Readings and Notes

An Introduction to Earth Science

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The Permian Period

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CH 11

THE PERMIAN PERIOD

Introduction: The Permian Period was a time of great crisis in Earth's history. The Permian saw the final closure of the Iapetus Ocean that had formed following the breakup of the super-continent of Rodinia in the late pre-Cambrian; the closure resulting in the formation of another super-continent, Pangea. It was during the Permian that two of Earth's major mountain chains, the Appalachians and the Urals, were created. The period was one of climatic extremes. By the end of the Permian, Earth had not only experienced its most widespread glaciation but also the formation of deserts the likes of which had never been seen before. In addition to all of the physical events that were to occur during the period, the close of the Permian was the time of the most severe extinction that has ever occurred in all of Earth's history when more than 95% of all marine life was wiped out. The Permian was indeed, a crisis in the history of Earth.

Life of the Permian:

Permian Animals: The close of the Pennsylvanian saw the egg-laying ***anmiotes*** split into two different groups, the **reptiles** and the **synapsids** or "*mammal-like*" reptiles. During the Early Permian, both the reptiles and the synapsids underwent a radiation that resulted in a large number of terrestrial carnivorous predators and herbivores. The major carnivore of the day was a synapsid, the fin-backed ***Dimetrodon*** (**Figure 1**). The animal was a truly fearsome creature reaching a length of nearly 20 feet, weighing several hundred pounds, and equipped with powerful jaws complete with peg-like teeth, including a set of elongated canine teeth with which it could both stab and rip its victim to pieces. Dimetrodon's fin was most likely an adaption that allowed the animal to quickly regulate its body temperature by orienting it relative to the Sun. The rapid rise in body temperature would allow the animal to generate the burst of energy needed to capture an unsuspecting prey. Today's finned reptiles use the fin for the same purpose. Although the large carnivorous synapsids were the rulers of the land, there were herbiverous synapsids as well. One such synapsid was the plant-eating **Lystrosauria** that was equipped with a sharp, plant-cutting beak (**Figure 2**).

By the Late Permian, the fin-backed synapsids had disappeared and were replaced by another group that not only looked increasingly mammal-like but possessed teeth that had diversified with both canine teeth for stabbing and tearing and multi-cuspid teeth for grinding. By the late Permian, the synapsids outnumbered the reptiles more than 10 to 1. There is no doubt that the scene was being set for the eventual evolution and dominance of the mammals; but that would have to wait until the Triassic.

Permian Plants: During the Permian, the gymnosperms took over the terrestrial environment from the spore-bearing plants and would become the dominant plants of the Mesozoic Era. What brought the seed-bearing plants to dominance was the spreading arid conditions. As the vast coal swamps dried up and other moist environments diminished or were eliminated, life became increasingly difficult for the spore-bearing plants. While spore-bearing plants require an aqueous environment so that their eggs can be fertilized by the water-bourne sperm, the seeds of the gymnosperms were able to tolerate and survive within the dryer and more severe climatic conditions that were spreading across the land. The male pollen grain of the gymnosperm is carried to the egg by the wind where the sperm passes through a moist tube to the egg-bearing seed, a process that eliminates the need for water. Although the lycopods, sphenopsids, and seed ferns survived (and indeed they are still with us today), they became small and were relegated to whatever moist area continued to exist.

The Glossopteris Flora: Because of the role it played in the evolving theory of plate tectonics, a few comments about the **Glossopteris Flora** are in order. Glossopteris was a tree-sized seed fern that was especially abundant in the Permian coal-associated rocks of Gondwana although they have also been found on other continents as well. It was the presence of the Glossopteris Flora in the Permian rocks of South America and South Africa that was part of the evidence used by Alfred Wegener to support his idea of continental drift. It can be argued, and demonstrated, that specific flora found on widely separated continents could have been the result of the seeds having been carried long distances by the wind. What was so important about the Glossopteris flora was the fact that the seeds were so large that they could not possibly have been carried from one continent to another by the wind; the only explanation for their being found in rocks of the same age on these different continents was that the continents were once part of a large super-continent that broke up

The Permian Extinction: The extinction that occurred at the end of the Permian was the most devastating ever to occur on Earth. It is estimated that nearly 95% of all marine species were eliminated. The fauna that had dominated the marine environment from the very beginning of historic time was literally wiped out. With nearly every marine niche evacuated, an entirely new cast of characters was to eventually evolve and occupy the sea. However, because of the extent of the extinction, it would take millions of years and would be well into Triassic time before marine life recovered.

