A GEOLOGIC TIME SCALE 2004

An international team of over 40 stratigraphic experts, many actively involved in the International Commission of Stratigraphy (ICS), have helped to build the most up-to-date international stratigraphic framework for the Precambrian and Phanerozoic. This successor to *A Geologic Time Scale 1989* by W. Brian Harland *et al.* (Cambridge, 1989) begins with an introduction to the theory and methodology behind the construction of the new time scale. The main part of the book is devoted to the scale itself, systematically presenting the standard subdivisions at all levels using a variety of correlation markers. Extensive use is made of stable and unstable isotope geochronology, geomathematics, and orbital tuning to produce a standard geologic scale of unprecedented detail and accuracy with a full error analysis. A wallchart summarizing the whole time scale, with paleogeographic reconstructions throughout the Phanerozoic is included in the back of the book. The time scale will be an invaluable reference source for academic and professional researchers and students.

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A Geologic Time Scale 2004

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Dedication

We dedicate this third edition of the Geologic Time Scale book to W. B. (Brian) Harland†. He was an inspiring leader in practical stratigraphy, its philosophical roots, and its prime product: The Geologic Time Scale!

† Deceased.

With the acceptance of a reliable time scale, geology will have gained an invaluable key to further discovery. In every branch of science its mission will be to unify and correlate, and with its help a fresh light will be thrown on the more fascinating problems of the Earth and its Past.

Arthur Holmes, 1913, *The Age of the Earth*

Contents

List of contributors *page* xii
Preface xv
Acknowledgments xvii
List of abbreviations and acronyms xix

PART I INTRODUCTION 1

1 Introduction 3
F. M. GRADSTEIN
1.1 A Geologic Time Scale 2004 3
1.2 How this book is arranged 4
1.3 Conventions and standards 6
1.4 Historical overview of geologic time scales 7

2 Chronostratigraphy: linking time and rock 20
F. M. GRADSTEIN, J. G. OGG, AND A. G. SMITH
2.1 Time and rock 20
2.2 Standardization of the chronostratigraphic scale 21
2.3 Case examples of GSSPs 42
2.4 Major subdivisions of the geologic time scale 43
2.5 Examples of stratigraphic charts and tables 45

PART II CONCEPTS AND METHODS 47

3 Biostratigraphy: time scales from graphic and quantitative methods 49
F. M. GRADSTEIN, R. A. COOPER, AND P. M. SADLER
3.1 Introduction 49
3.2 Graphic correlation 49
3.3 Constrained optimization 51
3.4 Ranking and scaling 52

4 Earth's orbital parameters and cycle stratigraphy 55
L. A. HINNOV
4.1 Introduction 55
4.2 Earth's orbital parameters 55
4.3 Orbitally forced insolation 57
4.4 Orbital signals in cycle stratigraphy 59
4.5 Estimating orbital chronologies 61

5 The geomagnetic polarity time scale 63
J. G. OGG AND A. G. SMITH
5.1 Principles 63
5.2 Late Cretaceous–Cenozoic geomagnetic polarity time scale 65
5.3 Middle Jurassic–Early Cretaceous geomagnetic polarity time scale 74
5.4 Geomagnetic polarity time scale for Middle Jurassic and older rocks 85
5.5 Superchrons and polarity bias 86
5.6 Summary and conclusions 86

6 Radiogenic isotope geochronology 87
M. VILLENEUVE
6.1 Introduction 87
6.2 Types of uncertainties 87
6.3 Dating methods 88
6.4 Summary and conclusions 95

7 Strontium isotope stratigraphy 96
J. M. MCARTHUR AND R. J. HOWARTH
7.1 Introduction 96
7.2 Materials for strontium isotope stratigraphy 98
7.3 *A Geologic Time Scale 2004* (GTS2004) database 98
7.4 Comments on the LOWESS fit 102

8 Geomathematics 106
F. P. AGTERBERG
8.1 History and overview 106
8.2 Paleozoic applications 110
8.3 Late Cretaceous and Paleogene applications 117
8.4 Concluding remarks 124

PART III GEOLOGIC PERIODS 127

9 The Precambrian: the Archean and Proterozoic Eons 129
L. J. ROBB, A. H. KNOLL, K. A. PLUMB, G. A. SHIELDS, H. STRAUSS, AND J. VEIZER
9.1 Introduction 129
9.2 History and recommended subdivision 130

9.3 Nomenclature of the subdivisions 132
9.4 The Neoproterozoic 132
9.5 Isotope stratigraphy in the Precambrian 133
9.6 Biostratigraphy in the Neoproterozoic 136
9.7 Neoproterozoic ice ages and chronometric constraints 139
9.8 Summary 140

10 Toward a "natural" Precambrian time scale 141
W. BLEEKER
10.1 Introduction 141
10.2 Current Precambrian subdivisions and problems 141
10.3 A "natural" Precambrian time scale 142
10.4 Conclusions 146

