Readings and Notes | An Introduction to Earth Science

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The Devonian Period

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Ch 6

THE DEVONIAN PERIOD

Introduction: Until the 19th century, the rocks exposed throughout the provinces of Devonshire and Cornwall in southwestern England had long been considered to be Carboniferous in age because of their content of fossil plants. Closer investigation by Murchison and Sedgwick in 1836, however, showed that only the uppermost portion of these rocks contained fossil plants. Because the lower portion of the rock sequence was devoid of plant fossils, was highly deformed, and resembled the rocks of northwest Wales which they had recently studied, Murchison and Sedgwick assigned the rocks to the Cambrian System. However, local fossil collectors had submitted fossil corals collected from this same interval to Professor William Lonsdale who found them to be intermediate in evolutionary development between the corals of the Silurian and those of the Carboniferous. Based on this observation, Lonsdale suggested that this section of rock might be correlated with the Old Red Sandstone, a thick sequence of sandstones and shales located stratigraphically below the Carboniferous throughout much of Great Britain. It took two years before further study convinced Murchison and Sedgwick that Lonsdale was correct in his interpretation; it was Lonsdale who proposed the name **Devonian** for the system of rocks that existed between the Silurian and the Carboniferous. Unfortunately, the Devonian rocks in Great Britain are highly deformed by folding and faulting and are therefore very difficult to decipher. Perhaps the best sequence of Devonian rocks in the world are located in New York.

The Devonian in Laurentia: Except for the eastern margin, most of Laurentia at the end of the Silurian was a low, flat, exposed continental surface and would remain so until the Middle

Devonian, explaining why there are no known Lower Devonian rocks in the Cordilleran region of western Laurentia. During the Early Devonian, only the Appalachian Basin was submerged beneath a shallow sea that extended from Newfoundland to Mississippi. Beginning in Middle Devonian time, the Appalachian embayment extended westward into the Mississippi Valley region while another sea encroached from the north along the Cordilleran trough southward to Utah and Nevada (**Figure 1**). Throughout the remainder of the Devonian, both the Appalachian and the Cordilleran basins accumulated thousands of feet of sediment while the craton in between remained either slightly emergent or just barely awash.

Mountain Building:

The Eastern Margin of Laurasia: During the Lower Devonian, most of the eastern portion of Laurasia remained a carbonate platform accumulating the carbonate sediments now seen in the Helderberg Formation (Figure 2). Beach sands consisting of almost pure quartz accumulated along the eastern margin of the Appalachian basin These sands probably represent the remains of a sandy regolith that had accumulated on the remains of the old Taconic Highland that were transported by streams to the eastern edge of the Appalachian Basin. Unlike the sands that contributed to the sandstone formations at the base of the Cambrian and Silurian, these sands did not represent uplift in the highland region. Today, these beach sands can be seen in **Oriskany Sandstone**. In addition to being a minor ridge-former in the Valley and Ridge Province of the modern Appalachians, the Oriskany Sandstone has played an important role in the economics of Appalachia. Historically, the Orishany Sandstone has produced more gas and oil than any other rock unit in the Appalachians. In addition to its importance as a source of petroleum, at Berkeley Springs, West Virginia, the sandstone is 100% pure silica and is one of the purest glass sands found anywhere in the world.

The Middle Devonian begins with a continuation of carbonate accumulation in the foreland basin with the creation of the **Onondaga Limestone** that extends the entire width of the basin from New York to the Cincinnati Arch where it thins (refer to Figure 2). Corals were abundant at the time in the warm, shallow sea and reefs grew to impressive dimensions. One of the most famous examples of Devonian reef limestones forms the rapids in the Ohio River at Louisville, Kentucky known as The Falls of the Ohio. Until navigational dams and locks were constructed, The Falls of the Ohio represented a major obstruction to river traffic along the lower reached of the Ohio River.

