Creatures of Cambrian May Have Lived On

By JOHN NOBLE WILFORD

Ever since their discovery in 1909, the spectacular Burgess Shale outcrops in the Canadian Rockies have presented scientists with a cornucopia of evidence for the “explosion” of complex, multicellular life beginning some 550 million years ago.

The fossils, all new to science, were at first seen as little more than amazing curiosities from a time when life, except for bacteria and algae, was confined to the sea — and what is now Canada was just south of the Equator. In the last half century, however, paleontologists recognized that the Burgess Shale exemplified the radiation of diverse life forms unlike anything in earlier time. Here was evolution in action, organisms over time responding to changing fortunes through natural experimentation in new body forms and different ecological niches.

But the fossil record then goes dark: the Cambrian-period innovations in life appeared to have few clear descendants. Many scientists thought that the likely explanation for this mysterious disappearance was that a major extinction had wiped out much of the distinctive Cambrian life. It seemed that the complex organisms emerging in the Cambrian had come to an abrupt demise, disappearing with few traces in the later fossil record.

Not everyone was convinced, however, and now a trove of 480-million-year-old fossils in Morocco appears to strike a blow to the idea of a major extinction. The international team of scientists who discovered the 1,500 fossils said their find shows that the dark stretch in the fossil record more probably reflects an absence of preservation of fossils over the previous 25 million years.

The team reports in the current issue of the journal Nature that the large number of “exceptionally preserved” Moroccan species exhibits apparently strong links to Cambrian species known from fossil beds in China, Greenland and, most notably, the Burgess Shale. The scientists think this solves the mystery. The Moroccan fossils, they said, establish that Burgess Shale-type species “continued to have an important role in the diversity and ecological structure of deeper marine communities well after the Middle Cambrian.”

The Moroccan fossils include sponges, worms, trilobites and mollusks like clams, snails and relatives of the living nautilus. Another fossil was similar to today’s horseshoe crab, a biological throwback familiar to beachcombers. Now, the scientists said, its antiquity appears to be even greater — some 30 million years earlier than previously thought, possibly in the late Cambrian.

The discovery team’s principal scientist and lead author of the journal article was Peter Van Roy, a Belgian paleontologist who is a postdoctoral fellow at Yale University.
has worked in Moroccan fossil beds the last 10 years, but it was only last year on a field trip, financed by the National Geographic Society, that he and other scientists uncovered the riches of a site near the Atlas Mountains and the city of Zagora.

Scientists from Britain, France, Ireland, Morocco and the United States participated in the research and were co-authors of the team report. A local fossil collector, Mohammed Ou Said Ben Moulal, directed Dr. Van Roy to the rock outcrops he had scouted.

Soon it became clear, Dr. Van Roy said last week in an e-mail message from Morocco, that the team had “really discovered the whole gamut of these Burgess animals, the majority of which had never been found after the Middle Cambrian.”

A leading member of the team, Derek E. G. Briggs, director of the Peabody Museum of Natural History at Yale, cut his academic teeth studying the Burgess Shale. Dr. Briggs figured prominently in “Wonderful Life: The Burgess Shale and the Nature of History,” the 1989 book by Stephen Jay Gould about what the author called the “weird wonders” of the Cambrian period.

In the book, Dr. Gould, who died in 2002, pondered the mystery of the relatively sudden burst of new life designs in the Cambrian, followed by their apparent disappearance. “What turned it off so quickly?” he asked. A few pages before, quoting Charles Darwin, he seemed to despair of finding the fossils to answer the question.

“Darwin wrote,” Dr. Gould recalled, “that our imperfect fossil record is like a book preserving just a few pages, of these pages few lines, of the lines few words, and of those words few letters.”

Darwin’s metaphor pertained to the chances of preservation for bones and teeth. So referring to the predominance of soft-body anatomies of Cambrian life, Dr. Gould asked, “What hope can then be offered to the flesh and blood amidst the slings and arrows of such outrageous fortune?”

Dr. Briggs said in an interview that scientists for some time have suspected that “we were just not finding the right deposits and only seeing a small piece of the picture of what was going on in life back then.”

