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The Cambrian Period

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THE CAMBRIAN PERIOD

Introduction: The **Cambrian Period** extends from 570 million years ago to 505 million years ago. Notwithstanding the discovery of the Ediacara fauna, the Cambrian Period of the **Paleozoic Era** has historically been taken as the beginning of historical time based on the first appearance of abundant fossil remains. It is interesting to note, however, that where first described, the lower Cambrian was not very fossiliferous. The story of the founding of the early periods of the Paleozoic is an interesting one. It centers around two of the most distinguished geologists of the 19th century, Adam Sedgwick, a professor at Cambridge University and Rodney Impey Murchison, a rich Scottish landowner. After returning from service in the Napoleonic wars, Murchison retired to his estates in Scotland and became a man of leisure. A friend, Sir Humphry Davy, convinced him to go to London to take courses in the sciences. During 1824, Murchison took courses in geology and joined the Geological Society of London where he met and began to associate with two of the foremost geologists of the time, William Buckland of Oxford University and Adam Sedgwick of Cambridge University. Murchison accompanied Sedgwick to geological expeditions to southern England, to the Scottish Highlands, to the Alps of France and Italy and to Germany. It was during these early years that Sedgwick and Murchison formed a strong personal and professional friendship. Under the tutelage of Sedgwick and combined with his own readings, Murchison would become one of the most distinguished scientists of the day. In fact, he eventually become the Director of The Geological Survey of Great Britain. It was his friendship with Adam Sedgwick, however, that set the scene for some of the most interesting geologic investigations of the day.

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In 1831, Murchison and Sedgwick set out to map the sequence of rocks then referred to as the *Transition Series* , an assemblage of rocks that included a highly deformed sequence of sediments between the base of the Old Red Sandstone and the crystalline rocks of the crystalline basement. The Old Red Sandstone represents the base of the Devonian System throughout Great Britain. They chose Wales in which to conduct their study because of the extensive exposures of the Transition Series there.

Sedgwick began his work in northwestern Wales where he worked out the proper sequence of rocks within a highly deformed region. The rocks lay immediately above the crystalline rocks of the pre-Cambrian basement and were not very fossiliferous. Sedgwick assigned the rocks to a new system than he called the **Cambrian System**, named after *Cambria*, the Roman name for Wales. Because the rocks contained very few fossils, his basis for defining the system was that the rock sequence consisted of a series of sedimentary rocks that sat directly on ancient crystalline rocks. In fact, even when fossils were occasionally present in the sedimentary rocks, Sedgwick made no use of them, a mistake that he would live to regret.

Meanwhile, Murchison had begun his work at the base of the Old Red Sandstone and worked westward. In time he would work out the propoer stratigraphic sequence of several thousand feet of rock. Fortunately for Murchison, his rocks were fossiliferous and unlike Sedgwick, he concentrated on describing their fossil content. Murchison assigned the rocks to a separate system primarily based on their fossil content that included trilobites, brachiopods, and crinoids. He eventually assigned the rocks to a new system he called the **Silurian System** after the *Silures*, an ancient Welsh tribe.

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In 1835, Sedgwick and Muschison published a joint paper in which they proclaimed these two new periods of geologic time and systems of rocks based on their studies in Wales. At that time, they were of the opinion that Sedgwick's Cambrian System lay entirely below Murchison's Silurian System. As their work progressed and as other geologists began investigating the rocks of Wales, especially in field trips, a favorite pastime of geologists worldwide, new data emerged that made it apparent that the lower half of Murchison's Sliurian was stratigraphically the same as the upper portion of Sedgwick's Cambrian. Murchison suggested to Sedgwick that he would include the upper portion of Sedgewick's Cambrian System into his Silurian System. Sedgwick refused and, in fact, insisted instead that the lower portion of Murchison's Silurian System be made part of the his Cambrian System. The problem that Sedgwick was faced with was the fact that, because he had not described the fossil content of his rocks, he had no way to extend their presence outside his immediate area of investigation. On the otherhand, because Murchison had methodically collected fossil data, he could show that his lower Silurian rocks did indeed correlate with the upper rocks of Sedgwick's Cambrian System. When Murchison continued to insist that only the older, generally unfossiliferous rocks be assigned to the Cambrian System, a feud broke out between the two that was to render these once close friends personal and professional enemies for the rest of their lives.