Following the accumulation of the Onondaga limestones, the rocks record a major change along the eastern margin of Laurentia. The Hamilton Group represents a thick wedge of fine-grained clastic sediment that began to pour off a rising highland to the east, signaling that the second orogeny in Appalachia, the **Acadian Orogeny,** had begun. Following the collision of Baltica with the northeastern margin of Laurentia during the Late Silurian, another micro-continent, Avalonia, was converging on the eastern margin of the continent.(**Figure 3**). Because a large new landmass was added to Laurentia with the collision of Baltica, the name of the continent was changed from Laurentia to **Laurasia**. The two largest landmasses now become Gondwana to the south and Laurasia to the north.

As Avalonia approached and the eastern highland began to rise once again, this time as the **Taconic Highlands**, the foreland basin deepened in preparation to receive the vast volume of sediment that would soon be shed westward. The collision of Avalonia would occur first along the New England/Nova Scotia portion of the continent and would progressively work southward, scissor-like, toward the Carolinas.

The Hamilton Group represents the beginning of another major delta complex, the **Catskill Delta**, that would build westwards from the base of the Acadian Highland just like the Queenston Delta built westward from the base of the Taconic Highland. By the end of Devonian time, the basin will be filled. The first clastic sediments shed into the basin were muds that accumulated on the deepening basin floor where anoxic conditions preserved the abundant organic materials that resulted in the creation of the black shales of the **Hamilton/Marcellus Formation.** Today, the black shales of the Hamilton/Marcellus Formation can be seen making up most of the valley floors throughout the Valley and Ridge Province of Appalachia.

In time, the streams flowing off the rising Acadian Highland began to carry silts and sands into the basin that gave rise to the shales and thin sandstones of the **Brallier Formation**. By this time, the water within the basin had shallowed to the point where anoxic conditions no longer existed as can be seen by the change in color from the black shales of the Hamilton/Marcellus to the buff-colored shales of the Brallier. As uplift in the highland continued, the shale-dominated Brallier Formation gave way to the sandstone-dominated **Chemung Formation** (refer to Figure 2). To the east, conglomerates within the Chemung attest to the energy of the streams that were flowing off the steepening slopes of the Acadian Highlands and their ability to transport large particle sizes in bedload.

By the Late Devonian, the Catskill Delta had built completely across the Appalachian basin with the final sediments being deposited in very shallow, oxygenated waters, possibly exposed to the atmosphere as the exposed surface of the prograding delta complex. The result was the formation of the redbeds of the **Catskill Formation**. Note that the sequence of rocks from the Hamilton Group to the Catskill redbeds records the Acadian Orogeny and the uplift of the Acadian Highlands in exactly the same fashion that the sequence of Ordovician rocks from the black shales of the basal Martinsburg Formation to the redbeds of the Juniata Formation record the Taconic Orogeny and the uplift of the Taconic Highland. History does indeed repeat itself.

Just as the culmination of the Taconic Orogeny is recorded by the presence of the basal sandstones of the Silurian Tuscarora Formation, the climax of the Acadian Orogeny is recorded by the presence of the sandstones of the basal Mississippian **Pocono Formation.** In both cases the formations represent coarse sands and larger clastics deposited across the width of the foreland basin as a vast coastal plain. As the Devonian Period closes, the eastern margin of Laurasia is a mountainous highland probably comparable in grandeur to the modern Alps.

The Western Margin of Laurasia: During the Middle Devonian, the Cordilleran region of western Laurasia was being affected by tectonic activity for the first time. The westward movement of Laurasia had apparently given rise to an island arc called the **Klamath Arc** that was located west of the continental margin (**Figure 4**). Sediments and volcanics derived from the arc were carried eastward and deposited in the Cordilleran Basin between the arc and the continental margin. Today, an assemblage of .shales, cherts, and volcanics can be seen in the Klamath Mountains and in the Sierra Nevada that record the development of the Klamath Arc. These rocks were deposited in the Cordilleran Basin during the time interval from the Middle Devonian to the Early Mississippian and record the progressive convergence of the Klamath Arc and the western margin of the continent. Sometime between Late Devonian and Early

Mississippian time, the marine sediments that had accumulated in the basin along the leading edge of the Klamath Arc as an accretionary wedge were thrust up and over the carbonates that had been accumulating in the Cordilleran Basin along a major thrust fault called the **Roberts Mountain Thrust** (**Figure 5**). These events are referred to as the **Antler Orogeny**, the first of many orogenic episodes that would construct the western margin of North America that we see today.