The list of animals affected by the extinction is long and include some that had survived in the marine environment for tens and even hundreds of millions of years. Trilobites that had survived several previous episodes of extinction did not survive the Permian extinction. The fusulinids that were so abundant right up to the Late Permian were nearly all gone by the beginning of Triassic time. The productid brachiopods disappeared as did the fenestellid and branched bryoxoans. The archaic nautiloids went to extinction with only a few ammonoid genera surviving into the Mesozoic.

The extinctions were not restricted to the marine environment with many terrestrial forms being victims. The plant community experienced a change from the typical Pennsylvanian flora dominated by lycopods and ferns to gymnosperms such as conifers, cycads, and ginkgoes. The animals did not fair any better with 75% of all terrestrial vertebrates going to extinction.

The obvious question is, what was the cause of such a world-wide extinction? As one might suspect, there is no one scenario that enjoys universal agreement. The most prevailing theory is that Earth experienced a world-wide cooling that was brought about by vast glaciation on the newly-formed super-continent of Pangea, glaciation that had begun earlier on Gondwana. The extent of the cooling was so universal that it affected both the temperatures of the atmosphere over the land as well as that of the ocean. You will recall that glaciation and subsequent world-wide cooling was also given for the Ordovician and Devonian extinctions. One of the problems with the glaciation theory is the fact that the data indicate that the glaciation apparently peaked in the Middle Permian, not at the end of the period. In fact, the data indicate that there was an episode of rapid warming at the end of Permian time due, presumably, to a run-away greenhouse effect as the carbon dioxide content of the atmosphere increased.

Several reasons have been proposed for the increased carbon dioxide content. Certainly, a significant number of terrestrial plants were eliminated as the surface of Gondwana was covered by glaciers; plants that would have removed atmospheric carbon dioxide during photosynthesis. Secondly, the onset of arid conditions resulted in the drying up of the vast swamp environments that survived from the Pennsylvanian, again reducing the number of CO_2-consuming plants. Thirdly, the decrease in the availability of water resulted in a marked decrease in the amount of carbonic acid that was available for chemical weathering. You will recall that carbonic acid created by the reaction of carbon dioxide and water is the major agent of chemical weathering. According to this theory, as the concentration of greenhouse gases in the atmosphere increased and the temperatures rose, abnormally high stresses being placed on all of the existing organisms, especially the marine animals that were not able to adjust.

Another theory proposes that the extinction was the result of the elimination of a great percentage of the shallow marine environments in which most marine life exists. It is true that as all of the Paleozoic continents finally converged to form Pangea, vast stretches of the coastal shallow water environments where the great percentage of marine life exists were eliminated. The problem with this theory is that Pangea is believed to have formed by Middle Permian time, long before the massive extinction took place.

In addition to the areas of Pangea covered with glacial ice, the creation of the super-continent resulted in vast deserts forming in the interior of the continent as the moisture content of the prevailing winds was precipitated along the continental margins. The Upper Permian is dominated by eolian sandstones and evaporites, both of which attest to severe drought over vast areas of the super-continent. The climatic extremes brought on by concurrent glaciation and desert conditions could well have stressed both terrestrial and marine environments beyond the ability of the inhabitants to adapt and thereby survive.

Another event that occurred in the Late Permian was the eruption of enormous volumes of basaltic lavas in what is now Siberia. The ash released into the air alone would have significantly filtered out the Sun's radiant energy to the point that world-wide atmospheric temperatures could have been affected.

