On the Geologic Time Scale 2008

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Abstract

This report summarizes the international divisions of the geologic time scale and ages. Over 35 chronostratigraphic units have been formalized since 2000, with about one third of the almost 100 geologic stages of the Phanerozoic still awaiting international definition. The same numerical time scale is used as in *Geologic Time Scale 2004* for the majority of stage boundaries. Exceptions are made if the definitions for stage boundaries are at a different level than the previous "working" versions (e.g., base of Serravallian, base of Coniacian, and bases of Ghzelian, Kasimovian and Serpukhovian). In most cases, numerical changes in ages are within GTS2004 age error envelopes.

On-screen display and production of user-tailored time-scale charts is provided by the ***Time-Scale Creator***, a public JAVA package available from the ICS website (*www.stratigraphy.org*) and *www.tscreator.com*.

Introduction

The geologic time scale is the framework for deciphering the history of our planet, Earth. We are constantly improving our knowledge of Earth history, and simultaneously attaining an advanced state of standardization in naming the units that elucidate this history. The time scale is expressed both in physical rock units and in abstract time units, the latter often with a numerical uncertainty. The two come together in time/rock units, or chronostratigraphic units in the geological vernacular. Few time/rock units are complete from base to top in outcrops (see Hilgen et al., 2006).

Any geologic time scale represents a status report. This report summarizes the international divisions of the geologic time scale and ages, and lists milestones of the last decade to achieve stability in stratigraphic taxonomy. The stratigraphic scale is dealt with in more detail by Ogg et al. (2008), and the interested reader is also referred to *TimeScale Creator*, a public database visualization software system available through the website *www.tscreator.com* (see below).

For consistency and clarity, it was decided by Ogg *et al*. (2008) to use the same numerical time scale that was used in *Geologic Time Scale 2004* (Gradstein *et al*., *GTS2004*) for the majority of the stage boundaries, except if the definitions for those boundaries are at a different level than the previous "working" versions (e.g., base of Serravallian, base of Coniacian, and bases of Ghzelian, Kasimovian and Serpukhovian). In most cases, numerical changes in ages are within GTS2004 age error envelopes.

To avoid misleading readers by using the term "age" to refer to a time span instead of a linear date, we will generally use the term "stage" to refer to both the time interval and the rocks deposited during that time interval. The practice of using the term "stage" for both time and for rock has the advantage of clarifying that chronostratigraphy and geochronology are different aspects of the same procedure, and liberating "age" for general use. The practice conforms to Harland et al. (1990), Comité Francais de Stratigraphie (1997), and GTS2004.

Divisions of Geologic Time

One of the main benefits of the geologic time scale is that it provides geologists with a common and precise language to discuss and unravel Earth's history, preferably with an understanding of the degree of uncertainty in correlation. One of the goals of the International Commission on Stratigraphy (ICS) is to unite regional stage scales by reaching consensus on a standardized nomenclature and hierarchy for international stages defined by precise Global Stratotype Sections and Points (GSSPs).

The choice and definition of an appropriate boundary is important. "Before formally defining a time/rock unit lower boundary by a GSSP, its practical value – i.e., its correlation potential – has to be thoroughly tested. In this sense, *correlation precedes definition*." (Remane, 2003). Or to say it more eloquently: "*Without correlation, successions in time derived in one area are unique and contribute nothing to understanding Earth history elsewhere*." (McLaren, 1978). Most GSSPs coincide with a single primary marker, which is generally a biostratigraphic event, but other events with widespread correlation, such as a rapid change in isotope values or a geomagnetic reversal, should coincide or bracket the GSSP. Other criteria include avoidance of obvious hiatuses near the boundary interval and accessibility.

This task proved to be more challenging than envisioned when the GSSP effort began in the 1980s. The choice of the primary criteria for an international stage boundary can be a contentious issue, especially when competing regional systems or vague historical precedents are involved. Preference for stratigraphic priority is laudable when selecting GSSPs, but subsidiary to scientific and practical merit if the historical versions are unable to provide useful global correlations. Therefore, the Cambrian and the Ordovician subcommissions of ICS developed a global suite of stages that have demonstrated correlation among regions, in contrast to any of the American, British, Chinese or Australian regional suites. However, such regional stages are very useful; and Gradstein *et al*., (2004) and Ogg *et al*. (2008) present selected inter-regional correlation charts.