Devonian Life: The Devonian was a time of great evolutionary advances. Plants that had been restricted to the wet, marshy fringes of the aquatic environment during the Silurian were to evolve into forests that covered the land for the first time in the Devonian. Insects first appeared in the Lower Devonian and before the period was over, lobe-finned fish that had been venturing out onto land since the Silurian replaced their fins with feet and became the first amphibians.

The Devonian seas swarmed with animals of many kinds. Where the water was warm, reefs were constructed of corals that, in some cases, had reached large sizes. One cup coral, for example, produced a corolla that was 3 inches in diameter and 2 feet long. Colonial corals formed heads 8 feet in diameter with individual reefs reached enormous dimensions. Similar to modern reefs, the reefs of the Devonian were communities within which many different kinds of animals and plants lived. In addition to the coral, for example, many types of bryozoa and crinoids lived on the reefs while brachiopods and bivalved molluscs attached themselves to the reef surface.

Brachiopods reached their zenith during the Devonian. More than 700 kinds of brachiopods have been described from the Devonian of North America alone with the longhinged spirifers being the most dominant form (**Figure 6**). Mud-loving pelecypods became common on the Devonian sea floor with many of the burrowers looking much like the modern razor clam.

The declining populations of nautiloids were replaced in the Devonian by the ammonoids that became the most prominent invertebrate swimmer and predator. Where most nautiloids were straight-shelled, ammonites had tightly spiraled shells. Another major difference between nautiloid and ammonoid shells that can be clearly seen in fossils was the line of attachment of the septa to the shell. The septa was the back "wall" of the living chamber to which the animal was attached. As the animal grew larger, it would abandon the old chamber, build an new extension to the shell and reattach itself to a new septa formed at the mouth of the old living chamber. In nautiloids, the septa were flat and, as a result, the line of attachment of the septum with the shell, the "suture", was a straight line (**Figure 7**). In the ammonoids, however, the septa became increasingly crenulated, apparently for added strength, and as a result, the sutures took on a more complex pattern (**Figure 8**). The ammonoids diversified rapidly and produced a series of consecutive species, each one of which was widespread, distinctive in shell design, and relatively short-lived; three attributes that made them ideal index fossils from the Devonian to the close of the Cretaceous when they went to extinction along with the dinosaurs.

Although locally abundant, trilobites continued their decline. Although they were on the way out, the largest trilobite of all time evolved in the Devonian with one species of Dalmanites reaching a length of nearly 30 inches. In contrast to those whose numbers were dwindling, the populations of four animal forms, crinoids, blastoids, echinoids, and starfish, were on the rise.

The Ascendancy of the Fish; Although fish remains were found in the Ordovician, they remained rare until the Devonian where they increased not only in numbers but also in kinds. By the end of the period, the great orders of fish were present and had not only dominated the seas but had also moved into fresh water streams and lakes.

The first jawed fish, the **acanthodian** that had evolved in the Late Silurian, was in decline near the end of the Devonian, but not before they gave rise to descendants that would come to occupy the top of the marine and fresh-water food chain. Soon, fish were not only feeding on invertebrates, but also on other fish. The top fish predator of the fresh water environment was the **placoderm**, a heavily-armored fish that apparently first appeared in the freshwater environment and only afterward migrated to the marine environment (**Figure 9**). By the late Devonian, a marine genus, *Dunkleosteus*, attained a length of 7 feet (**Figure 10**). The head and front of all placoderms were heavily-armored while the tails remained unarmored to provide the flexibility needed for locomotion.

The most important group of fish in the Devonian sea was the **shark**. Present only in the latter portion of the Devonian, sharks may have been the last major group of fish to evolve. Although the Devonian sharks were relatively primitive, they did grow to lengths of 3 feet and may have been the major enemy of the armored placoderms.