For that reason, Dr. Briggs said, he expected other scientists would be less surprised by the discovery than reassured. The fossil record for a long stretch after the Middle Cambrian may be spotty and minimal, but has not vanished. The Moroccan fossils not only reveal the continuation of many Cambrian life forms, he said, but show “the high potential that there are other places for finding these Cambrian-like organisms persisting in time.”

As a consequence, the discovery team wrote, the Moroccan sediments offer promising links between the Cambrian Explosion of multicellular life, exemplified in the Burgess Shale, and the early stages of what is known as the Great Ordovician Biodiversification Event, which is considered “one of the most dramatic episodes in the history of marine life.”

This led to the emergence of fish about 400 million years ago and the migration of four-limbed vertebrates from water onto land 360 million years ago. After the catastrophic mass extinction at the end of the Permian period, about 250 million years
ago, the dinosaurs came to the fore in a reptilian world, and after their extinction 65 million years ago, mammals came into their own, hominids evolving probably less than 8 million years ago, modern humans less than 200,000 years ago.

That any of these early Ordovician remains endured verges on the miraculous. Some with shells could be expected to fossilize, but most of these were soft-bodied creatures, prone to rapid decay. The Moroccan fossil beds, Dr. Briggs noted, were once the muddy bottom of an ocean. Storms stirred up the seabed, burying doomed creatures safe from scavengers and in recesses with little or no oxygen to promote decomposition. The sediment chemistry transformed iron and sulfide into pyrite, which coated and preserved the shapes of the animals, including their appendages, and mineralized internal tissue.

“The exquisite preservation of the soft anatomy,” Dr. Van Roy said, “allows more complete, accurate reconstructions of their genetic affinities and ecology than has hitherto been possible.”

Hard at work last week in the Moroccan fossil beds, Dr. Van Roy said, “I obviously intend to exploit this fantastic research opportunity to the fullest.”

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**SET IN STONE** Among the 1,500 fossils found near the Atlas Mountains in Morocco by an international team of scientists was that of an extinct member of the arthropod family, above and in the drawing below, from about 480 million years ago. Its closest living relatives include horseshoe crabs, spiders and scorpions. By Peter Van Roy

**OUT OF THE SEA** An essentially complete example of an eocrinoid, an extinct relative of the sea urchin. At right, a xiphosurid, the oldest horseshoe crab found so far. By Peter Van Roy
The New York Times, May 21, 2002

Stephen Jay Gould, 60, Is Dead; Enlivened Evolutionary Theory

By CAROL KAESUK YOON

Stephen Jay Gould, the evolutionary theorist at Harvard University whose research, lectures and prolific output of essays helped to reinvigorate the field of paleontology, died yesterday at his home in Manhattan. He was 60.

The cause was cancer, said his wife, Rhonda Roland Shearer.

One of the most influential evolutionary biologists of the 20th century and perhaps the best known since Charles Darwin, Dr. Gould touched off numerous debates, forcing scientists to rethink sometimes entrenched ideas about evolutionary patterns and processes.

One of his best known theories, developed with Niles Eldredge, argued that evolutionary change in the fossil record came in fits and starts rather than a steady process of slow change.

This theory, known as punctuated equilibrium, was part of Dr. Gould's work that brought a forsaken paleontological perspective to the evolutionary mainstream.

Dr. Gould achieved a fame unprecedented among modern evolutionary biologists. He was depicted in cartoon form on "The Simpsons," and renovations of his SoHo loft in Manhattan were featured in a glowing article in Architectural Digest.

Famed for both brilliance and arrogance, Dr. Gould was the object of admiration and jealousy, both revered and reviled by colleagues.

Outside of academia, Dr. Gould was almost universally adored by those familiar with his work. In his column in Natural History magazine, he wrote in a voice that combined a learned Harvard professor and a baseball-loving everyman. The Cal Ripken Jr. of essayists, he produced a meditation for each of 300 consecutive issues starting in 1974 and ending in 2001. Many were collected into best-selling books like "Bully for Brontosaurus."

Other popular books by Dr. Gould include "Wonderful Life," which examines the evolution of early life as recorded in the fossils of the Burgess Shale, and "The Mismeasure of Man," a rebuttal to what Dr. Gould described as pseudoscientific theories used to defend racist ideologies.