A solution to the problem came in 1879 when Professor Lapworth of Birminghan University suggested that the disputed rock interval be designated a separate system he called the **Ordovician System**, named after another ancient tribe of Welshmen, the *Ordovices*. Although widely accepted in the geologic community, there are some geologists who do not recognize the Ordovician as either a system of rocks or a period of time because there is no type locality at which it was first described. It might be pointed out that had the feud lasted much longer, the richly fossiliferous rocks of Cincinnati, Ohio, would have become the type locality.

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The Breakup of Rodinia

Approximately 1 billion years ago the super-continent of **Rodinia** was completed with the advent of the Grenville Orogeny. In the late pre-Cambrian, Rodinia began to break up, forming a new ocean, the **Iapetus**, surrounded by a number of continental masses of various sizes **(Figure 1)**. One of the larger continents, **Laurentia**, consisted mostly of what is now North America and Greenland. Obviously. Laurentia will serve as a focal point in many of our following discussions. Three other fairly large continents included **Baltica** (what is now Europe eastward to the Ural Mountains), **Gondwana** (all of the present southern continents except, at the time, for South America), and **South America** In addition there were two micro-continents, the **Piedmont Micro-Continents** and **Avalonia**. There were other continents that would eventually converge to form most of Asia but since our discussions will concentrate on the eventual formation of North America, we will not consider these further.

As these newly-formed continents diverged, the earliest Cambrian seas began to flood onto the surface of Laurentia. By the time Rodinia broke up, several million years of weathering and erosion had worn the surface of Laurentia down to a surface of relatively low relief that became covered with a layer of weathered material. The combination of erosion and structural warping of the craton resulted in the formation of basins and arches that controlled the distribution of the Cambrian sea as it flooded onto the continent. The largest single topographic

feature of the craton during Cambrian time was a long, broad, low-relief **Trans-Continental Arch** that extended from the region of the Great Lakes to Arizona. Two major basins formed on opposite sides of the arch early in the period, the **Appalachian Basin** to the east of the arch and the **Cordilleran Basin** to the west, both of which were bordered on the seaward side by narrow highlands. The Appalachian Basin actually began as a down-faulted rift valley similar in origin to the East African Rift Valley as the continents began to separate to form the Iapetus Ocean (**Figure 2**). Because the Trans-Continental Arch remained above sea level during most of the Cambrian, weathering and erosion of the arch was to to provide a source of sediments (**Figure 3**).

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As Laurentia moved westward, the passive eastern edge of the continent became the site of Cambrian deposition that initially consisted of sands derived from the continental interior. As the sediments accumulated along the edge of the continent, the continued application of tensional forces resulted in the edge of the continent continuing to downwarp, allowing the construction of a geocline similar to that now extending seaward from the eastern margin of North America (**Figure 4**). Before the close of the Cambrian, another basin called the **Ouachita Trough** would form along the souther portion of the craton extending from northern Mexico, across Texas and Oklahoma to the Gulf border (**Figure 5**). As the borderlands underwent repeated episodes of uplift and erosion during the Paleozoic Era, the highlands would provide the sediment that is present in most of the Paleozoic rocks we see today. Throughout most of Cambrian time, the central portion of the craton remained relatively stable.

During the early Cambrian, the seas were restricted to the basins and covered no more than about 10% of the entire craton at any one time. The Lower Cambrian deposits in both the Appalachian and Cordilleran basins are largely quartzites that range in thickness up to several thousands of feet; shales are conspicuously absent. Within the Appalachian Basin, these sands were originally lithified to form sandstones, and later were metamorphosed during subsequent mountain-building episodes and converted to meta-quartzites. We will discuss the rocks of the individual basins later.

