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GEOLOGIC TIMESCALE

The geologic timescale is the framework for deciphering the history of planet Earth. It is used by geologists and other scientists to describe the timing and relationships between events that have occurred during the history of the earth.

Nomenclature

The history of the earth is broken up into a hierarchical set of divisions for describing geologic time. In increasingly smaller units of time, the generally accepted divisions are eon, era, period, epoch, and age. The Phanerozoic eon represents the time during which the majority of macroscopic organisms, algal, fungal, plant, and animal, lived. When first proposed as a division of geologic time, the beginning of the Phanerozoic, approximately 542 million years ago (mya), was thought to coincide with the beginning of life. In reality, this eon coincides with the appearance of animals that evolved external skeletons, like shells, and the somewhat later animals that formed internal skeletons, such as the bony elements of vertebrates. The time before the Phanerozoic is usually referred to as the Precambrian. The Phanerozoic consists of three major divisions: the Cenozoic, the Mesozoic, and the Paleozoic eras. The *zoic* part of the word comes from the root *zoo,* which means animal. *Cen* means recent, *meso* means middle, and *paleo* means ancient. These divisions reflect major changes in the composition of ancient faunas, each era being recognized by its domination by a particular group of animals. The Cenozoic has sometimes been called the age of mammals, the Mesozoic the age of dinosaurs, and the Paleozoic the age of fishes. This is an overly simplified view; it has some value for the newcomer but can be a bit misleading. For instance, other groups of animals lived during the Mesozoic. In addition to the dinosaurs, animals such as mammals, turtles, crocodiles, frogs, and countless varieties of insects also lived on land. In addition, there were many kinds of plants living in the past that no longer live today. Ancient floras went through great changes too, and not always at the same times that the animal groups changed.

Few discussions in geology can occur without reference to geologic time, which is often discussed in two forms: (1) Relative time (chronostratic), subdivisions of the earth's geology in a specific order based upon relative age relationships; these subdivisions are given names, most of which can be recognized globally, usually on the basis of fossils. (2) Absolute time (chronometric), numerical ages in millions of years or some other measurement. These are most commonly obtained via radiometric dating methods performed on appropriate rock types.

History

The first people who needed to understand the geological relationships of different rock units were miners. Mining had been of commercial interest since at least the days of the Romans, but it wasn't until the 1500s and 1600s that these efforts produced an interest in local rock relationships. By noting the relationships of different rock units, Nicolaus Steno in 1669 described two basic geologic principles. The first stated that sedimentary rocks are laid down in a horizontal manner, and the second stated that younger rock units were deposited on top of older rock units. To envision this latter principle, think of the layers of paint on a wall. The oldest layer was put on first and is at the bottom, while the newest layer is at the top. An additional concept was introduced by James Hutton in 1795, and later emphasized by Charles Lyell in the early 1800s. This was the idea that natural geologic processes were uniform in frequency and magnitude throughout time, an idea known as the principle of uniformitarianism. Steno's principles allowed workers in the 1600s and early 1700s to begin to recognize rock successions. However, because rocks were locally described by the color, texture, or even smell, comparisons between rock sequences of different areas were often not possible. Fossils provided the opportunity for workers to correlate geographically distinct areas. This contribution was possible because fossils are found over wide regions of the earth's crust.

For the next major contribution to the geologic timescale we turn to William Smith, a surveyor, canal builder, and amateur geologist in England. In 1815 Smith produced a geologic map of

England in which he successfully demonstrated the validity of the principle of faunal succession. This principle simply stated that fossils are found in rocks in a very definite order. This principle led others who followed to use fossils to define increments within a relative timescale.

Arthur Holmes (1890–1965) was the first to combine radiometric ages with geologic formations in order to create a geologic timescale. His book, *The Age of the Earth,* written when he was only 22, had a major impact on those interested in geochronology. For his pioneering scale, Holmes carefully plotted four radiometric dates, one in the Eocene and three in the Paleozoic, from radiogenic helium and lead in uranium minerals, against estimates of the accumulated maximum thickness of Phanerozoic sediments. If we ignore sizable error margins, the base of the Cambrian interpolates at 600 mya, curiously close to modern estimates. The new approach was a major improvement over a previous "hourglass" method that tried to estimate maximum thickness of strata per period to determine their relative duration, but had no way of estimating rates of sedimentation independently. In 1960, Holmes compiled a revised version of the age-versus-thickness scale. Compared with the initial 1913 scale, the projected durations of the Jurassic and Permian are more or less doubled, the Triassic and Carboniferous are extended about 50%, and the Cambrian gains 20 million years at the expense of the Ordovician.