Dr. Gould was born on Sept. 10, 1941, in Queens, the son of Leonard Gould, a court stenographer, and Eleanor Gould, an artist and entrepreneur. Dr. Gould took his first steps toward a career in paleontology as a 5-year-old when he visited the American Museum of Natural History with his father.
"I dreamed of becoming a scientist, in general, and a paleontologist, in particular, ever since the Tyrannosaurus skeleton awed and scared me," he once wrote. In an upbringing filled with fossils and the Yankees, he attended P.S. 26 and Jamaica High School. He then enrolled at Antioch College in Ohio, where he received a bachelor's degree in geology in 1963.

In 1967, he received a doctorate in paleontology from Columbia University and went on to teach at Harvard, where he would spend the rest of his career. But it was in graduate school that Dr. Gould and a fellow graduate student, Dr. Eldredge, now a paleontologist at the American Museum of Natural History, began sowing the seeds for the most famous of the still-roiling debates that he is credited with helping to start.

Studying the fossil record, the two students could not find the gradual, continuous change in fossil forms that they were taught was the stuff of evolution. Instead they found sudden appearances of new fossil forms (sudden, that is, on the achingly slow geological time scale) followed by long periods in which these organisms changed little.

Evolutionary biologists had always ascribed such difficulties to the famous incompleteness of the fossil record. But in 1972, the two proposed the theory of punctuated equilibrium, a revolutionary suggestion that the sudden appearances and lack of change were, in fact, real. According to the theory, there are long periods of time, sometimes millions of years, during which species change little, if at all.

Intermittently, new species arise and there is rapid evolutionary change on a geological time scale (still interminably slow on human timescales) resulting in the sudden appearance of new forms in the fossil record. This creates punctuations of rapid change against a backdrop of steady equilibrium, hence the name.

Thirty years later, scientists are still arguing over how often the fossil record shows a punctuated pattern and how such a pattern might arise. Many credit punctuated equilibrium with promoting the flowering of the field of macroevolution, in which researchers study large-scale evolutionary changes, often in a geological time frame.

In 1977, Dr. Gould's book "Ontogeny and Phylogeny" drew biologists' attention to the long-ignored relationship between how organisms develop -- that is, how an adult gets built from the starting plans of an egg -- and how they evolve.

"Gould has given biologists a new way to see the organisms they study," wrote Dr. Stan Rachootin, an evolutionary biologist at Mount Holyoke College. Many credit the book with helping to inspire the new field of evo-devo, or the study of evolution and development.

Dr. Gould and Dr. Richard Lewontin, also at Harvard, soon elaborated on the importance of how organisms are built, or their architecture, in a famous paper about a feature of buildings known as a spandrel. Spandrels, the spaces above an arch, exist as a necessary outcome of building with arches. In the same way, they argued, some features of organisms exist simply as the result of how an organism develops or is built. Thus researchers, they warned, should refrain from assuming that every feature exists for some adaptive purpose.

In March, Harvard University Press published what Dr. Gould described as his magnum opus, "The Structure of Evolutionary Theory." The book, on which he toiled for
decades, lays out his vision for synthesizing Darwin's original ideas and his own major contributions to macroevolutionary theory.

"It is a heavyweight work," wrote Dr. Mark Ridley, an evolutionary biologist at University of Oxford in England. And despite sometimes "almost pathological logorrhea" at 1,433 pages, Dr. Ridley went on, "it is still a magnificent summary of a quarter-century of influential thinking and a major publishing event in evolutionary biology."

Dr. Gould was dogged by vociferous, often high-profile critics. Some argued that his theories, like punctuated equilibrium, were so malleable and difficult to pin down that they were essentially untestable.

After once proclaiming that Dr. Gould had brought paleontology back to the high table of evolutionary theory, Dr. John Maynard Smith, an evolutionary biologist at University of Sussex in England, wrote that other evolutionary biologists "tend to see him as a man whose ideas are so confused as to be hardly worth bothering with." Sometimes these criticisms descended into accusations that were as personal as intellectual. Punctuated equilibrium, for example, has been called "evolution by jerks."