Over 35 chronostratigraphic units have been formalized since 2000 (Table 1), with about one third of the almost 100 geologic stages of the Phanerozoic still awaiting international definition with precise GSSPs. Delays with boundary definitions may arise from a desire to achieve calibration to other high-resolution scales (e.g., base of Langhian stage in Miocene awaiting astronomical tuning), inability to reach majority agreement, or other difficulties. In these cases, Ogg et al. (2008) presents the current status or temporary working definition of the yet-to-be-defined stages within each period. One example is the base of Quaternary, for which the ICS has recommended the climate-based definition used by the International Union for Quaternary Research, but the new definition is meeting administrative delays.

A special case is the Precambrian, the >4 Ga long time interval from the formation of Earth (T_0=4.567 Ga) to the base of the Cambrian, at 542 Ma. The Precambrian is currently subdivided in terms of round number ages (or Global Standard Stratigraphic Ages: GSSA) based on a global correlation of major geodynamic events compiled in the 1980s. Since that time, there have been significant advances in the knowledge of the Precambrian and there is room for significant improvements to the Precambrian time scale, based on the stratigraphic record, including GSSPs, where practical. The youngest period of the Precambrian – the Ediacaran - has already achieved formal time/rock status (Table 1) and work is underway to define a GSSP for the base of the next oldest period, the Cryogenian. Proposals are being developed for a revision of other intervals of Precambrian time, some based on GSSPs and others on GSSAs. Primary amongst these new proposals is the definition of a formal Hadean interval, possibly at the Eon level, for the period of time from the formation of Earth to the age of the oldest known preserved rock on Earth (~ 4.03 Ga) that provides the start of a stratigraphic record on our planet. Other revisions of Precambrian time considered are: • An Eoarchean–Paleoarchean boundary GSSP at the base of the ~3.49 Ga Dresser Formation in the Warrawoona Group, the first definitively fossiliferous horizon that is preserved within a continuous stratigraphic succession. • A ~2.45 Ga Archean-Proterozoic boundary, reflecting the transition from chemical weathering to physico-mechanical weathering under higher pO_2 conditions, with a GSSP in the Hamersley Basin, Australia. • Potential GSSPs on either side of the 2.32–2.06 Ga Lomagundi-Jatuli C-isotopic event, at the disappearance of the S-MIF signature and of highly positive 13C values, respectively; the former reflecting the onset of the Great Oxidation Event of the atmosphere through microbial processes within a series of global glaciations. • GSSPs at the onset and termination of sulphidic oceans at ~1.84 Ga, and ~0.8 Ga, respectively, the latter approaching the onset of global glaciations in the Cryogenian that are associated with the second great rise in atmospheric oxygen. The next step is further consultation with the geoscience community to develop and submit formal GSSP proposals.

How to recognize Geologic Stages

Geologic stages are recognized, not by their boundaries, but by their content. The rich fossil record remains the main method to distinguish and correlate strata among regions, because the morphology of each taxon, and the unique range of that taxon in the rock record, are the most unambiguous way to assign a relative age. The evolutionary successions and assemblages of each fossil group are generally grouped into zones. The TSCreator program at *www.tscreator.com* includes a majority of zonations and/or event datums (first or last appearances) for widely used groups of fossils through time.

Trends and excursions in stable-isotope ratios, especially of carbon 12/13 and strontium 86/87, have become an increasingly reliable method to correlate among regions. Some of the carbon-isotope excursions are associated with widespread deposition of organic-rich sediments. Ratios of oxygen 16/18 are particularly useful for the glacial-interglacial cycles of Pliocene-Pleistocene, and have been extended into Miocene. Sea-level trends, especially rapid oscillations that caused widespread exposure or drowning of coastal margins, can be associated with these isotopic-ratio excursions; but the synchronicity and driving cause of pre-Neogene sequences is disputed. Ogg et al. (2008) includes major sequences as interpreted by widely used publications, but many of these remain to be documented as global eustatic sea-level oscillations.

Geomagnetic polarity chrons are well established for correlation of marine magnetic anomalies of latest Jurassic through Holocene to the magnetostratigraphy of fossiliferous strata. Pre-Kimmeridgian magnetic polarity chrons have been verified in some intervals, but exact correlation to biostratigraphic zonations remains uncertain for many of these. The geomagnetic scale in Ogg et al. (2008) is partly an update of that compiled for *GTS2004*.

