TALKING ABOUT TIME: THE GEOLOGICAL TIME SCALE 2004

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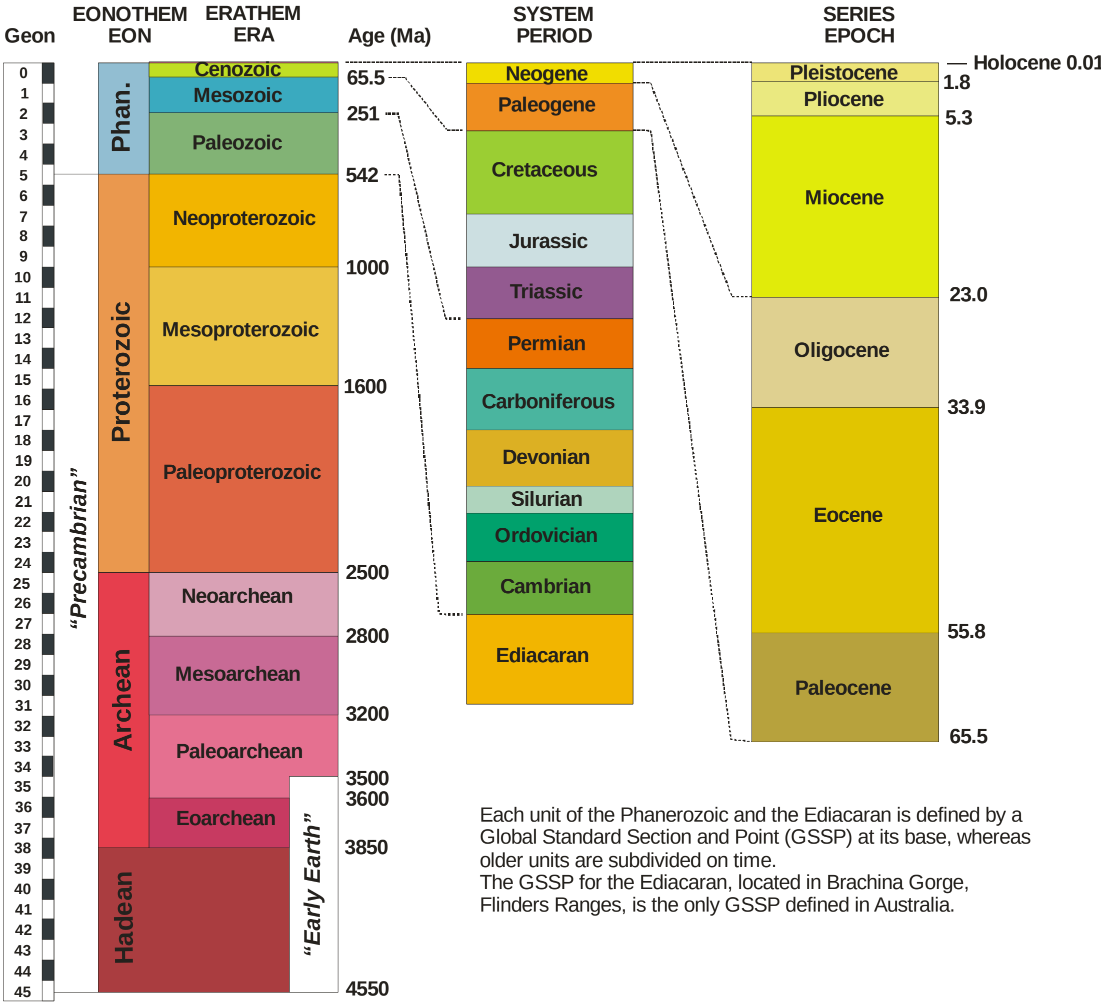
The Geological Time Scale (GTS) is one of the great achievements in the Earth Sciences. It represents the formal subdivision of the rock (and regolith) record of Earth's history into standardized global stratigraphic units as an aid to international communication. The recently published GTS2004 (Gradstein *et al*. 2004 a,b) and accompanying charts are the first major revision of the Geological Time Scale since GTS1989 (Harland *et al*. 1990). Recent revisions, and proposed revisions, are part of the ongoing mandate of the International Commission on Stratigraphy (ICS) – see http://www.stratigraphy.org/.

