

The Scientific Controversy Over the Cambrian Explosion

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Darwin called his theory "descent with modification." The phrase reflected Darwin's belief that all organisms are modified descendants of a common ancestor that lived in the distant past. The only illustration in Darwin's book *The Origin of Species* shows the "tree of life" pattern one would expect to find in the fossil record if his theory were true. The common ancestor would come first, as a single species at the base of the tree. Minor differences among individuals would appear first, and these differences would eventually increase until one species had become two or more. Differences among species would then grow until some species became so different they would be classed as separate genera; genera would diverge to become separate families, families would diverge to become separate orders, and so on. Eventually differences would become so great that where there had originally been one major division or "phylum," there would now be two. Today there are several dozen animal phyla. The major ones include the nematodes (roundworms), annelids (earthworms and leeches), mollusks (clams and snails), arthropods (lobsters and insects), echinoderms (starfish and sea urchins) and chordates (fishes and mammals).

If Darwin's theory were true, then a long accumulation of minor differences must have preceded the major differences we now see among the animal phyla. As Darwin himself wrote, before the different phyla appeared there must have been "vast periods" during which "the world swarmed with living creatures" (Excerpt A, p. 83). In the fossil record, however, most of the major animal phyla appear fully formed at the beginning of the geological period known as the Cambrian, with no fossil evidence that they branched off from a common ancestor. Darwin was aware of this, acknowledging in *The Origin of Species* that "several of the main divisions of the animal kingdom suddenly appear in the lowest known fossiliferous rocks." He called this a "serious" problem which "at present must remain inexplicable; and may be truly urged as a valid argument against the views here entertained" (Excerpt A, pp. 82, 85).

(A) Charles Darwin, *The Origin of Species*, Sixth Edition (New York: D, Appleton, 1890), Chapter X.

Darwin remained convinced that his theory was true, however. He speculated that ancestors of the different phyla had not been found because the fossil record was imperfect. If, as it seemed, rocks before the Cambrian had been deformed by heat and pressure, or eroded away, then fossil ancestors might never be found. He acknowledged, though, that he really had "no satisfactory answer" to the problem (Excerpt A, p. 84).

Subsequent fossil collecting, however, has yielded many fossils of organisms that lived before the Cambrian. Fossil beds in Canada (the Burgess shale) and China (the Chengjiang fauna) have also yielded much richer collections of Cambrian fossils than were available to Darwin and his contemporaries. Reviewing the evidence in 1991, Berkeley paleontologist James Valentine and his colleagues noted: "During the past 40 years, rocks older than what had now been considered to be the base of the Cambrian have indeed yielded fossils that now permit much more detailed assessments of early metazoan [i.e., multicellular animal] evolution" (Excerpt B, p. 280). Valentine and his colleagues found that "it has not proven possible to trace transitions" between the phyla, and the evidence points to a Cambrian "explosion" that "was even more abrupt and extensive than previously envisioned" (Excerpt B, pp. 281, 294). The authors concluded that "the metazoan explosion is real; it is too big to be masked by flaws in the fossil record" (Excerpt B, p. 318).

Some scientists have suggested that fossil ancestors for the animal phyla are missing not because the rocks have been deformed or eroded, but because animals before the Cambrian lacked hard parts, and thus never fossilized in the first place. According to this hypothesis, the Cambrian explosion merely represents the sudden appearance of shells and skeletons in animal that had evolved long before. The fossil evidence, however, does not support this hypothesis. First, as Harvard paleontologist Stephen Jay Gould and Cambridge paleontologist Simon Conway Morris have pointed out, the majority of Cambrian explosion fossils are soft-bodied (Stephen Jay Gould, *Wonderful Life* [New York: Norton, 1989]; Simon Conway Morris, *The Crucible of Creation* [Oxford: Oxford University Press, 1998]). Second, the fossil evidence points to the appearance of many new body plans in the Cambrian, not just the acquisition of hard parts by existing phyla. According to Berkeley paleontologist James Valentine, the Cambrian explosion "involved far more major animal groups than just the durably skeletonized living phyla." It was "new kinds of organisms, and not old lineages newly donning skeleton-armor, that appeared" (Excerpt C, p. 533). Valentine concluded: "the record that we have is not very supportive of models that posit a long period of the evolution of metazoan phyla" before the Cambrian (Excerpt C, p. 547).