Some who study smaller-scale evolution within species, called microevolutionists, reject Dr. Gould's arguments that there are unique features to large-scale evolution, or macroevolution. Instead, they say that macroevolution is nothing more than microevolution played out over long periods. Dr. Gould also had heated battles with sociobiologists, researchers using a particular method of studying animal behavior, and there are many there who reject his ideas as well.

Others criticized him for championing theories that challenge parts of the modern Darwinian framework, an act some see as aiding and abetting creationists. Yet Dr. Gould was a visible opponent of efforts to get evolution out of the classroom.

An entertaining writer credited with saving the dying art form of the scientific essay, Dr. Gould often pulled together unrelated ideas or things. (He began one essay by noting that Abraham Lincoln and Charles Darwin were born on the same day.) A champion of the underdog (except in his support of the Yankees), he favored theories and scientists that had been forgotten or whose reputations were in disrepair.

Dr. Gould also popularized evolutionary ideas at Harvard, sometimes finding his lecture halls filled to standing-room only. But while his adventures typically took place in the library, colleagues said that Dr. Gould, whose specialty was Cerion land snails in the Bahamas, was also impressive in the field.

Noting that in graduate school Dr. Gould dodged bullets and drug runners to collect specimens of Cerion and their fossils, Dr. Sally Walker, who studies Cerion at the University of Georgia, once said, "That guy can drive down the left side of the road," which is required in the Bahamas, "then jump out the door and find Cerion when we can't even see it." Then, she recalled, this multilingual student of classical music and astronomy and countless other eclectia might joyously break out into Gilbert and Sullivan song.

Dr. Gould is survived by his wife; his mother; his two sons from a previous marriage, Jesse Gould of Cambridge, Mass., and Ethan Gould of Boston; his stepson, Jade Allen of
Gainesville, Fla.; and his stepdaughter, London Allen of Manhattan. His previous marriage, to Deborah Lee of Cambridge, ended in divorce.

Dr. Gould had an earlier battle with cancer in 1982. When abdominal mesothelioma was diagnosed, he reacted by dragging himself to Harvard's medical library as soon as he could walk.

In a well-known essay titled, "The Median is not the Message," he described discovering that the median survival time after diagnosis was a mere eight months. Rather than giving up hope, he wrote that he used his knowledge of statistics to translate an apparent death sentence into the hopeful realization that half those in whom the disease was diagnosed survived longer than eight months, perhaps much longer, giving him the strength to fight on.

"When my skein runs out, I hope to face the end calmly and in my own way," he wrote. However, "death is the ultimate enemy -- and I find nothing reproachable in those who rage mightily against the dying of the light." He survived the illness through experimental treatment, but died of an unrelated cancer, in a bed in his library among his beloved books.

Dr. Gould received innumerable awards and honors, including a MacArthur "genius" grant the first year they were awarded. He served as president of the American Association for the Advancement of Science, was a member of the National Academy of Sciences and won the National Book Award and the National Book Critics Circle Award. He was the Alexander Agassiz Professor of Zoology at Harvard and the Astor Visiting Research Professor of Biology at New York University.

Whether eloquently and forcefully championing new or forgotten ideas or dismantling what he saw as misconceptions, Dr. Gould spent a career trying to shed light on an impossibly wide variety of subjects.

He once wrote, "I love the wry motto of the Paleontological Society (meant both literally and figuratively, for hammers are the main tool of our trade): Frango ut patefaciam -- I break in order to reveal."

Spectacular Fossils Record Early Riot of Creation

By JOHN NOBLE WILFORD

NEW fossil discoveries in China, hailed as among the most spectacular in this century, show that the dramatic transformation of life from primeval single-cell organisms to the complex multicellular precursors of modern fauna was more sudden, swift and widespread than scientists had thought.

From cream-colored sediments of what was a sea floor 570 million years ago, paleontologists have extracted specimens of 70 species of trilobites, worms, sponges and various ancestors of crustaceans, spiders and insects. They are not only the oldest such fossils ever found but, more remarkably, their soft-body parts as well as skeletal and shell remains are unusually well-preserved.