Assigning Numerical Ages

The Neogene is the only interval in which high-resolution ages can be assigned to most biostratigraphic, geomagnetic and other events, including stage GSSPs. Especially for the interval younger than about 14 myr, series of investigations have compiled the record of climatic-oceanic changes associated with periodic oscillations in the Earth's orbital parameters of precession, obliquity and eccentricity as derived from astronomical models of the solar system. The entire Oligocene has now also been tuned based on ODP Site 1218 (Pälike *et al.,* 2006). In addition, the Eocene/Oligocene boundary stratotype section at Massignano, Italy has been tuned in consistency with the Site 1218 tuning. Several tuning options have been proposed for the entire Paleocene and part of the Early Eocene (Westerhold *et al*., in press). Application of the astronomically calibrated Fish Canyon sanidine Ar/Ar dating standard indicates that the oldest option is correct, and a revised tuning for the older part of the Paleocene Zumaya section in Spain is presented (Kuiper et al., *in press*).

Orbital-cycle ("Milankovitch") durations have been achieved for portions of older periods (e.g. Cretaceous and Jurassic, and the geomagnetic scale for Late Triassic); but the calibration of these intervals to numerical ages depend upon constraints from radiometric ages.

Dates derived from radio-isotopic methods on minerals in volcanic ashes interbedded with fossiliferous sediment provide a succession of constraints on estimating numerical ages for the geologic time scale. These methods and discussion of uncertainties are summarized in *Geologic Time Scale 2004* and other publications. The ages of events and stage boundaries that are between the selected radiometric dates are interpolated according to their relative position in composite sediment sections, their relative correlation to a smoothed scale of marine magnetic anomalies, their level within an orbital-cycle-scaled succession, or less quantitative means. A goal of geochronologists and database compilers is to progressively narrow the uncertainties on such interpolations and converge on exact numerical ages for all events.

The resolution of geologic time and the uncertainties in Geologic Time Scale 2004 are graphically depicted in Figure 1. In the years after the computation of the numerical scales in *GTS2004,* major advances have occurred in radiometric dating, including: (1) improved analytical procedures for obtaining Uranium-Lead ages from zircons that shifted published ages for some levels by more than 1 myr, (2) an astronomically-dated neutron irradiation monitor for ^{40}Ar-^{39}Ar methods implying that earlier reported ages should be shifted older by nearly 1%, (3) technological advances that reduce uncertainties and enabled acquisition of reduced-error results of the Rhenium-187 to Osmium-187 (Os-Re) chronometer in organic-rich sediments (e.g.154.1 ± 2.2 Ma on the proposed base-Kimmeridgian GSSP (Selby, 2007). and (4) the continued acquisition of additional radiometric ages. These exciting advances have led to several suggestions for revision of assigned or interpolated ages for geologic stages and component events, and also help to fill gaps in age data for Mississippian, Triassic and Cretaceous. Such a comprehensive revision is being compiled by the different groups for the enhanced *GTSnew* book (see below).

For consistency and clarity, it was decided by Ogg *et al*. (2008) to use the same numerical time scale that was used in *Geologic Time Scale 2004* (GTS2004; Gradstein *et al*., *2004*) for the majority of the stage boundaries, except if the new definitions for those boundaries are at a different level than the previous "working" versions (e.g., base of Serravallian, base of Coniacian, and bases of Ghzelian, Kasimovian and Serpukhovian). In Table 1 we list changes in numerical ages between

GTS2004 and the geologic scale of Ogg et al. (2008). In most cases, numerical changes in ages are comfortably within GTS2004 age error envelopes.

The slightly updated geologic time scale itself is shown in Figure 2; for details of production the reader is referred to the literature and the websites cited. The geomagnetic scale is partly an update of that compiled for *GTS2004*. The widely used 'Tertiary' has no official rank. The status of the Quaternary is not decided; its base may be assigned as the base of Gelasian.

TimeScale Creator

One goal of ICS is to provide detailed global and regional "reference" scales of Earth history. Such scales summarize our current consensus on the inter-calibration of events, their relationships to international divisions of geologic time and their estimated numerical ages.

