Geological time scale

The history of the Earth can be displayed in the form of a calendar which is based on the observation of rocks formed through time. Depending on the location, the formation of rocks has recorded different (regional) histories describing the magmatic, tectonic, hydrospheric, or biospheric evolutions, and thus different calendars have been generated. Geologists (stratigraphers) are attempting to unify these different calendars. Stratigraphers define rock units bracketed between two boundaries that can be correlated worldwide. The succession of these modern units is the global geological time scale.

Stratigraphical units. In general, the evolution of the Earth is continuous, so fixing the location of the unit boundaries can be achieved only through convention (decisions are made under the aegis of the International Commission on Stratigraphy). Stratigraphers use a variety of tools for characterizing the age of a rock, including physical ages, fossils, magnetism, and chemical properties, all of which have evolved through time. There are three intervals in the history of the Earth (Archean-Proterozoic, Phanerzoic, Plio-Quaternary) with each one showing distinct material available for characterizing rocks; thus, there

<table>
<thead>
<tr>
<th>Eon</th>
<th>Era</th>
<th>Period</th>
<th>Ma</th>
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Fig. 1. Agreed-upon geological time scale of the pre-Phanerozoic history of the Earth. The beginning of the Earth is estimated to be 4,470 to 4,570 Ma, with a preferred age at 4,550 Ma.
are three successive kinds of geological time scale. In
the earliest time scale, during Archean and Proterozoic
eons, fossils are rare or absent in most rocks, and
the major tool is the physical dating process
based on naturally unstable isotope decay used by
geochronologists. For this interval of time, the bound-
aries of the calendar units are defined by selected nu-
merical ages (Fig. 1). These ages are conventionally
abbreviated Ma (Mega anna, or million years, follow-
ing recommendation of the Subcommission on Geo-
chronology).

During the Phanerozoic Eon certain animals and
plants elaborated skeletons or exoskeletons that,
when preserved as fossils, provide an additional
means of time correlation (Fig. 2). Up to about 5 Ma,
these fossils become the major tool for determin-
ing the relative age of a rock. Together with other
physicochemical characteristics, fossils allow a de-
nition of stages which cover an average duration of
about 5 Ma each. For the last 5 Ma, Ple-Quaternary
time, there is evidence that the evolution of the envi-
ronment on Earth is diversified and well represented
in the geological record.

Most stratigraphical tools can be used continu-
ously in this young interval, each tool providing a
specific time scale. Because several tools can often
be used to characterize (that is, to date) a single rock,
it is easy to connect all these time scales. A variety
of easily interchangeable time scales are useful.
However, the absolute time dimension for all time
scales can be calibrated only by using geochronol-
ogy. The progress toward a common terminology
and geological time scale benefits from three fac-
tors: better definition of the conventional units, bet-
ter geochronological calibration, and a potential for
extrapolating between calibrated ages.

**Geochronological calibration.** Progress in geochro-
nomical calibration benefits from both new tech-
nology and new geochronological information. Dur-
ing the 1990s, the precision and reproducibility of
the measurements obtained using mass spectrom-
metry have increased significantly. This improvement
offers the possibility of dating minute quantities of
certain material with remarkable precision. Using
the uranium-lead (U-Pb) dating method, the age of
the single crystal of zircon, 200 micrometers in length
and 10 μm in diameter, can be measured. More sig-
nificantly, several portions of this same crystal can
be dated separately, allowing for verification of the
internal consistency of the data obtained from the
single crystal. For the potassium-argon (K-Ar) dating
method, developments in the irradiation techniques
which transform the original potassium into argon
allow single biotite mica flakes 500 μm in diameter
and 10 μm thick to be dated. Laser heating can also
give several ages obtained from different points of a
single crystal.

Explosive volcanic eruptions producing ash
clouds blown over large areas are common. The abil-
ity to date small quantities of material has led to the
search for minor volcanic events within the strati-
 graphical record. This advance is important because
the same volcanic material covers both marine and
continental areas, sometimes at the scale of a conti-
inent, allowing correlation of distant deposits. In ad-
dition, there is great interest in this method since ex-
plosive volcanism often scatters a variety of minerals,
including uranium-bearing and potassium-bearing
ones. Thus, the geochronologist can perform mea-
surements on independent isotopic systems in order
to make a reciprocal check of the validity of the cal-
culated ages. The calibration of the geological time
scale is mostly realized through the study of crystal-
bearing volcanic dust discovered in sediments. Pre-
cise dating can also be achieved through a variety
of other datable materials. For example, a few tens
of milligrams of microtektite particles (scattered in
wide areas when an asteroid collides with the Earth)
can be dated. Another example is calcite crystal-
ized in palaeosols during cyclic deposition in shal-
low basins. Because this calcite is associated with
organic matter which favors uranium enrichment,
and is formed essentially at the time of deposition,
calcite crystals become a potentially datable material
using uranium-lead methods.