W. B. Harland and E. H. Francis as part of a Phanerozoic timescale symposium coordinated a systematic, numbered radiometric database with critical evaluations. Items in The Phanerozoic Time-Scale: A Symposium, were listed in the order as received by the editors. Supplements of items were assembled by the Geological Society's Phanerozoic Time-Scale Sub-Committee from publications omitted from the previous volume or published between 1964 and 1968, and items relating specifically to the Pleistocene were provided primarily by N. J. Shackleton. The compilation of these additional items with critical evaluations was included in *The Phanerozoic Time-Scale: A Supplement* published in 1971 by Harland and Francis. In 1978, R. L. Armstrong published a reevaluation and continuation of The Phanerozoic Time-Scale database. This publication did not include abstracting and critical commentary. These catalogs of items and of Armstrong's continuation of items were denoted "PTS" and "A," respectively, in later publications.

In 1976, the Subcommission on Geochronology recommended an intercalibrated set of decay constants and isotopic abundances for the U-Th-Pb, Rb-Sr, and K-Ar systems with the uranium decay constants by Jaffey et al. in 1971 as the mainstay for the standard set. This new set of decay constants necessitated systematic upward or downward revisions of previous radiometric ages by 1%–2%.

In *A Geological Time Scale,* Harland et al. standardized the Mesozoic–Paleozoic portion of the previous PTS-A series to the new decay constants and included a few additional ages. Simultaneously, in 1982 G. S. Odin supervised a major compilation and critical review of 251 radiometric dating studies as Part II of *Numerical Dating in Stratigraphy.* This "NDS" compilation also reevaluated many of the dates included in the previous "PTS–A" series. A volume of papers on The Chronology of the Geological Record from a 1982 symposium included reassessments of the combined PTS–NDS database with additional data for different time intervals. After applying rigorous selection criteria to the PTS–A and NDS databases and incorporating many additional studies (mainly between 1981 and 1988) in a statistical evaluation, Harland and coworkers presented *A Geological Time Scale 1989.*

The statistical method of timescale building employed by *GTS82* and refined by *GTS89* derived from the marriage of the chronogram concept with the chron concept, both of which represented an original path to a more reproducible and objective scale. Having created a high-temperature radiometric age data set, the chronogram method was applied that minimizes the misfit of stratigraphically inconsistent radiometric age dates around trial boundary ages to arrive at an estimated age of stage boundaries. From the error functions, a set of age/stage plots was created (Appendix 4 in *GTS89*) that depicts the best age estimates for Paleozoic, Mesozoic, and Cenozoic stage boundaries. Because of wide errors, particularly in Paleozoic and Mesozoic dates, *GTS89* plotted the chronogram ages for stage boundaries against the same stages with relative duration scaled proportionally to their component chrons. For convenience, chrons were equated with biostratigraphic zones. The chron concept in *GTS89* implied equal duration of zones in prominent biozonal schemes, such as a conodont scheme for the Devonian.

The Bureau de Récherches Géologiques et Minières and the Société Géologique de France published a stratigraphic scale and timescale compiled by Odin and Odin. Of more than 90 Phanerozoic stage boundaries, 20 lacked adequate radiometric constraints, the majority of which were in the Paleozoic.

The International Stratigraphic Chart is an important document for stratigraphic nomenclature (including Precambrian), and included a summary of age estimates for stratigraphic boundaries.

During the 1990s, a series of developments in integrated stratigraphy and isotopic methodology enabled relative and linear geochronology at unprecedented high resolution. Magnetostratigraphy provided correlation of biostratigraphic datums to marine magnetic anomalies for the Late Jurassic through Cenozoic. Argon–argon dating of sanidine crystals and new techniques of uranium–lead dating of individual zircon crystals yielded ages for sediment-hosted volcanic ashes with analytical precessions less than 1%. Comparison of volcanic-derived ages to those obtained from glauconite grains yielded systematically younger ages, thereby removing a former method of obtaining direct ages on stratigraphic levels. Pelagic sediments record features from the regular climate oscillations produced by changes in the earth's orbit, and recognition of these "Milankovich" cycles allowed precise tuning of the associated stratigraphy to astronomical constants.

Aspects of the *GTS89* compilation began a trend in which different portions of the geologic timescale were calibrated by different methods. The Paleozoic and early Mesozoic portions continued to be dominated by refinements of integrating biostratigraphy with radiometric tie points, whereas the Late Mesozoic and Cenozoic also utilized oceanic magnetic anomaly patterns and astronomical tuning. A listing of the radiometric dates and discussion of specific methods employed in building *GTS2004* can be found in Gradstein, Ogg, and Smith's *A Geologic Time Scale 2004*.