Except for the sharks, most of the early fish including the armored jawless fish and the placoderms did not survive the Devonian; the acanthodians lasted until the Permian. Two groups of fish that appeared during the Devonian are still represented today; the ***ray-finned fish*** and the ***lobe-finned fish***. Today, 99% of all bony fish are ray-finned fish. The difference between the ray-finned and lobe-finned fish is in the structure of their fins. In ray-finned fish, the fins are supported by spine-like bones that radiate from the body while in the lobe-finned fish, the fins are supported by stout bones that gave the fin more strength. It would be the lobed fin that would ultimately give rise to our arms. Another important characteristic of the lobe-finned fish was the possession of internal nostrils and, eventually, lungs that allowed them to breathe out of water. There were three main groups of lobe-finned fish: 1) the **lungfish**, three genera of which survive today in fresh water and that can survive periods of drought by burrowing into the muddy bottom of a drying lake, 2) the **coelacanth** that, until it was caught by a fisherman off the coast of Africa in 1937 was considered to be extinct, and 3) a group that eventually evolved into the amphibians and all other land vertebrates.

Animals Move onto the Land: In 1928, a Danish expedition to eastern Greenland uncovered the remains of a tetrapod (four-footed animal) in Devonian sediments correlative to the Old Red Sandstone. Close observation showed the skulls to be quite similar to fish. The discovery of one hind limb attached to a complete tail in 1948 combined with the previous finds led to the reconstruction of the first primitive amphibian, ***Ichthyostega*** **(Figure 11)**. It is important to note that nearly 80 million years passed between the time vascular plants first appeared on land in the Late Silurian and the first appearance of amphibians in the late Devonian. The reason for the delay in the acquisition of the land by animals is because a green plant-based food web had to be established to provide the food supply before animals could successfully colonize the land.

Amphibians, represented today by salamanders, toads, and frogs, are still not completely adapted to the land. Although some may spend 99% of their life on land, all amphibians must return to the aquatic environment to reproduce where they lay large numbers of unprotected eggs that hatch into tadpoles that breathe by means of gills and exist in a fish-like form until legs bud from their bodies and lungs develop as their gills are resorbed. Only then can they leave the water and breathe air directly.

The reason for the development of a means for breathing air directly and for movement onto land undoubtedly had something to do with the conditions that developed during the Late Devonian. The redbeds that characterize the Upper Devonian worldwide indicates the filling of basins and the repeated exposure of the sea bottoms to the atmosphere. Animals living in these shrinking aquatic environments had to devise as means of survival until more favorable conditions returned. Many were not able to adapt and died as lake and sea bottoms became dry land. At such a time, it would be of great advantage to be able to gulp air directly into a primitive lung. In addition, those animals with stout, bone-strengthened fins could pull themselves out of the water to forage for food or even to migrate overland to other pools of water (**Figure 12**). With the increased efficiency of the lungs to absorb oxygen from the air and with the conversion of the lobed fin into an actual foot, land vertebrates had achieved the land (**Figure 13**). Although amphibians were now on land, they would not become an important part of the land ecosystem until the Carboniferous when the Age of the Amphibian would swing into high gear.

Forests Cover the Land: Before the Devonian, land plants were restricted to the cyanobacteria, algae, and fungi that were able to grow in moist terrestrial environments marginal to bodies of water. Until the Devonian, the great expanse of the continent was barren. Rocks were, of course, being attacked by both chemical and mechanical weathering and the processes of mass wasting and stream erosion were fully operative. At times, glaciers scoured the land adding glacial debris to the stream and wind derived sediments that made up the regolith. But there was no soil and there was no humus, two components of the regolith that are essential ingredients for the growth of modern plants.