On-screen display and production of user-tailored time-scale charts is provided by the ***Time-Scale Creator***, a public JAVA package available from the ICS website (*www.stratigraphy.org*) and *www.tscreator.com*, (Gradstein & Ogg, 2006) In addition to screen views and a scalable-vector graphics (SVG) file for importation into popular graphics programs, the on-screen display has a variety of display options and "hot-curser-points" to open windows providing additional information on events, zones and boundaries.

The database and visualization package are envisioned as a convenient reference tool, chart-production assistant, and a window into the geologic history of our planet. They will be progressively enhanced through the efforts of stratigraphic and regional experts.

Geologic Time Scale *New*

At the time of this writing, a major comprehensive update of the Geologic Time Scale is underway, targeted for publication in collaboration with Cambridge University Press, a fruitful collaboration that started more than a decade ago. All international boundaries (GSSPs, explained below) should be established by that date. The book will be a full color, enhanced, improved and expanded version of *GTS2004,* including chapters on Planetary scales, the Cryogenian-Ediacaran Periods, a Prehistory scale of human development, a survey of Sequence Stratigraphy, and an extensive compilation of stable isotope chemostratigraphy. A thorough review is being made of geodynamic and geobiological events through the Precambrian, with the aim of identifying possible new timescale boundaries for this long interval of time, based more closely on the known rock record. Age assignments will utilize revised inter-calibration standards and error analysis for different methods of radiogenic isotope analysis. The entire Cenozoic and significant portions of the Mesozoic will have high-resolution scaling based on astronomical tuning or orbital cycles.

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Selected On-Line References

International Commission on Stratigraphy – *www.stratigraphy.org* – for current status of all stage boundaries, timescale diagrams, *TimeScale Creator*, the *International Stratigraphic Guide*, links to subcommission websites, etc.

EarthTime (maintained by Samuel Bowring, MIT) -- *www.earth-time.org/* -- Major initiative and information on high-resolution radiometric dating and better calibration of methods.

EarthTime Europe/GTSNext - www.earthtime-eu.eu. Major initiative with Klaudia Kuiper, Frits Hilgen *et al.* to significantly improve GTS using orbital tuning and calibrate radiogenic isotope dating to the astronomical clock.

Palaeos: The Trace of Life on Earth (compiled and maintained by Toby White) -- *www.palaeos.com*/ -- and others it references at end of each period. There is also a WIKI version being compiled at *Palaeos.org*. The Palaeos suite has incredible depth and is written for the general scientist.

Smithsonian paleobiology site -- *paleobiology.si.edu/geotime/introHTML/index.htm* – After entering, then select Period or Eon by clicking on [*Make a Selection*] in upper right corner of screen.

Web Geological Time Machine (compiled by Museum of Paleontology, University of California) -- *www.ucmp.berkeley.edu/exhibits/geologictime.php* – and an accompanying History of Life through Time -- *www.ucmp.berkeley.edu/exhibits/historyoflife.php*.

Wikipedia online encyclopedia (a public effort) -- *en.wikipedia.org/wiki/Geologic_time_scale* -- has excellent reviews of each geologic period and most stages.

Historical Geology on-line (Pamela J.W. Gore; for University System of Georgia) -- *gpc.edu/~pgore/geology/historical_lecture/historical_outline.php* -- Great image-illustrated site, plus lots of links to other relevant sites from Index page.

Plate Reconstructions (images and animations), some selected sites: Paleomap Project (by Christopher Scotese) -- *www.scotese.com/* . Global Plate Tectonics and Paleogeography (Ron Blakey, Northern Arizona University) -- *jan.ucc.nau.edu/~rcb7/* , both global and paleogeography of the southwestern USA. Plates (Institute of Geophysics, Univ. Texas at Austin) -- *www.ig.utexas.edu/research/projects/plates/* . Geology: Plate Tectonics (compiled by Museum of Paleontology, University of California) -- */www.ucmp.berkeley.edu/geology/tectonics.html* .

Tables and Figures

Table 1. International chronostratigraphic stages and series names and definitions established since the year 2000.

Table 2. Changes in numerical ages between GTS2004 and the Geologic Time Scale of Ogg *et al*. (2008) in Figure 2. In most cases, numerical changes in ages are comfortably within GTS2004 age error envelopes.

Figure 1. The resolution of geologic time and the uncertainties in Geologic Time Scale 2004 (modified after Miller, 2006). Major advances in radiometric dating and new dates are reducing the relatively large uncertainties in the 140 -175 Ma and 300-400 Ma intervals.

