GEOLOGIC TIME SCALE 2004 – WHY, HOW, AND WHERE NEXT!

F.M.Gradstein [1] and J.G.Ogg [2]

1. Geological Museum, University of Oslo, N-0318 Oslo, Norway. Email: *felix.gradstein@nhm.uio.no*
2. Department of Earth & Atmospheric Sciences, Purdue University, West Lafayette, Indiana 47907-1397, USA.

Note: This article summarizes key features of Geologic Time Scale 2004 (~ 500 p. , Cambridge University Press). The Geologic Time Scale Project, under auspices of the International Commission on Stratigraphy, is a joint undertaking of F.M.Gradstein, J.G.Ogg, A.G.Smith, F.P.Agterberg, W.Bleeker, R.A.Cooper, V.Davydov, P.Gibbard, L.Hinnov, M.R. House (†), L.Lourens, H-P.Luterbacher, J.McArthur, M.J.Melchin, L.J.Robb, J.Shergold, M.Villeneuve, B.R.Wardlaw, J.Ali, H.Brinkhuis, F.J.Hilgen, J.Hooker, R.J.Howarth, A.H.Knoll, J.Laskar, S.Monechi, J.Powell, K.A.Plumb, I.Raffi, U.Röhl, A.Sanfilippo, B.Schmitz, N.J.Shackleton, G.A.Shields, H.Strauss, J.Van Dam, J.Veizer, Th.van Kolfschoten, and D.Wilson.

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Abstract

A Geologic Time Scale (GTS2004) is presented that integrates currently available stratigraphic and geochronologic information. Key features of the new scale are outlined, how it was constructed, and how it can be improved

Since Geologic Time Scale 1989 by Harland and his team, many developments have taken place:
(1) 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 stages have been replaced with new subdivisions that allow global correlation.
(2) New or enhanced methods of extracting high-precision age assignments with realistic uncertainties from the rock record. These have led to improved age assignments of key geologic stage boundaries and other global correlation horizons.
(3) Statistical techniques of compiling integrated global stratigraphic scales within geologic periods.

The construction of Geologic Time Scale 2004 (GTS2004) incorporated different techniques depending on the data available within each interval. Construction involved a large number of specialists, including contributions by past and present subcommissions officers of ICS, geochemists working with radiogenic and stable isotopes, stratigraphers using diverse tools from traditional fossils to astronomical cycles to database programming, and geomathematicians

Anticipated advances during the next four years include:

- Formal definition of all Phanerozoic stage boundaries.
- Orbital tuning of polarity chrons and biostratigraphic events for the entire Cenozoic and part of Cretaceous.
- A detailed database of high-resolution radiometric ages that includes “best practice” procedures, full error analysis, monitor ages and conversions.
- Resolving age dating controversies (e.g., zircon statistics and possible reworking) across Devonian/Carboniferous, Permian/Triassic, and Anisian/Ladinian boundaries.
- Improved and standardized dating of several ‘neglected’ intervals (e.g., Upper Jurassic – Lower Cretaceous, and Carboniferous through Triassic).
- Detailed integrated stratigraphy for Upper Paleozoic through Lower Mesozoic.
- On-line stratigraphic databases and tools (e.g., CHRONOS network).

The geochronological science community and ICS are focusing on these issues. A modified version of the time scale to accompany the standardization (boundary definitions and stratotypes) of all stages is planned for the year 2008.

Introduction

The geologic time scale is the framework for deciphering the history of the Earth and 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.

Continual improvements in data coverage, methodology and standardization of chronostratigraphic units imply that no geologic time scale can be final. This brief overview of the status of the Geologic Time Scale in 2004 (GTS2004), documented in detail in Gradstein *et al*. (2004) is the successor to GTS1989 (Harland *et al.*, 1990), which in turn was preceeded by GTS1982 (Harland *et al.*, 1982). GTS2004 also succeeds the International Stratigraphic Chart of the International Commission on Stratigraphy (ICS), issued four years ago (Remane, 2000).