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The questions to be answered are: 1) what was the source of the pure quartz sand, 2) what happened to the clay minerals that are always produced in the greatest volume by the chemical weathering of granitic rocks, and 3) were the sands spread out in thin sheets by wind, water, or both? The answers lie in the basal Cambrian sandstones themselves. The Cambrian sandstones are the most mature sands on Earth which means that: 1) the composition of the sands is 99% quartz and 2) the individual grains are highly rounded. Combined with the widespread distribution in thin sheets, sands of this character indicate that the source was a land surface of very low relief and of tectonic stability. The degree of rounding seen worldwide in Cambrian sandstones coupled with the frosted character of the grains indicated that the rounding was due to wind abrasion. Experiments have shown that wind abrasion is 100 times as effective at rounding quartz grains as is traction in the bedload of a stream or by ocean bottom currents. Perhaps a half billion years before the Cambrian seas ever transgressed into the interior of the craton and therefore before Cambrian sedimentation began, the cratonic surface had been subjected to weathering that generated a thick regolith cover. Over long periods of time this material was subjected to repeated episodes of wind, stream, and glacial erosion and deposition.

Millions of years of being winnowed by the wind and water had removed the fine-grained materials and carried them off, presumably beyond the margin of the continent into the deep ocean, leaving behind layers of clean, wind-blown quartz sand. The result of this pre-Cambrian erosion was the formation of a profound unconformity between the crystalline rocks of the pre-Cambrian and the overlying Cambrian sediments. As the Cambrian seas invaded the craton, wave action and tidal currents reworked these wind- and stream-deposited sands and spread them out in broad sheets on the floor of the encroaching sea. Throughout this period of time, invertebrates were not abundantly present. As a result, the fossil record is poor at best, usually consisting of only worm borings and remains.

By the end of Early Cambrian time, the Trans-Continental Arch had been worn down to scattered islands with very low relief. By the onset of Middle Cambrian time, little or no sediment was being provided from the cratonic interior. The lack of clastic sedimentation coupled with the fact that the continent straddled the equator, set the scene for the accumulation of the carbonate sediments. During Middle and Upper Cambrian time carbonates accumulated both in the Cordilleran Basin while along the eastern margin of Laurentia a carbonate platform built seaward **(Figure 6)**.

The separation of the Cambrian into Lower, Middle, and Upper is based on unconformities that formed as the seas briefly retreated from the continents. These fluctuations in sealevel were apparently world-wide. What caused them is not agreed upon but it most likely was due to episodes of crustal warping involving both the continental masses as well as the oceanic crust. By the end of Cambrian time, more than 75% of the surface of Laurentia was inundated by a shallow sea, creating an environment not unlike that over the present continental shelves. As the Cambrian Period came to a close, the sea withdrew from the surface of Laurentia resulting in the complete emergence of the continent and subsequent formation of a break in the sedimentary record. Apparently no uplift of Laurentia accompanied the emergence of the continent because when the seas returned to the continent in the Ordovician, the Ordovician sediments accumulated on the surface of Cambrian sediments with very little in the way of a physical break. For this reason, it is often difficult without the presence of fossils to locate the Cambrian-Ordovician boundary in North America. This is in sharp contrast to the scenario in Europe where the Cambrian sediments were intruded by volcanics, were highly deformed, and reduced by erosion before they were covered by Ordovician sediments.

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The Cambrian Rocks of the Cordilleran Basin: The Cambrian rocks that formed within the Cordilleran Basin are exposed today from the Canadian Rockies to Mexico **(Figure 7)**. Within the Canadian Rockies, the Cambrian is most spectacularly exposed where the entire Cambrian section has been uplifted along giant thrust sheets. Throughout the Cordilleran region, the Lower Cambrian consists largely of thousands of feet of quartzite with minor interbedded shales. We will shortly see that a comparable though much thinner section of sediments accumulated in the Appalachian Basin. There is no doubt that the erosion of the pre-Cambrian rocks exposed throughout the low-lying cratonic interior generated enormous volumes of quartz sand that was transported to what apparently were relatively shallow basins. The fact that by Middle Cambrian time, deposition is dominated by carbonates indicated that little if any clastic sediments were being supplied from either the interior craton or the offshore borderland. The extensive limestones ($CaCO_3$) also indicate that the climate was warm; the result of the continent

being located astraddle the equator. Within the basin, carbonate sedimentation continued through the Upper Cambrian where limestones achieve thicknesses of 3000 to 4000 feet.

