Also in this issue...

What is a Dinosaur?  page 19
Our Invisible Close Relatives  page 23

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“Priscilla”
Photo of original fossil specimen located at
Florida Museum of Natural History
Gainesville, FL
Why Glaciers Matter

By Warren Allmon

Louis Agassiz (1807-1873) was a complicated man. This Swiss naturalist is probably most famous today as one of the last scientifically credible opponents of evolution in the years immediately following the publication of Darwin’s *On the Origin of Species* in 1859. He also founded Harvard’s Museum of Comparative Zoology and the departments of Zoology and Geology at Cornell University. Agassiz’s first real claim to fame, however, was as a geologist. He was the first to recognize that enormous glaciers had once been much more widespread on the Earth’s continents than they are today. In other words, he invented the Ice Age.

As a young man, Agassiz hiked in the Alps of his native Switzerland and noticed the large and scenic glaciers on the sides of the mountains; he also noticed features of the geology in the valleys below the existing glaciers that were difficult to explain simply through the action of the streams and rivers that then flowed through them. By carefully comparing the ongoing action of modern glaciers and the traces that they clearly left behind – such as deposits of gravel and large boulders and scratches on the rocks – with the obviously older features of the surrounding geology, Agassiz concluded that the giant sheets of ice that graced the modern Alps were but vestiges of much larger ice sheets that extended across much of western Europe in the not-so-distant geologic past.

Agassiz’s work on glaciers was published in a set of beautiful large folios in 1840 (copies of which are in the PRI Library). His theory was a brilliant early example of the new modern geology, which had gotten its start scarcely a decade earlier with the publication of the three-volume *Principles of Geology* by Englishman Charles Lyell. Like Lyell, Agassiz recognized that interpreting the history of the Earth depended upon comparing modern patterns, and processes that produce them, to patterns observable in the geological record.

Also in common with Lyell, Agassiz accepted a long prehistory for the Earth, during which glaciers and other geological phenomena had acted to change and shape the Earth’s surface. Unlike Lyell, however, Agassiz thought that most geological changes were abrupt and discontinuous, even catastrophic, and that they were directed by a supernatural hand. He called his ancient glaciers “God’s great plows,” and held that Divine action had swept the globe clean of life numerous times, via ice or other means, and created new species (and whatever else was needed) from scratch. He thus accepted change in the history of life, but not continuity. In other words, he could not accept Darwin’s “descent with modification” or the historical causality that it requires.

Like Switzerland, the geology and landscape around Ithaca, New York, everywhere show features that are inexplicable except as the traces left by the action of glaciers long ago. Elongated hills, oriented north-to-south (called “drumlins” by geologists), deposits of gravel in particular shapes and places, linear striations on hilltops, and the depths and shapes of the Finger Lakes themselves—all testify to changes that we cannot easily imagine on a sunny autumn day looking out on the blue water and orange-and-red foliage of Cayuga Lake and its surrounding hills.

The tragedy of Louis Agassiz is not just that his resistance to evolution in his final years condemned him to an increasingly marginal place in the intellectual firmament that he had once dominated. It is that he could not accept the logical conclusions to which his careful observations and scientific reasoning inexorably led: that the Earth had changed.

Ironically, we face the same tragedy today. The best science that we have tells us that the Earth’s glaciers are shrinking, and that this is due to the increase in global temperature that is caused primarily by the human production of greenhouse gases. Yet persistent—and recently resurgently influential—segments of our society continue to deny this causal connection and its implications for the future of our planet.

Louis Agassiz was once America’s leading scientist. He had many admirable qualities and is remembered today in some quarters for some noteworthy accomplishments. We now think, however, that he was very wrong about how the Earth works and why. His story is one that we should remember when we look at the glaciers of today and what they are almost certainly telling us.
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On the cover: Whitney Glacier, on Mount Shasta in California was the first glacier identified in the continental United States. It was discovered by Clarence King, a Yale University graduate, working for the California Geological Survey, in September 1870. Whitney Glacier is the longest glacier in California, measured at over 3 kilometers long in 1986. See article on page 10. Photograph by John Scurlock.
FEATURE ARTICLE

Imperiled Glaciers of the American West 10
by Andrew G. Fountain & Elizabeth Safran

FROM THE MEMBERSHIP

Our Invisible Close Relatives 23
by James G. Morin

BOOK REVIEWS

Ain't Misbehavin', by Tony Ekdale 28
Teaching Paleobiology in the 21st Century?, by Nan Crystal Arens 28
Two Tomes, by Carl Mehling 30
New York State Fair • PRI once again had its booth at the New York State Fair, near the entrance to the 4-H Youth Building. We had a brand-new pile of Devonian shale, which, together with new signs and banners, attracted more than twice our previous total of visitors for the 12 days of the Fair. Many happy children left the booth, clutching a fabulous, fully-labeled fossil that they had excavated themselves!

Science on the Half Shell • Our new temporary exhibition, "Science on the Half Shell: How and Why we Study Evolution," opened in September at the Museum of the Earth. Major funding came from two research grants on bivalves (clams, etc.) from the National Science Foundation. This will be PRI’s first traveling exhibition, beginning in early 2011. The exhibition, open at Museum of the Earth through January 17, is supported locally by M&T Bank and Maxie’s Supper Club, which provided oysters and clams on the half-shell during the opening reception.

Duggan-Haas Sails the Ocean Blue • Don Duggan-Haas, PRI’s Education Research Associate (second from left in the photo, wearing a survival suit), spent ten days in September sailing off the coast of British Columbia on the JOIDES Resolution, one of the world’s leading oceanographic research vessels. Don was there through the International Ocean Drilling Program’s Deep Earth Academy and School of Rock, in which educators participate in cruises to deepen their knowledge of ocean science, develop ocean-focused educational materials, and help program scientists with public outreach. Don’s work on board included drafting an ocean-based virtual fieldwork experience (VFE), which will tie the shipboard work to PRI’s "ReaL Earth Inquiry" or "Teacher-Friendly Guide" project.

USA Science & Engineering Festival • In October, PRI participated in the USA Science & Engineering Festival on the National Mall in Washington, DC. This event brought together over 400 science-based institutions and corporations from across the country, celebrating science and technology. PRI was one of 75 official "Festival Partners," featured on a Periodic Table of Science in America (in the position of boron, below) During the festival, PRI offered an activity that allowed visitors of all ages to dig into Devonian shale and search for fossils. The event was a fantastic opportunity to place PRI on a national stage, reaching thousands of children and adults, promoting our mission and increasing scientific literacy. See more on page 26.
Treasures In Our Collections

Axel A. Olsson: A Life on His Terms
By Pat Charwat

An amazing figure in PRI’s history is the noted paleontologist, writer, and collector Axel Adolph Olsson. Born in Gloversville, New York, to Swedish immigrants on April 19, 1889, Olsson attended Massachusetts Institute of Technology for a year before transferring to Cornell University. There, Gilbert Harris, the future founder of PRI, became his mentor. Olsson studied, assisted Harris in his lab, and had papers published before receiving his AB degree in 1912. As a graduate student, Olsson was an invertebrate paleontology instructor but his quest for adventure and work in the petroleum industry at exotic locations repeatedly drew him away from working on his dissertation and teaching at Cornell.

An early Olsson adventure occurred during the summer of 1915 as World War I threatened. He was accused of being a German spy. He and several other students were accompanying Harris on his boat, the \textit{Ecphora}, on a 3,000-mile cruise to research the Atlantic coastal plain. While exploring the area around the Chowan River, in North Carolina, Olsson and another student, Bayard Taylor, were arrested near the small town of Harrellsville because residents became suspicious of their "strange behavior" investigating "worthless" rocks in riverbeds, yards, and gardens. They were taken before a Committee of Investigation and had difficulty proving that they were actually Cornell University students. They were finally released after providing shipping receipts for the many specimens they had sent back to the university.

In 1916, on leave from Cornell, Olsson and another former Cornell student, Karl Paterson Schmidt, were doing advance work for Dr. Carlotta Maury in the politically unstable Dominican Republic. There they suddenly found themselves surrounded by revolutionaries. This time, however, Olsson pretended to be German and he and Schmidt were escorted safely through the front lines by the rebels. On another expedition, this time to Panama and the Pearl Islands, Olsson wrote of running into hostile natives. He seemed to thrive in these settings.

Olsson abandoned all work on his doctorate and academia in 1922, preferring consulting for some of the world’s most influential oil companies. He spent 30 years in Latin America, and later the western U.S., Canadian Rockies, and eastern Canada. After retiring in the late 1940s, he lived for a while near Philadelphia, but was soon attracted to southern Florida with its fascinating fossils and intriguing Upper Cenozoic stratigraphy, which he researched extensively.

A confirmed bachelor for over 80 years, Olsson embarked on one of his greatest adventures on September 11, 1971, when he married Elsie Carlton Lawton. Three years later, the University of Miami honored his lifetime of extensive research and achievements by awarding him an honorary Doctor of Science degree. Throughout the years, he remained in close contact with PRI, serving as a lifetime member of the Board of Trustees including three terms as its president. The PRI Type and Figured Collection contains hundreds of Olsson specimens and his work appeared in numerous PRI publications. After a full life on his own terms, Dr. Axel A. Olsson passed away on October 26, 1977.

Pat Charwat is a dedicated volunteer in the Collections Department at Paleontological Research Institution. Email charpatti2@aol.com.
PRI and its Museum of the Earth continue to grow! • Elizabeth Slocum Brando is PRI’s new Associate Director for Institutional Advancement. She was most recently the Director of Marketing at the Fenimore Art Museum in Cooperstown, NY, and before that the Director of Development at the Children’s Museum of the Arts in New York City. She holds bachelor’s and MBA degrees from the University of Arizona, and lives in Whitney Point, New York, with her husband and three-year-old daughter Olivia. • Cathy Blackburn is our new Director of Exhibits. Cathy has a BFA in Visual Design and a graduate degree in Cultural Resources Management. She began in marketing and 3-D design in Hawaii, and as Chief Museum Designer for the Frye Art Museum in Seattle, oversaw design and marketing for over 100 exhibits. She operated her own exhibit design firm, Cathy Blackburn Design, for a number of years. • David Campbell, who inherited his interest in mollusks from his PRI-member parents, joined the Collections staff in October. ”Diverse David” comes to us from a postdoc on freshwater snails, following a Masters on Eocene gastropods and a Ph.D. on bivalve evolution. • Maya Weltman-Fahs joined the staff in September as Assistant to the Director. Maya is an Ithaca native. She has a Bachelors in Environmental Science from the University of California Santa Cruz, and spent time in San Francisco at a prisoner advocacy law firm before earning a Masters in Climate Science and Policy from Columbia University in 2010.

Six new members were elected to the PRI Board of Trustees in October. • Peter Bardaglio is former Provost of Ithaca College, coordinator of the Tompkins County Climate Protection Initiative, and Senior Fellow at Second Nature, Inc. • John Handley is a statistician at Xerox in Rochester, NY, and an accomplished amateur paleontologist. • John Hermanson is Professor of Anatomy in the College of Veterinary Medicine at Cornell University. • Bryan Isacks is Professor Emeritus in the Department of Earth & Atmospheric Sciences at Cornell. • David Meyer is Professor of Geology at University of Cincinnati. • James Morin is Professor of Ecology and Evolutionary Biology and former Director of Shoals Marine Laboratory at Cornell University.