Why a new geologic time scale in the year 2004 may be summarized as follows:

- Nearly 50 of 90+ Phanerozoic stage boundaries are now defined, versus < 15 in 1990
- International stage subdivision are stabilizing, whereas in 1990 about 15% were still invalid
- The last 23 million years (Neogene) is now orbitally tuned with 40 kyr accuracy
- High-resolution cycle scaling now exists for Paleocene, mid-Cretaceous, lower Jurassic, and mid Triassic
- Superior stratigraphic reasoning in Mesozoic integrates direct dating, seafloor spreading (M-sequence), zonal scaling and orbital tuning for a detailed, albeit partially rather uncertain timescale.
- Superior stratigraphic scaling now exists in the Paleozoic, using high-resolution zonal composites
- A 'natural' geologic Precambrian time scale is going to replace the current artificial scale
- More accurate and more precise age dating exists with over 200 Ar/Ar and U/Pb dates that incorporate external error analysis (note that only a fraction of those dates were available to GTS89)
- Improved mathematical/statistical techniques combine zones, polarity chrons, stages and ages to calculate the best possible time scale, with estimates of uncertainty on stage boundaries and durations

At the end of this brief document a listing is provided of outstanding issues that, once resolved, will pave the way for an updated version of GTS2004, scheduled for the year 2008.

Overview

Since 1989, there have been major developments in time scale research, including:

(1) Stratigraphic standardization through the work of the International Commission on Stratigraphy (ICS) has

greatly refined the International Chronostratigraphic Scale. In some cases, like for the Ordovician and Permian Periods, traditional European or Asian-based geological stages have been replaced with new subdivisions that allow global correlation.

(2) New or enhanced methods of extracting linear time from the rock record have enabled high-precision age

assignments. Numerous high-resolution radiometric dates have been generated that has led to improved age assignments of key geologic stage boundaries, at the same time as the use of global geochemical variations, Milankovitch climate cycles, and magnetic reversals have become important calibration tools.

(3) 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 high-resolution composite standards that scale the stages.

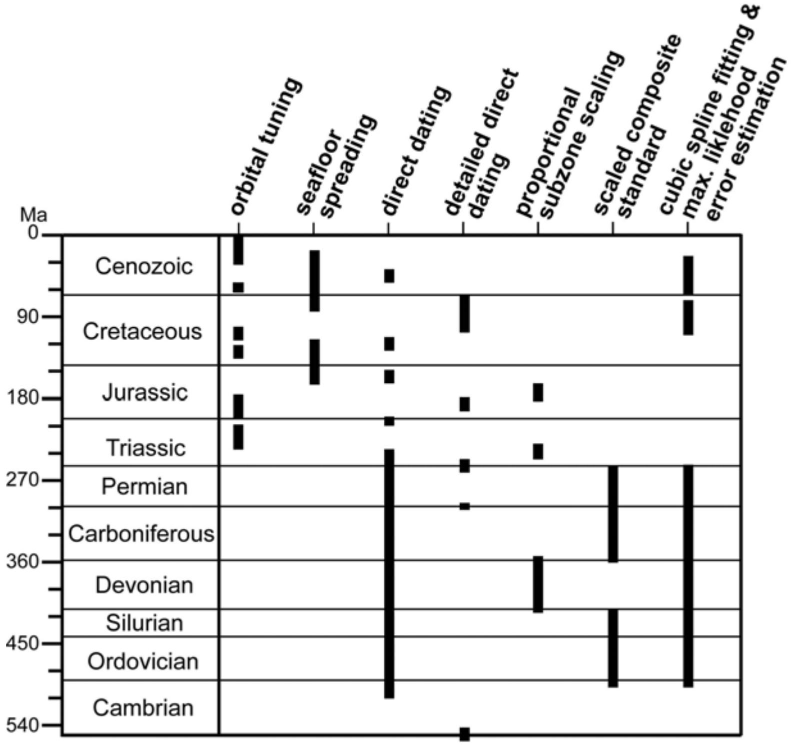
The compilation of GTS2004 has involved a large number of geoscience specialists, listed above, including contributions by past and present chairs of subcommissions of ICS, geochemists working with radiogenic and stable isotopes, stratigraphers using diverse tools from traditional fossils to astronomical cycles to database programming, and geomathematicians.

The methods used to construct Geologic Time Scale 2004 (GTS2004) integrate different techniques depending on the quality of data available within different intervals, and are summarized in figure 1. The set of chronostratigraphic units (stages, periods) and their computed ages and durations, which constitute the main framework for Geologic Time Scale 2004 are shown in the International Geologic Time Scale of figure 2.

The main steps involved in the GTS2004 time scale construction were:

Step 1. Construct an updated global chronostratigraphic scale for the Earth's rock record

Step 2. Identify key linear-age calibration levels for the chronostratigraphic scale using radiometric age dates, and/or apply astronomical tuning to cyclic sediment or stable isotope sequences which had biostratigraphic or magnetostratigraphic correlations.