(B) James W. Valentine et al., "The Biological Explosion at the Precambrian-Cambrian Boundary," *Evolutionary Biology* 25 (1991): 279-356.

(C) James W. Valentine, "The Macroevolution of Phyla," pp. 525-553 in Jere H. Lipps & Philip W. Signor (editors), *Origin and Early Evolution of the Metazoa* (New York: Plenum Press, 1992).

Recent studies have also emphasized the abruptness of the Cambrian explosion. After reviewing the geological dating of rocks near the Precambrian-Cambrian boundary, Bowring and his colleagues reported in 1993 that the Cambrian explosion of animal phyla was "unlikely to have exceeded 10 million years" (Excerpt D, p. 1297). As Valentine, Jablonski and Erwin pointed out in 1999, this is "less than 2% of the time from the base of the Cambrian to the present day" (Excerpt E, p. 852). Since the time from the Cambrian to the present is only about one seventh of the time since the origin of life on Earth, this means the Cambrian explosion was geologically very abrupt, indeed.

According to Valentine, Jablonski and Erwin, extensive new data "do not muffle the explosion, which continues to stand out as a major feature in early metazoan history" (Excerpt E, p. 851).

(D) Samuel A. Bowring et al., "Calibrating Rates of Early Cambrian Evolution," *Science* 261 (1993): 1293-1298.

(E) James W. Valentine, David Jablonski & Douglas H. Erwin, "Fossils, molecules and embryos: new perspectives on the Cambrian explosion," *Development* 126 (1999): 851-859.

What significance does the Cambrian explosion have for evaluating Darwin's theory that all animals are modified descendants of a common ancestor? As we have seen, Darwin himself considered it a serious problem (Excerpt A). Although Darwin's theory predicts that animal evolution should proceed from the "bottom up," with the largest differences emerging last, James Valentine and his colleagues wrote in 1991 that the pattern of the Cambrian explosion "creates the impression that metazoan evolution has by and large proceeded from the 'top down' " (Excerpt B, p. 294). Harry Whittington, an expert on the Cambrian fossils from the Burgess shale, wrote in 1985: "It may well be that metazoan animals arose independently in different areas. I look sceptically upon diagrams that show the branching diversity of animal life through time, and come down at the base to a single kind of animal" (Excerpt F, p. 131). Evolutionary biologist Jeffrey Levinton, though convinced of the common ancestry of animals, acknowledged in 1992 that the Cambrian explosion -- "life's big bang," as he called it -- remains "evolutionary biology's deepest paradox" (Excerpt G, p. 84). Although "the body plans that evolved in the Cambrian by and large served as the blueprints for those seen today," Levinton saw "no reason to think that the rate of evolution was ever slower or faster than it is now. Yet that conclusion still leaves unanswered the paradox posed by the Cambrian explosion and the mysterious persistence of those ancient body plans" (Excerpt G, pp. 84, 90). In 1999, University of California biologist Malcolm Gordon wrote: "Recent research results make it seem improbable that there could have been single basal forms for many of the highest categories of evolutionary differentiation (kingdoms, phyla, classes)" (Excerpt H, p. 331). Gordon concluded: "The traditional version of the theory of common descent apparently does not apply to kingdoms [i.e., plants, animals, fungi, bacteria] as presently recognized. It probably does not apply to many, if not all, phyla, and possibly also not to many classes within the phyla" (Excerpt H, p. 335).

(F) Harry B. Whittington, *The Burgess Shale* (New Haven, CT: Yale University Press, 1985).

(G) Jeffrey S. Levinton, "The Big Bang of Animal Evolution," *Scientific American* 267 (November, 1992): 84-91.

(H) Malcolm S. Gordon, "The Concept of Monophyly: A Speculative Essay," *Biology and Philosophy* 14 (1999): 331-348.