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The Dolomite "Problem": Many of the Cambrian carbonate rocks, and those of the Ordovician, Silurian, and Devonian strata to follow, are actually **dolomites**, a carbonate rock made of the mineral dolomite ($CaMg(CO_3)_2$ rather than calcite ($CaCO_3$). Although magnesium is three times more concentrated in seawater than calcium (10% versus 3%), the fact that calcium is less soluble than magnesium means that it more readily precipitates from solution. Calcite can be of either a ***chemical*** or ***bio-chemical*** origin. Because the solubility of calcite is temperature controlled, calcite precipitates in warm water and dissolves in cold. This explains why calcite is actively being precipitated at shallow-water sites such as the Bahamas and the Florida Keys while at depths in excess of about 15,000 feet it dissolves. Bio-chemical calcite is precipitated by organisms in the form of external shells or skeletons. Most carbonate rocks originate from bio-chemically precipitated calcite.

Although dolomite is a common mineral formed by the evaporation of seawater and can, therefore, precipitate directly from seawater, evidence indicates that most dolomites do not form by direct precipitation. In addition, there are no known organisms that secrete dolomitic shells or skeletons. All of the evidence is that dolomite forms as the result of the recrystallization, or ***dolomitization*** of existing calcite by the substitution of magnesium for calcium in the calcite lattice:

$$2CaCO3 + Mg^{2+} \rightarrow CaMg(CO_3)_2 + Ca^{2+}.$$

Experimentally, it appears that the concentration of magnesium must be 8 to 10 times greater than calcium in order for dolomitization to proceed. One mechanism suggested for dolomitization to occur is to percolate high-salinity brines through limestone under highly evaporative conditions such as those that exist in modern sabkha environments along the southern shores of the Persian Gulf. Another possibility is the repeated mixing of fresh and salt water in the pores of limestones causing cyclic changes in salinity that appear to affect the relative solubilities of magnesium and calcium, favoring the formation of dolomite. With all the work that has been done on the topic of dolomitization, the process is still not well understood.

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Cambrian Rocks of the Cratonic Interior: With the beginning of Upper Cambrian time, the seas began to spread inland from the basins onto the craton. It took until Upper Cambrian time before the seas advanced across the low-lying craton interior. As the seas advanced toward the Trans-Continental Arch, wave action eroded the quartz-rich regolith and laid down the layer of sand that forms the basal Cambrian sandstones within the continental interior. As the warm waters encroached on the low-lying areas of the Trans-Continental Arch, carbonate deposition began. It is interesting to note that although only Upper Cambrian rocks are exposed in the cratonic interior; the sequence of lithologies with quartzites at the bottom overlain by carbonates being exactly the same as that found in the flanking basins (**Figure 8**). The only real difference is that the individual strata are much thinner on the craton. The type locality for the Upper Cambrian.are exposures of these rocks in the vicinity of St. Croix Falls in Minnesota and Wisconsin.