**Two examples of refinement.** One example of re-
cent refinement concerns the dating of the Focene-
Oligocene boundary. That boundary has long been
known as the Grande Coupure (great break) in the
history of European land-mammal evolution. There
have been a few European studies which docu-
mented an age at about 34 Ma. But the age of the
boundary was assumed to be about 37–38 Ma by
some North American geologists. Palaeontologists did
not like the latter age because, in North America, the
38-Ma-old mammals were dated using contempor-
aneous volcanic flows and seemed less evolved than
those known to be at the stratigraphical boundary
in Europe. The problem was solved due to a better
boundary stratotype discovered near Ancona in east-
central Italy. Minerals sampled from several layers
of volcanic dust interbedded in the marine deposits
of the stratotype were dated. The results indicated an
age of about 33.7 ± 0.5 Ma for the boundary. This
result confirmed the latter of the two previous pro-
posals demonstrating that the evolution of mam-
mals in Europe and North America was synchro-
nous.

Another significant example of the beneficial com-
bination of improved stratigraphical definition and
modern geochronological dating is given by the
Precambrian-Cambrian boundary. The base of the
Cambrian (and of the Phanerozoic Eon) had long
been placed at the first occurrence of skeletonized
fossils including trilobites (arthropods). Later, a Tur-
bonian pretrilobite stage was added below it in view
of the presence of older faunal remains, such as ar-
chacocystids (calcitized sponge-like forms), which
have been well documented on the Siberian Plat-
form. Before 1980, the earliest skeletonized fauna
were estimated to be between 570 and 590 Ma. How-
ever, independent geochronological data were gath-
ered from northern France, southern Britain, Mo-
rocco, and Israel in the early 1980s. These data were
obtained from levels located below the first occurrence of trilobites in the different countries. The data showed that trilobites were younger than 530 (±10) Ma. In the following years, older faunas known as small shelly fossils contemporaneous with trace fossil assemblages were discovered in China, Australia, the Siberian Platform, and Canada. A modern Precambrian-Cambrian conventional boundary was definitely fixed in 1992 at the base of this fauna in Canada. From new geochronological information obtained from volcanic zircon sampled from the above locations, an age of 540 (±5) Ma was documented for that boundary. This has been of great consequence, considering that the end of the Cambrian is about 500 Ma. The apparently extraordinary radiation of skeletalized metazoans observed within the Cambrian took only a few tens of millions of years (instead of 100 Ma as thought in the mid-1980s). This extraordinary radiation must be compared to the evolution observed over the next 500 Ma during which no new important phyla were created. Two examples that help provide better understanding of geological phenomena connected to the precise dating of geological strata are the short duration of the important biological cuts occurring at the Permian-Triassic (Paleozoic-Mesozoic) boundary and the Cretaceous-Palaeogene (Mesozeo-Cenozoic) boundary.

Extrapolation procedures. The direct geochronological calibration method will never allow for the continuous calibration of every point of geological history, since datable material is much too scarce in rocks. However, continuous dating can be refined through the use of interpolation procedures between geochronologically calibrated points. This principle consists in combining those tie points with a continuous geological phenomenon. Commonly used phenomena are rhythm sedimentation and the oceanic record of past magnetic fields. When the rhythmic deposition of sediments can be related to the orbital (Milankovitch) parameters of the Earth, the time scales of which are reasonably well understood, the duration of deposition can be estimated when combined with nearby measured ages.

Another procedure considers the aperiodic change (reversal) of the direction of the Earth’s magnetic field that is recorded in the oceanic plates being continuously formed at mid-ocean ridges (separating two tectonic plates). For a given plate, the distance between two magnetic reversals is proportional to the time durations between reversals and spreading rate (which can be calculated from two geochronologically dated points). Thus, geological ages can be calculated for each point of the record, though with some degree of uncertainty.

The geological time scale is gradually becoming unified through an internationally agreed upon scale which is replacing a variety of regional scales. It is ironic that such an important improvement in calibrating this vast expanse of time is linked to the discovery of volcanic dust interbedded in sedimentary rocks.