The Cambrian Explosion

The waves of evolutionary novelty that appeared in the seas during the Early Cambrian have few parallels in the history of life. Many groups of fossils appeared quite suddenly in the fossil record, thanks to their evolution of skeletons, sometimes at comparatively large body size. Given the Ediacaran legacy of metazoans and relatively high oxygen levels, however, it is most likely that the Cambrian explosion simply records the invention and exploitation of skeletons for many good reasons associated with locomotion (walking, digging and swimming), size, support, defense, and other functions, made even more complex by the fact that animals interact ecologically with other species as they evolve.

A skeleton may support soft tissue, from the inside or from the outside, and simply allow an animal to grow larger. Therefore, sponges could grow larger and higher after they evolved supporting structures of protein or mineral (Fig. 4.10), and they could reach further into the water to take advantage of currents and to gather food. Large size also protects animals from predators large and small. A large animal is less likely to be totally consumed, and in an animal like a sponge that has little organization, damage can eventually be repaired if even a part of the animal survives attack. As skeletons evolved, even for other reasons, they helped animals to survive because of their defensive value.

Early echinoderms had lightly plated skeletons just under their surfaces, and the most reasonable explanation of their first function is support, accompanied or followed by defense.

For other animals, skeletons provided a box that gave organs a controlled environment in which to work. Filters were less exposed to currents, so perhaps they would not clog so easily from silt and mud (Fig. 2.1). A boxlike skeleton would also have given an advantage against predation. Molluscs and brachiopods may have evolved skeletons for these reasons.

In yet other animals, hard parts may have performed more specific functions. We have already seen that worms tend to burrow head-first in sediment. But after penetrating the sediment they squirm through it (Fig. 4.14). A worm that evolved a hardened head covering could use a different and perhaps better technique, shoveling sediment aside like a bulldozer. Richard Fortey suggested that the large head shield of trilobites was evolved and used in this fashion.

Plants invaded the land

It is difficult to imagine how the landscape looked in Precambrian and early Paleozoic times, before terrestrial plants became widespread. Moist terrestrial environments must have been populated by algae, cyanobacteria, and fungi, but forests and meadows were absent, and there must have been large areas of barren rock and soil with little or no humus (decayed organic matter). Thus one of the most important events revealed by the fossil record of Silurian and Devonian life was the invasion of terrestrial habitats by plants.

The basic requirements for the terrestrial existence of large multicellular plants are quite different from those for plants that live in water. Unlike water, air is much less dense than the tissues of a plant, so if a plant is to stand upright in air, it must have a rigid stalk or stem. A tall plant must also be anchored by a root system or a buried horizontal stem, either of which serves the further indispensable function of collecting water and nutrients from the soil.

The first upright plants to make their way onto land lacked the roots, leaves, and efficient means of transporting nutrients that made their descendants so successful. Essentially, these plants were simple rigid stems. Fragments of such early plants have been found in Silurian rocks. Silurian plants seem to have been pioneers that lived near bodies of water, and they may actually have been semiaquatic marsh dwellers rather than fully terrestrial plants.

Animals moved ashore

Fragmentary remains of simple terrestrial animals are known from Late Silurian rocks, but few animals occupied terrestrial habitats before Devonian time. It is not surprising that animals colonized terrestrial habitats in large numbers only after vascular plants were well established because a food web must be built upward from the base; herbivores require plant food.

Assemblages of early terrestrial invertebrate animals are well preserved in the Lower Devonian Rhynie Chert of Scotland, in the Middle Devonian Gilboa Formation of northern New York State, and in the Lower Devonian Battery Point Formation of Quebec. The invertebrate fossils of these formations fall into two ecological categories. First, there are millipedes and flightless insects that fed on organic detritus. Second, there are scorpions, centipedes, and spiders—all of which were carnivores. Conspicuous in their absence are herbivores, such as leaf-eating or juice-sucking insects. Thus we can see that dead plant material, not living plant tissue, provided the nutritional foundation for the earliest terrestrial animal communities.

Not until Devonian time did vertebrate animals make their transition onto land. Anatomical evidence indicates that the four-legged vertebrates most closely related to fishes are the **amphibians**—frogs, toads, salamanders, and their relatives (see p. 75). In fact, amphibians lay their eggs in water and spend their juvenile period there. Then most kinds of amphibians metamorphose into air-breathing, land-dwelling adults. Living amphibians are small animals that differ substantially from the large fossil amphibians found in Paleozoic rocks.

As we have seen, some early fishes possessed a lung long before amphibians evolved. They put this organ to use to breathe air occasionally, perhaps when a stream or lake dried up, but it was available for full-time exploitation by animals that moved onto land. This is yet another example of the "opportunism" of evolution. Unlike the gill supports that evolved into jaws earlier in vertebrate evolution, the lung required very little evolutionary modification to open up an entirely new mode of life.

For decades paleontologists recognized that certain Devonian lobe-finned fishes possessed traits resembling those of amphibians: unusual, complex tooth structures, for example (Figure 14-18). Nonetheless, there were no known fossils of forms representing early stages of the transition to life on land. Then, in 2004, a group of paleontologists discovered the fossil remains of a creature that was actually intermediate between lobe-finned fishes and amphibians in its overall body form. The scientists had been searching for the remains of such a transitional animal in Late Devonian meandering river deposits on Ellesmere Island in northern Canada—and, quite remarkably, they found them! This creature, to which they gave the generic name *Tiktaalik*, had fishlike fins and scales as well as a fishlike lower jaw. But it also had many amphibian-like traits: well-developed toe bones in its front fins, for example, and flexible wrist bones (Figure 14-19). It did not have toes, however, and probably could not have walked effectively on land. Nonetheless, its limb structures would have permitted it to prop up its body and thus to stand in shallow water with the upper part of its head above the surface. In this position, its flat crocodile-like head, with eyes on the upper surface, would have permitted it to view its surroundings. Also useful for this activity would have been its flexible neck: its shoulder bones, unlike those of fishes, were not locked into its skull. In fact, *Tiktaalik* is the earliest animal known to have possessed a flexible neck. Nostril-like apertures on top of its skull would have permitted it to breathe with its eyes just above the surface of the water. Thus, like the lobe-finned fishes from which it evolved, it apparently had lungs like those of amphibians for respiration in air as well as gills like those of fishes for respiration in water. In morphological terms, at least, *Tiktaalik* is a "missing link," or rather, it is a link that is no longer missing from the fossil record. It documents the pathway by which vertebrates invaded land.

Trees grew in swamps

Plants gave the Carboniferous Period its name, and in no other geologic interval are plant fossils more conspicuous. Wetlands were far more extensive than they are today. Soft coal (see Figure 2-24) from this period typically contains recognizable stems and leaves. Coal deposits developed chiefly in lowland swamps, where fallen tree trunks accumulated in large numbers. It takes several cubic meters of wood to make one cubic meter of coal, and most coal-swamp trees were not even woody, but had pith-filled trunks surrounded by relatively soft tissue. Thus the vast coal beds of Late Carboniferous age must represent an enormous number of original plants. Another factor contributing to the formation of these large coal deposits was the absence of termites, which had not yet evolved. Today termites consume much of the dead wood in warm regions of the world.