Figure 2. The Geologic Time Scale 2008 (after Ogg *et al*., 2008). The geomagnetic scale is partly an update of that compiled for GTS2004. The widely used 'Tertiary' has no official rank. The status of the Quaternary is not decided; its base may be assigned as the base of the Gelasian Stage. For details of GTS production the reader is referred to the literature and the websites cited. Colour printing was funded by Idemitsu Petroleum Norway.

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Chronostratigraphic System, Stage and Series names and definitions established in ICS since 2000

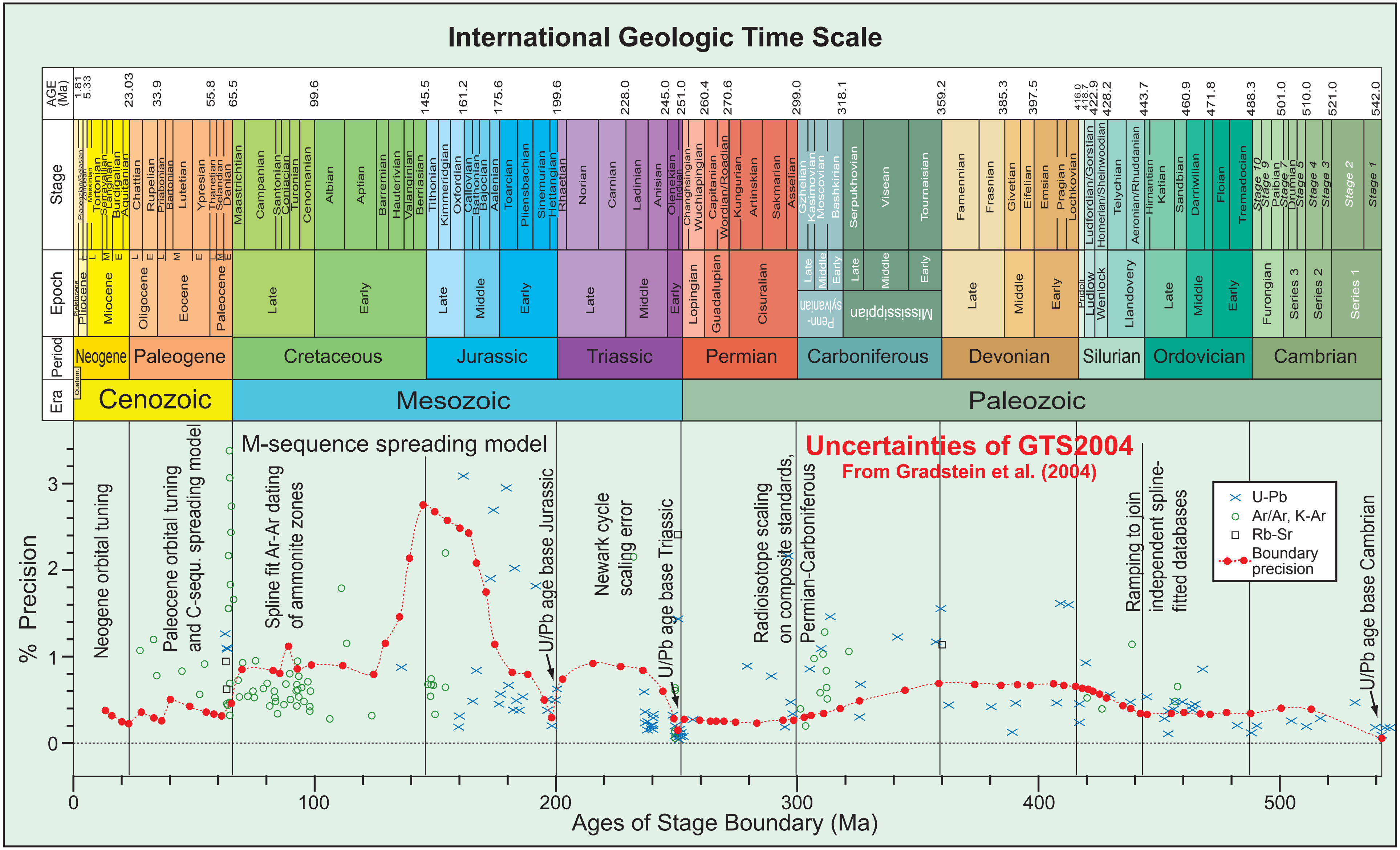
Quaternary	Base Holocene Series (*pending*) Base Quaternary System (*pending*)
Neogene:	Base Zanclean Stage (Base Pliocene Series) Base Messinian Stage Base Tortonian Stage Base Serravallian Stage
Paleogene:	Base Ypresian Stage (Base Eocene Series)
Cretaceous:	Base Maastrichtian Stage Base Turonian Stage Base Cenomanian Stage
Jurassic:	Base Aalenian Stage Base Pliensbachian Stage Base Sinemurian Stage
Triassic:	Base Carnian Stage (*pending*) Base Ladinian Stage Base Induan Stage (Base Triassic System)
Permian:	Name and Base Changhsingian Stage Name and Base Wuchiapingian Stage Base Capitanian Stage Base Wordian Stage Base Roadian Stage
Carboniferous:	Mississippian and Pennsylvanian subsystem Names and Lower, Middle and Upper series subdivision of each and stage nomenclature for each Base Visean Stage (*pending*)
Silurian:	Base redefinition for Ruddinian Stage (Base Silurian)
Ordovician:	Name and Base Hirnantian Stage Name and Base Katian Stage Name and Base Sandbian Stage Name and Base Dapingian Stage Name and Base Floian Stage Base Tremadocian Stage
Cambrian:	Name and Base Furongian Series Name and Base Paibian Stage Name and Base Guzhangian Stage Name and Base Drumian Stage Name Terreneuvian Series Name Fortunian Stage
Neoproterozoic:	Name and Base Ediacaran System

