abiotic or biotic factors alone is likely to provide only limited answers. In addition to soils, the impact of herbivores on tropical forests may vary with elevation and along gradients or discontinuities in soil flooding (*10*), light (*11*), and fire (*12*). But for now, the Fine *et al.* work adds to the mounting evidence that herbivory is a major factor determining the plant composition of tropical forests.

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GEOLOGY

A New Period for the Geologic Time Scale

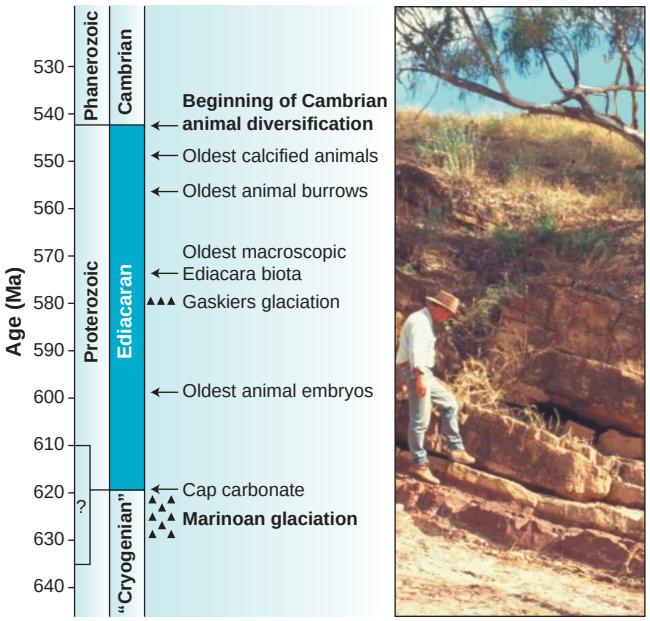
Andrew H. Knoll, Malcolm R. Walter, Guy M. Narbonne, Nicholas Christie-Blick

The geologic time scale stands as a major achievement of 19th-century science, a coherent record of our planet's history fashioned from myriad details of individual rock outcroppings. The eras, periods, and finer divisions of the scale not only codify geologic time, they reflect our accumulated understanding of Earth's past—or at least its more recent past. The Cambrian Period, with its fossil record of animal diversification, began only 543 million years ago (Ma), when Earth was already 4000 million years old (see the figure). In the 19th century and for much of the 20th century, the beginning of the Cambrian (also the beginning of the Paleozoic era and the Phanerozoic eon) marked the most distant temporal reaches of Earth's tractable historical record. The absence of skeletonized fossils that mark Phanerozoic time made Precambrian rocks difficult to correlate, and so the fine stratigraphic divisions of the younger record gave way to broad intervals that permitted only limited insight into foundational events of Earth history. In 1991, perhaps out of resignation, the International Union of Geological Sciences (IUGS) approved a division of Precambrian time into eons, eras, and periods defined strictly by chronometric age, without reference to events recorded in sedimentary rocks (*1*). The eras stuck, but the proposed period names are seldom used.

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This tradition was swept aside in March this year with the approval by IUGS of an addition to the geologic time scale: the Ediacaran Period (*2*). This newly ratified period, which directly precedes the Cambrian, is the first Precambrian interval to be defined according to the principles that govern the Phanerozoic time scale. It is also the first stratigraphically defined new period of any sort to be added since 1891 when Williams divided the Carboniferous Period in two (Mississippian and Pennsylvanian). The distinctive character of the Ediacaran interval has been recognized for decades, and numerous geologists—including Sokolov, Termier and Termier, and Cloud and Glaessner (*2*)—have proposed formal definitions of this interval. Now, in accordance with international rules, the new period has been defined by an event recorded in a single section of rock outcropping termed the global stratotype section and point (GSSP). (The GSSP is the reference section that defines the "standard" for recognition of the base of the new period worldwide.) The initial GSSP of the Ediacaran Period lies at the base of a texturally and chemically distinctive carbonate layer that overlies glaciogenic rocks in an exposure along Enorama Creek in the Flinders Ranges, South Australia (*2*) (see the figure). The period's end coincides with the beginning of the Cambrian Period, which is defined by its own initial GSSP residing in Newfoundland, Canada.

Formalisms aside, international ratification of the new period reflects our expanding knowledge of Earth's deep physical and biological history. The Ediacaran Period, in fact, constitutes a distinct chapter in that history, bounded below by global ice ages and above by the diversification of animal life—and characterized most vividly by the unusual, mostly soft-bodied fossils that give it its name. The unique morphologies of the Ediacara biota have spawned widely varying systematic interpretations—from giant protists and lichens to seaweeds and extinct experiments in multicellularity. Most paleontologists, however, agree that the assemblage includes early cnidarian-grade animals, as well as burrows and trails and perhaps body fossils of early bilateral organisms (bilaterians) (*3*).



Looking for a few good rocks. (**Left**) Major events associated with the Ediacaran Period. Brackets indicate uncertainty in the chronometric age of the GSSP. (**Right**) The formally defined base (GSSP) of the Ediacaran Period in Enorama Creek, Australia, is located at the contact of Marinoan glacial rocks and overlying Ediacaran cap carbonates (at the right foot of the geologist).

Dates are important. The beginning of the period remains to be determined precisely, but the uranium-lead (U-Pb) zircon dating method gives a maximum age of 635.5 ± 1.2 Ma for zircons from volcanic ash within glacial diamictites in Namibia (*4*). Meanwhile, a Pb-Pb date of 599 ± 4 Ma for postglacial phosphorites from China (*5*) provides a minimum age for the beginning of the Ediacaran Period. The earliest known animal fossils—microscopic eggs, embryos, and segmented skeletal tubes—are found in the phosphorites (*6*). Following one last, regionally distributed glaciation, moderately diverse macroscopic fossils appear in ~575 Ma rocks from Newfoundland (*7*). Bilaterian animal trails enter the record no later than 555 Ma, and calcified skeletons (of a distinctively Ediacaran, not Cambrian, aspect) by 549 Ma (*8*). Ediacaran assemblages persisted until the end of the period, separated from Cambrian diversification by a major, short-lived perturbation in the carbon isotopic record.