The fossils give scientists their first glimpse of the strange creatures that populated the seas in the early stage of what is known as the Cambrian explosion. The Cambrian geological period, from 570 million to 500 million years ago, saw the appearance of increasingly complex marine animals in a riot of shapes and anatomical designs anticipating much of life as it is today.

Scientists are not sure what touched off this riotous proliferation of more advanced life forms after three billion years in which life never rose above the rudimentary level of bacteria, algae and some primitive worms. Life did not begin appearing on land until after the Cambrian period.

Dr. Jan Bergstrom, a paleontologist at the Swedish Museum of Natural History in Stockholm who analyzed the Chinese fossils, said they suggested that the Cambrian transition was "a revolution perhaps more than evolution."

Most of the Chinese fossils, Dr. Bergstrom said, resemble species identified in the Burgess Shale, the 530-million-year-old fossil beds in the Canadian Rockies that have been the main source of knowledge of that crucial period.

The similarities are the basis for the conclusion that the diversification and proliferation of new life forms must have occurred rapidly at the outset of the Cambrian period.

"Evolution of these creatures seems to have been a sudden and widespread phenomenon," Dr. Bergstrom and colleagues wrote in the current issue of Research and Exploration, a scholarly journal of the National Geographic Society.

The Chinese fossils were discovered in 1984 at Chengjiang, in the southern province of Yunnan, by Dr. Hou Xianguang of the Nanjing Institute of Geology and Paleontology. Dr. Chen Junyuan, also of the institute, is continuing excavations at the site.

But the first descriptions of the fossils were largely confined to Chinese publications and received little attention from scientists elsewhere. This is changing, though, with the new analysis led by Dr. Bergstrom, an authority on trilobites, ubiquitous creatures of that period that have long been extinct. His collaborators include Maurits Lindstrom, a geologist at Stockholm University, and Dr. Chen and Dr. Hou.
As the full import of the discovery is recognized, scientists are describing the fossils as "genesis material" and one of the most exciting finds since the ancient marine life in the Burgess Shale was first explored in 1909. "All eyes are on Stockholm," said Gregory D. Edgecombe, a paleontologist at the American Museum of Natural History in New York. He said the preservation of the Chinese fossils was even better than in the Burgess material.

Dr. Andrew Knoll, a Harvard University expert on early life, said: "We knew from the Burgess that there was a tremendous diversity of life in the Cambrian. Most of everything that was going to happen, all the ways of making invertebrate animals, had already happened by the mid-Cambrian. Now, it seems the new life forms were invented within the first few million years of the Cambrian."

A few million years is but a blink of the eye in the geological and evolutionary time scale. And Dr. Bergstrom said it was quite possible that at this time "you could have the formation of an entirely new type of animal within thousands of years."

Calling the Chinese fossils "fascinating and important," Dr. Steven M. Stanley, a paleontologist at Case Western Reserve University in Cleveland and author of "The New Evolutionary Timetable," said he was not surprised that they resembled the Burgess specimens. "We've known there had to be rapid diversification of life at that time," he said. Unusually Well Preserved

The Chengjiang fauna lived on the sea bottom or just below or above it, along a broad continental shelf beneath fairly shallow waters. Even some of the animals without hard skeletons or shells were preserved intact, which is extremely rare. Skeletonized animals make up more than 99 percent of the fossil record.

Dr. Bergstrom could only speculate on the conditions leading to such deposits of ancient invertebrate life.

"A violent storm probably stirred up the sea bottom and the mud settled over a large area, cutting off the animals' oxygen and preserving them," he said. "You can go 30 miles in one direction and 12 in another and still come up with fossils."

Despite their great age, a majority of the fossil species at Chengjiang belong to animal groups that still exist, including sponges, certain worms, bivalves of the brachiopod group and arthropods. Indeed, arthropods dominate the fossil bed with at least 30 species. These include three species of trilobites and several creatures with long tails that looked like shrimp. The arthropods' descendants are crustaceans, insects and spiders, and the family resemblances can be seen that far back.