Methods used to construct Geologic Time Scale 2004 (GTS 2004)

Step 3. Interpolate the combined chronostratigraphic and chronometric scale where direct information is insufficient.

Step 4. Calculate or estimate error bars on the combined chronostratigraphic and chronometric information In order to obtain a time scale with estimates of uncertainty on boundaries and on unit durations.

Step 5. Peer review the geologic time scale through ICS.

The first step, integrating multiple types of stratigraphic information in order to construct the chronostratigraphic scale, is the most time-consuming; in effect, it summarizes and synthesizes centuries of detailed geological research. The second step, identifying which radiometric and cycle-stratigraphic studies would be used as the primary constraints for assigning linear ages, is the one that is evolving most rapidly since the last decade. Historically, Phanerozoic time scale building went from an exercise with very few and relatively inaccurate radiometric dates, as used by Holmes (1947, 1960), to one with many dates with greatly varying analytical precision (like GTS89, or to some extent Gradstein *et al*., 1994). Next came studies on relatively short stratigraphic intervals that selected a few radiometric dates with high internal analytical precision (e.g., Obradovich, 1993, Cande & Kent, 1992, 1995; Cooper, 1999) or measured time relative to the Present using astronomical cycles (e.g., Shackleton *et al*., 1999; Hilgen *et al.*, 1995, 2000). This new philosophy of combing high resolution with precise ages is also adhered to in this scale.

In addition to selecting radiometric ages based upon their stratigraphic control and analytical precision, we also applied the following criteria or corrections:

A. Stratigraphically constrained radiometric ages with the U-Pb method on zircons were accepted from the isotope dilution mass spectrometry (TIMS) method, but generally not from the high-resolution ion microprobe (HR-SIMS, also known as "SHRIMP") that uses the Sri Lanka (SL)13 standard. An exception is the Carboniferous Period, where there is a dearth of TIMS dates, and more uncertainty.

B. ^{40}Ar-^{39}Ar radiometric ages were re-computed to be in accord with the revised ages for laboratory monitor standards: 523.1 ± 4.6 Ma for MMhb-1 (Montana hornblende), 28.34 ± 0.28 Ma for TCR (Taylor Creek sanidine) and 28.02 ± 0.28 Ma for FCT (Fish Canyon sanidine). Systematic ("external") errors and uncertainties in decay constants are partially incorporated. No glauconite dates are used.

The bases of Paleozoic, Mesozoic and Cenozoic are bracketed by analytically precise ages at their GSSP or primary correlation markers – 542 ± 1.0 Ma, 251.0 ± 0.4 Ma, and 65.5 ± 0.3 Ma –, and there are direct age-dates on base-Carboniferous, base-Permian, base-Jurassic, and base-Oligocene; but most other period or stage boundaries prior to the Neogene lack direct age control. Therefore, the third step, linear interpolation, plays a key role for most of GTS2004. This detailed and high-resolution interpolation process incorporated several techniques, depending upon the available information:

1. A composite standard of graptolite zones spanning the uppermost Cambrian, Ordovician and Silurian interval was derived from 200+ sections in oceanic and slope environment basins using the constrained optimization (CONOP) method. With zone thickness taken as directly proportional to zone duration, the detailed composite sequence was scaled using selected, high precision zircon and sanidine age dates. For the Carboniferous through Permian a composite standard of conodont, fusulinid, and ammonoids events from many classical sections was calibrated to a combination of U-Pb and ^{40}Ar-^{39}Ar dates with assigned external error estimates. A composite standard of conodont zones was used for Early Triassic. This procedure directly scaled all stage boundaries and biostratigraphic horizons.
2. Detailed direct ammonite-zone ages for the Upper Cretaceous of the Western Interior of the USA were obtained by a cubic spline fit of the zonal events and 25 ^{40}Ar-^{39}Ar dates. The base-Turonian age is directly bracketed by this ^{40}Ar-^{39}Ar set, and ages of other stage boundaries and stratigraphic events are estimated using calibrations to this primary scale.
3. Seafloor spreading interpolations were done on a composite marine magnetic lineation pattern for the Upper Jurassic through Lower Cretaceous in the Western Pacific, and for the Upper Cretaceous through lower Neogene in the South Atlantic Oceans. Ages of biostratigraphic events were assigned according to their calibration to these magnetic polarity time scales.
4. Astronomical tuning of cyclic sediments was used for Neogene and Upper Triassic, and portions of the Lower and Middle Jurassic, middle part of Cretaceous, and Paleocene. The Neogene astronomical scale is directly tied to the Present; the older astronomical scale provides linear-duration constraints on polarity chrons, biostratigraphic zones and entire stages.
5. Proportional scaling relative to component biozones or subzones. In intervals where none of the above information under Items 1 – 4 was available it was necessary to return to the methodology employed by past geologic time scales. This procedure was necessary in portions of the Middle Triassic, and Middle Jurassic. The Devonian stages were scaled from approximate equal duration of a set of high-resolution subzones of ammonoids and conodonts, fitted to an array of high-precision dates (more dates are desirable).