The major chronostratigraphic units of the GTS are familiar to all geoscientists, or should be (Figure 1). But are they? Some recent changes may come as something of a surprise to many of you and are discussed here.



Each unit of the Phanerozoic and the Ediacaran is defined by a Global Standard Section and Point (GSSP) at its base, whereas older units are subdivided on time.
The GSSP for the Ediacaran, located in Brachina Gorge, Flinders Ranges, is the only GSSP defined in Australia.

Figure 1: Major subdivisions of the international Geological Time Scale 2004 (GTS2004), from Gradstein *et al.* (2004 a, b). Geon scale from Hofmann (1990).

PRINCIPLES OF THE GTS

Geologists use relative age terms such as "Cretaceous" in the same way that historians use relative age terms such as "Renaissance" or "Ming Dynasty". Indeed, until the advent of modern numerical dating methods, the GTS was a relative timescale, based on the stratigraphic principle of superposition and the evolutionary sequence of fossils. However, geologists have long recognized that a term such as "Cretaceous" can have two subtly different meanings:

1. As a chronostratigraphic or "time-rock" unit (e.g., rocks of the Cretaceous System);

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2. As a geochronologic unit or "time" unit (e.g., the time interval of the Cretaceous Period).

Thus each chronostratigraphic unit of the GTS has an exactly equivalent geochronologic unit (Table 1), and we are taught to refer to Lower Cretaceous rocks, but Early Cretaceous time!

Table 1: Equivalent chronostratigraphic and geochronologic units of the GTS

Chronostratigraphic unit	Geochronologic unit
Eonothem	Eon
Erathem	Era
System	Period
Series	Epoch
Stage	Age

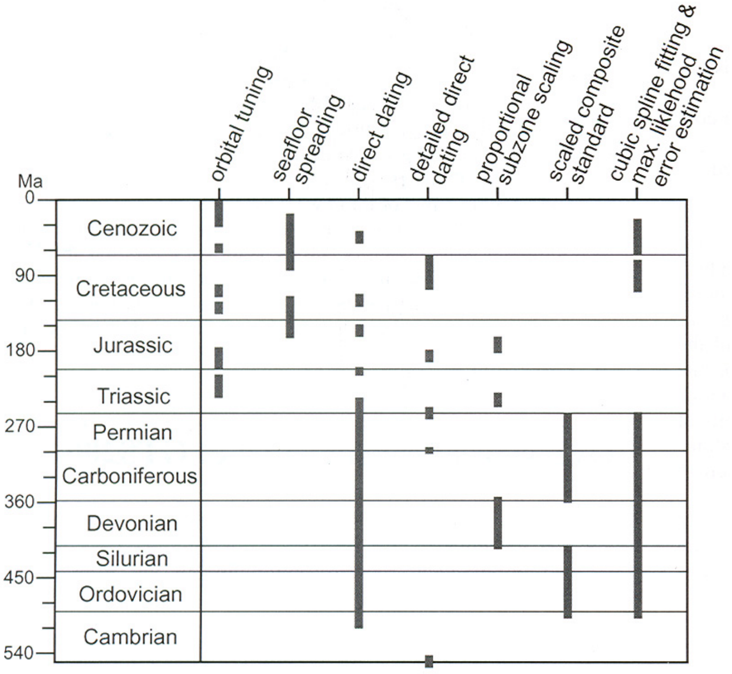
In many ways, the dual time and time-rock nomenclature is confusing, and there have been recent proposals to abandon it (e.g., Zalasiewicz *et al*. 2004).

By 2008, each chronostratigraphic and corresponding geochronologic unit of the GTS will be formally defined at its base by a Global Stratotype Section and Point (GSSP), or Global Standard Stratigraphic Age (GSSA). As of this year, more than half of the ca. 90 stage-level divisions of the Phanerozoic are defined by GSSPs, or "golden spikes". Note that the GTS is a hierarchical classification, so that, for example, the GSSP for the base of the Paleogene Series/Epoch is also the GSSP for the base of the Neogene System/Period and the base of the Cenozoic Erathem/Era.