For plants to occupy the land, they had first to develop a means of retaining water within their bodies as well as develop tissues which would allow them to grow vertically against the constant pull of gravity. In addition, without the surrounding supply of food-laden water, they had to develop a means of acquiring nutrients from the ground. The important evolutionary event was the development of the **vascular system**. The vascular system consists of two sets of tubes, one set to carry water and nutrients from the roots to the most distal part of the plant and another set of tubes to distribute the food manufactured by the plants to the entire plant. The first vascular plant was the Early Devonian genus ***Rhynia***, found in the Rhynie Chert near Rhynie, Aberdeen, Scotland (**Figure 14**). The plants consisted of vertical stems that terminated in a bulbous organs called a *sporangia* that contained spores. The largest example of the genus was ***Baragwanathia*** that grew to a height of about 3 feet. Because the vascular tissues of Rhynia were limited to the lower portion of the stem, the stem was relatively weak and inefficient at both acquiring and distributing nutrients. Soon, however, plants called **lycopods** evolved with better developed and more efficient vascular systems that effectively displaced the original Rhynia. Today, lycopods are restricted to club mosses and so-called "ground pine". During the Devonian, most lycopods were creeping forms that may have sent vertical stems to heights of a few feet. By the Carboniferous, however, lycopod trees were growing to heights of more than 100 feet. Typically, lycopods had long, slender leaves that were attached to the stem in a spiral arrangement. As a result, the stems of lycopods had distinctive diamond-shaped leaf scars arranged in spirals around the stem (**Figure 15**). The sporangia of the lycopods were arranged in tight clusters called *cones*. In many lycopods, the male and female cones were separated from each other so that cross-pollenation with other plants was more likely to occur than self-pollenation, thereby enhancing the possibility of genetic variability.

A second important group of plants that evolved during the Devonian were the **sphenopsids**. Sphenopsids had long, segmented stems with the leaves arranged around the stem at the joints. The stems of the sphenopsids were similar in appearance to modern bamboo (**Figure 16**). The only modern example of this group are horsetails, or ***Equisetum***. A common name for horsetails is the "scouring rushes". The name comes from the fact that the early settlers would pulverize the silica-rich stems and use the pulp as a scouring pad.

The third type of spore-bearing plant that evolved during the Devonian was the **true fern**. Today, there are more than 10,000 species of fern that grow in damp, shaded areas. During the Devonian, ferns were relatively small plants but by the Carboniferous, they would grow to the size of large trees with their large leaves allowing an increased efficiency for capturing solar energy. With the land covered by plants for the first time, the rates of erosion were significantly reduced while at the same time exudates from the plant roots enhanced the rate of chemical weathering and the subsequent production of soil. It was only when the land plants became fully established that the development of a land-based food web allowed the successful invasion of the land by vertebrates.

Late Devonian Extinction: Near the end of the Devonian Period, more than 40% of all marine

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Devonian Tectonics: While the collision of Baltica during the Caledonian Orogeny did not affect Appalachia tectonically, it did add a very large land mass to the northeastern portion of Laurentia extending the continent all the way to the Ural Mountains of western Asia. Because this landmass consisted of a relatively large portion of Asia, the name was changed from Laurentia to Laurasia.

While the close of the Silurian left Europe rugged and mountainous, what was to become North America remained low and flat. The Devonian Period began with the accumulation of sequences of limestones within Appalachian Basin from Newfoundland to Mississippi. No marine deposits are known from the western Cordilleran Basin. Because of the scarcity of early Devonian limestones within the continental interior, we know that only about 5% of the continent was covered by the sea. Based on the fact that most of the eastern portion of Laurasia was a broad carbonate platform, we know that by the onset of the Devonian, the Taconic Mountains had been worn down, nearly to sealevel. Pure quartz sands derived from the erosion of the deep roots of the Taconic Mountains were transported and deposited as beach sands along the eastern portion of the Appalachian Basin. Today, these beach sands can be seen in the Oriskany Sandstone, another major ridge-formers in the Valley and Ridge portion of the modern Appalachians. In addition, because of its combined porosity and permeability, the Oriskany has produced more oil and gas than any other rock unit in the Appalachians. Although most of the Oriskany is lithified by carbonate cement, there is one well known locale, a quarry near Berkeley Springs, West Virginia, where the Oriskany is cemented by pure quartz, creating a 100% pure quartz sandstone that has been used for decades as one of the purest glass sands in the world.