The actual geomathematics employed for above data sets (Items 1,2,3 and 5) constructed for the Ordovician-Silurian, Devonian, Carboniferous-Permian, Late Cretaceous, and Paleogene involved cubic spline curve fitting to relate the observed ages to their stratigraphic position. During this process the ages were weighted according to their variances based on the lengths of their error bars. A chi-square test was used for identifying and reducing the weights of relatively few outliers with error bars that are much narrower than could be expected on the basis of most ages in the data set.

Stratigraphic uncertainty was incorporated in the weights assigned to the observed ages during the spline-curve fitting. In the final stage of analysis, Ripley's MLFR algorithm for Maximum Likelihood fitting of a Functional Relationship was used for error estimation, resulting in 2-sigma (95% confidence) error bars for the estimated chronostratigraphic boundary ages and stage durations. These uncertainties are discussed and displayed in the time scale charts as part of Gradstein *et al.* (2004), and also shown on the ICS official web pages under *www.stratigraphy.org*. The uncertainties on older stage boundaries generally increase owing to potential systematic errors in the different radiometric methods, rather than to the analytical precision of the laboratory measurements. In this connection we mention that biostratigraphic error is fossil event and fossil zone dependent, rather than age dependent.

In Mesozoic intervals that were scaled using the seafloor spreading model, or proportionally scaled using paleontological subzones, the assigned uncertainties are conservative estimates based on variability observed when applying different assumptions (see discussions in the Triassic, Jurassic and Cretaceous chapters of GTS2004). Ages and durations of Neogene stages derived from orbital tuning are considered to be accurate to within a precession cycle (~20 kyr), assuming that all cycles are correctly identified, and that the theoretical astronomical-tuning for progressively older deposits is precise.

GTS Quo Vadis?

The changing philosophy in time scale building has made it more important to undertake high-resolution geochronologic study of critical stratigraphic boundaries, and at the same extend the astronomical tuning into progressively older sediments. Paleogene and parts of Cretaceous are prime candidates for a high-resolution orbital time scale, although chaos theory appears to limit the ultimate resolution achieved in the Neogene. Good examples of high-resolution studies are Bowring *et al*. (1989) for basal-Triassic, Amthor *et al*. (2003) for basal-Cambrian, and Hilgen *et al.* (2000) for Messinian. The philosophy is that obtaining high-precision age dating at a precisely defined stratigraphic boundary avoids stratigraphic bias and its associated uncertainty in rock and in time. In this respect, it is of vital importance to geochronology that ICS not only completes the definition of all Phanerozoic stage boundaries, but also actively considers definition of subdivisions within the many long stages itself. Striking examples of such long stages currently lacking internal standardization are Campanian, Albian, Aptian, Norian, Carnian, Ladinian, Anisian and Visean. Among long periods the Cambrian stand out as rather undivided; it presents a formidable challenge to stratigraphers with its long interval of limited biostratigraphic resolution and high continental partitioning. Despite the challenges ICS is optimistic that the consensus process to define and subdivide all stages and periods should be completed in a timely manner. Regional and philosophical arguments between stratigraphers should be actively resolved to reach consensus conclusions with focus on the global correlation implications. Stratigraphic standardization precedes linear time calibration.