If Ediacaran fossils characterize the period, why don't they define it? The simple answer is that the fossils are scarce and, consequently, there are large uncertainties regarding correlation. Among sedimentary basins, the first appearance of Ediacara-type fossils can differ by 10 million years or more. This is why the Ediacaran Period departs rather abruptly from Phanerozoic convention in defining the beginning of the period by a climatic/geochemical event. The unusual depletion of ^{13}C in the texturally striking carbonates that veneer Marinoan glacial rocks is recognized globally and widely accepted as a paleoceanographic signature of rapid deglaciation, although mechanistic interpretations differ (*9*, *10*). More generally, large secular variations in the isotopic compositions of carbon, sulfur, and strontium have come to play an important part in the correlation of Neoproterozoic (1000 to 543 Ma) sedimentary rocks. This works well because younger Proterozoic strata record huge secular variations in the composition of seawater that reflect not only global ice ages, but also biospheric oxidation and global tectonic events. Indeed, the Neoproterozoic has emerged as a primary focus of Earth systems history, as scientists seek to understand the complex interactions between planet and life that gave rise to the Phanerozoic world. Testifying to this effort, the new Ediacaran Period provides a first extension of the geologic time scale into Earth's Precambrian past. It will not be the last.

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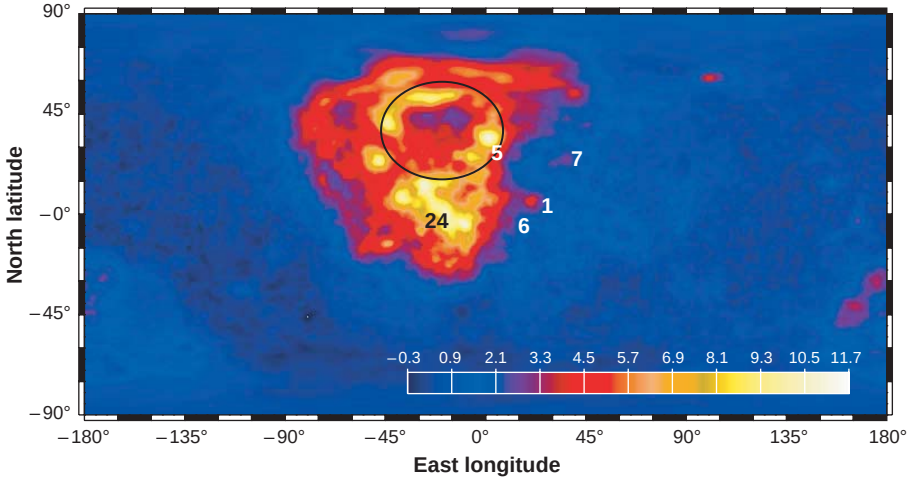
PLANETARY SCIENCE

A Unique Chunk of the Moon

Randy L. Korotev

In 1982 a team of U.S. scientists collecting meteorites in Antarctica found a fragment of the Moon. The 31-g meteorite, now called Allan Hills (ALHA) 81005, had once been a rock or a piece of a rock that existed at or near the Moon's surface. At some time in the past, a meteoroid collided with the Moon and accelerated the rock to lunar escape velocity. After orbiting Earth for less than 200,000 years, the rock was captured by Earth's gravitational field, landed in Antarctica, and was buried by snow. There it became a miniscule part of a huge glacier, which also carried other meteorites that had fallen over the years. The glacier's flow is impeded by the Transantarctic Mountains, and near the mountains meteorites are continually exposed at the surface as wind and sun ablate and sublime away the ice that encases them. The collecting team immediately recognized that ALHA 81005 did not look like the other meteorites that they were collecting, all of which were fragments of asteroids. Meteorite curators at the NASA Johnson Space Center, having seen a lot of Moon rocks from the Apollo missions, suspected that it was a Moon rock. Further studies have confirmed their suspicion (*1*). The stone was the first to be recognized as a lunar meteorite, although three others not yet classified had been collected in Antarctica 3 years earlier by a team from the Japanese National Institute of Polar Research. Since 1979, about 30 lunar meteorites have been found, all in deserts. On page 657 of this issue, Gnos *et al.* (*2*) describe the most unique lunar meteorite found to date. This 206-g stone, known as Sayh al Uhaymir (SaU) 169, was found in the Sultanate of Oman in January 2002.

On the basis of the wide ranges in composition, mineralogy, texture, and cosmic-ray exposure ages, the 30 lunar meteorites likely represent at least 20 impacts on the lunar surface, although the crater of origin is not known for any of them. For any given lunar meteorite, the fact that we don't know where on the Moon it originates is a serious detriment to geologic interpretation of data derived from the stone. However, the meteorites are samples from many random locations, and this characteristic provides important information not available from the Apollo samples, all of which were collected on six missions to the central nearside (see the figure).



Rich in radioactive elements. Distribution of thorium on the lunar surface [adapted from (*5*)]. Color scale shows thorium abundance in μg/g. The numbers represent the locations of the six Apollo landing sites (1 = Apollo 11, 2 = Apollo 12, and so on; landing sites 2 and 4 are adjacent). The ellipse indicates the position of the Imbrium basin. The center of the figure is the center of the nearside, as viewed from Earth. Most of the Moon's thorium and other incompatible elements are concentrated in the northwest quadrant of the nearside.

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