As with regolith, not all rocks are suitable for high-precision radiometric dating. So how are the ages of the units in the GTS determined? Several methods are employed (Table 2):

1. Astronomical calibration by orbital tuning of cyclic sedimentary sequences to changes in the Earth's orbital parameters (eccentricity, obliquity and precession). This has been accomplished for the whole of the Neogene System (0-23 Ma) and parts of the Paleogene, Cretaceous, Jurassic and Triassic;
2. Sea-floor spreading rates, calibrated through the Geomagnetic Polarity Time Scale (GPTS), which in turn is calibrated by ^{40}Ar/^{39}Ar dating;
3. Direct dating, principally of zircons and sanidine in volcanic rocks, using TIMS U/Pb and ^{40}Ar/^{39}Ar, respectively. SHRIMP U/Pb ages are generally not used, except in the Carboniferous where there is a lack of more precise TIMS ages;
4. Proportional stratigraphic thickness and fossil zones, tied to an array of high precision numerical ages, through mathematical curve fitting.

Table 2: Dating methods used to construct GTS2004. Different methods are used according to the quality of data available for different time intervals (from Gradstein et al. 2004a).



RECENT CHANGES

GTS2004 incorporates a number of significant changes, with possibly the most noticeable being the loss of the Tertiary and Quaternary Systems/Periods. Sorry folks, but it's technically incorrect to refer to the Cretaceous/Tertiary boundary anymore, it's now the Cretaceous/Paleogene boundary! The Italian mining engineer, Giovanni Arduino (1714-1795) was the originator of the terms when he distinguished four orders of strata—Primary, Secondary, Tertiary and

Quaternary (Schneer 1969). However, the Primary and Secondary were long ago abandoned, and it seems that Tertiary and Quaternary have suffered a similar fate, or have they? While considered to rather archaic terms by many stratigraphers, there is a groundswell of support for reinstating and formally redefining the Quaternary (cf. Pillans & Naish in press). Indeed, the ICS has just announced that a task force will be set up to investigate its reinstatement.

The "Precambrian" is still used to describe rocks older than the Cambrian, but it is not a formal chronostratigraphic or geochronologic unit of the GTS. There is still a journal called *Precambrian Research*, and geologists still find it a useful term to use.

A new subdivision of the Neoproterozoic, the Ediacaran System/Period, is notable on two counts:

1. It is the first unit to be defined with a GSSP in Australia;
2. It is the only unit of the "Precambrian" to be defined with a GSSP. All the other units are defined on time using GSSAs, though other GSSPs may well be established in the future.

Remember that numerical ages for all Phanerozoic chronostratigraphic units are continually being refined. The GSSPs don't generally change, once they are established, but the boundary ages are not fixed in the same way as they are for GSSAs in the Precambrian.

IMPLICATIONS FOR CRC LEME

Communication is the key implication; GTS2004 ensures that earth scientists have a common language so that when we talk about geological time we know exactly what we mean.

Regolith research is also playing a role in the definition of one GSSP because I am currently chair of the ICS working group to define the GSSP for the base of the Middle Pleistocene Subseries (= top of the Lower Pleistocene Subseries). The Lower/Middle Pleistocene boundary has for many years been informally recognized at the Matuyama/Brunhes polarity transition (0.78 Ma). The working group is considering candidate GSSPs that contain the M/B reversal in marine rocks so that the golden spike can be placed at, or as close to, the M/B as possible (GSSPs are normally defined in marine sediments because marine fossils are one of the most useful ways of correlating the boundary to other sedimentary sequences around the world). The association of the Lower/Middle Pleistocene boundary with a magnetic reversal makes good sense, because it provides one of the few ways of recognizing the boundary in non-fossiliferous sediments, including regolith (Pillans 2003). Australasian tektites provide an additional marker horizon close to the boundary (Pillans 2004).

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