Future challenges to time scale building, presented in detail in Gradstein *et al*. (2004), may be summarized as follows:

a. Achieve formal definition of all Phanerozoic stage boundaries, and interior definition of long stages.
b. Directly link polarity chrons and cycles for the 13 - 23 Ma orbitally tuned scale.
c. Orbitally tune the Paleogene time scale, 23 - 65.5 Ma, and extend tuning ‘down’ in Cretaceous.
d. Achieve a consensus Ar/Ar monitor age (? 28.24 ± 0.01 Ma from orbital tuning).
e. Achieve consensus values for decay constants in the K-Ar istopes family.
f. Achieve full error propagation on all published, high-resolution ages; create listings in a master file.
g. Resolve the seemingly intractable zircon controversies across Devonian/Carboniferous, Permian/Triassic, and Anisian/Ladinian boundaries, either through more sampling or re-evaluation of different laboratory techniques.
h. Undertake detailed age dating of several rather ‘neglected’ intervals, including Upper Jurassic – Lower Cretaceous (M-sequence spreading and ‘tuned’ stages), base Carboniferous (Kellwasser extinction event; glaciation), and within Albian, Aptian, Norian, Carnian, Visean, and intra Permian.
i. Achieve more detailed composite standard zone schemes for Upper Paleozoic and Lower Mesozoic.

We note with satisfaction that the geochronological science community and ICS are actively focussing on the challenging stratigraphic and geochronologic issues listed. A new version of the present time scale may be in place at the time of the 33rd International Geological Congress in 2008, concurrent with consensus on all stage boundary stratotypes.

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References

Amthor, J. E., Grotzinger, J. P., Schroder, S., Bowring, S. A., Ramezani, J., Martin, M. W., and Matter, A., 2003: Extinction of *Cloudina* and *Namacalathus* at the Precambrian boundary in Oman, *Geology*, 31 (5), p. 431-434.

Bowring, S. A., Erwin, D. H., Jin, Y. G., Martin, M. W., Davidek, K., and Wang, W., 1998: U/ Pb zircon geochronology and tempo of the end-Permian mass extinction, *Science*, v. 280, no. 5366, p. 1039-1045.

Cande, S. C., and Kent, D. V., 1992: A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic, *Journal of Geophysical Research*, 97, p. 13917-13951.

Cande, S.C. and Kent, D.V., 1995: Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic, *Journal of Geophysical Research*, 100, p. 6093-6095.

Cooper, R.A., 1999: The Ordovician time scale - calibration of graptolite and conodont zones: *Acta Universitatis Carolinae Geologica*, 43 (1/2), p. 1-4.

Gradstein, F. M., Agterberg, F. P., Ogg, J. G., Hardenbol, J., van Veen, P., Thierry, T., and Huang, Z., 1994: A Mesozoic time scale. *Journal of Geophysical Research*, 99 (B12), p. 24051-24074.

F.M.Gradstein, J.G.Ogg, A.G.Smith, F.P.Agterberg, W.Bleeker, R.A.Cooper, V.Davydov, P.Gibbard, L.Hinnov, M.R. House (†), L.Lourens, H-P.Luterbacher, J.McArthur, M.J.Melchin, L.J.Robb, J.Shergold, M.Villeneuve, B.R.Wardlaw, J.Ali, H.Brinkhuis, F.J.Hilgen, J.Hooker, R.J.Howarth, A.H.Knoll, J.Laskar, S.Monechi, J.Powell, K.A.Plumb, I.Raffi, U.Röhl, A.Sanfilippo, B.Schmitz, N.J.Shackleton, G.A.Shields, H.Strauss, J.Van Dam, J.Veizer, Th.van Kolfschoten, and D.Wilson. 2004: A Geologic Time Scale 2004*. Cambridge University Press*, ~ 500 p.

Harland, W. B., Cox, A. V., Llewellyn, P. G., Pickton, C. A. G., Smith, A. G., and Walters, R., 1982: A geologic time scale 1982, *Cambridge University Press*, 131 p.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G., and Smith, D.G., 1990: A geologic time scale 1989, *Cambridge University Press*, 263 p.

Hilgen, F. J., Krijgsman, W., Langereis, C. G., Lourens, L. J., Santarelli, A., and Zachariasse, W. J., 1995: Extending the astronomical (polarity) time scale into the Miocene, *Earth and Planetary Science Letters*, 136, p. 495-510.

Hilgen, F. J., Bissoli, L., Iaccarino, S., Krijgsman, Meijer, R., Negri, A., and Villa, 2000: Integrated stratigraphy and astrochronology of the Messinian GSSG at Oued Akrech (Atlantic Morocco), *Earth and Planetary Science Letters*, 182, p. 237-251.

Holmes, A., 1947: The construction of a geological time-scale, *Transactions Geological Society of Glasgow*, 21, p. 117-152.