In September, PRI Outreach staff hosted Junko Anso, the Curator of Paleontology at the Fukui City Museum of Natural History in Japan. At her relatively small museum, curators perform many roles, including outreach, and she received a grant from Japan’s Ministry of Education to study the development of our outreach program, in hopes of finding applications to her own institution. Junko chose PRI through our website; she looked at natural history museum websites from around the U.S., and decided that the level and kind of outreach activity at PRI, and the comparable size of PRI to her home institution, made PRI a good candidate. She will be writing a report and making a presentation of her findings back in Japan. Junko noted, ”This intern experience is not only for Fukui City Museum but also for all museums in Japan, because this internship program is provided from the Japanese Ministry of Education.”
Evolution and Darwin

Enhancing Evolution: The Ethical Case for Making Better People by John Harris. Stem cell research, human gene modification, and cloning are topics that make many people uneasy. John Harris provides a uniquely logical basis for supporting the use of such practices, arguing that not only would genetic engineering be not unethical, but it would be immoral to abstain from using our knowledge to better humankind. Princeton University Press, 272 pp., ISBN 978-0-69114-816-8, $18.95 (paperback), November 2010.


Global Climate Change
The Long Thaw: How Humans Are Changing the Next 100,000 Years of Earth’s Climate by David Archer. Written for a general audience, this book provides the past, present, and future of Earth’s climate change, using non-technical language to analyze problems and what we need to do to prevent drastic consequences. Princeton University Press, 192 pp., ISBN 978-0-69114-811-3, $16.95 (paperback), September 2010.


Earth Science
Understanding the Changing Planet: Strategic Directions for the Geographical Sciences by the Committee on Strategic Directions for the Geographical Sciences in the Next Decade & the National Research Council. This volume describes how geographical sciences can help humans understand how the Earth has changed in the past and what changes will come in the future. National Academies Press, 172 pp., ISBN 978-0-30915-075-0, $44.00 (paperback), June 2010.


Paleobiology


New from PRI Publications! Upper Cambrian Chitons (Mollusca, Polyplacophora) from Missouri, USA by John Pojeta, Jr., M. J. Vendrasco, & Guy Darrough. Bulletins of American Paleontology no. 379, September 2010, $40.00, see http://www.museumoftheearth.org.
From Dinos to Ducks: Further Evidence That Birds Evolved From Dinosaurs

Canadian paleontologist Corwin Sullivan recently discovered not just one, but two new species of dinosaurs the fossils of which present excellent evidence that birds evolved from dinosaurs. As a researcher at the Chinese Academy of Sciences in Beijing, Sullivan first came across the predator *Deinonychus*, which had wings with feathers and stood like a penguin. Its wrist bones very closely resemble those of modern birds. The other specimen is *Xixianyuks zhangi*, the fossils of which come from the Late Cretaceous Period of Henan Province. *X. zhangi* probably looked similar to a Roadrunner: about a half-meter long, with two legs that had small thigh bones and longer lower legs and feet. Sullivan determined that, because of this leg formation, *Xixianyuks* most likely ran fast and efficiently through its ancient habitat. Sullivan’s discoveries present paleontologists with strong similarities between modern birds and dinosaurs, offering new evidence to the well-established theory that birds evolved from these ancient species. Sullivan’s discovery of *Deinonychus* was detailed in the March issue of *Proceedings of the Royal Society B*, *Xixianyuks* was discussed in a March issue of *Zootaxa*.

**Cat Crocodile**

If you think your cat is vicious, try coming face to face with *Pakasuchus kapilimai*, a 105-million year old crocodilyform that bears strong resemblance to modern mammals. *Pakasuchus* literally means "cat crocodile"; *kapilimai* is the last name of the leader of the study, Saidi Kapilimai, who discovered the fossils of this ancient reptile in Tanzania. Most interesting to scientists is *Pakasuchus*’ resemblance to mammals, a stronger likeness than that of the modern crocodile. *P. kapilimai* had nostrils on the tip of its nose, indicating that it was more land-dwelling than the modern croc, whose nostrils are positioned on the top of the nose for easy breathing while submerged under water. Like our feline friends, *Pakasuchus* had long skinny legs and a more upright posture than the modern crocodile. Modern crocs have relatively uniform teeth throughout the jaw, whereas *P. kapilimai* had differentiated teeth, as mammals do, including canines, premolars, and molars. Paleontologists believe that due to its sliding jaw, *Pakasuchus* most likely chewed its food — an ability previously thought unique to mammals. Details of the study were published in the August 11 issue of *Nature*.

**Our Neanderthal Relatives**

No, your brother is not a Neanderthal. However, modern humans and the extinct humanoids are more closely related than we thought. Until recently, paleontologists thought humans and Neanderthals were only related through a 500,000-year-old common ancestor. But thanks to Svante Paabo and fellow researchers at the Max Planck Institute for Evolutionary Anthropology, most anthropologists now believe that humans and Neanderthals actually interbred much later in history, anywhere from 80,000 to 50,000 years ago. Paabo and his team studied three 40,000-year-old Neanderthal bones, mapping their genes and comparing the Neanderthal DNA with that of five different modern humans. The study concluded that humans share from 1 to 4 percent of their genes with Neanderthals. The findings were described in detail in the May 27 issue of *Science*.

**Gigantic Discovery**

In April 2010, Martin Whyte of the University of Sheffield discovered the tracks of a giant six-legged "sea scorpion" (eurypterid) while out for a walk. The tracks of the sea scorpion, named *Hibbertopterus*, were found in northeastern Fife, in the U.K., and are estimated to be about 330 million years old. The fossils indicate that *Hibbertopterus* was't your average sea scorpion; this beast measured in at approximately two meters long and one meter wide. The tracks, which consist of three rows of crescent-shaped footprints with a central groove created by the massive creature's tail, are alleged to be the largest known tracks of a eurypterid or any invertebrate animal living today. This track provides evidence that the animal was related to modern-day scorpions and horseshoe crabs, and contrasts with the evidence that suggests that the giant creatures lived in water most of their lives.
Sunflowers Have Long Southern Roots

The Asteraceae or Compositae is the largest family of vascular plants. It is also one of the most diverse, including over 23,000 wild species (from daisies, dandelions, and sunflowers, to lettuce and artichokes) that inhabit all continents except Antarctica, especially in temperate to tropical areas. Scientists have recently discovered its oldest known member — an exceptionally well-preserved fossil nearly 50 million years old. Most other known fossils of this family are pollen grains, which, although informative, are limited in what they can reveal about these ancient plants. The new fossil includes leaves, flowers, and pollen, and looks somewhat like a dandelion. It was found in Eocene deposits of northwestern Patagonia, in southernmost South America, an area now dry and windy but known to have been more tropical when the new fossil was blooming. Previous study of the family using DNA sequences of living species suggested that the family originated in South America; the new fossil supports this hypothesis. This discovery could also yield important clues about why this particular plant family has been so successful. The study was published, by V. D. Barreda of Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" and colleagues, in the September 24 issue of Science.

Super Smart Sarahsaurus

About 200 million years ago, a mass extinction occurred and many species were eliminated from the Earth — but not dinosaurs. Until recently, paleontologists were mostly in agreement that dinosaurs originated in South America, then spread upward and outward, conquering competing species wherever they found a suitable habitat. A recent fossil discovery by Tim Rowe at the University of Texas disputes this knowledge. Rowe and fellow researchers found a new dinosaur species called Sarahsaurus, the details of which were published in the October 6 online edition of Proceedings of the Royal Society B. This new species' fossils indicate that it migrated into North America after the mass extinction of competitors, not before. Rowe wrote that paleontologists are now considering the possibility that dinosaurs didn’t push other species out; they waited for natural disasters to strike, and when they found an area that had been cleared of all competing species, they chose to settle there. Dinosaurs were apparently not as pushy as we thought, and perhaps smarter than we ever knew.

Prehistoric Volcanoes

Volcanoes that erupted millions of years ago exploded with much greater force than those of today, says geologist Huiming Bao at Louisiana State University. These ancient volcanoes shot potent gases into the atmosphere. Sulfur dioxide, one of these toxic volcanic gases, goes through a chemical change in the atmosphere, morphing into sulfur aerosols. Such aerosols were recently found in Nebraska, leading Bao to believe that the volcanoes that emitted them were incredibly explosive. Sulfur aerosols, scientists say, are a leading cause for climate change, possibly causing past climate change events such as dry fogs in Europe and cold winters in North America. Scientists also believe that a fierce explosion, on par with the ancient volcanic eruptions, could occur again, in Yellowstone National Park. This research was published in the June 17 issue of the journal Nature.

Creepy Crawlies

Paul Seldon, Professor of Invertebrate Paleontology at the University of Kansas, and his colleague Diying Huang at the Nanjing Institute of Geology and Paleontology in China, recently described a new spider fossil that dates all the way back to the Jurassic Period, 165 million years ago. The specimens, which were discovered in Mongolia, are older than the only two other similar specimens by over 40 million years, and are said to be connected to modern-day spiders. Although spider fossils do not usually preserve well, these fossils were most likely trapped in volcanic ash, preserving them with astonishing detail. Researchers found that the male specimens share almost all of the features of the modern family Plectreuridae, a group that, until now, has only been found on the North American continent and Cuba. These ancient specimens were found on a small continent called the North China Block, a world away from their modern counterparts. Seldon and Huang noted that although this family has changed very little over the course of 165 million years, their distribution has shrunken considerably. The research team speculated that a change in vegetation during the Ice Age or other notable climatic events probably limited resources for the spiders and pushed them into the deserts of North America. This research was published in the February 6 issue of the journal Naturwissenschaften.

*This issue of PaleoNews was reported by Laura Komor*
Imperiled Glaciers of the American West

By Andrew G. Fountain & Elizabeth Safran

The influence of glaciers in the United States is now widely recognized, both through the geographic signatures of once great ice sheets in the northern tier of the country and through examples of active alpine glaciers in places like Glacier National Park or Mount Rainier National Park. However, until the first half of the 19th century, glaciers and glacial activity in the continental U.S. went unrecognized. Then Louis Agassiz arrived.

Louis Agassiz (1807-1873), a biologist by training, also studied geology and paleontology in Paris. His hikes in alpine Switzerland spurred an interest in glaciers and glacial deposits and developed his eye for such phenomena. A number of scientists had noted the presence of erratic boulders and other glacial deposits well beyond the limits of active glaciers. Agassiz and his collaborator Karl Schimper hypothesized that the distribution of deposits reflected the growing and shrinking of glaciers through climate change. The period of extensive glaciation was dubbed "Ice Age." This novel scientific idea generated significant controversy. To resolve some of the criticisms, Agassiz mounted a field campaign on the Aar Glacier in Switzerland that included construction of a hut on the glacier itself. The results of this study were published in a two-volume treatise in 1840, but general acceptance of the Ice Age hypothesis took several more decades.

Agassiz left Switzerland in 1846 for a lecture series at the Lowell Institute in Boston and eventually secured an appointment at Harvard University. During his time in Massachusetts and surrounding states, he explored the geologic features of the northeastern U.S. He soon observed many glacial features and extended his ideas about the Ice Age to include North America. He was one of the most famous scientists of his day, and his ideas on glaciers and glaciations spread widely. To this day, scientists continue to explore the geologic evidence left by ancient ice sheets in an attempt to understand the linkage between ice sheet behavior and climate change. Given the present concerns over climate warming, these studies now have renewed energy and purpose. The guiding principle is that by understanding the past we might be able to predict the future.

Literature contemporary with Agassiz’s explorations in the U.S. include few if any allusions to glaciers in the lower 48 states. Glaciers along coastal Alaska and Canada were certainly known to the earliest explorers, such as Russian fur traders and Captain Cook of the British Royal Navy. But it would be another 100 years before glaciers in the continental U.S. were conclusively identified. That discovery was left to

The upper reaches of the Whitney Glacier, Mount Shasta, California. This was the first glacier identified in the continental U.S., discovered by Clarence King in September 1870. Photograph by John Scurlock.
a student of the famous James Dana, a native of Utica, New York. Dana had studied chemistry and the natural sciences at Yale University. His scientific skills had earned him an invitation to join the global voyage of the Wilkes Expedition. It was Dana, as a young man, who developed a system of classifying minerals known to all geologists today. He became perhaps the pre-eminent American geologist, a few years behind Agassiz, returning to Yale University as a professor in the 1850s. That student of Dana was Clarence King (1842-1901), who received a degree in chemistry while studying geology with Dana. Although the Civil War was raging, King went west and volunteered to work with the California Geological Survey under the leadership of John Whitney, after whom the highest peak in California (and the lower 48 states) is named. It was in California that King would identify the first glacier in the continental U.S.