During the Middle Devonian, a marked change occurred along the eastern margin of Laurasia as a highland began to rise and the Appalachian Basin began to subside. Fine-grained sediments began to be transported westward into the deepening Appalachian Basin that by now had become anoxic. Because of the lack of oxygen, a sequence of rocks began to form beginning with organic-rich black shales, These include the Marcellus and the Attica shales that are among the most prolific producers of natural gas in the world. As the basin continued to fill and the upper waters began to be oxygenated, the sequence changed upward through a formation of shales and interlayered sandstones called the Brallier Formation which changes to a sequence of largely sandstones intermixed with shales called the Chemung Formation and finally ending with a sequence of redbeds called the Hampshire or Catskill Formation. This sequence represents another clastic wedge similar to the Ordovician Queenston Clastic Wedge that recorded the rise of the Taconic Mountains during the Ordovician as the Piedmont Micro-Continents collided with the eastern margin of Laurentia. In comparison, the Devonian clastic wedge, called the Catskill Clastic Wedge, records the uplift of the Acadian Mountains as the continent of Avalonia converged on and collided with the eastern margin of Laurasia. It is important to recognize that the clastic wedges record the onset and evolution of an orogeny.

The Cordilleran Province: By the Middle Devonian, the continent was submerged as far west as the Mississippi Valley. In the western portion of the continent, waters from what is now the Arctic Ocean began to spread southward across Canada in a seaway nearly 1,000 miles wide and eventually joined the embayment that occupied the Cordilleran Basin in Utah and Nevada. Throughout the rest of the period, the western and eastern portions of the continent remained persistently submerged while the central states were either barely awash or slightly emergent. During the Middle and Late Devonian time, approximately 40% of the continent was submerged, but by the close of the period, emergence was gradual and eventually complete.

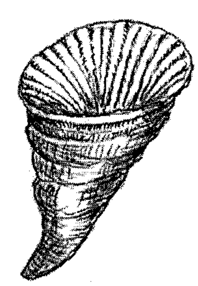

Figure 35. Cup Coral.

Life: The Devonian seas swarmed with marine invertebrates of all kinds. Where the seas were clear, corals created reefs. The coralla of cup corals reached dimensions of 3 inches across and 2 feet high (Figure 35). Honeycomb corals were dominant in the reefs, Bryozoa of all kinds and crinoids also lived on the reefs. Brachiopods were now at their zenith; no fewer than 700 kinds are known in North America alone. Pelecypods apparently loved the muddy ocean bottoms as sources of food and became more common and diverse than ever (Figure 36), Gastropods, first appearing in the Lower Cambrian, were not well preserved and cephalopods were varied but only locally abundant. Although trilobites were on the decline with relatively few kinds found, they were locally abundant with one species, Dalmanites, reaching a length of 30 inches, probably the record for all time for the trilobites. Other Groups that were less common that were an the increase were the blastoids (Figure 37), echinaids (Figure 38), and starfish (Figure 39).

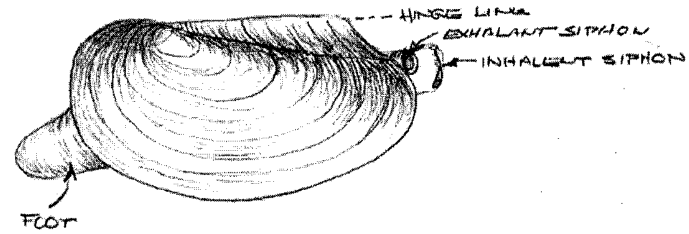

Figure 36. Drawing of Pelecypod.

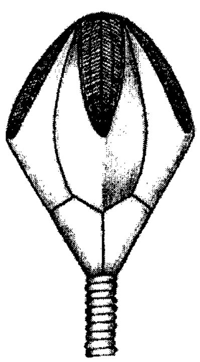

Figure 37. Blastoid.