Holmes, A., 1960: A revised geological time-scale. *Transactions of the Edinburgh Geological Society*, 17, p. 183-216.

NUNA, 2003: New Frontiers in the fourth dimension: generation, calibration and application of geological timescales; NUNA Conference, Geological Association of Canada; Mont Tremblant, Quebec, Canada, March 15-18, 2003. See *http://www.nunatime.ca*.

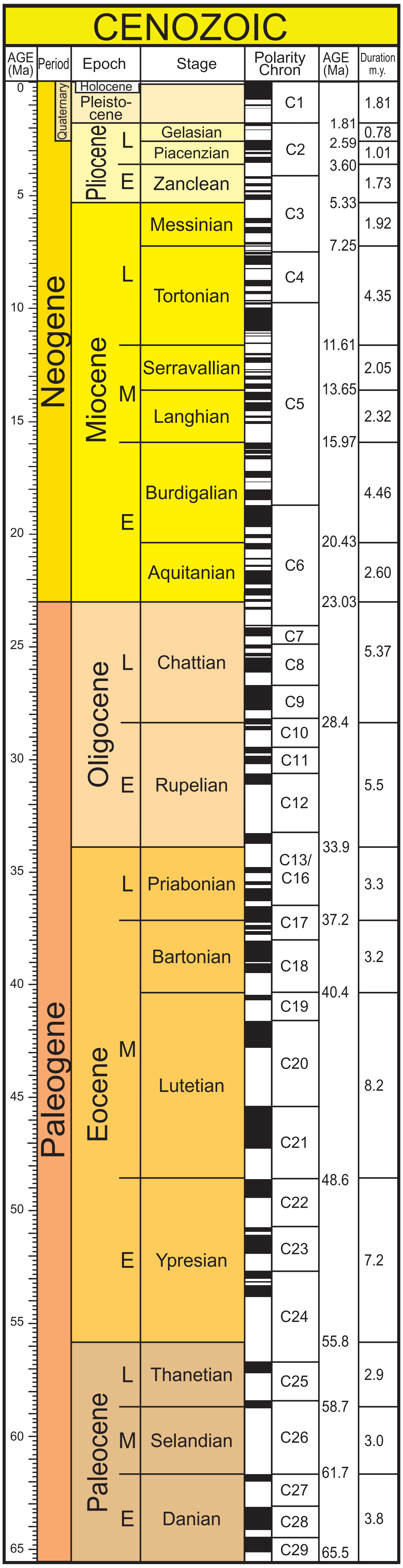
Obradovich, J. D., 1993: A Cretaceous time scale, *in* Caldwell, W. G. E., and Kauffman, E. G., eds., Evolution of the Western Interior Basin, *Geological Association of Canada*, Special Paper 39, p. 379-396.

Remane, J., 2000: International Stratigraphic Chart, with Explanatory Note Paris, Sponsored by ICS, IUGS and UNESCO. *31st International Geological Congress*, Rio de Janeiro 2000, p 16.

Shackleton, N. J., Crowhurst, S. J., Weedon, G. P., and Laskar, J., 1999: Astronomical calibration of Oligocene-Miocene time, *Philosophical Transactions of the Royal Society of London*, A, (357), p. 1907-1929.