Not long after the Civil War, King returned to Washington and lobbied hard for a geological survey of the forty-ninth parallel with himself as lead geologist. This was to be the first of four major government-sponsored geological surveys of the west, the other three being the Powell, Hayden, and Wheeler expeditions. At the age of 25, King received Congressional funding and headed west with a team to survey the territory from Wyoming to California. In September 1870, toward the end of this six-year expedition, King was climbing Mount Shasta. His visit was perhaps partly motivated by the fact that his old professor, James Dana, had explored the mountain in 1841 and had published the first geologic treatise about it. During King’s journey up the mountain, he found exposed ice, deep crevasses, and a huge snowfield upslope of the ice. King knew immediately that this was a glacier because he had visited Switzerland earlier in his life and had seen the real thing.

That it took so long for glaciers to be discovered in the continental U.S. is not as surprising as it might initially seem. First, few people at the time had ever seen a glacier. Second, the west was just being explored and populated by white settlers, and few had leisure time for mountain recreation, occupied as they were by the heavy labor of farming and ranching. Finally, the Earth was still in the grip of the Little Ice Age, and mountains were often covered with deep snow late into the summer. Glacial ice was seldom exposed, except perhaps to the rare adventurer who’d seize a fine summer day to walk through deep snow to high elevations.

Once King announced his discovery, many others followed. During the remaining decades of the 19th century, John Muir identified glaciers in the Sierra Nevada of California, Ferdinand Hayden found them in the Wind River Range of Wyoming, and Raphael Pumpelly found them in the Lewis Range of what is now Glacier National Park in Montana.

Unlike the glaciers of Switzerland or Alaska, glaciers in the American West are relatively small, most not much more than 0.1 square kilometers (24 acres) in area. A glacier is defined by snow and/or ice that is present year-round and that moves. Movement can be identified by crevasses, striations on local bedrock, or "glacier flour" that colors glacial streams an opaque minty green. Both the striations and glacial flour tell us that a glacier is sliding and grinding rocks together, leaving shallow grooves in the bedrock and producing fine particles from abrasion. Glaciers can be of any size, because even very small ice features can move if the terrain is sufficiently steep.

Glaciers populate most states of the mountainous western U.S., including Washington, Oregon, California, Montana, Idaho, Wyoming, and Colorado. Even Utah is thought to host one glacier on Mt. Tamponagos, just outside of Salt Lake City (but it isn’t clear whether this is a glacier or a rock-covered deposit of stagnant ice). The most glacier-populated state in the continental U.S. is Washington, with over 3,000 glaciers or permanent snowfields covering an area of about 450 square kilometers (112,000 acres). The largest* glacier is also found in Washington, on the slopes of Mount Rainier: the Emmons Glacier, at 10.6 km². By comparison, Alaska contains approximately 90,000 km² of ice.

It comes as a surprise to many that Washington has the most glaciers of any western state. The Cascade Range between Seattle and the Canadian Border accounts for approximately half of the state’s glaciers, and the Olympic Peninsula accounts for another quarter. Mount Rainier and Mount Adams account for the remaining quarter. Wyoming is the next most glaciated state with about 73 km² of ice cover and 1,475 glaciers or perennial snowfields. From Washington, the mean elevation of the glaciers rises to the south and to

*It is impossible from a practical perspective to say what is the smallest glacier. At very small sizes, both movement and perennial versus seasonal characteristics are hard to assess. The smallest named glacier is the Lathrop Glacier, 0.003 km² in large phase, on Mt. Theilsen in Oregon.
The rise to the south is due to warmer climate and to more intense sunshine, and the rise to the east is due to drier climate. Of course, local exceptions exist, but this trend holds over the region. In Washington, the mean elevation of a glacier can be as low as 1,500 m (almost 5,000 feet), which lies below the tree line, whereas in the Sierra Nevada and in Colorado, mean glacier elevation is 2,500 m and 3,300 m, respectively. Most glaciers face the direction in which solar radiation is minimized: north in the Northern Hemisphere. This indicates that the glaciers are responsive to small climate variations. The volcanoes of the Cascade Range in California, Oregon, and Washington, such as Mt. Rainier and Mt. Baker, are exceptional. These mountains are sufficiently tall to accumulate perennial snow and ice on all sides of the mountain, although the glaciers on the northern side tend to be larger than those on the southern side.

Glacier studies in the U.S. got their first major boost in the late 1940s and 1950s as a consequence of the Cold War (no pun intended). The battle space for confronting the Russians included the Arctic, and our early detection capabilities included radar outposts there. Similarly, the U.S. increased its research efforts in Antarctica to keep pace with Russian interests. Projects on the physics and structure of glaciers were conducted in the U.S. as a cost-effective analog to studies in the polar regions.

The first major reconnaissance of glaciers in the American West dates to the International Geophysical Year (IGY) of 1957, a world-wide coordinated series of measurements that included many geophysical phenomena. The International Hydrological Decade followed the IGY, and the need to define and monitor high alpine hydrological processes over the long-term motivated additional observations of glaciers. Long-term studies on two glaciers were initiated in the West, one of which is still maintained at South Cascade Glacier in the Cascades of Washington. High quality, detailed measurements of weather, stream flow, and glacier mass change are part of the core data collection program. South Cascade Glacier became the site of many breakthrough studies that have advanced the science of glaciology significantly. Important to our current times, the record of mass change measurements at South Cascade Glacier is the longest in the Western Hemisphere and the second longest in the world. Thus, this glacier is very important as a climate change indicator.

The study of glaciers used to be a fairly arcane subject with little public appeal beyond outdoor groups and hiking clubs. But with growing public understanding of climate change, glacier studies now enjoy new prominence. Glaciers in the American West, like elsewhere, have been constantly changing — and are currently receding. In recent geologic history, glaciers were most extensive during the few hundred years prior to and including the late 19th century, a period called the Little Ice Age. Global cooling during that period is reflected in the paintings of Pieter Bruegel the Elder (deep winter in Holland); in the Christmas Story of Charles Dickens (cold wintry Christmas in London), and in our own cold winter at Valley Forge. The end of the Little Ice Age was associated with warmer air temperatures that caused the glaciers to retreat in the early part of the 20th century. Fortunately, this retreat occurred just after the advent of photography, and we have photos of what the glaciers looked like at that time. We also have extensive geologic evidence in the form of curvilinear piles of unsorted gravel, sand, and silt.

The iconic image of George Washington and his troops at Valley Forge, during the cold winter of 1777, has as much geological meaning as historical. It represents the period known as the Little Ice Age. Painting by Edward P. Moran in the U.S. Library of Congress.
(moraines) that mark the former edges of the glaciers. These moraines result from the transport of debris from the interior to the boundaries of the ice.

Glacier size is a balance between snow accumulation in the winter and melting in the summer. Depending on the relative magnitude of these two processes, glaciers grow or shrink. During the 1930s and 1940s, glaciers retreated rapidly. In the 1950s and 1960s, glaciers slowed and either stopped or advanced only slightly due to a cooler, snowier period. Retreat resumed in the 1980s and has accelerated in recent decades. Studies show that, over the past 100 years, precipitation patterns in the western U.S. have not changed significantly. Certainly there were decades with more or less winter precipitation, but there is no long-term trend. In contrast, temperatures rapidly warmed in the western U.S. (like the rest of the globe) after the turn of the last century, then stabilized or cooled slightly in the 1950s and 1960s, and have warmed significantly in the past few decades. Glacial size has clearly tracked this temperature trend. However, glaciers in different regions have not responded identically. All have retreated, but those in Glacier National Park and in the Sierra Nevada have retreated the most, losing about 66% of their area since 1900. Glaciers in the Pacific Northwest have lost 30-40% of their area, as have glaciers in Colorado. The cause of these differences is not clear but might involve enhanced snowfall in the Northwest which partly offsets the increased melt.

Very few glaciers have completely disappeared in modern times. Glaciers are resilient landscape features because as they melt and retreat, they commonly shrink into valleys shaded from the sun, and the steep valley walls increase snow accumulation through avalanching. Many of the glaciers in the Front Range of Colorado are fed largely by wind drift and avalanching rather than by direct snowfall. In addition, the mean elevation of a glacier increases as shrinkage occurs at lower elevations. Higher elevations correspond to lower temperatures, so as the glacier shrinks, the rate of retreat slows. These landforms can therefore be very persistent, at least according to the strict definition of a glacier — a perennial feature that moves. However, from a practical point of view — say from the perspective of hydrological or recreational interests — a glacier can get so small that it is effectively gone.

Glacier shrinkage is a concern for several reasons. First, glaciers act as natural reservoirs that store water as ice and release it during the warmest, driest part of the summer. Thus, glacier-fed streams are more reliable water sources than those draining ice-free watersheds. This has important implications for high alpine hydrology and ecology. Humans also rely on glacial water to some degree. In Norway and Switzerland, power companies use water directly from the glaciers, and similar projects have been considered in Canada and Alaska. Our glaciers in the American West are generally too small for these kinds of applications, but their contribution to regional water flow cannot be overlooked. On the northern side of Mt. Hood in Oregon, for example, melt water from the Eliot and Coe glaciers contributes substantially to the internationally renowned apple and pear orchards downstream. Late summer stream flow is expected to be substantially reduced later this century if climate warming continues.

Glacial melt ultimately flows to the oceans, and together with melt from the two great ice sheets, Greenland and Antarctica, they account for one third of the total sea-level rise in the last century. (The remaining two thirds is caused by thermal expansion of ocean water due to warmer global temperatures.) Water released from melting mountain glaciers and ice caps is expected to dominate the contribution of new water to the oceans for the rest of this century, although the relative contributions from Greenland and Antarctica will
certainly increase. A decade ago, sea level was predicted to rise one third of a meter by the year 2100. Current estimates are closer to one meter.

Finally, for those of us who live in the Cascade Range of California, Oregon, and Washington, glacier retreat poses significant alpine hazards. The volcanoes of the range are stratovolcanoes, composed of layers of ash, rock, and lava. The edifices of these volcanoes are weak and easily eroded by glaciers. As the glaciers retreat, they leave behind deep, steep-sided valleys. The valley walls, no longer buttressed by the presence of ice, are susceptible to failure. Most commonly they collapse during intense rainstorms that swell the rivers, which in turn undercut the already steep adjacent slopes. The bouldery gravel that makes up the valley walls flows into streams, forming a slurry of rock and mud called a "debris flow." This mixture follows the stream channel, eroding the banks, incorporating trees, and ultimately covering valley bottoms, including roads, with a rocky, bouldery mass. In the Pacific Northwest, a number of mountain highways were closed for months following a severe, debris flow-generating storm in November 2006. We expect debris-flow hazards related to deglaciation to continue and perhaps increase in the foreseeable future.

Although they are small, the glaciers of the American West play important roles in alpine hydrology and ecology, regional patterns of water runoff, global rates of sea-level rise, and the shifting potential of geologic hazards. So, it's important to keep studying them. That they are shrinking due to climate change is a practical and aesthetic concern shared by many. It would indeed be ironic if the Continental American glacier, so late to be discovered, became an extinct landform so early in our scientific understanding. But then, maybe they weren't here to stay for long anyway — many seemed to be just hanging on early in the last century. In this view, we are fortunate to overlap with these transitory features in this particular geologic moment of time.

References and Further Reading
Glaciers of the American West (the author’s research website), http://glaciers.us.