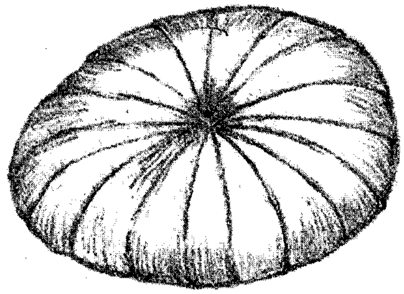

Figure 38. Echinoid.

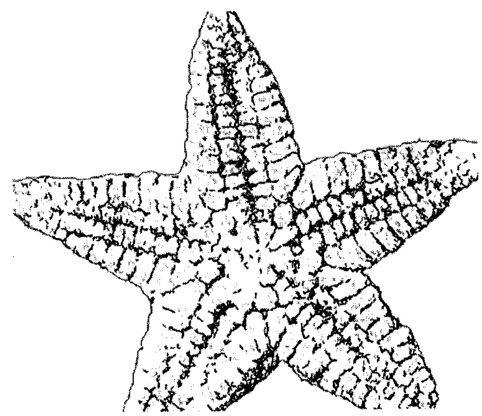

Figure 39. Starfish.

The Rise of Fish: The Devonian Period is known as the Age of the Fish. Although scattered fragments of bony plates have been found as early as Middle Ordovician, fish remains were extremely rare until the Devonian. The Devonian was a period of rapid evolution for the fish. Before the end of the period, several of the great orders of fish were present and were widely distributed in seas, lakes, and streams. Sharks were common in the sea, but their remains were limited to teeth and fin-spines since their skeletons were cartilaginous and readily decomposed and their scales were microscopic and nearly impossible to locate. A distantly-related group of fish, the Arthrodires (Figure 40), had the anterior portion of the body covered with an armor of bony plates. While no complete fossil was ever found in West Virginia, bone fragments of an armored fish called Dunkleosteus, was found during at a road construction site in Randolph County. While some of these fish attained lengths of 20 feet, and were successful in the Late Devonian, they were destined for a short lifetime and became extinct early in Mississippian time. More important were the Choanichthyes, a stock of air breathing fish that dominated the Devonian time but was now approaching extinction. This is the stock from which all the higher vertebrates were to develop. At least five genera of this group are still extant but, unfortunately, they occupy distant parts of the world and are largely unknown. Perhaps most remarkable is Protopterus, the African lungfish, that still lives in the upper Nile River where it experiences humid winters and dry summers. During the wet season, the fish breathes by way of gills. However, when the streams dry up, they burrow unto the mud, make a jug-like chamber where it goes into a resting stage similar to hibernation. During this period of time, its swim bladder serves as a rudimentary lung that allows it to

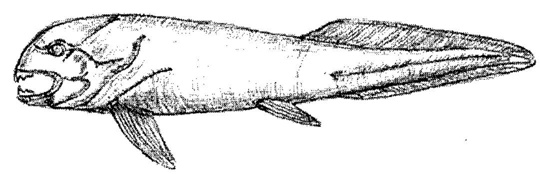

Figure 40. Arthrodire.

breathe air by way of a connection to its throat. Another living lungfish is Neocerotodus, the Australian lungfish, that is found in the rivers of arid northern Australia. With a swim bladder that supplements the gills at all times, it continues to swim during the dry season and comes to the surface for air as the water becomes increasingly stagnant.

During the Devonian, the Choanichthyes included two groups, the Dipnoi to which the living examples belong (Figure 41), and the Crossopterygii that show a combination of features that make them almost a perfect link between fishes and the lower tetrapods (Figure 42); that is, the four-legged, air-breathing vertebrates. Their fins had a stout, muscular basal lobe beyond which the fins extended as the forerunner of the limb of the higher animals. It was the Devonian crossopterygian, Eusthenopteron, with its stout fins and swim bladders serving as primitive lungs that first left their stagnant pools and wandered along the banks in search of food or who could venture overland to other more fresh water pools (Figure 43). Eventually it was a crossopterygian that during the Late Devonian time evolved into the first tetrapods belonging to the dominant group of Paleozoic amphibians, the Labyrinthodontia, so named for the elaborate infolding of its teeth (Figure 44). One could not imagine a more perfect link between fishes and primitive amphibians than these two creatures.