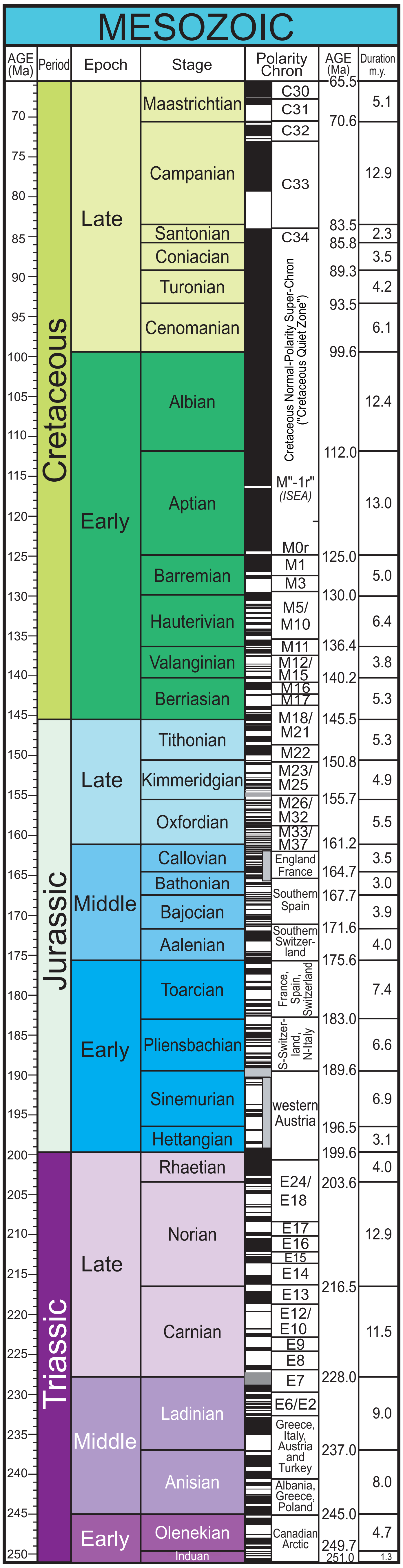
GEOLOGIC TIME SCALE

PHANEROZOIC



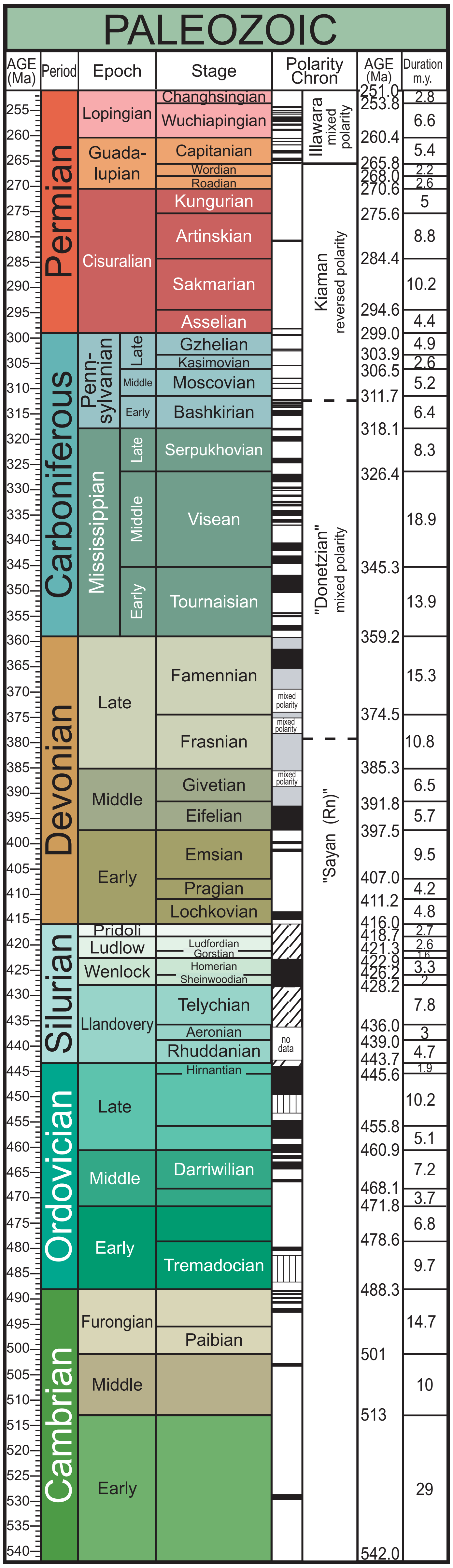
CENOZOIC

Period	Epoch	Stage	Polarity Chron	AGE (Ma)	Duration m.y.
Neogene (Quaternary)	Holocene		C1	0	
	Pleistocene			1.81	1.81
	Pliocene L	Gelasian	C2	2.59	0.78
		Piacenzian		3.60	1.01
	Pliocene E	Zanclean		5.33	1.73
	Miocene L	Messinian	C3	7.25	1.92
		Tortonian	C4	11.61	4.35
	Miocene M	Serravallian		13.65	2.05
		Langhian	C5	15.97	2.32
	Miocene E	Burdigalian		20.43	4.46
		Aquitanian	C6	23.03	2.60
Paleogene	Oligocene L	Chattian	C7 C8 C9	28.4	5.37
	Oligocene E	Rupelian	C10 C11 C12	33.9	5.5
	Eocene L	Priabonian	C13/C16	37.2	3.3
		Bartonian	C17 C18	40.4	3.2
	Eocene M	Lutetian	C19 C20 C21	48.6	8.2
	Eocene E	Ypresian	C22 C23 C24	55.8	7.2
	Paleocene L	Thanetian	C25	58.7	2.9
	Paleocene M	Selandian	C26	61.7	3.0
	Paleocene E	Danian	C27 C28 C29	65.5	3.8