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Cambrian Rocks of The Appalachian Basin: The sequence of Cambrian rocks within the Appalachian Basin are similar to those seen in the Cordilleran Basin with the Lower Cambrian being dominated by sandstones and the Middle and Upper Cambrian by carbonates **(Figure 9)**. During Cambrian and into Middle Ordovician time, the east coast of Laurentia was a classic passive continental margin with an associated geocline. During Lower Cambrian time, clean sands derived from the cratonic interior were deposited on the upper surface of the geocline (the continental shelf) while the finer sediiments were transported beyond the edge of the shelf and deposited in the abyssal depths. Throughout the middle and southern Appalachians (from Pennsylvania south), the basal Cambrian quartzites range up to 4000 feet thick and are responsible for many of the ridges in the eastern portion of the Valley and Ridge Province. These sands are now exposed in the vicinity of Harpers Ferry, West Virginia where they are identified as the **Weverton** and **Antietam** quartzites. As the cratonic interior ceased being a source of sediments, deposition on the geocline became dominated by carbonates as a carbonate platform built seaward (refer to Figure 6). A good explanation for the accumulation of such thick carbonates is that as the material accumulated on the continental shelf, the shelf slowly sank under the weight of the sediment combined with the tensional forces that caused continued displacement along the underlying normal faults, resulting in the water depth staying within the range required to create additional sediment. Today, these carbonates can be seen in the **Waynesboro, Elbrook**, and **Conococheaque** formations. Throughout much of the Appalachian region, the carbonate rocks are sparingly fossiliferous and are therefore difficult at times to distinguish from the overlying Ordovician carbonates. This is especially true where limestones have been dolomitized; the process of dolomitization tends to erase any fossil impressions that may have existed in the limestone.

Cambrian Rocks within the Ouachita Basin: To the south in the vicinity of the Ozarks, the Upper Cambrian formations lie directly on pre-Cambrian rocks that represented the exposed land surface onto which the waves of the Upper Cambrian seas lapped. The same sequence of basal quartzites followed by carbonates also prevails within the Ouachita Basin **(Figure 10)**.

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Cambrian Life:

Introduction: Textbooks often refer to the "Cambrian Explosion of Life", although the explosion did not come at the dawn of the Cambrian. Although very simple life had existed in the seas for more than three billion years, with the **Ediacara fauna** clearly indicating that complex forms had evolved by the late pre-Cambrian, fossils in the lowermost portion of the Lower Cambrian are sparse. You will remember that Sedgwick's Cambrian rocks were in general unfossiliferous, although some of the scarcity could be attributed to deformation. It wasn't until the middle of the Lower Cambrian that abundant fossils began to appear. The first of these was the **Tommotian Fauna** that were first discovered in Siberia. The fauna includes a number of skeletal remains that cannot be assigned to any living phylum nor can they be shown to have any relationship with any post-Cambrian fossils. The Tommotian Fauna include the oldest known sponges, the predecessors to the modern-day molluscs, and brachiopods. The finding of what have been identified as teeth would also indicate the presence of predators in the Early Cambrian seas, possibly explaining why skeletons appeared. The Tommotian Fauna did not survive the end of Lower Cambrian time and were replaced with a variety of skeletonized animals that were not only much larger than any of the Tommotian Fauna but also belonged to phyla that have survived to the present.

The first unicellular life-forms that have been identified with confidence as animals that were capable of building shells or some type of structure that allowed fossilization were the **foraminifers** and **rediolarians.** Foraminifers are planktonic forms that formed shells by adding chambers in rows, coils, or spirals. In some cases, the shells were constructed of silt-sized particles while others were capable of secreting calcium carbonate. The shell was equipped with holes through which tentacles of protoplasm extended for feeding. Formainifers range from the Cambrian to the present. In the modern seas, remains rain down from the oceans surface continuously where they accumulate on the ocean bottom as a material called **globigerina ooze** because of the prevalence of the species *Globigerina*.

Radiolarians are also single-celled planktonic organisms that have also been members of the plankton since the Cambrian, although they did not become abundant until Mesozoic time. Most radiolarians form shells from opaline silica. In some areas of modern oceans, remains of radiolaria accumulate to form a **siliceous ooze**.