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Speculations on Sauropods

By John A. Catalani

My interest in fossils and paleontology started in the sixth grade when I was introduced to dinosaurs (sound familiar?). My parents took me to the world-famous Field Museum of Natural History in Chicago. The skeletons of *Gorgosaurus* (mounted vertically and now called *Albertosaurus*) and *Brontosaurus* (then with the wrong skull and now *Apatosaurus*) were the most awesome fossils I had ever seen. Although my interests took a different path leading to my nautiloid passion, I still have a fascination for these critters. Even though my favorite dinosaur was, and still is, *Triceratops*, several others hold a special interest for me, including the sauropods. After seeing those mounted skeletons at the Field Museum, I naturally checked out some books (no Internet then, folks) from my local branch library on these magnificent animals.

In those books were reconstructions of prehistoric animals by such artists as Charles R. Knight and Zdenek Burian. Anyone who has seen Burian’s drawing of *Brachiosaurus* submerged in water with just its head poking out cannot help but be impressed with both the animal and the speculation that these animals used water to support their enormous bulk. Okay, today we know that it would be impossible for the animal to expand its lungs to breathe at that depth due to excessive water pressure. And more recently, it has been calculated that sauropods, even *Brachiosaurus*, were buoyant enough to float long before their bodies would have been submerged, rendering moot the breathing issue. Be that as it may, it was the image itself that was instrumental in burning *Brachiosaurus*, the animal, into our brains.

Illustration of a Brontosaurus (nowadays called Apatosaurus), by Charles R. Knight (1897). The idea that Apatosaurus was wholly or mostly aquatic is now considered outdated.

One of the most iconic images that I can remember is one painted by Knight that depicted a group of brontosaurs (yes, I know, apatosaurus) in a tropical environment. Several animals were pictured in the water, one with raised neck and head. The one pictured on land displayed a neck sloping downward, feeding on ground vegetation. Another of Knight’s images showed us a *Diplodocus* rearing up on its hind legs, using its tail for balance.

Although some might deride these early restorations, I view them the way the artists probably did: representations of prehistoric animals that embodied the accepted scientific evidence at that time. Through the years, such reconstructions represent snapshots of our changing views of the prehistoric world based on new fossil discoveries. These early images by Knight and others stimulated our imaginations and inspired a generation of paleontologists. Speculations on the life habits of extinct animals go through waves of reinterpretation as new specimens are found and analyzed — we should not disparage these early attempts.

So, how do illustrators and scientists reconstruct sauropod posture today? Well, as usual, it depends on which type of sauropod you are talking about and which paleontologist you are talking to. Now, I am certainly not a specialist in sauropod (or any dinosaur) osteology or physiology, but I am fascinated with the depiction of these enormous creatures. One method of investigating the physiological limits of extinct animals is to compare them to animals alive today. Arguably, the most interesting and frustrating aspect of sauropods is that, unfortunately, there are no living analogs to compare with these behemoths. Sauropods are most often compared to elephants but, although elephants are today’s largest land herbivores, sauropods were several times the mass and more than an order of magnitude larger. Plus, of course, elephants do not possess either the long necks or long, tapering tails that characterize sauropods. Giraffes are equipped with a long neck but lack the great mass, long tail, and tree-trunk-like legs. Whales are as, and in some cases more, massive than sauropods but, because of their marine habitat, are essentially weightless. Sauropods, then, were equipped with a unique set of morphological features that defy comparison to extant animals and thus provide researchers with a unique set of challenges when speculating on their physiological makeup and life habits, including metabolism, posture, feeding...
There has been a great diversity in depictions of neck postures for sauropods running the full gamut from near vertical to horizontal to downward sloping. The giraffe comparison, however, has dominated traditional reconstructions of all types of sauropods and, as a result, their necks were portrayed vertically, often in a graceful S-shape, placing the head many feet above the ground. The key elements in reconstructing the posture of sauropods involves not only the determination of that neck at rest — the "osteological neutral pose" and whether this was their habitual pose — but also the degree of flexibility and range of motion of that long neck.

In one study, Kent Stevens and J. Michael Parrish used digital reconstructions to look at neck orientations and feeding strategies of two diplodocids — that is, sauropods with smaller front legs than hind legs. The two animals studied were, not surprisingly, Apatosaurus and Diplodocus. Critical elements of the skeletons of these two sauropods were rendered by the computer using accurate dimensional measurements. Because neck biomechanics regulates the mobility of the neck, the movements between adjacent cervical vertebrae were reconstructed in detail, including the overlapping facets, called zygapophyses, that slide past each other as two adjacent vertebrae move. The authors contended that these facets were limited to a maximum reduction in overlap of 50%. Neck movement was also, of course, controlled and limited by ligaments, muscles, and tendons, particularly the nuchal ligament located in a V-shaped notch at the top of the cervical vertebrae. Stevens and Parrish determined that, for both sauropods, the neutral (and presumably habitual) pose occurred with the cervical vertebrae relaxed, with maximum bone contact of the zygapophyses, and with the nuchal ligament taut. Based on this, the authors speculated that in the neutral pose, both sauropods held their necks relatively straight and at a slight downward angle, resulting in a posture with the head close to the ground. As to the flexibility of the necks, both animals could bend their necks laterally about the same, resulting in a 13-foot deflection of the head to either side. However, when it came to raising the head, the more flexible neck of Apatosaurus probably allowed it to rise almost 20 feet off the ground, whereas Diplodocus could raise its head only 13 feet. It appears that their most comfortable feeding strategy would have been to browse on ground-level vegetation. Additionally, the authors suggested that both animals were able to lower their heads below ground level. This would have allowed them to feed on vegetation below water in lakes and rivers while still standing on land.

Stevens and Parrish also dismissed the ability of these two sauropods to assume a tripodal stance (that is, to rear up on hind legs, balanced by the tail) because, with mainly low-nutritional conifers as the reward, it was not worth the exertion. However, with each of the neck vertebrae full of weight-saving pneumatic cavities and with the center of mass located near the hips, a tripodal stance for diplodocid sauropods was feasible both to facilitate reproduction and also to extend their feeding range.

In a more recent article, Stevens and Parrish commented on Brachiosaurus, a sauropod that was constructed differently than the diplodocids. Brachiosaurids had longer front legs than hind legs and an upward-rising back that would have resulted in a "neck that rises steeply at its base." It was for this reason that the neck posture of Brachiosaurus was depicted in the giraffe-like S-shape with the head almost 40 feet above the ground. A detailed analysis of the cervical and dorsal vertebrae in several specimens, however, convinced the authors that Brachiosaurus would have had "a remarkably straight neck at the base, quite contrary to most restorations." They further stated that "restoring the neck of Brachiosaurus as extending straight from the shoulders, however does not change its undisputed role as high browser" because the height of its head in the neutral pose would have been at least as high as that of Apatosaurus at maximum dorsal extension. They also thought that the neck of Brachiosaurus was flexible enough to reach the ground without splaying its legs. Stevens and Parrish concluded that "we have yet to find any sauropod with evidence of osteological adaptations for an upraised neck in the undeflected, neutral pose." Also, it seems unlikely that Brachiosaurus could assume a tripodal stance because its center of mass was located substantially forward from the hips.

Not everyone, however, is in agreement with the horizontal neck scenario. Mike Taylor and his colleagues studied X-rays of various living animal groups and found that animals with upright leg postures (mammals and birds) hold their necks vertically. Also, modern animals display a high degree of flexibility of the neck vertebrae so that the overlapping facets mentioned above have a greater range of motion than that assumed by Stevens and Parrish. Giraffes can engage in...
Glaciers: Cool as Ice

Imagine standing near the South Pole on ice that is almost 9,000 feet thick. The ice is so thick that you could fit eight Empire State Buildings stacked on top of each other under the ice. The ice sheet has been building for thousands of years and is the result of the climate being cold all year. The only moisture that ever falls is in the form of snow. The imaginary ice sheet that you are standing on is a glacier. A glacier is a large body of ice on a land surface. Glaciers cover 10% of the Earth’s land mass today, and 75% of the freshwater on Earth is contained in glacial ice.

Glaciers form when snow falls and accumulates in areas that are cold most of the year with little snowmelt in the summer, therefore the snow fall accumulation is greater than the snowmelt. As the snow piles up, it becomes heavier and creates more pressure on the snow at the bottom. The pressure causes the snow to compress and become ice.

A glacier might seem like a giant ice cube that sits in one place, however it actually moves very slowly. Because glaciers are made of ice (a form of water), scientists refer to their movements as “flowing.” Over hundreds or thousands of years, glaciers can “advance” (flow forward by adding new snow and ice to the front) or “retreat” (flow backwards by melting snow and ice from the front of the glacier).
Glacial Landscapes

As glaciers advance and retreat, they change the shape, or landscape, of the Earth. As glaciers move, they crush and scrape the soil and rock below. Sometimes huge chunks of rock and debris freeze to the bottom of a glacier and get moved long distances before being deposited by the melting glacier. These “foreign” rocks are called glacial erratics. Geologists study the origins of glacial erratics to learn the path that the glaciers took across an area. The large rock near the entrance to the Museum of the Earth is a glacial erratic that was moved to Ithaca during the last Ice Age, approximately 2 million years ago.

Formation of the Finger Lakes
Did you know that the beautiful Finger Lakes in upstate New York were created by glaciers? The eleven Finger Lakes were once a series of rivers that flowed north. During the last Ice Age, 2 million years ago, large glaciers moved south from Hudson Bay in Canada and covered much of New York. As these large ice masses repeatedly advanced and retreated, they carved deeply into these river valleys. It took almost 2 million years for the glaciers to carve out the deep Finger Lakes. The glaciers retreated from New York only 11,000 years ago!

Today, the Finger Lakes have steep, high walls at the southern ends from the gouging of the glaciers. Ithaca is at the southern end of Cayuga Lake. Cayuga Lake is 435 feet deep, but geologists think that the actual lake depth could be twice as much — there might be as much as 1,000 feet of glacial sediment below the current lakebed!
Make Your own Mini Glacier!

Supplies:
• One paper cup
• A mixture of sediment (rocks, gravel, sand, and dirt)
• Water
• Freezer

Activity:
1. Place a small amount of sediment in the bottom of the paper cup. Add enough water to fill 1/3 of the cup with water.
2. Place the cup with water and sediment in the freezer. Leave the cup in the freezer for 1 day, until the water is solid ice.
3. Repeat steps #1 and #2 until you have filled the cup with 3 layers of frozen sediment and water. It might take 3-4 days to freeze completely.
4. Once all of the water in the cup is frozen solid into ice, peel the paper cup away from the frozen block. This frozen mixture of ice and sediment is your mini glacier.
5. Take your mini glacier outside and find a sloping area of sand or dirt. If you don’t have a sloping area available, ask your parents if you can build a small slope of dirt or sand in your yard. Place your mini glacier at the top of the slope and watch how it changes over time and how it changes the landscape of the slope.
6. Set a schedule of when you will come back to check on your glacier throughout the day (every 15 minutes, every hour, etc.). Record your observations throughout the day. As you observe your glacier, think about the following questions:
   • What happens to the sediment in your mini glacier as it melts?
   • Is it a hot day or a cold day? How long did it take for your mini glacier to melt?
   • What would need to happen to stop your mini glacier from melting?

More fun with mini glaciers:
• Make several mini glaciers with different amounts of water and sediment in each, then compare your results.
• Test mini glaciers during different seasons (winter, spring, summer, and fall) and compare your results.
• Make mini glaciers in a variety of sizes using differently sized paper cups or containers such as milk cartons, then compare your results.
Glacial Maze

Can you help the snowflake find its way to the glacier? Don’t get lost along the way!
neck movement to the point at which overlap is minimal. The authors maintained that sauropods behaved similarly and “must have habitually held their necks extended and their heads flexed,” resulting in a near-vertical orientation of the mid-cervical vertebrae. An erect neck and an elevated head, then, would have been the habitual pose for sauropods and the “osteological neutral pose” would have represented “merely the midpoint between the postural extremes.”