MESOZOIC

Period	Epoch	Stage	Polarity Chron	AGE (Ma)	Duration m.y.
Cretaceous	Late			65.5	
		Maastrichtian	C30 C31	70.6	5.1
		Campanian	C32 C33	83.5	12.9
		Santonian	C34	85.8	2.3
		Coniacian	Cretaceous Normal-Polarity Super-Chron ("Cretaceous Quiet Zone")	89.3	3.5
		Turonian		93.5	4.2
		Cenomanian		99.6	6.1
	Early	Albian		112.0	12.4
		Aptian	M"-1r" *(ISEA)* M0r	125.0	13.0
		Barremian	M1 M3	130.0	5.0
		Hauterivian	M5/M10	136.4	6.4
		Valanginian	M11 M12/M15	140.2	3.8
		Berriasian	M16 M17	145.5	5.3
Jurassic	Late	Tithonian	M18/M21 M22	150.8	5.3
		Kimmeridgian	M23/M25	155.7	4.9
		Oxfordian	M26/M32 M33/M37	161.2	5.5
	Middle	Callovian	England France	164.7	3.5
		Bathonian	Southern Spain	167.7	3.0
		Bajocian		171.6	3.9
		Aalenian	Southern Switzerland	175.6	4.0
	Early	Toarcian	France, Spain, Switzerland	183.0	7.4
		Pliensbachian	S-Switzerland, N-Italy	189.6	6.6
		Sinemurian	western Austria	196.5	6.9
		Hettangian		199.6	3.1
Triassic	Late	Rhaetian	E24/E18	203.6	4.0
		Norian	E17 E16 E15 E14	216.5	12.9
		Carnian	E13 E12/E10 E9 E8 E7	228.0	11.5
	Middle	Ladinian	E6/E2 Greece, Italy, Austria and Turkey	237.0	9.0
		Anisian	Albania, Greece, Poland	245.0	8.0
	Early	Olenekian	Canadian Arctic	249.7	4.7
		Induan		251.0	1.3



PALEOZOIC

Period	Epoch	Stage	Polarity Chron	AGE (Ma)	Duration m.y.
Permian	Lopingian			251.0	
		Changhsingian	Illawara mixed polarity	253.8	2.8
		Wuchiapingian		260.4	6.6
	Guadalupian	Capitanian		265.8	5.4
		Wordian	Kiaman reversed polarity	268.0	2.2
		Roadian		270.6	2.6
	Cisuralian	Kungurian		275.6	5
		Artinskian		284.4	8.8
		Sakmarian		294.6	10.2
		Asselian		299.0	4.4
Carboniferous	Pennsylvanian Late	Gzhelian		303.9	4.9
		Kasimovian		306.5	2.6
	Pennsylvanian Middle	Moscovian		311.7	5.2
	Pennsylvanian Early	Bashkirian	"Donetzian" mixed polarity	318.1	6.4
	Mississippian Late	Serpukhovian		326.4	8.3
	Mississippian Middle	Visean		345.3	18.9
	Mississippian Early	Tournaisian		359.2	13.9
Devonian	Late	Famennian	mixed polarity	374.5	15.3
		Frasnian	mixed polarity "Sayan (Rn)"	385.3	10.8
	Middle	Givetian	mixed polarity	391.8	6.5
		Eifelian		397.5	5.7
	Early	Emsian		407.0	9.5
		Pragian		411.2	4.2
		Lochkovian		416.0	4.8
Silurian	Pridoli			418.7	2.7
	Ludlow	Ludfordian		421.3	2.6
		Gorstian		422.9	1.6
	Wenlock	Homerian		426.2	3.3
		Sheinwoodian		428.2	2
	Llandovery	Telychian		436.0	7.8
		Aeronian		439.0	3
		Rhuddanian	no data	443.7	4.7
Ordovician	Late	Hirnantian		445.6	1.9
				455.8	10.2
				460.9	5.1
	Middle	Darriwilian		468.1	7.2
				471.8	3.7
	Early			478.6	6.8
		Tremadocian		488.3	9.7
Cambrian	Furongian				14.7
		Paibian		501	
	Middle			513	10
	Early			542.0	29

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 official website of the International Commission on Stratigraphy (ICS) under *www.stratigraphy.org* .