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Chief among the new arrivals at the close of Lower Cambrian time were the **trilobites**. Trilobites were **arthropods** with segmented, highly calcified shells that allowed them to be preserved in large numbers **(Figure 11)**. Lacking mouth parts, most trilobites were sediment feeders although some of the very smallest trilobites were actually planktonic forms that were suspension feeders. Once they appeared, trilobites quickly diversified, eventually making up 60 % of the Cambrian fauna. Although most were small, ranging between 1 to 4 inches in length, the giant of the Cambrian sea was *Paradoxides harlani* who was about 18 inches long and may have weighed 10 pounds. More than 600 species of trilobites are known from the Cambrian. Trilobites suffered several episodes of mass extinction during the Cambrian, each of which was followed by a radiation of new forms that quickly restored the trilobite community to a level of high diversity. The fact that each extinction took place during the deposition of a sedimentary layer only a few centimeters thick indicates that extinction took place over only a few thousand years. The new trilobite species are normally found in overlaying layers that are a meter or so in thickness, indicating that the period of radiative adaption following the extinction was not as fast as the extinction itself. As to what caused the extinctions; it has been noticed that in every case, the trilobites that went to extinction were warm-water forms and their replacements were cold-water forms. As a result, it is thought that the extinctions were due to periodic cooling of the seas that drove the trilobites that lived in the shallow, warm waters covering the continental shelf to extinction only to be replaced by species that lived in the deeper, cooler water just off the continental margin. Although trilobites would survive until the mass extinction at the close of Permian time, their dominance in the sea had ended by Ordovician time. Because of the heavy predation by the grazers during the Cambrian, stromatolites were probably all but lost in normal salinity waters.

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The second most important group of animals were the **brachiopods** that represented about 30 % of the Cambrian fauna. Brachiopods are bi-valved animals where the two shells differ in size and shape while each shell exhibits bi-lateral symmetry (**Figure 12**). Although very abundant during the Lower and Middle Cambrian time, they were relatively small with phosphatic shells. During the Upper Cambrian, forms with calcareous shells began to dominate the brachiopod community, a prelude to their dominance in the Ordovician seas to come. The two shells are joined along a hinge line through which extends a long fleshy stalk called the pedicle that allowed the animal to attach itself to hard surfaces. Some brachiopods simply rested on the sea floor without any attachment. Perhaps the most conspicuous soft organ of the brachiopod is the lophophore that consisted of two coiled tentacles that served to circulate water within the shell that, in turn, moved food particles toward the mouth. These currents also served to distribute oxygen and remove carbon dioxide. A few species of only three families of brachiopods still exist in modern oceans. One specific modern brachiopod, *Lingula*, is nearly indistinguishable from its Cambrian counterpart. Because Lingula has remained unchanged for 500 million years, it is often referred to as a "living fossil".

Although true corals and other reef-builders had not ret evolved, the niche they would eventually occupy was held by the ***Archeocyathinas***, animals that formed cone-shaped skeletons of calcite that consisted of two sieve-like walls separated by spacers (**Figure 13**). The name archaeocyatha means "ancient cups". Some authorities believe that they were primitive sponges while others feel that they are totally different structurally from modern sponges. In any case, they were, in fact, the earliest abundant reef-builders and as such were quite successful at establishing "reefs" worldwide in shallow, tropical seas. In Australia, archaeocyathid reefs have been found that were more than 150 feet thick and extending for over 125 miles. Although quite abundant during the early Cambrian, the *archeocyathids* went to extinction in the Middle Cambrian, eventually to be replaced with sponges and true corals.

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A fourth phylum represented in the Cambrian include the **molluscs** that, today, include clams, snails, and octupi. Many of the Tommotian forms were probable primitive molluscs. Although by the middle of Early Cambrian time gastropods (snails) and pelecypods (clams) had both appeared, their numbers remained very low until the Ordovician. Gastropods first appeared in the Lower Cambrian and by Ordovician time had become common place. Pelecypods, on the otherhand, did not become diversified until the Mesozoic. The oldest representative of the cephalopods were small conical forms discovered in the Early and Middle Cambrian of Europe. The group continued to diversify throughout the Cambrian and into the Silurian after which their numbers diminished. Today, only a single genus, *Nautilus*, survives.

