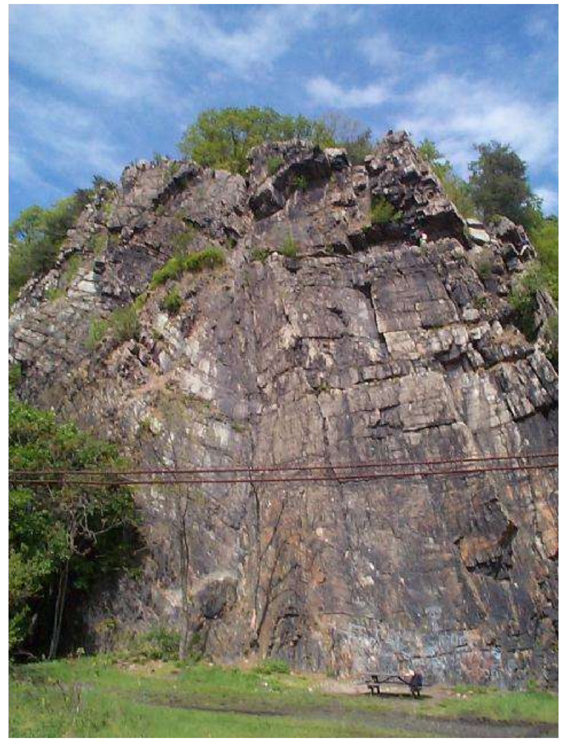


Carbaugh Reservoir, Adams County
Columnar jointing in metarhyolite

Carbaugh Run Quarry, Adams County
Artifacts made from metarhyolite



Carbaugh-Marsh Creek Fault,
Adams/Franklin counties
U.S. Rte. 30 marks the position of the fault



Chickies Rock, Lancaster County
One of the most famous anticlines on the East Coast.

Cherry Hill Road, Lancaster County
Two different directions of schistosity tells of two different collisions

Chimney Rock, York County
Erosional remnant of the Hellam Conglomerate of the Chickies Formation.

Conewago Falls, Lancaster County
Potholes in diabase can be seen when the water level is low. Pictured above is a pothole from the Holtwood gorge in Lancaster County.

Devil's Den, Adams County
The type site for diabase in southeastern Pennsylvania

County Line Quarry, York County
Looking from the north.

Delta, York County
Funkhauser Quarry looking west

Culp's Hill, Adams County
Looking north with South Mountain in the background

Eagle Rock, Lancaster County
Hammer Creek conglomerate

Fishing Creek Metabasalt,
Lancaster County

Frogtown Road, York County
Exposure of the Marburg Schist

Governor's Stable, Lancaster County
Classical rock and weathering features

Holtwood Metabasalt, York County
Pillow structures

Gut Road, York County
Exposure of the New Oxford quartz conglomerate near the base of the Triassic

Holtwood Overlook, Lancaster County
View looking south from pinnacle

Indian Rock, York County
An erosional remnant of the Chickies quartzite forming an anticline

LWB Quarry, York County
The largest carbonate operation in the county

Jacks Mountain Tunnel, Adams County
Folding in Weverton quartzite east of the tunnel

Lock 12 Octoraro Schist Exposure, York County

Kirk Farm Gravels, Lancaster County
Well-rounded quartz pebbles on a high terrace

Locust Lane, York County
Top half of Ollenlus trilobite

Miller Road Fanglomerate Exposure,
Lancaster County
Base of the New Oxford formation

Money Rocks County Park,
Lancaster County
Exposure of Chickies quartzite

Miller Road Roadcut, Lancaster County
New Oxford sandstone and softer shale
dipping to the northwest.
View looking northeast

Octoraro Formation Quartzite
Glen Rock, York County
Beds dipping vertically

Shenk's Quarry, Peach Bottom,
Lancaster County
Folding in the Peach Bottom slate

Pottery Hill, York County
Small quarry on the Gnatstown
Overthrust

Pigeon Hills, Adams County
Catoctin Metabasalt

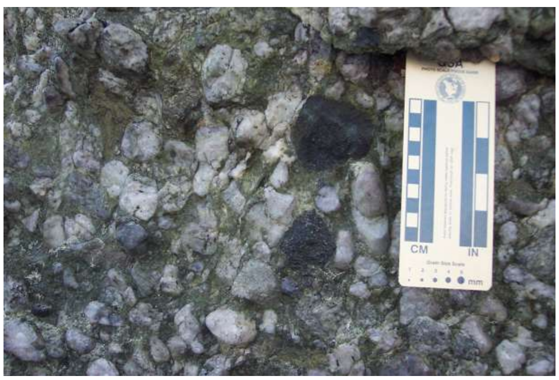
Prospect Quarry, Lancaster County
Folding in the Millbach Formation

Pinchot State Park, Old Toboggan Run,
York County
Classical diabase exposure

Raab County Park, York County
Small anticline exposed in the "quarry"

Rheems Quarry, Lancaster County
Folding in the Epler Formation

Rossville, York County
Mineralized copper zone in lower center



Rocky Ridge County Park, York County
Hellam conglomerate with dark rhyolite
and quartz pebbles

Rte. 194 Roadcut, Adams County
New Oxford conglomerate
Notice roundness of the clasts

Rohrer's Quarry, Lancaster County
Note discontinuous dip across the wall
indicating folding

Sam's Creek Metabasalt
Glen Rock, York County
Metabasalt exposed to the center-right