The above discussion is based on osteological evidence that seems to place limits on the orientation and flexibility of sauropod necks. However, the one factor that places the severest restrictions on how high sauropods could raise their heads relates to the circulatory system and the extremely high blood pressure presumably required to supply their brains with blood. Roger Seymour and Harvey Lillywhite addressed this concern and determined that blood pressure would have been so high (at least twice that of a giraffe) with the neck fully erect that “the heart would have suffered the serious mechanical disadvantage of thick walls.” As an example, the authors selected a 40+ ton Barosaurus with an endothermic metabolism and a vertical neck posture. The mass of the heart needed to supply blood to the brain was calculated to have been in excess of several tons. The heart of a fin whale of similar mass, however, weighs only approximately 400 pounds. On the other hand, a vertical neck posture might have been possible for brachiosaurids if they had ectothermic metabolism. For animals the size of sauropods, body volumes (which hold heat) would have been so large relative to their surface areas (which radiate heat) that losing heat would not have been a concern and they could have remained homeothermic — the simple act of walking would generate enough heat to replace any lost during cooler periods. In fact, an endothermic metabolism could have been a detriment to such large animals because they could not rid themselves of excess heat, a requirement for all endotherms, again due to the relatively small surface areas.

Evidence suggests that the seasonal, semiarid to subhumid climate of the Late Jurassic (e.g., the Morrison Formation of the American West) would have supported mostly low- to medium-height vegetation with low nutritional value. Despite these seemingly harsh conditions, the environment supported a diverse population of herbivores, about half of which were sauropods. Some wetlands were present but were probably localized both spatially and temporally. The plants that inhabited this ecosystem included ferns, cycads, ginkgos, and conifers of various sizes. Such vegetation would best be utilized by low- to medium-height browsers. The proposed horizontal necks with substantial lateral range of diplodocids would have been a perfect adaptation for utilizing this type of food resource (high-browsing brachiosaurids were a rare component of the fauna). Such a scenario would, of course, limit or remove any niche partitioning due to differential feeding heights and would seem to indicate unrealistic competition between sympatric species. However, besides the higher feeding ability of Brachiosaurus and tripodal diplodocids, differences in dentition might have sufficed to lessen the competition. Diplodocids were equipped with peg-like teeth that were probably used to crop plants or to strip branches of their leaves, whereas the spatula-shaped teeth of brachiosaurids and camarasaurids were probably used to bite tough vegetation.

George Engelmann and his colleagues suggested several strategies that sauropods might have employed as adaptations to living in such a climate. One likely solution, as mentioned above, would have been for these animals to use an ectothermic metabolism that required less food to maintain. Another possibility is that the digestive system of sauropods was more efficient than that of today’s large herbivores. Also, because large animals have large guts, sauropods could have processed and assimilated larger volumes of plant material, thus overcoming the low nutritional value. In fact, it is possible that the large body size of sauropods was an evolutionary adaptation to the semiarid environment and its vegetation of poor quality. Still another viable possibility is that, because large
animals can trek more efficiently than small animals, sauropod herds might have practiced seasonal migrations following changing climate and food resources.

As I mentioned earlier, our restorations of prehistoric animals and their environments go through waves of reinterpretation as new specimens are found and new speculations are explored. The sprawling, full-sized, lizard-like dinosaur models of Benjamin Waterhouse Hawkins erected near the Crystal Palace in London’s Sydenham Park reflected the speculation that these “terrible lizards” were built like, well, lizards. New specimens and advanced analytical techniques have shown us that comparing dinosaurs to upright-standing animals, such as mammals and birds, is more appropriate, particularly because dinosaurs are the ancestors of birds. The reconstructions that often accompany scientific reports announcing the discovery of, say, a new Devonian tetrapod or Cretaceous feathered dinosaur, represent our latest attempts to accurately portray extinct animals. When we view older restorations, instead of criticizing them for their inaccuracies, we should appreciate the historical perspective that they provide — a progression that has led us to reconstructions of extinct life that illustrate our current speculations on the prehistoric world.

Further Reading

John Catalani is retired from teaching science at South High School in Downers Grove, Illinois. His column is a regular feature of American Paleontologist. Email fossilnautiloid@aol.com.
Teaching the Teacher — What is a Dinosaur?

By Peter Dodson

My department chairman used to remind me that the role of universities is to generate new knowledge and the role of colleges to teach that knowledge. Sounds a little elitist to me. I practice my career in a research-intensive university where the burden of producing new knowledge lies heavily on my shoulders. I suppose that I have done my share over the years. Before I set to work several decades ago, nobody had ever heard of Avaceratops, Paralititan, Suuwassea, or Auroraceratops. Although I concede that these are not yet household names with the cachet of Tyrannosaurus, at least a few people have heard of the dinosaurs that my students and I have described. The other side of the coin is teaching. I do not labor in a research institute or a museum. I have a responsibility to teach. I spend a substantial block of time teaching the anatomy of dogs, horses, goats, and assorted other creatures to eager first-year veterinary students. I love the subject and my students over the years have honored me with a number of teaching awards.

I also teach paleontology in the Department of Earth and Environmental Science, of which I am a member. I alternate years, one year teaching dinosaurs and the next year a survey of fossil vertebrates. Ideally students will take both courses. Last spring, I had the pleasure of teaching a dinosaur course to 15 undergrads. I confess that I am grateful to textbook writers for books that make the teaching of a course so much easier. I had several to choose from, and selected a book by "the two Daves," David Fastovsky and David Weishampel. These distinguished gentlemen are well known to me. Dave Weishampel, my first graduate student, is a professor of anatomy at Johns Hopkins University School of Medicine and senior editor of our co-edited book The Dinosauria (2nd edition, University of California Press, 2004). Dave Fastovsky is a geologist and paleontologist at the University of Rhode Island. Ironically, Dave F. invited me to write a textbook with him, but I was occupied with The Horned Dinosaurs (Princeton University Press, 1996) at the time so I declined and Dave W. accepted instead. "The Daves" published their text, The Evolution and Extinction of the Dinosaurs, with Cambridge University Press in 1996, and brought out a second edition in 2005. Last year, they came out with Dinosaurs – A Concise Natural History (Cambridge University Press), which is considered a successor rather than a third edition. I found this last book as up-to-date as any textbook can be, attractive and inviting, with a suitably large font size for these presbyopic eyes. For my lectures, I used a remarkable set of PowerPoints from my always-generous student Jerry Harris, now a professor at Dixie State University in Utah. I hosted guest lectures by all three of my graduate students and by visiting scholar Dr. Phil Manning. I supplemented my lectures with various specimens brought to class, including modern osteology specimens, personal fossils, and casts. We took two field trips, one to the Philadelphia Zoo and the other to the American Museum of Natural History. A good time was had by all, or at least by all who cared to engage their brains.

The general question that I raise here concerns the need to keep current. This is a matter of concern for all licensed professionals – in the legal profession, the medical profession, etc. As a patient, we want our doctor to be up-to-date on the latest findings. There are annual or biannual continuing education requirements to ensure this. As a university professor, I am not subject to any such requirements. I am practicing anatomy and paleontology without a license. Fortunately, the anatomy of the dog has not evolved very much since I began teaching.

Seriously, how do we make sure that the information that we pass along to our students is current? We have a tendency to pass along what we have learned. In my case, my graduate learning is now nearly four decades in the past. I no longer use yellowed notes from the past only because PowerPoint doesn’t yellow! There are certain topics about which I am reasonably current, especially concerning horned dinosaurs of North America and Asia. But the onslaught of new information in every aspect of science is simply staggering. For example, have you heard of Jeyawati? Rubeosaurus? Kukufeldia? These are but three of the most recently described dinosaurs — all three were described in the summer of 2010 by...
Andrew McDonald, my student. Nice work, Andrew! One could make a career of reading everything new and not have time to accomplish any new work of one’s own. Hence our debt to textbook writers who take the trouble to bring out timely new editions. Boy, does that take work! Props to Michael Benton, Dave Fastovsky, Dave Weishampel, Don Prothero, and their kind!

A parallel problem to that of tracking new taxa is keeping track of new taxonomists. Ours is a reasonably personable field. Our principal society, the Society of Vertebrate Paleontology, attracts 1,000 to 1,200 people to its annual meeting, roughly 20% of the size of a typical Geological Society of America meeting. A specialty meeting, such as the Royal Tyrrell Museum’s horned dinosaur meeting, about which I have reported twice in these pages, brings out fewer than 200 devotees. We tend to know each other and wish to know each other’s students. Neither snobs nor prima donnas, we devotees. We tend to know each other and wish to know each other’s students. Neither snobs nor prima donnas, we want to be accessible at meetings. For one thing, our future students might be out there. I point out to my students how important it is to do a good job of that poster or talk, because students might be out there. I point out to my students how important it is to do a good job of that poster or talk, because of the high probability that they are talking to their future employer! But our field is so strong and growing so fast that it really becomes very difficult to know the players without a scorecard, as the saying goes. Some of the young players are absolute whiz kids really making their presence felt. But it is not easy to get to know them when you are an old fogey.

There is no question that modern electronic communications are a great boon to modern science. We can access journals from our desks without ever setting foot in our campus libraries. We can send our own publications zipping around the world literally at the speed of light, and powerful search engines make our work so much easier today. I am no power user but I find Thomson Reuters’ Web of Science extremely useful. I was demonstrating it to my new graduate student a few weeks ago and I even surprised myself. I accessed a famous 2008 theropod paper and clicked on the "cited by" feature. Lo and behold, I found a paper entitled “The Origin and Early Radiation Dinosaurs,” published in July 2010, only several weeks earlier. (Mind you, the same paper had been available on-line since May). This is the sort of paper that is guaranteed to be cited in future editions of textbooks. The collaborative authorship of the paper illustrates beautifully the course of modern paleontology. There are six authors; perhaps only a quarter of current papers have a single author, which was the norm when I was a student. In keeping with the importance of the topic, the authors collectively have wide experience. Two are British, and four American; four are early in their careers and two are certifiable graybeards, albeit a decade or so younger than I am. The first author is Steve Brusatte, who is so new that he has not yet received his Ph.D. from Columbia University, although he already has considerable involvement in theropod paleontology. He has co-authored several papers on new meat-eaters from sub-Saharan Africa with his undergraduate mentor, Paul Sereno. Sterling Nesbitt earned his Ph.D. from Columbia last year and now has a postdoctoral position at the University of Texas. Nesbitt has worked on both sides of the boundary between dinosaurs and basal archosaurs, having described the Triassic archosaur Effigia, and the basal theropod, Tawa. Randall Irmis, a 2008 Ph.D. from the University of California Berkeley, and now assistant professor at the University of Utah, is an expert on Triassic archosaurs and basal dinosaurs. Richard Butler recently earned his Ph.D. at Cambridge and is still on a postdoc at the State Museum in Munich. Butler is already widely published on dinosaur faunas of Europe, Africa, and China. The greybeards are Michael Benton of the University of Bristol and Mark Norell of the American Museum of Natural History, who is the doctoral adviser of both Brusatte and Nesbitt.

These six authors address a very important question: what is a dinosaur? I once knew what a dinosaur was. Today, the concept comes heavily freighted. A dictionary definition once read "any member of the extinct orders Ornithischia or Saurischia." No more. This old definition, which dates back to H. G. Seeley in 1887, fails today on several accounts. It was thought that each order arose separately from ancestral groups, implying that there was no such thing as a dinosaur; that is to say, it was an unnatural grouping of two unrelated groups. We once called the ancestral group thecodonts, but we now call the common ancestor an ornithodiran archosaur. In 1974, Robert Bakker, then a graduate student at Harvard University, and Peter Galton of the University of Bridgeport published a very important paper in which they reviewed the common structural features of ornithischians, saurischians, and birds, and advocated recognition of a class Dinosauria to emphasize the common ancestry of the entire...
group. These authors recognized features of the shoulder, humerus, hand, pelvis, ankle, and foot as defining characters of a very modern Dinosauria. In 1986, Jacques Gauthier published the first comprehensive, explicitly cladistic statement of theropod relationships. He mapped the distribution of 84 characters across the Archosauria, and defined monophyletic clades within and basal to Theropoda. He introduced the valuable terms Ornithodira, Tetanurae, Maniraptora, and Avialae, and provided a diagnosis of Dinosauria based on nine characters, only one of which (elongated vomers) is a cranial (skull) character. Birds are explicitly included in the monophyletic Dinosauria. Gauthier’s paper is a landmark in our understanding of dinosaur relationships, and subsequent work has tended to refine that understanding and flesh out details. One thing conspicuously absent from the new understanding of dinosaurs is the specification of taxonomic rank. Bakker and Galton each specified that the Dinosauria are a class of Vertebrata that comprises three subclasses — the Saurischia and Ornithischia, enjoying promotions from the level of order, and Aves, demoted from class to subclass. The practice today is to not specify taxonomic rank, according no special privilege to Linnaean categories such as class or order.