Another phylum represented in the Cambrian sea were the **echinoderms**. All living echinoderms are built on a five-fold radial symmetry and include starfish, sea urchins, sand dollars, crinoids, and sea cucumbers. The oldest animal identified as an echinoderm is a member of the Ediacara fauna that is considered to be the ancestor to star fish and sea urchins. Stalked echinoderms first appeared in the Middle Cambrian but do not become abundant until Ordovician and Silurian time. Compared to modern examples, Cambrian echinoderms were at best bizarre and included a number of shapes and structures that were never seen again beyond the Cambrian.

Representatives of the **Phylum Porifera**, were present in the Cambrian seas; in fact, all but one modern class of Porifera are found in the Cambrian fossil record. Some fossil sponges have been used as Cambrian index fossils. Although a few modern sponges live in fresh water, by far, most sponges have been predominantly marine animals.

Coelenterates in the form of fossil jellyfish impressions are found in the Late Cambrian but remains poorly represented in the Cambrian fossil record.

In summary, most of the Cambrian animals were extremely primitive and did not survive into the Ordovician. Many appear to be "experiments" of evolution that were eventually replaced or displaced by later stages of change. The Cambrian ecological communities were simple, the most complex probably being the stromatolite-cyanobacterial-archeocyathid "reefs". Trilobites roamed the sea floor sifting food from the sediment while the primitive molluscs were in rocky areas where they could attach themselves to the rock surface. There were none of the burrowers we find today nor were there widespread development of reef-building coral or sponges. Most noticeably amongst the Cambrian fossils was the absence of large predators.

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However, the life in the Cambrian sea consisted of far more than hard-shelled trilobites, brachiopods and molluscs. The **Burgess Shale Fauna** demonstrate that life on the ocean bottom consisted of a diverse assemblage of soft-bodied animals whose presence would have gone unnoticed had it not been for a very special site where their remains were encapsulated in anoxic muds. Of all the Cambrian fossil finds, the Burgess Shale Fauna is probably the most well known. The fossils were discovered by C.D. Walcott in 1910 when, as the story goes, a pack mule turned over a slab of black, Middle Cambrian shale along a mountain trail on the slopes of Mt. Wapta in British Columbia, Canada. The fossils are delicate films of carbon on the bedding planes of the shale, the residue of the original soft body. Walcott eventually described 70 genera and 130 species of animals from the site amongst which were sponges, jellyfish and worms, all in excellent state of preservation, many having no known affinities. Recent work has greatly increased the number of known species. The finding of soft-bodied animals such as those of the

Burgess Shale and the Ediacara Fauna points out the incompleteness of the fossil record. Had it not been for the fact that these animals fell into a depression on the ocean floor in a place covered with extremely fine-grained mud, rich in decaying organic matter to deplete any available oxygen and to generate the hydrogen sulfide necessary to discourage predators, neither assemblage would have been preserved and we would have been entirely unaware of the diversity of Cambrian life. For additionaal reading we would recommend Steven J. Gould's **Wonderful Life**.

Although there are distinct comparisons between the soft-bodied remains of the pre-Cambrian and Cambrian, one characteristic that distinguishes the Cambrian from the pre-Cambrian should be emphasized, namely the sudden appearance of armor. There is little doubt that armor was being developed during the interval between the pre-Cambrian and Cambrian, where no record of events exists. The explanation for the development of armor may lie in the fact that nearly all of the pre-Cambrian animals were either herbivorous or scavengers feeding in an ocean where both space and food were plentiful. At some point in time, at least locally, crowding began and the quest for available food supplies became more difficult. It is thought that predation began at this point and it was the predation that caused animals to develop armor for protection.

One last comment about the appearance of shells and skeletons in the Cambrian. The shells and skeletons of most Cambrian animals were made either of chitin, and organic material similar to our fingernails, or of calcium phosphate, the material of which all internal skeletons, with the exception of sharks, and teeth are made. It is known that modern organisms that secrete calcite shells cannot do so unless the oxygen content of the water is at least about 15% of the present atmospheric concentration. The lack of shells made of calcium carbonate in the Early

Cambrian is interpreted to mean that the oxygen content of the water was still quite low. It would, in fact, not be until the Ordovician that atmospheric oxygen concentrations reached modern levels.

Figures