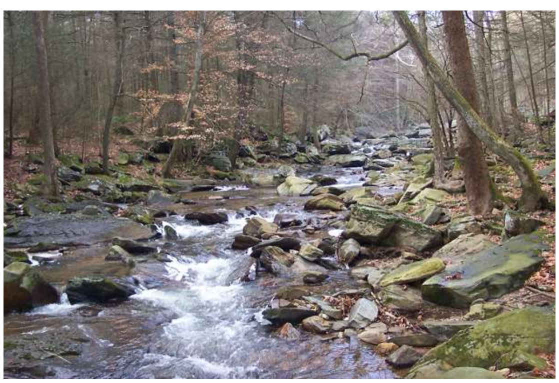
Sheep Bridge Road, York County
Gettysburg sandstone and shale

Sam Lewis State Park, York County
Looking north to Chickies Rock

Seitzland Folding, York County
In the York County Heritage Rail Trail
County Park

Shull's Rock, York County
View looking north toward Bainbridge

Stoney Brook Dike, York County
Diabase dike on left and hornfels to the right.



The Narrows, Adams County
Conewago Creek passing over Catoctin metarhyolite.

Trostle Quarry, Adams County
Heidelsberg Member of the Gettysburg formation siltstone

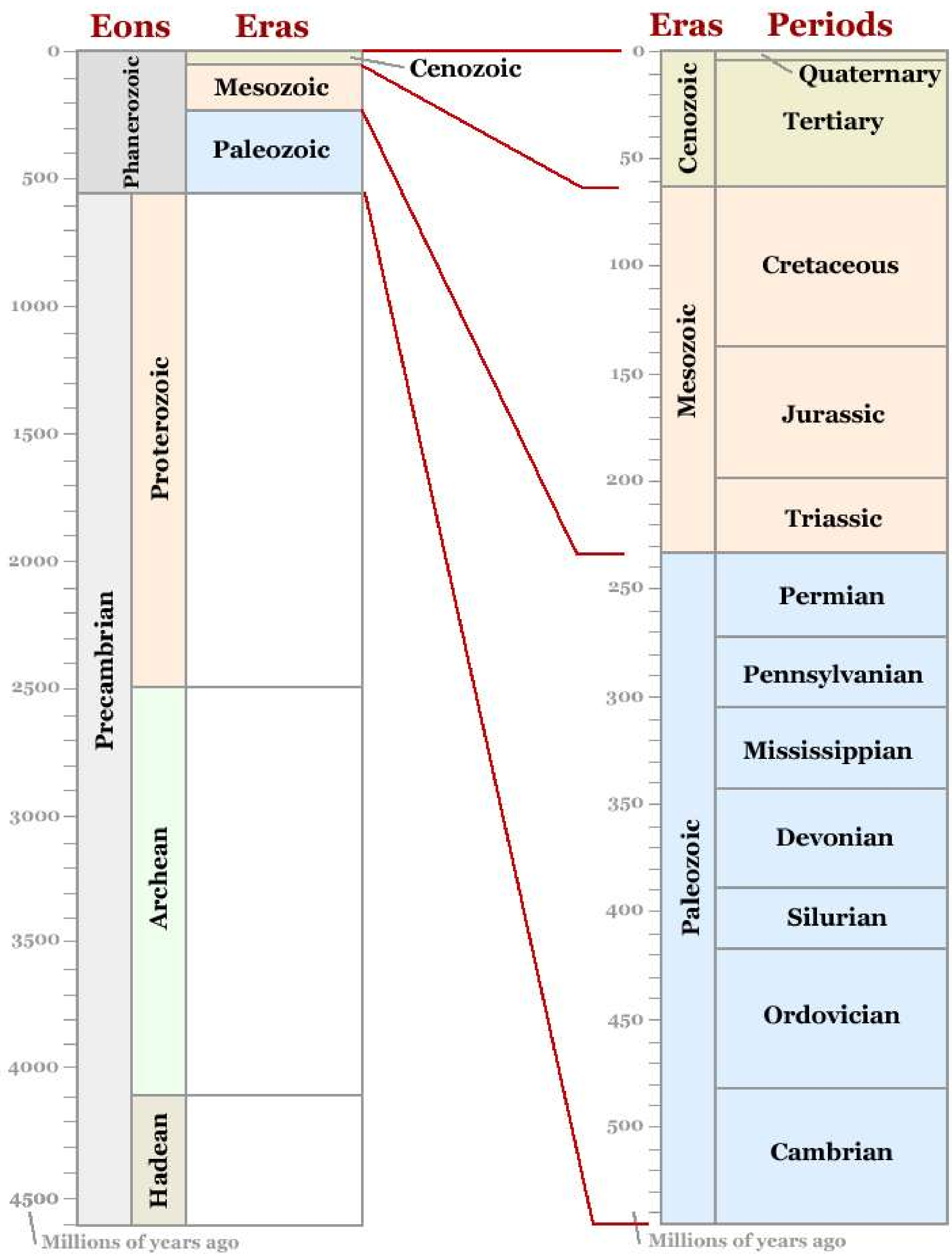
Weaverland Quarry, Lancaster County
Dramatic folding on north wall on lower level

York Haven quarry, York County
Diabase exposed here.

York Silica Sand Company
York County
Cross-bedding in quartzite showing two directions of ocean currents

York Springs fossil site
Adams County
Siltstone underlying sandstone

Geologic Time Scale

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E/FOCUS GUIDE
placing scale in picture area. Fine-focus on GSA seal.
IN
Scale