What has changed since the seminal work of Gauthier that enables a clearer understanding of the origin of dinosaurs? Since that time, more fossils of Triassic age have clarified the picture, allowing a more accurate view of character distributions. Dinosauria is now a subgroup of Dinosauria, which, in addition to dinosaurs, includes some animals that share features with dinosaurs but are primitive in other ways; these animals are known as basal dinosauromorphs. On the dinosaurian side of the boundary, Paul Sereno in the early 1990s collected new specimens of Herrerasaurus ischigualastensis from the Late Triassic of Argentina, and described a new small basal dinosaur, Eoraptor lunensis in 1993. The most recent basal dinosaurs from Argentina are Panphagia (“eats everything!”), described in 2009, and Chromogisaurus from 2010. New basal dinosaurs from Brazil include Saturnalia and Guibasaurus, both described in 1999, and Tawa from New Mexico in 2009. On the basal dinosauromorph side of the boundary, new taxa include Silesaurus from Poland, a pleasant surprise from a region not known for dinosaurs or their relatives. We also have Sacisaurus from Brazil in 2006, Asilisaurus from Tanzania in 2010, and Dromomerion from New Mexico in 2007. It is now recognized that there is an assemblage of dinosaur-like small tetrapodal archosaurs called silesaurids that show characters once thought to be confined to dinosaurs. We now know that basal dinosauromorphs co-existed alongside dinosaurs for 15 million years during the Late Triassic. Dinosaurs were not an overnight success that immediately led to the disappearance of less derived forms.

In phylogenetic systematics (cladistics), genealogical trees (phylogenies) are constructed on the basis of evolutionary novelties or derived anatomical characters (synapomorphies), but membership in a clade such as Dinosauria does not require that all such characters be present. Thus, a snake is still a member of the Tetrapoda even though it lacks legs because it is situated on the phylogenetic tree of tetrapods. Brusatte et al. accepted the definition of Dinosauria as “the least inclusive clade that contains Triceratops horridus and Paser domesticus.” The latter species, the House Sparrow, is taken to represent all theropods, although any other bird or theropod could have served as a proxy. Although as many as 50 characters have been used to diagnose Dinosauria, it turns out that very few are unique to Dinosauria. The authors recognize seven characters that consistently diagnose the Dinosauria, and a further seven characters of uncertain distribution that might diagnose the Dinosauria but might also characterize a more inclusive clade. Another dozen characters were previously cited as characters diagnostic of dinosaurs, but are now known to characterize more basal dinosauromorphs. The first list contains some relatively familiar characters, including an elongated deltopectoral crest on the humerus, an open acetabulum (hip joint), an expansion of a fossa for temporal muscles onto the skull roof, the presence of epipophyses on the cervical vertebrae, and reduction in the size of the fibular facet on the astragalus of the ankle. Among the somewhat more equivocal characters are the presence of a shelf on the ilium for the caudifemoralis brevis muscle, three or more sacral vertebrae, reduction of digits IV and V on the hand, and loss of the postfrontal bone from the skull. Possibly more disturbing is the list of characters no longer diagnostic of dinosaurs. These include the in-turning of the head of the femur (that contributes so greatly to upright posture), a birdlike ankle and foot, and the glenoid socket of the shoulder facing downward and backward. Characters such as these and others are now found among dinosauromorphs.

It becomes harder and harder for the non-specialist to recognize exactly which fossil is a dinosaur and which is not. For example, the possession of three sacral vertebrae was once taken as clear evidence of a dinosaur. Basal dinosauromorphs Lagerpeton and Marasuchus have but two sacrals, but now Silesaurus has three. The open acetabulum is included on the list of reliable characters that distinguish dinosaurs from dinosauromorphs, but the basal sauropodomorphs Saturnalia and Panphagia lack this feature. It is clear that discoveries from previously poorly-sampled deposits of Middle and Late Triassic age are going to continue to impact our understanding of dinosaurs. Some of the best young minds in paleontology are now focusing on this understudied time interval. The results are bound to be exciting.

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References
More Did You Know?

Glaciers!


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- Compiled by Sara Auer Perry PRI Education Staff

Meiji Techno’s latest stereo zoom microscope is the EMZ-13. With a seven to one zoom ratio and crystal clear optics, this stereo outperforms more expensive models from any manufacturer.

Model PKL is Meiji’s latest LED illuminated ergonomic low profile pole stand. It features adjustable solid state transmitted lighting via light emitting diode array and a powerful LumiLED for incident light. Both emit a very bright even illumination with luminosity and color temperature similar to fluorescent light.

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Our Invisible Close Relatives

By James G. Morin

Microeukaryotes are unicellular eukaryotic organisms that have been around for approximately two billion years. Yet our understanding of their evolutionary relationships with us and even with each other is only now beginning to emerge—and it is a fascinating story.

Time and the Eukaryotic Cell

Bacteria date back at least 3.5 (maybe 3.8) billion years. Eukaryotes date to 1.4-2.7 billion years, so bacteria had the planet all to themselves for at least a billion years! The first multicellular eukaryotes did not appear until 600-800 million years ago, so microeukaryotes were around for 500 million to a billion years without them. These are very long times! Hallmarks of eukaryotic cells are a complex cytoskeleton, internal functional specializations (by compartmentalization) including a nucleus and organelles, cell division by mitosis, sex, and phagocytosis. It is now also clear that eukaryotic cells are chimeras that evolved by "endosymbiosis," with a bacterial cell living within a host cell. Whatever the original cell was (and there is debate about that), alpha-proteobacteria formed a partnership and became incorporated into the early eukaryotes to become the first mitochondria. The genetic and morphological evidence for this critical event are very compelling. By combining two distinct, overlapping genomes, and with lateral transfer of genes, the partners joined forces with augmented genetic capabilities. We now know that there has been much shuffling, replacement, and change in the evolution of the genes between the bacterium (mitochondrion) and the host nucleus. In addition, a lot of coordination was necessary in the molecular traffic across the two sets of membranes. All eukaryotes show this basic cellular organization, but because perhaps two billion years has elapsed since those first eukaryotic chimeras formed, it is not surprising that a variety of microeukaryotic forms have evolved.

Evolving Ideas

Our understanding of the relationships among all living things has been changing for centuries. Before the time of Aristotle, organisms were considered animals (things that moved) or vegetables (things that did not move). Mushrooms, sponges, corals, "lower plants" (algae, mosses and ferns), and higher (green) plants were all first clased as vegetables. Linnaeus in Systema Naturae (1735) codified these two groups into Animalia and Plantae, although by then, sponges and corals were recognized as animals. Within these two great assemblages, fungi were distinct from, but still close to, green plants. Since Linnaeus, there have been many key advances that have contributed to a better understanding of the relationships of organisms. These have come out of explorations to all parts of the globe, the development of evolutionary theory, the quantification of relationships, and technology. With each new innovation, the quality and quantity of our understanding has expanded.

Optical microscopes for observing living things, ushered in by van Leeuwenhoek in 1674, revealed a whole new world of organisms that are invisible to the naked eye. These discoveries showed that the world contains a myriad of tiny things of fantastic design that sprout flagellae, cilia, pseudopods, oaminate skeletons, or cell walls. As microscopes improved, more organisms were discovered and blurred the distinction between plants and animals even more. During the 18th and 19th centuries, mycology (the study of fungi) was born, botany was flourishing, and natural history was on the rise. Microscopes helped lead the way in all of these disciplines, providing a window to the very small. But what are the relationships among these invisible organisms? How do they relate to us?

With the help of microscopes, by the mid-19th century, the fields of natural history, systematics, and evolution converged, stirring intense debate about relationships and the natural position of microscopic forms. Microbes were placed in a Kingdom separate from animals and plants, but there was much contention about them, especially over terminology. This Kingdom was variously labeled Protozoa (proposed by Owen in 1858, although first introduced as a phylum by Goldfuss in 1820), Prototista (coined by Hogg in 1860), or Protista (introduced by Haeckel in 1866). All were defined in approximately the same way, but with a few differences. Each initially included bacteria, microeukaryotes, and (oddly) a few multicellular eukaryotes such as sponges. Haeckel’s famous three-Kingdom system (background figure on this page) shows this version. The situation got even more confusing when others chimed in and redefined each of the terms to suit their own subjective ideas!

Understanding the fundamental distinction between bacteria and eukaryotic cells developed on various fronts between the late 19th and early 20th centuries, and it all revolved around technology—better optics, clinical lab techniques, and chemical methods to study cellular metabolism. First, it was noted that bacteria differed from eukaryotic cells by their lack of interior structures such as a nucleus and their generally smaller size (less than 5 microns versus more than 10 microns for eukaryotic cells, although we now know that bacteria can be as big as 700 microns, and eukaryotes as
small as 0.8 microns!). During this time, chromosomes were shown to be the seat of inheritance, Chaton demonstrated in 1925 that cell division was fundamentally different between bacteria and eukaryotes, and in 1937 he proposed the terms prokaryote and eukaryote to denote this major distinction. At about the same time (1938), Copeland raised Haeckel’s bacterial group, Moneres, to the level of a fourth Kingdom. Surprisingly, although fungi were long recognized as distinct, it was not until 1969 that Robert Whittaker formally proposed them as a fifth Kingdom separate from plants. This five kingdom structure — Monera, Protista, Animalia, Fungi, and Plantae — has been embraced, elaborated, and extensively detailed by Margulis (1982) and others.

After World War II, rapid advances in biochemical methodologies and electronic instrumentation, including the electron microscope in the 1930s, became available as powerful new research tools. Refined collecting techniques revealed new species, genera, classes, and even new phyla of microscopic organisms. With each new technological advance, our window into the world of unicellular eukaryotes expanded. But with each new discovery, evolutionary relationships became more blurred. Some biologists continued to place all microeukaryotes in the Kingdom Protista (or Proctista), but many zoologists placed motile eukaryotes in the Kingdom Animalia, whereas some botanists claimed the photosynthetic ones as plants. Because some of these microbes were both motile and photosynthetic (notably dinoflagellates and euglenoids), these were even claimed by both! Based mostly on external features, various microeukaryotes have been categorized as flagellates, ciliates, amoebozoans, sporozoans, diatoms, dinoflagellates, foraminiferans, or radiolarians. These distinctions became problematic when it was shown that some flagellates could morph into amoebae and back again, and some slime molds could be unicellular or multicellular depending on conditions.

The year 1966 marked the start of the world-wide cladistics revolution when Willi Hennig published his seminal work *Phylogenetic Systematics* in English (initially published in German in 1950); this work provided explicit and testable methods for deciphering the history of life. It embraced Darwin’s central tenet of descent with modification but emphasized that all lineages from one ancestor form a single, monophyletic group (clade). Hennig argued that any clade must include the immediate ancestor and all of its descendants, and can be differentiated from other clades by unique features shared only with members of that clade. Only these unique characters (synapomorphies) provide useful information about that clade’s relationships to other clades. In this system, clades that include some but not all descendants, like the Protocista, are called paraphyletic and should be avoided. Although phylogenetic systematics often caused contention and was slow to be adopted, it now is accepted by most who study the relationships of organisms. Phylogenetic systematics has really only been possible since the development of computers and statistically based computational methods that have allowed the processing of enormous datasets.