The bottom line is that so many different events occurred during the Permian, with each one having the potential to drastically change the environmental conditions that existed both on land and in the sea. It is easy to see how the combination of all of these events acting over a long period of time could create such drastic changes in both terrestrial and marine conditions, changes to which the animals and plants could not adapt. The result was a mass dying both on land and in the ocean.

The Alleghenian Orogeny: The two orogenies that affected the eastern margin of Laurasia, the Taconic Orogeny at the close of the Ordovician and the Acadian Orogeny at the close of the Devonian involved the collision of relatively small continental masses. The Taconic Orogeny was the result of the collision of the Piedmont Micro-Continents while Avalonia, the continent involved in the Adadian Orogeny, was not much larger. Because of their relatively small mass, deformation was restricted to the continental margin with the creation of a coastal highland while the foreland basin to the west was down-warped and continued to received the sediments stripped from the highland. Following the Acadian Orogeny, the Acadian highland continued to be a source of sediment as the sea withdrew from the craton during the Mississippian. The sediments stripped from the eastern landmass and carried by streams westward during Pennsylvanian time eventually filled the Appalachian foreland basin and spilled out over the Cincinnati Arch into the craton interior as a vast coastal plain **(Figure 3)**.

By the end of the Pennsylvanian, the Appalachian foreland basin had collected sediment and recorded the Paleozoic history of the eastern margin of the continent since Cambrian time. Beginning in Late Pennsylvanian time, things were to change drastically as Gondwana approached Laurasia from the southeast. With South America now joined, Gondwana was an enormous continental mass, orders of magnitude larger than either the Piedmont Micro-Continents or Avalonia. The collision of Gondwana with Laurasia was one of the final events in the creation of Pangea. The amount of energy involved was so great that not only were the rocks along the eastern margin of the existing continent subjected to intense metamorphism but the sediments that had accumulated in the Appalachian foreland basin since the Cambrian where uplifted and deformed as part of a mountain range that was every bit as grand as the modern Himalaya; those mountains were the Appalachian Mountains. Simultaneous with the deformation of the Appalachian Basin and the creation of the Appalachian Mountains, the Ouachita Basin was deformed to create the Ouachita Mountains as a westward continuation of the Appalachian Mountains (**Figure 4**).

The Making of the Appalachian Mountains: First, it must be recognized that the Appalachian Mountains as we see them today are the result of two separate phases: 1) the creation of the structures, the folds and the faults, that we see in the exposed outcrops and 2) the surface expression or the topography of the region. The geologic structures date back to the Alleghenian Orogeny that culminated at the close of Permian time while the topography is the result of the uplift and erosion of the eastern portion of North America that occurred during the Cenozoic Era; processes that continue to shape and sculpt the landscape today. Let us begin with the formation of the structures..

The sequence of events that occurred during the Alleghenian Orogeny are summarized in

Figure 5. It is quite clear from the east to west change in the degree of faulting and the increased symmetry and decreased amplitudes of the folds that the point of collision of Gondwana and Laurentia was to the east and that the amount of deformational energy decreased westward. Based on the structures and the subsequent sculpting by various processes of erosion, earth scientists have subdivided the Appalachians into four **physiographic provinces** (**Figure 6**).

The most deformed rocks exposed at the surface are within the **Piedmont Physiographic Province** (refer to Figure 6). The Piedmont extends eastward from the base of the Blue Ridge Mountains, under the Coastal Plain, and out to the edge of the continental shelf, now buried beneath the geocline that extends along the entire eastern margin of the continent. Rocks within the Piedmont are highly metamorphosed and tightly folded, indicating deformation deep within the core of the continent-continent collision that created Pangea. Because the rocks were created under extreme conditions of temperature and pressure, when exposed to the atmosphere, they tend to weather very rapidly as their assemblage of high-temperature, high-pressure mineral components are converted to an assemblage of minerals that are stable at atmospheric conditions, primarily a mixture of rock fragments, clay minerals, and quartz. As a result, the rocks of the Piedmont are largely buried beneath a thick layer of **regolith**. In many places the rocks have been so intensely weathered in place that they have been converted to a **saprolite** that often preserves the texture of the original rock within the framework of the new assemblage of minerals.