So the Cambrian explosion is real, and for some biologists it is at least paradoxical and mysterious from the perspective of Darwin's theory. For other biologists, it actually constitutes evidence against Darwin's hypothesis that all animals evolved from a single common ancestor. Yet some scientists continue to defend Darwin's theory by arguing that the Cambrian explosion is perfectly consistent with it. One of these is Alan Gishlick of the National Center for Science Education, a group that opposes any criticisms of Darwinian evolution in biology classrooms. In written comments submitted to the Texas State Board of Education at their textbook-adoption hearing July 9, 2003, Gishlick criticized a book by biologist Jonathan Wells, *Icons of Evolution* (Washington, DC: Regnery Publishing, 2000). In his comments, Gishlick wrote that the Cambrian explosion actually occurred "over a 15-20 million year period" and that "the 'top-down' appearance of body plans is, contrary to Wells, compatible with the predictions of evolution" (Excerpt I, p. 15). Gishlick's claim about the duration of the Cambrian explosion is at odds, however, with the published views of James Valentine and his colleagues (Excerpt B, p. 279; Excerpt E, pp. 851-853) and Samuel Bowring and his colleagues (Excerpt D). Furthermore, if by "evolution" Gishlick means "Darwinian evolution," then his claim that a "top-down" pattern is consistent with evolution conflicts with the published views of Harry Whittington (Excerpt F) and Malcolm Gordon (Excerpt H). Clearly, Gishlick's disagreements are not just with Wells.

Gishlick also argued that the major differences between animal phyla are not so major after all. He wrote: "The most primitive living chordate *Amphioxus* is very similar to the Cambrian fossil chordate *Pikia* [sic -- actually *Pikaia*]. Both are basically worms with a stiff rod (the notochord) in them. The amount of change between a worm and a worm with a stiff rod is relatively small, but the presence of a notochord is a major 'body-plan' distinction of a chordate. Further, it is just another small step from a worm with a stiff rod to a worm with a stiff rod and a head (e.g., *Haikouella*; Chen et al., 1999) or a worm with a segmented stiff rod (vertebrae), a head and fin folds (e.g., *Haikouichthyes*; Shu et al., 1999). Finally add a fusiform body, fin differentiation, and scales; the result is something resembling a 'fish' " (Excerpt I, p. 15). Yet Gishlick's fanciful scenario ignores most of what biologists know about worms and chordates. There are several fundamental anatomical differences between worms and chordates, which can be found in any good biology textbook; possession of a notochord is only one of them. If chordates were simply worms with a stiff rod, they might not even be classed as a separate phylum. Furthermore, from an evolutionary perspective worms and chordates are not closely related. In standard evolutionary trees (such as the ones reproduced here from the Sixth Edition of Campbell & Reece's *Biology*), chordates (green arrow at top of pp. 636 & 640 in Excerpt J) are considered closer to echinoderms (starfish and sea urchins) than they are to any of the worm phyla (two of which are indicated by the pink and orange arrows at the top of the same diagrams in Excerpt J). Gishlick cites two scientific articles to support his argument: The first points out that the most primitive chordates might have rudimentary brains and thus be closer to chordates with heads than previously thought, but it doesn't address the problem of how the first chordate originated (Excerpt K, p. 522). The second article actually contradicts Gishlick's suggestion that once a worm possesses a stiff rod it could easily evolve into a vertebrate. According to Shu and his colleagues, "the derivation of the first vertebrates from the cephalochordates [i.e., more

primitive chordates] must have entailed a major reorganization of the body" (Excerpt L, p. 46). Once again, Gishlick's disagreements are not just with Wells.

(I) Alan Gishlick, "Comments on the Discovery Institute's 'Analysis of the Treatment of Evolution in Biology Textbooks'," submitted to the Texas Education Agency in connection with their July 9, 2003 public hearing on textbook adoption.

(J) Neil A. Campbell & Jane B. Reece, *Biology*, Sixth Edition (San Francisco: Benjamin Cummings, 2002).

(K) J.-Y. Chen, Di-ying Huang & Chia-Wei Li, "An early Cambrian craniate-like chordate," *Nature* 402 (1999): 518-522.

(L) D.-G. Shu et al., "Lower Cambrian vertebrates from South China," *Nature* 402 (1999): 42-46.

Since the abruptness and extensiveness of the Cambrian explosion are so well documented, there is no excuse for a biology textbook to deal with the animal fossil record without even mentioning it. Furthermore, since some biologists maintain that the Cambrian explosion presents a challenge -- or at least a "paradox" -- for one of the fundamental tenets of Darwin's theory, any biology textbook that doesn't discuss that challenge fails to provide students with the resources to think critically about the most widely taught scientific explanation for evolution.