Finally there has been the molecular revolution started by Watson, Crick, Franklin, and Wilkins who, in 1953, demonstrated that genes were encoded in DNA. Subsequent unraveling of the genetic code, understanding transcription and translation of DNA, determining the role of restriction enzymes, developing the polymerase chain reaction (PCR) for gene amplification, and other advances have led to the field of molecular genomics. Publication of gene sequences has increased exponentially: the first gene (1972), virus (1976), bacterium (1995), single-celled eukaryote (yeast in 1996), multicellular eukaryote (a nematode, 1998), and higher plant (2000). Currently over 1,600 genomes are completed and over 6,000 more are in progress. Melding phylogenetic principles with molecular genomics has opened up the field of molecular phylogenetics and it has revolutionized our view of organisms’ relationships. We can now ask: how are organisms related at the molecular and genetic levels?

So what are microeukaryotes and multicellular eukaryotes relationships? The old view of amoebae, flagellates, ciliates, and sporozoans is long gone. During the middle of the 20th century, a bewildering array of hypothetical relationships was proposed, fueled in part by discovery of whole new groups that did not fit well anywhere. Things were pretty chaotic and hard to understand even if you were an expert. They still are. Compounding these issues is the fact that new phylogenies have shifted taxa formerly thought to be related into widely distantly related groups. As a result, a single clade can now cut across disciplines, each having its own vocabulary and nomenclature previously distinct from the others. For example mycologists, protozoologists, protistologists, botanists, and parasitologists now find themselves working on the same clades and struggling to understand and share disparate terminology and ideas.

**Today’s Hypothesis**

Over the past 20 years or so, the accumulating evidence has supported a new view that there are six monophyletic “super-groups” of eukaryotes, four of which contain multicellular taxa. There is still much contention between various "camps" about the exact composition and names of each group, what evidence is useful, and which methods are best. Still, key molecular differences have been found among the panoply of microeukaryotes. The resulting phylogenies have allowed re-examination of differences seen by light and electron microscopy to show which elements have led to spurious conclusions in the past. Useful structural synapomorphies include the internal cristae of mitochondria, the structure, placement, and arrangement of flagellum, and certain surface structures.

Eukaryotes today are represented by two major branches:unikonts and bikonts (*kont* = pole). Ancestrally, unikonts have a single anterior flagellum, and bikonts have two. The six supergroups are:
(1) **Opisthokonta** *(opistho = at the back):* You are an opisthokont unikont! Opisthokonts have a single posterior flagellum (the arrangement in human sperm) and plate-like mitochondrial cristae. Most are multicellular. This group includes Fungi, Animalia, and the small group Choanoflagellata. So, contrary to phylogenies as recent as 40 years ago, fungi are closer to animals than plants!

(2) **Amoebozoa** *(amoeba = changing):* These unikonts have a single anterior flagellum in some stages or some taxa and also display broad (lobose) pseudopods; some are multicellular. Amoebozoans include free-living and parasitic amoebae, and some (but not all) slime molds.

(3) **Rhizaria** *(rhiz = root):* Rhizarians are microeukaryotic bikonts that include the familiar radiolarians and foraminiferans. Although superficially similar to amoebozoans, the cytoskeletal elements of rhizarians produce long, narrow pseudopods (hence their name) with which they capture prey, instead of the broad, lobose pseudopods of amoebozoans. Most also have a protective, often highly sculptured shell or test of silica or calcium carbonate.

(4) **Excavata** *(excavata = outside cave):* The name comes from a ventral food groove in many taxa of this mostly microeukaryotic group. Most have two or more flagellae and disc-shaped mitochondrial cristae. Included are the euglenoids, including the familiar photosynthetic *Euglena*, the parasitic trypanosomes *(e.g., Trypanosoma that causes sleeping sickness)*, the diplomonads including *Giardia* (a common worldwide intestinal parasite), and the parabasalids including *Trichomonas*, which causes the most common sexually transmitted disease in humans in industrialized countries.

(5) **Archaeplastida** *(archaeplasta = ancient form):* This supergroup includes most of the multicellular (green and red) algae, all higher plants, and some microeukaryotes. Archaeplastids are characterized by primary plastids (chloroplasts that contain chlorophyll a) and platycristae in their mitochondria. Chloroplasts evolved via endosymbiosis over a billion years ago. Cyanobacteria became engulfed by a microeukaryote and the resulting symbiosis gave rise to about half of the photosynthesis (oxygen production) on Earth today! Changes in chlorophyll structure and storage materials gave rise to the red and green algae; the plants proper evolved from a green-algal ancestor.

(6) **Chromalveolata** *(chrom = color; alveoli = small hollow pit):* This is a diverse and complicated group with two major branches. The Alveolata possess a unique system of closely packed sacs beneath the cell membranes. They are mostly microeukaryotes, including dinoflagellates, which are dominant in the phytoplankton, the ciliates, and some of the most deadly parasites *(e.g., malaria)* on the planet. The Stramenopiles *(stramin = straw)* are characterized by lateral hairs on one of the two flagella and tubular mitochondrial cristae. This group includes the enormous multicellular brown algae (kelps and rockweeds), two dominant phytoplankters (diatoms and coccolithophores), a small group of slime molds (slime nets), and water molds (oomycetes). About half of the globe’s oxygen is produced by chromalveolates. Chromalveolates’ photosynthetic capacity appears to have arisen by secondary endosymbiosis between two eukaryotes: a non-photosynthetic microeukaryote and microeukaryotic archaeplastid. In other words, a descendent of a primary endosymbiosis event was itself engulfed and incorporated by yet another microeukaryote!

So in summary, there is a consensus is building about the complex phylogeny of microeukaryotes and their bulky, multicellular descendents. New technology and new data have changed everything. Our view of eukaryote phylogeny is radically different from Haeckel’s time, which is different from Whitaker’s time. Phylogenies 50 years from now are likely to have changed again, but less so than in the past. Our ideas too might be relegated to a “dusty” computer file, superceded by technological advances to come. It is an exciting time of discovery, so stay tuned.

An expanded version of this essay, with a list of suggestions for further readings can be found on the AP website *(http://www.museumoftheearth.org/publications)* under this issue.

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Perhaps the greatest beauty of fossils — from the massive skeletons of brutish dinosaurs to the delicate shells of ancient trilobites — is the endless bounty of secrets found buried within. Standing at the forefront of time’s history, it’s only through fossils that humankind can even begin to appreciate life’s grand history. It’s a history four billion years in the making, and it’s a story that will continue to unfold long after our own species, Homo sapiens, is long extinct from the Earth.

Found within the wine-producing hills of the Finger Lakes region, the Paleontological Research Institution and its Museum of the Earth are dedicated to the preservation of extinct beasts and their fossilized remains, as well as the stories locked within their dusty bones and shells. Opening its doors to over 30 thousand visitors per year, the Museum showcases nearly 600 fossil specimens to present the story of life’s amazing, four-billion-year history. Clues to this history, however, are not confined to the spaces defined by the Museum’s concrete walls. In central New York, limestone and shales make up the Earth, and within these layers are buried clues to the area’s prehistoric past: broken shells and skeletons of animals that once thrived in a vast inland sea.

Three hundred and eighty million years ago, on the very spot where the Museum sits today, clam-like animals called brachiopods littered the sea floor, their shells opened slightly to capture food floating by. Varieties of corals carrying the shapes of horns and honeycombs lived in great colonies. Sea lilies swayed in the surf on their long, fragile stalks. Bug-like trilobites crawled about the mud, digging for food and occasionally flitting into the open waters above. And fishes swam about: the bony-headed placoderms — now extinct — were at the pinnacle of their evolution, with forms like the 20-foot-long Dunkleosteus dominating the food chain, while primitive sharks and the ancient relatives of today’s goldfish began their evolutionary odyssey.

Today, explorers of all ages comb the hills and valleys of central New York, keeping a watchful eye for brachiopods, sea lilies, and — that prized fossil — a trilobite, complete from head to tail. To find such fossils is a wonder; to think that one’s eyes are the first to ever see that creature and know of its existence is breathtaking.

On October 23rd and 24th, PRI participated in the USA Science & Engineering Festival. Held on the National Mall in Washington, DC, the festival represented a celebration of science and technology, bringing together institutions and societies from across the country to teach visitors young and old about everything from microbes and meteors to rockets and robots. For its part, PRI transported over 1,500 pounds of New York shale to the festival. There, over the course of two days, more than 5,000 kids, parents, and grandparents were able to dig for their very own brachiopod or trilobite, and they were able to take home their discovery to share with brothers, sisters, classmates, and teachers.

Too often, life’s history is learned via the printed page or the spoken word. To explore Earth’s past — our past — with those actual dusty shells and skeletons in one’s hand, is a tremendous step beyond. That long-extinct trilobite is no longer a creature of stone but a creature of life, crawling over one’s fingers and tickling the skin with its shifting antennae and scurrying legs. For many at the festival, it was their first-ever fossil discovery. Wonder, excitement, and an appreciation for the planet’s past filled the air! Through its many programs and tireless staff, the Paleontological Research Institution strives to bring the Earth and its history to life, and for two beautiful days this past October — at the steps of the U.S. Capitol — we did just that.

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PRI team members Sara Auer Perry, Kelly Cronin, Kelly Kennard, Steve Durham, Sarah Degen, and Richard Kissel helped over 5,000 visitors of all ages find fossils at the USA Science & Engineering Festival.
Ain’t Misbehavin’


Behavior is the true essence of life. Let’s face it – if it’s alive, it behaves; if it doesn’t behave, it’s not alive! That’s why the prospect of deciphering how ancient organisms acted in the distant past is such a fascinating idea, and that’s why a new publication dealing with fossil behavior is sure to arouse keen interest among paleontologists.

This book is just what the title promises – it is an exhaustive compendium of diverse information about the fossilized evidence of the behavior of ancient animals. It is neither a textbook with lucid explanations of complex concepts, nor a symposium volume of detailed case studies, nor an engaging narrative of intrepid scientific adventures. Rather, the book is filled with a plethora of anecdotes and data that provide a springboard into further explorations of the vast literature on fossil behavior. It clearly is not the sort of enthralling read that one might take to the beach on a lazy summer afternoon or curl up with in front of the fireplace on a chilly winter evening.

The authors – Boucot a brachiopod paleontologist and Poinar a parasitologist and paleoentomologist – act more as compilers of annotated references from paleontologic literature than as commentators and interpreters of that literature. The book is hyperorganized into a series of enumerated chapters, subchapters, sub-subchapters, and sometimes even sub-sub-subchapters. This scheme makes the information instantly accessible and gives it an encyclopedic flavor. The references section totals 85 pages, and the three indices (Author, Taxonomic, and Subject) total 27 pages; together they amount to more than one-fourth of the entire book!

The scope of topics covered is enormously wide, which results in such a superficial treatment that most individual topics get no more than a paragraph, and some are allotted just a single sentence. This strategy of maximum breadth at the expense of depth is maddeningly unsatisfying to a reader who would delve into the book in search of a thorough understanding of any particular subject, but it directs the reader to pertinent primary sources so that the eager aficionado can dig more deeply into the subject. Some notable exceptions to this extreme brevity include slightly longer descriptions of organisms (mostly insects) trapped in fossil amber in such a way as to reveal their activity at the exact time of death.

There are four pages of remarkable photos of amber-encased insect pairs caught in the very act of mating, followed by seven pages of photos of insect parents captured alongside their tiny eggs.

Because the subject of animal behavior is so wide-ranging, this compendium includes an extremely diverse array of topics. There are 36 chapters (not counting “Summary and Conclusions”), dealing with such disparate areas as mutualism, parasitism, predation, and infectious diseases in the fossil record. Schooling, herding, and reproductive behavior of ancient animals are documented ever so briefly. The extensive trace fossil record of dwelling, resting, feeding, and locomotion behaviors is distilled down to about a dozen pages.