Later, during the Triassic when Pangea began to rift apart, the Piedmont became the site of down-faulted basins (**Figure 7**).. These basins quickly filled with debris generated by the weathering off the uplifted block. The weathering, transportation and deposition of the debris was so fast that much of the feldspars of the original rock were preserved in the new sediments, giving rise to the **arkoses** that are commonly found within the basin sediments. Lakes that formed within the basin apparently were watering holes for many of the animals that roamed the region, their presence being recorded in fossil foot prints and trails. Notable amongst these were dinosaurs.

To the west of the Piedmont is the **Blue Ridge Physiographic Province** (refer to Figure 6). The Blue Ridge Mountains consist of Cambrian and pre-Cambrian basement rocks that include a mixture of igneous, metamorphic and meta-sediments that were metamorphosed about a billion years ago during the Grenville Orogeny , the final orogenic event that formed the super-continent of Rodinia. In its central portion, the Blue Ridge Province consists of a gigantic anticlinorium that extends from South Mountain on the west to Catoctin Mountain on the east separated by Middletown Valley. South Mountain is held up by the basal Cambrian Weaverton Quartzite, Middletown Valley within the core of the anticlinorium is floored by meta-basalts while Catoctin Mountain is capped by a sequence of pre-Cambrian basaltic and rhyolitic lavas that were extruded during the Grenville Orogeny, now metamorphosed to greenstones. The Blue Ridge Mountains widen and rise in elevation southward where they represent the highest elevations in the eastern portion of the continent with many peaks in excess of 6,000 feet.

The physiographic province to the west of the Blue Ridge is the **Valley and Ridge Province** which, in the central portion of the Appalachians, is subdivided into an eastern **Great Valley** and a western **Appalachian Mountain** sub-provinces. The rocks within the Valley and Ridge Province and the Appalachian Plateaus Province to the west represent the sediments that accumulated within the foreland basin that existed along the eastern margin of Laurentia (later to be referred to as Laurasia) beginning during Cambrian time. Referred to as the **Appalachian**

Basin, the foreland basin accumulated sediments throughout the entire Paleozoic and thereby recorded the events that occurred during the era within the eastern portion of Laurentia. The structures that characterize the entire Valley and Ridge Province are asymmetric folds broken on their western overturned limbs by high-angle thrust faults (Figure 6). The compressive forces that were generated by the collision of Gondwana and Laurentia resulted in the formation of major horizontal thrust faults within the weaker shale-rich rock formations called **sole faults** from which **splay faults** broke off and carried old rocks to the surface (refer to Figure 6). Within the Great Valley, commonly called the Shenandoah Valley, the splay faults brought the Cambro-Ordovician carbonates that had formed during the opening phase of the Paleozoic Wilson Cycle to the surface. Because all carbonates are composed primarily of water-soluble $CaCO_3$, the exposed rocks quickly weathered to form a broad valley. As carbonates weather, any insoluble materials originally contained within the rock is released and covers the weathered rock surface with a thin layer of soil. Because of the ever-present content of iron, carbonate soils are characteristically red. As a result of the soil cover, few outcrops of the carbonates occur within the valley. However, where exposed in quarries, the rocks exhibit extreme overturning, some to the point of recumbency. In the easternmost edge of the valley, some of the carbonates show indications of low-grade metamorphism. Throughout the greater portion of the valley, the rocks are not metamorphosed.