Eon	Era	System/Period	GSSP/GSSA	Basal boundary selection criteria
Proterozoic	Neoproterozoic	**Ediacaran**	**GSSP (~635)**	**Base of carbonate layer overlying glaciogenic rocks**[1]
		Cryogenian	*GSSP (~850)*	*?*
	Mesoproterozoic		*GSSP/GSSA (1840)*	*Onset of sulphidic oceans*
	Paleoproterozoic		*GSSP (~2060)*	*End of L-J C-isotopic event*
		Lomagundi-Jatuli	*GSSP (~2300)*	*Onset of L-J C-isotopic event*
	Eoproterozoic		*GSSP (~2450)*	*Onset of clastic seds./end of BIF in Hamersley Basin*
Archean	Neoarchean		*GSSP/GSSA (~2780)*	*Onset of crust-forming superevent*
	Mesoarchean		*GSSP/GSSA (~3240)*	*Transition from plume to plate tectonics*
	Paleoarchean		*GSSP (~3490)*	*Base of oldest stromatolitic seds.*
	Eoarchean		*GSSA (4030)*	*Earth's oldest rock*
Hadean			*GSSA (T_0=4567)*	*Formation of Earth*

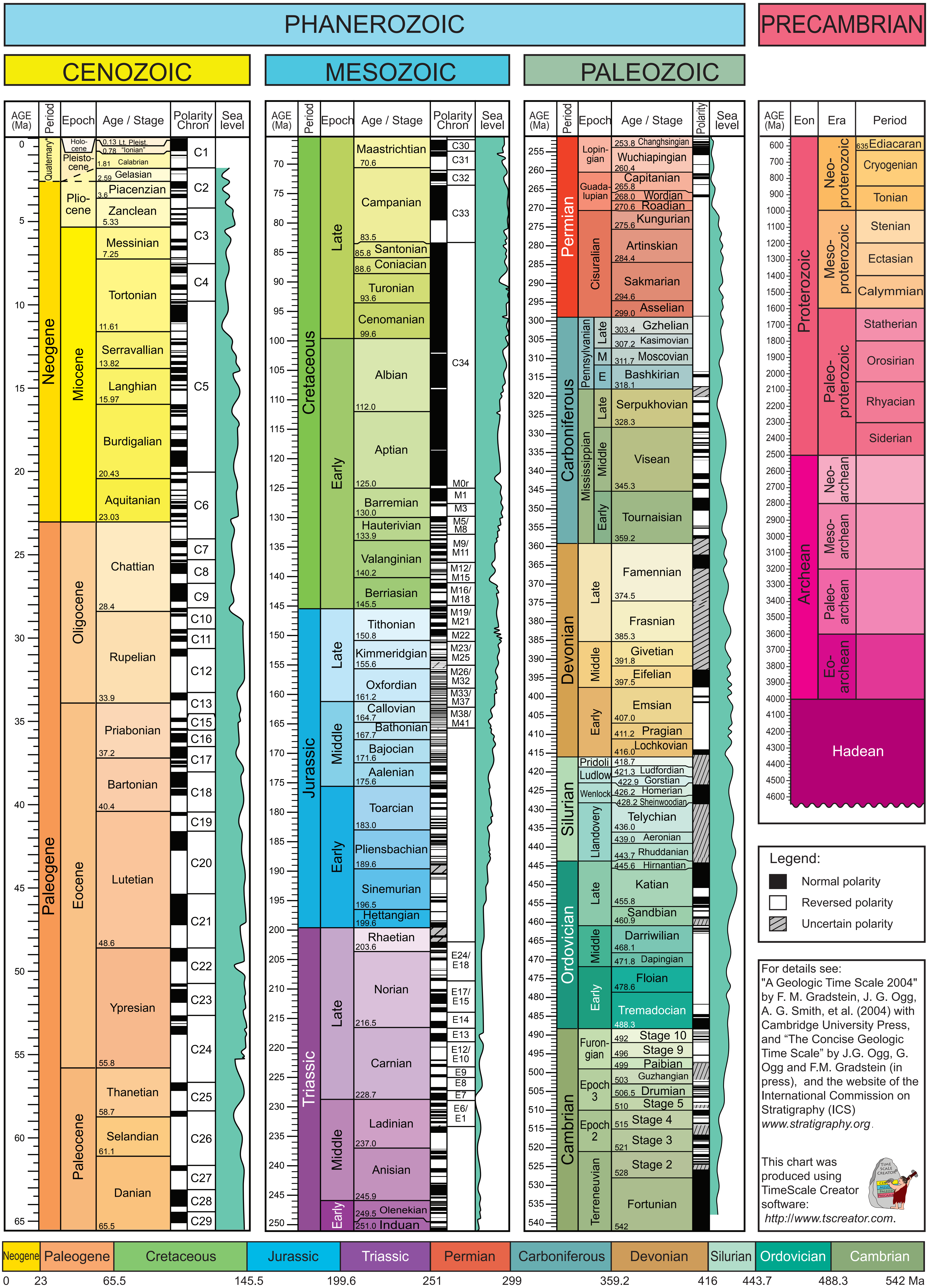
Change in age of GTS units due to new definitions		
Chronostrat Unit	GTS2004	GTS2008
	Gradstein et al.(2004)	Ogg et al.(2008)
base Holocene	11.5 Ka	11.7 ka
base Serravallian	13.65 Ma	13.82 Ma
base Selandian	61.7	61.1
base Coniacian	89.3	88.6
base Hauterivian	136.4	133.9
base Carnian	228	228.7
base Anisian	245	245.9