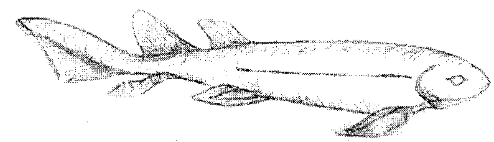

Figure 41. Dipnoi.

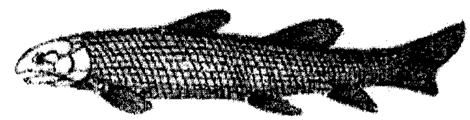

Figure 42. Crossopterygii.

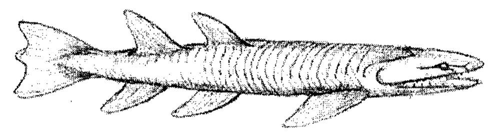

Figure 43. Eusternopteron.

During the Late Devonian, another group of fish began to assert their dominance, the bony fish (Osteichthyes). The bony fish represent the most numerous, varied, and successful of all the aquatic vertebrates. They are adapted to life in both fresh and salt water and have lived in practically all water environments on Earth. In addition, they include the majority of living fish and many extinct forms.

Figure 44. Labyrinthdontia.

Land Plants and the Evolution of Forests: While evidence of land plants was very scarce before Devonian time, by the Middle Devonian there was a considerable diversification of trees, some of which left stumps up to 2 feet in diameter. Early Devonian vascular plants are known collectively as the psilophytes flora, from a common genus, Psilophyton. The most perfect specimens are from Rhynie, Scotland, where they are encased in chert along with numerous insect remains. Two of the plants, Rhynia and Hornea had no leaves and only grew to a few centimeters in height. A third, Asteroxylon, was larger and had scale-like leaves. A late Devonian group of plants called the Archaeopteris flora had large fern-like leaves with clusters of spore-bearing organs. Some scientists consider these plants to be a possible link between ferns and seed-bearing plants. In general, the dominant Late Devonian plants were larger than the Middle Devonian types and bore root systems, had stronger stems and could disperse their spores and seeds more widely.

Three hundred and sixty million years ago, most plants reproduced by spores. Today, most plants that we see reproduce by seeds; a method that has proven very successful and reliable in carrying the genetic code from one generation to the next. Seeds from very early in this experimental period have been discovered in Devonian rocks in Randolph County, West Virginia. Only a quarter of an inch or so in length, preserved as a carbon film and borne within a hand-like cupule, these seeds are the oldest known in the world. It has not yet been proven as to which plant they belonged, but the list is rapidly being narrowed as the study continues.

We know a lot about plants based on their modern descendants. They were mainly lowland plants, growing along shores and valley bottoms. There were scouring rushes or horsetails (today's Equisetum is a descendant) "seed ferns" (Archaeopteris) and lycopods (spore-bearing plants) such as Prolepidodendron which eventually gave rise to the immense forests that covered the land in the next period.

Invertebrates: Marine animals had acquired most of their basic adaptions before the coming of the Late Paleozoic and settled down to a life of intense competition for food and living space. Marine animals sporting legs, swimming organs, and fins indicated that they were highly mobile while others developed the ability to crawl or burrow. At the same time, a greater number of animals developed both defensive and offensive mechanisms and structures. For example, many of the sharks had heavy, flat teeth adapted for the crushing of shells. Slow-moving animals such as trilobites, inarticulate brachiopods, and graptolites were either extinct or in decline as the more mobile and better protected forms flourished. Food gathering and food protecting techniques improved. Passive feeders dependent on passing water currents for food were gradually replaced by animals that were able to move about to gather food or were able to create self-generated currents to acquire food.