Within the Appalachian Mountain portion of the Valley and Ridge, the rocks are folded into asymmetric to overturned folds that are usually broken on the steeper west limb by a high-=angle thrust fault (**Figure 8**). Throughout the region, the folds formed as the entire rock section above a basal sole fault in the Ordovician Martinsburg Formation, allowed the rocks to be moved westward. Eventually, as the folds formed and the rock section became unable to consume additional stresses by folding, the thrust faults formed and carried the rocks further westward. Most of the rocks within the Appalachian Mountain sub-province range in age from Ordovician carbonates exposed in watergaps and within the cores of breached anticlines (**Figure 9**) to the basal Mississippian Pocono Formation. The major ridge-formed within the province is definitely the basal Silurian Tuscarora Sandstone. The structures seen in the Ouachita Mountains indicate that they are basically an extension of the Appalachian Valley and Ridge Province. The two mountain ranges are now separated by the Mississippi Embayment whose sediments buried the structures

West of the Valley and Ridge Province, the basal sole fault rises to the Harrel/Marcellus Formation that underlies the **Appalachian Plateaus Province**. As the name implies, there are multiple plateaus within the province, actually seven, where each is delineated based largely on surface topography (**Figure 10**). The most extensive plateau is the **Unglaciated Allegheny Plasteau**, the easternmost portion of which is referred to as the **Allegheny Mountain Section** or the **High Plateau** by some geologists. Structurally, the High Plateau is a transitional segment of the plateau between the high-amplitude, asymmetric folds of the Valley and Ridge Province to the east and the essentially flat-lying rocks of the **Low Plateau** to the west (**Figure 11**). Most of the rocks within the Plateaus Province are Pennsylvanian in age with some Mississippian and upper Devonian rocks exposed within the High Plateau where erosion has breached the basal Pennsylvanian Pottsville sandstones that cap most of the ridges, exposing the less resistant rocks below.

The Unglaciated Plateau west of the Allegheny Mountain or High Plateau Section is commonly referred to as the **Low Plateau** Although symmetrical folds exist within the Low Plateau, the amplitudes of the folds are so low that the rocks throughout the region appear essentially horizontal when seen in outcrop. The youngest rocks in the eastern United States are exposed in the Low Plateau. Perhaps what is most important about the Pennsylvanian rocks exposed throughout the Low Plateau is the presence of the coals for which the Pennsylvanian System is famous world-wide.

Few faults are apparent at the surface throughout the plateaus. The splay faults that are responsible for the folds die out within the cores of the folds and rarely reach the surface (**Figure 12**). The western terminus of the plateau is taken by some geologists as the point where the basal sole thrust comes to the surface, representing the western limit to the compressive forces involved with the Alleghenian Orogeny.

Surface Processes Sculpt the Final Scene: Following the Alleghenuian Orogeny at the close of Permian time about 250 million years ago, there is every reason to believe that the Alleghenian Highlands were every bit as grand as the modern Himalaya. About 200 million years ago during the Triassic, Pangea began to break up. As North America split from North Africa, a part of the Alleghenian Highland west westward with North America to form the basis of the Appalachian Mountains while the eastern portion remained with North Africa, remnants of which can be seen today in the Atlas Mountains. Over the next 50 to 100 million years, the Alleghenian Highland was reduced to a flat, featureless plain by the combined processes of weathering, mass wasting, and erosion. Although no surface indication remained of the once-grand mountain range, its presence was still recorded in the underlying structures ~~below~~.

Beginning about 60 million years ago, the entire eastern portion of the continent was uplifted about 5000 feet into a broad arch that extended from the mid-continent to the Atlantic coast **(Figure 13)**.. Streams were rejuvenated throughout the region and a new topographic expression evolved throughout the region, controlled and dictated by the underlying structures and rock materials as the streams sculpted the surface. Resistant rocks such as the quartzose sands of the Pottsville, Pocono, Tuscarora, and Weaverton formations formed ridges while less resistant rocks such as shales and limestones formed valley floors. What arose were the physiographic provinces described above. It is important to understand that the structures one sees in the rocks exposed in road cuts, hill sides and cliffs throughout Appalachia are the result of a mountain building episode that occurred 250 million years ago during the Permian Period while the topography one sees today is the result of uplift and renewed processes of weathering, mass wastine and erosion that have occurred over the past 60 million years during the Cenozoic Era, processes that are still going on today, constantly changing the lay of the land .