Calibration

Because the timescale is the main tool of the geological trade, insight on its construction, strengths, and limitations greatly enhances its function and its utility. According to Gradstein, all scientists should understand how the evolving timescales are constructed and calibrated, rather than merely using the numbers in them.

The calibration to linear time of the succession of events recorded in the rock record has three components: (1) The international stratigraphic divisions and their correlation in the global rock record, (2) the means of measuring linear time or elapsed durations from the rock record, and (3) the methods of effectively joining the two scales.

For convenience in international communication, the rock record of Earth's history is subdivided into a chronostratigraphic scale of standardized global stratigraphic units, such as "Paleogene," "Eocene," "*Morozovella velascoensis* planktic foraminifera zone," or "polarity Chron C24r." Unlike the continuous ticking clock of the chronometric scale (measured in years before the present), the chronostratigraphic scale is based on relative time units in which global reference points at boundary stratotypes define the limits of the main formalized units, such as Neogene. The chronostratigraphic scale is an agreed convention, whereas its calibration to linear time is a matter for discovery or estimation. By contrast, Precambrian stratigraphy is formally classified chronometrically; that is, the base of each Precambrian eon, era, and period is assigned a numerical age.

Continual improvement in data coverage, methodology, and standardization of chronostratigraphic units implies that no geologic timescale can be final. *A Geologic Time Scale 2004* (*GTS2004*) provides an overview of the status of the geological timescale and is the successor to *GTS1989*.

Since 1989, there have been several mayor developments. Stratigraphic standardization through the work of the International Commission on Stratigraphy (ICS) has greatly refined the international chronostratigraphic scale. In some cases, traditional European-based geological stages have been replaced with new subdivisions that allow global correlation. New or enhanced methods of extracting linear time from the rock record have enabled high-precision age assignments. An abundance of high-resolution radiometric dates has been generated and has led to improved age assignments of key geologic stage boundaries. Global geochemical variations, Milankovitch climate cycles, and magnetic reversals have become important calibration tools. Statistical techniques of extrapolating ages and associated uncertainties to stratigraphic events have evolved to meet the challenge of more accurate age dates and more precise zonal assignments. Fossil event databases with multiple stratigraphic sections through the globe can be integrated into composite standards.

The compilation of *GTS2004* has involved a large number of specialists, including contributions by past and present chairs of different subcommissions of ICS, geochemists working with radiometric and stable isotopes, stratigraphers using diverse tools from traditional fossils to astronomical cycles to database programming, and geomathematicians. The set of chronostratigraphic units (stages, eras) and their computed ages, which constitute the main framework for *A Geologic Time Scale 2004,* are summarized in the chart available online from the ICS.

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See also Chronostratigraphy; Darwin, Charles; Dating Techniques; Earth, Age of; Geological Column; Geology; Neogene; Paleogene; Synchronicity, Geological; Time, Measurements of

Further Readings

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GEOLOGY

Geology is the scientific study of planet Earth and its history, through 4,600 million years to the present. This natural science is traditionally divided into two branches: physical geology and historical geology. Physical geology focuses on physical structure, materials, and geological processes of the earth. Historical geology examines the origin of our planet and life, and all the climatic, geographic, oceanographic, and biological events that have taken place across geological time. This dual division is rather arbitrary, therefore both points of view (physical and historical) are found currently integrated within the framework of plate tectonics, the current paradigm of geological science.

Physical Geology

Physical geology includes such disciplines as: geophysics (applies principles of physics to the study of the earth); geochemistry (the study of the chemical characteristics of minerals and rocks); mineralogy and petrology (the study of the origin, properties, structure, and classification of minerals and rocks, respectively); hydrogeology (the study of the origin, occurrence, and movement of water masses); structural geology (the study of the deformational history of rocks and regions and of the forces responsible); geomorphology (the study of the origin and modification of landforms); volcanology (the study of volcanoes and magma formation processes); sedimentology (the study of sedimentary rocks and the processes by which they were formed); and engineering geology (the study of the interactions of the earth's crust with human-made structures such as tunnels and mines).

Some areas of specialization for professional geologists related to physical geology include exploration and extraction of natural resources (mineral deposits, coal, oil, etc.), prediction and evaluation of geological hazards (landslides, earthquakes, volcanic eruptions, or meteoritic impacts), evaluation of the stability of construction sites, the search for supplies of clean water, and analysis of environmental problems such as soil and coastal erosion.