A quirky but somewhat intriguing feature is a “Reliability” assessment of each and every topic. The case of a “velociraptorine feeding on a pterosaur” (Chapter 6C11t) is rated as Category 1 for the unquestioned certainty of the behavioral interpretation based on a “frozen behavior” criterion. The case of failed “predation on dacyrocaninids” (Chapter 6A1zf) is rated as Category 2B for raising only a little doubt of the interpretation based on a “functional morphology” criterion. But the case of “algal and fungal Paleozoic microborings in corals” (Chapter 9Aj) is rated as “fairly speculative” within Category 6 “because of the varied uncertainties.”

I myself feel uncertain as to whom this book should be recommended. It is so replete with undefined technical jargon and arcane taxonomic names that I imagine it would be out of reach for most amateur paleontologists. However, professionals in the field might find it a helpful resource for background information about a great diversity of paleontologic topics.

- Tony Ekdale

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Teaching Paleobotany in the 21st Century?


Cleal and Thomas’ An Introduction to Plant Fossils is, in some ways, the antithesis of Taylor, Taylor, and Krings’ Paleobotany: The Biology and Evolution of Fossil Plants (2nd ed., 2008, Academic Press). At 248 pages, this is a trim and portable book, in contrast to the 1,252 pages of encyclopedic detail offered by Taylor and colleagues. Nothing against the Taylor approach. I own copies of all editions and recommend it to students who want to study fossil plants beyond the introductory level. But I have never been able to teach with it.
In contrast, Cleal and Thomas have created a book that could be used in the classroom, that fits easily in the undergraduate backpack, and whose chapters can be digested amid FaceBook, chemistry homework, the other things undergraduate science students are called to do.

Such a book, designed for teaching, begs two important questions: Should we be teaching paleobotany at the undergraduate level? And if so, what should we be teaching?

As you might imagine – because I wear a paleobotanical hat from time to time – my answer to the first question is a resounding YES! From that parochial point of view, paleobotanists must ignite passion in beginning students if the field is to continue to thrive. But the reality is that I have taught paleobotany to hundreds of undergraduates, yet can count those who have gone on to graduate study in the field without exhausting the fingers of one hand. More importantly, I have found in my own teaching that paleobotany provides an excellent venue for more general lessons in evolution, Earth history, and function of the Earth system. With due respect to my colleagues, sexier fossil groups like dinosaurs and trilobites do not illuminate these themes quite as well.

So if we should be teaching paleobotany, what should we be teaching? This is a much more difficult question. The traditional paleobotany class begins with a review of plant anatomy and preservation, hits the high points of Earth’s early history, then steps off on the Ordovician appearance of land plants and marches resolutely toward the present, angiosperm-dominated world. This is very much the course for which Cleal and Thomas have written. They begin with the intriguing question, “what is a plant?” Next, they describe the fossil record and its uncertainties, provide an interesting history of the field, and describe the process of studying fossil plants. Then, as is typical of most such books, they devote a chapter each to the major grades and clades of land plants: early land plants, lycophytes, sphenophytes, ferns, gymnosperms, and angiosperms. A particularly interesting teaching gimmick in each of these chapters is a box that guides the student in identifying the plant group at hand. The book concludes with an overview of vegetation history: from the diminutive coastal communities of the Early Devonian, to the first forests just a few tens of millions of years later, to the great Paleozoic coal swamps; from the fern-cycad prairies and conifer forests of the Jurassic to the angiosperm blitzkrieg of the Late Cretaceous, and a world reshaped by Tertiary climate change. It is a solid course, a comprehensive and completely consensus overview. Cleal and Thomas have taken a just-the-facts-ma’am approach that acknowledges some of our contemporary debates, but steers well clear of them. It is a book wisely designed for a long shelf life.

But is this the sort of course that is going to grab the 21st century undergraduate and teach those larger lessons that are so important for the educated voter – whether or not she (and the majority today seem to be women) becomes a paleontologist? I’m not so sure. Now I am writing from the American point of view, whereas Cleal and Thomas write from a European, and particularly British, perspective. I’ll be the first to acknowledge that students are different. But as an American educator, my students find the recitation of organismal form and consensus opinions a bit flat. Not that such a course would get bad reviews — American students are conditioned to memorize facts, fill in worksheets, and regurgitate details on standardized tests. They find such an approach comforting. But what do we really need to be teaching them?

We need to teach them how science works. Students need to know that the scientific process starts with a question, posed from that uncomfortable place of not knowing. They need to understand that research doesn’t always lead to the answer we expect, and that is actually a good thing. They must understand that creativity is not just for the artist and that sometimes we have to make up new techniques and test outrageous ideas. And they need to realize that answers come from digging in and thinking hard, not from skimming lightly over the surface and going out for a coffee. We need to convey that fossils can be puzzling, ambiguous, and downright confusing. We need to teach them how to pose testable hypotheses in the historical sciences. We need to talk about the debates over questions for which we just don’t have good answers. And we need to model how a professional debate proceeds, with ideas and evidence and inference. The excitement of paleontology is that one chance discovery between two layers of sediment can rewrite what we thought we knew for a fact. So it is probably less important to teach the “facts.” Don’t get me wrong; we can’t escape teaching the basics of plant anatomy and the cavalcade of extinct plants. But these foundational data need to be liberally mixed with the controversies and unanswered questions because, more than ever before, our students need to understand that science has not answered all the questions, and probably never will. They need to see that the world is wonderfully complex and just waiting for them to figure it out.

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Two Tomes


Together, two recent releases, *Evolution: The Story of Life* and *Prehistoric Life: The Definitive Visual History of Life on Earth*, present a sweeping overview of paleohistory. Although not published by the same entity, their similar size, complementary contents, and basically concurrent release dates offer an encyclopedic pair of companion volumes.

*Evolution*, written by Douglas Palmer and competently illustrated by Peter Barrett is a refreshing approach to a topic with no shortage of predecessors. Growing out of the requisite chapters outlining the basics of evolution and its history, the book presents an illustrated walk through the entire story of life via the world’s most important fossil sites. This panoramic collection of 100 two-page spreads of as many localities and their paleobiotas represents the meat of the book and is the book’s most impressive attribute. Kudos to the gutsy Barrett for taking on such a formidable task.

Accompanying each painting is a variety of supporting information: a timeline marking the site, geographical and environmental locality details then and now, a brief explanatory text, plus photos and descriptions of the fossils found there. Of course, all the famous lagerstätte get their dues, including very recent discoveries such as New Mexico’s Hayden Quarry, but a rich selection of lesser-known, but just as important sites flesh out the story.

Following this section is a very ambitious dissection of the tree of life, dividing it into manageable sections incorporating the organisms from the paintings. Next is a descriptive site list, handsomely reinforced with two-page photo spreads showing many of the localities mentioned (a reference all-too-often ignored in this kind of compendium). Rounding out the book are several more reference chapters and, finally, a double-sided foldout with the complete 3.46-billion-year timeline on one side and, on the reverse, an extraordinary thumbnail view of *all* of its paintings, stitched together chronologically.

The oddly placed Cambrian explosion and major extinction foldouts (appearing between the Chengjiang and Burgess Shale spreads and the Paleocene and Eocene spreads, respectively) might just be production slips, but some of the other errors are more surprising. The entry on the Ordovician of Trenton, New Jersey, should actually be Trenton Falls, New York. Not merely a typo, the error accretes and is thus transmitted throughout the supporting text. And conspicuously missing in the spreads is the well-documented story of whales: only one Cenozoic scene is marine.

*Prehistoric Life* is published by DK Publishing, and true to DK’s style, this book calls on a huge cast of expert contributors: literally dozens, including Palmer, the author of our other volume, covering every facet of paleontology. As with other DK titles, this one is rich with imagery, boasting over 2,500 color images, including passable computer-generated restorations.

Of course, the book can’t and shouldn’t call itself “definitive,” as the full title indicates, but I’d settle for “comprehensive.” The heart of the book is a very even-handed catalog of the Earth’s past species, illuminated in rich detail with introductory texts, diagrams, charts, and maps for each time period, with particulars for every spotlighted organism. Each entry has a beautiful, often anatomically-labeled, photo of the fossil and includes not only descriptive text, but also critical stats, size comparison, and, often, restorations and explanatory diagrams. Also peppered throughout are sidebars bringing in related topics and profiling scientists of the past.

Best of all, the fossil characters and their interpretations are extremely current, such as *Odontocheles* (the Triassic, toothed, half-shelled turtle) and *Titanoboa* (the largest snake). Both of these stories broke as this book was being produced. And commendably, “non-charismatics,” like rostroconchs, are given a rare chance to make a name for themselves amongst all the flashier fossils.

But the book is no mere catalog. The incredible fossil stories are given context with a foundational section briefly dealing with such topics as extinction events, plate tectonics, evolution, the geological timescale, and the varieties of fossils. Special attention is given to our own human fossil record. Finally, a glossary and a complete list of known non-avian dinosaurs with brief descriptions closes out the volume.

Some of the design choices are unfortunate. All of the names of taxa that appear in headers are in non-italics. But more worrying is the use of all capitals for some of the bino-
mens found in headers. Maybe I’m being too pedantic, but I find them almost as jarring as misspellings. And some of the errors are inexplicable, like the shot of a slab of the Eocene teleost Gasius cithorys used as the iconic representation for the Devonian section, or the Carboniferous Phlegethontia slithering over lily pads, from a flowering plant that probably didn’t go back much more than 130 million years.

Although both books are visually stunning, it’s clear that neither was produced merely as “coffee table” fare – an enormous amount of research went into their creation. They are remarkably up to date: both include Darwinius, the controversial Eocene primate from Messel. Minor spelling and factual errors are more than made up for by each volume’s overwhelming scope and depth. If not for yourself, and if not merely for the bizarrely reasonable price (each lists at around $40), I seriously recommend seeding the library of the next generation of naturalists with this pair.       - Carl Mehling

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FOSSIL FOCUS

By Ursula Smith

Until recently, the phylum Bryozoa was unique among all animal phyla in not having fossils making their first appearance during the Cambrian Period, 500 million years ago. But earlier this year, scientists at the New York State Museum, in Louisiana, and at the Universidad National Autonoma de Mexico discovered the first Late Cambrian bryozoan. Although bryozoans were late-comers, the phylum underwent an evolutionary radiation in the Early Ordovician similar to those that other phyla experienced during the Cambrian.

Bryozoa are actually colonies of many individual zooids (tiny soft-bodied anemone-like bodies) living together. The surface of the bryozoan colony is covered with tiny openings, each leading to the living chamber of a zooid. Colonies are found in all sorts of aquatic habitats, although most are marine. They can form a wide variety of different shapes and don’t all produce calcareous hard parts to support the zooids; the non-marine species use a jelly-like substance instead. Those colonies that do produce hard parts create many different shapes. Today, the most common is the encrusting form, in which the colony grows in a thin layer over surfaces of rock or shell or seagrass blades. Other forms are more three-dimensional, with the zooids supported above the surface in delicate fan-like or clump-like forms. Tree-like colonies, in which the zooids are supported on branching structures, are extremely common in the fossil record, and at first glance, look remarkably like branching corals.

The Archimedes bryozoan pictured here is perhaps the most aesthetically pleasing of the Bryozoa, and certainly has an extremely unusual shape for any fossil or living organism. Its corkscrew nature is fascinating, and is, of course, the source of its name—Archimedes from the Archimedes screw (a machine that employs a screw inside a tube to move water up an incline). The specimens pictured here are quite small fragments of a larger colony which would have been attached to the sea floor and stood erect to elevate the zooids into the water.

Ursula Smith is a recent Ph.D. from the Department of Earth and Atmospheric Sciences at Cornell University.
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