For example, the Alalcomenaeus, also found in the Burgess Shale, has distinctive large appendages on its head. Similarly, Jianfengia looks like a small shrimp, and though it lacks typical antennas, it does have "great appendages" on the head.

The second most common group consists of sponges, most of which bear a striking similarity to the Burgess Shale sponge fauna. Other creatures were distantly related to the jellyfish, some flat and others shaped like a corkscrew or spindle. The tallest stood almost two feet above the sea floor. One carried a large disk with concentric air chambers divided into numerous partitions.
Dr. Bergstrom's team is not sure what to make of some of the specimens. The largest animal found, a two-foot-long predator, had stout, segmented arms and a round mouth encircled with cutting "knives." One puzzle is whether this is a type of worm or an arthropod.

Other fascinating specimens include worms with a proboscis armed with spines and a long creature that looks like a worm with a shelly hat. **Worm With 'Kneecaps'**

"The real shocker for me is the worm that looks like it has kneecaps," said Dr. Ellis L. Yochelson, a paleontologist at the Smithsonian Institution. He was referring to an animal known as *Microdictyon*.

In earlier discoveries, scientists had noticed the tiny shell-like plates that Dr. Yochelson likened to kneecaps. But they had no way of knowing or suspecting that the plates would sit on a wormlike animal.

In their report, Dr. Bergstrom and his colleagues said these plates were situated in 10 pairs along the body of the Microdictyon. From the area of each pair of plates extended a pair of very long legs or tentacles. "The body design," they said, "seems completely unlikely, but it must once have been functional."

Dr. Yochelson said: "The record of extremely complicated organisms has been pushed back significantly by this find. And it says there was a much shorter interval than expected for the evolution of multicellular animals with hard parts."

Photos: Paleontologists have discovered 70 fossil species in sediment of what was a sea floor 570 million years ago. This fossil appendage of early trilobite-like arthropod was found in the Cambrian layer in China. (Uno Samuelsson/National Geographic) (pg. C1); Fossil arthropod called *Jianfengia* was found in the Cambrian sedimentary layer at Chengjiang, China. (Uno Samuelsson/National Geographic) (pg. C10) Map: Map of China showing location of Chengjiang. (pg. C10)
Headliners; Echoes From an Explosion of Early Life

FOR billions of years evolution was stuck in a rut, with algae, bacteria and other one-celled creatures holding dominion over the seas.

Then about 570 billion years ago, in a time now called the Cambrian explosion, the carnival of life began. Dozens of species of trilobites, sponges, worms and other multicellular animals bloomed, including those that turned out to be the precursors of man.

Until recently knowledge of these days came largely from the Burgess Shale, a fossil bed in Western Canada formed 530 million years ago when, through some unknown catastrophe, a menagerie of marine invertebrates was trapped in a mountain of mud. Now scientists studying another of these paleontological snapshots -- a fossil bed formed some 40 million years before the Burgess -- are discovering that the Cambrian explosion was even more rapid than they had supposed.

In 1984 Chinese scientists discovered a fossil bed formed near the very beginning of the Cambrian era, 570 million years ago. In recent weeks, Western scientists have reported that the fossils found at Chengjiang, in the southern province of Yunnan, are remarkably similar to those in the Burgess Shale. The suggestion, said Dr. Jan Bergstrom, a paleontologist at the Swedish Museum of Natural History in Stockholm who analyzed the Chinese fossils, is that the Cambrian transition was "a revolution perhaps more than evolution."

"Evolution of these creatures seems to have been a sudden and widespread phenomenon," Dr. Bergstrom and his colleagues wrote in the current issue of Research and Exploration, a scholarly journal of the National Geographic Society.

Scientists don't know what touched off the Cambrian explosion or why it was followed millions of years later by the Cambrian decimation, in which many of the creatures that arose to test the waters just as suddenly disappeared. Among the casualties was a two-foot-long predator, the largest of the animals found at Chengjiang, which had stout, segmented arms and a round mouth encircled with cutting "knives." Also lost was a kind of worm whose snout was armed with spines.

Photo: Fossil of a small arthropod that was found in sediment of what was a sea floor 570 million years ago in southern China. (Chip Clark/National Geographic Research & Exploration)