The Permian of the Mid-Continent: During the Early Permian, a shallow sea extended northward to southeastern Nebraska and eastern Kansas **(Figure 14)**. The lower Permian rocks throughout the region are a mixture of thin marine shales and limestones containing a normal suite of marine fossils. In progressively younger rocks, however, the fossils decrease in both kinds and numbers until they disappear. Overlying these rocks is a thick formation of gray shale containing thick beds of salt overlain by red beds that are devoid of fossils **(Figure 15)**. The Permian rocks sequence in the mid-continent clearly indicates that during the Early Permian a vast shallow epeiric sea extended from what is now the western Great Plains as far east as Ohio. To the south, the sea bordered on Llanoria, the landmass associated with the Ouachita Basin. In time, the climate became increasingly arid to the point where evaporation from the sea exceeded precipitation. Eventually, the sea was reduced by evaporation to a vast dead sea centered over Kansas and Oklahoma. As the salinity of the waters increased, the animals died out; eventually the water became a brine from which evaporite minerals began to precipitate. A connection across Mexico allowed the lost water to be replenished as evaporation continued. Eventually, the sea became totally landlocked and completely evaporated During the Late Permian, sand dunes now represented by the Whitehorse Sandstone buried the evaporites. This dead sea marks the last stand of the Paleozoic epeiric seas east of the Cordilleran.

The Permian of the Southwest: The most impressive accumulation of Permian rocks anywhere in the world are found in western Texas and southeastern New Mexico where Permian strata total about 14,000 feet in thickness. During Permian time, the region was within the Ouachita foreland basin, often referred to as the Guadalupe Basin. The sea extended from Llanoria in the south to the ancestral Rockies in the north **(Figure 16)** Within the main basin there were two smaller basins, the Delaware Basin in southwestern Texas and southeastern New Mexico, and the Midland Basin in west-central Texas. While the Midland Basin rapidly filled with sediment, reefs consisting of sponges, algae, and lacy bryozoans began to grow around the margin of the Delaware Basin. As sea levels rose, the reef complex built upward in order to maintain the living portion within the photic zone. Eventually, the reef stood about 2,000 feet higher than the basin floor **(Figure 17)**. Until the Late Permian, the Delaware Basin was connected to the open sea by way of what has been called the Hovey Channel that allowed the influx of new, oxygenated seawater. In time as the basin deepened, the bottom waters became anoxic as indicated by the decrease and eventual elimination of fossils in the basin sediments. Near the end of Permian time when the climate in the region became arid and the influx of fresh marine waters was not enough to offset evaporation within the basin, the basin filled with evaporite minerals. Today one can stand in the middle of the Delaware Basin and observe the reef complex now exposed in the Guagalupe Mountains as the Capitan Limestone.

The Permian of the Cordilleran Region: During the early Permian, a shallow sea covered southern and eastern Nevada, much of Utah, southeastern Idaho, and western Wyoming (**Figure 18**). The most impressive exposures of Permian rocks in the far west are to be seen in the Grand Canyon where the rocks from the top of the Mississippian **Redwall Limestone** to the rim of the inner gorge are Permian in age with the **Kaibab Limestone** forming the rim of the inner gorge (**Figure 19**). In northern Utah and southeastern Idaho the most widely distributed and well-known Permian formation is the **Phosphoria Formation** that consists of a black phosphatic shale overlain by a cherty limestone.

The Western Margin of Laurasia: During the Permian, a chain of island arc volcanoes existed offshore (**Figure 20**). Sediments stripped from the exposed volcanic islands were deposited into the sea adjacent to the continental margin. Beginning in the Late Permian and continuing into the Triassic, an orogeny similar to the Antler Orogeny, called the **Sonoma Orogeny**, thrust marine sediments up onto the continental margin and for the first time completely eliminated the basin that had existed between the island arc and the continental margin (**Figure 21**). The result of the suturing of the island arc and the marine sediments to the continental margin resulted in a significant westward growth of the continent.

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