base Olenekian	249.7	249.5
base Gzhelian	303.9	303.4
base Kasimovian	306.5	307.2
base Serpukhovian	326.4	328.3
base stage 10, Cambrian		492
base stage 9, Cambrian		496
base Paibian	501	~ 499
base Guzhangian		~ 503
base Drumian		~ 506.5
base stage 5, Cambrian		~ 510
base stage 4, Cambrian		~ 515
base stage 3, Cambrian		~ 521
base stage 2, Cambrian		~ 528
base Ediacaran	~ 600	635

Resolution of Geologic Time

GTS2004 uncertainties



GEOLOGIC TIME SCALE



For details see:
"A Geologic Time Scale 2004" by F. M. Gradstein, J. G. Ogg, A. G. Smith, et al. (2004) with Cambridge University Press, and "The Concise Geologic Time Scale" by J.G. Ogg, G. Ogg and F.M. Gradstein (in press), and the website of the International Commission on Stratigraphy (ICS) *www.stratigraphy.org*.

This chart was produced using TimeScale Creator software: *http://www.tscreator.com*.

* Definition of the Quaternary and revision of the Pleistocene are under discussion. Base of the Pleistocene is at 1.81 Ma (base of Calabrian), but may be extended to 2.59 Ma (base of Gelasian). The historic "Tertiary" comprises the Paleogene and Neogene, and has no official rank.