11 The Cambrian Period 147
J. H. SHERGOLD AND R. A. COOPER
11.1 History and subdivisions 147
11.2 Cambrian stratigraphy 157
11.3 Cambrian time scale 159

12 The Ordovician Period 165
R. A. COOPER AND P. M. SADLER
12.1 History and subdivisions 165
12.2 Previous standard divisions 169
12.3 Ordovician stratigraphy 171
12.4 Ordovician time scale 176

13 The Silurian Period 188
M. J. MELCHIN, R. A. COOPER, AND P. M. SADLER
13.1 History and subdivisions 188
13.2 Silurian stratigraphy 193
13.3 Silurian time scale 198

14 The Devonian Period 202
M. R. HOUSE† AND F. M. GRADSTEIN
14.1 History and subdivisions 202
14.2 Devonian stratigraphy 208
14.3 Devonian time scale 213
14.4 Appendix 220

15 The Carboniferous Period 222
V. DAVYDOV, B. R. WARDLAW, AND F. M. GRADSTEIN
15.1 History and subdivisions 222
15.2 Carboniferous stratigraphy 233
15.3 Carboniferous time scale 237

16 The Permian Period 249
B. R. WARDLAW, V. DAVYDOV, AND F. M. GRADSTEIN
16.1 History and subdivisions 249
16.2 Regional correlations 256
16.3 Permian stratigraphy 263
16.4 Permian time scale 264

17 The Triassic Period 271
J. G. OGG
17.1 History and subdivisions 271
17.2 Triassic stratigraphy 280
17.3 Triassic time scale 288

18 The Jurassic Period 307
J. G. OGG
18.1 History and subdivisions 307
18.2 Jurassic stratigraphy 326
18.3 Jurassic time scale 339

19 The Cretaceous Period 344
J. G. OGG, F. P. AGTERBERG, AND F. M. GRADSTEIN
19.1 History and subdivisions 344
19.2 Cretaceous stratigraphy 365
19.3 Cretaceous time scale 371

20 The Paleogene Period 384
H. P. LUTERBACHER, J. R. ALI, H. BRINKHUIS, F. M. GRADSTEIN, J. J. HOOKER, S. MONECHI, J. G. OGG, J. POWELL, U. RÖHL, A. SANFILIPPO, AND B. SCHMITZ
20.1 History and subdivisions 384
20.2 Paleogene biostratigraphy 389
20.3 Physical stratigraphy 401
20.4 Paleogene time scale 403

21 The Neogene Period 409
L. LOURENS, F. HILGEN, N. J. SHACKLETON, J. LASKAR, AND D. WILSON
21.1 History and subdivisions 409
21.2 Neogene stratigraphy 419
21.3 Toward an astronomically tuned Neogene time scale (ATNTS) 430

22 The Pleistocene and Holocene Epochs 441
P. GIBBARD AND T. VAN KOLFSCHOTEN
22.1 Pleistocene series 441
22.2 Terrestrial sequences 443
22.3 Ocean sediment sequences 448

22.4 Land–sea correlation 449
22.5 Pleistocene–Holocene boundary 451
22.6 Holocene Series 451

PART IV SUMMARY 453

23 Construction and summary of the geologic time scale 455
F. M. GRADSTEIN, J. G. OGG, AND A. G. SMITH
23.1 Construction of GTS2004 455
23.2 Future trends in geologic time scales 462

Appendix 1 Recommended color coding of stages 465
F. M. GRADSTEIN AND J. G. OGG
Appendix 2 Orbital tuning calibrations and conversions for the Neogene Period 469
L. LOURENS, F. HILGEN, N. J. SHACKLETON, J. LASKAR, AND J. WILSON
Appendix 3 Geomathematics 485
F. P. AGTERBERG
Bibliography 487
Stratigraphic Index 587
General Index 589

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Preface

This study presents the science community with a new geologic time scale for circa 3850 million years of Earth history. The scale encompasses many recent advances in stratigraphy, the science of the layering of strata on Earth. The new scale closely links radiometric and astronomical age dating, and provides comprehensive error analysis on the age of boundaries for a majority of the geologic divisions of time. Much advantage in time scale construction is gained by the concept of stage boundary definition, developed and actively pursued under the auspices of the International Commission on Stratigraphy (ICS), that co-sponsors this study.

It was in 1997 that Alan Smith approached two of us (F.M.G. and J.G.O.) with the request to undertake a new edition of *A Geologic Time Scale 1989* (GTS89) for Cambridge University Press. This was just after the "Phanerozoic Time Scale" with the A3 format time scale colour chart as insert, sponsored by Saga Petroleum in Norway, had appeared in *Episodes*. Although we realized this new request was a tall order, we optimistically accepted. A proposal was formulated and improved through peer review. As with GTS89, the new edition of the book would not necessarily give the very latest developments in any field, but would present a balanced overview designed to be educational and useful for advanced university students. In particular progress with the concept and defining of stage boundaries had delineated most international geologic stages.

Initially, a rather limited slate of specialists was engaged, and we optimistically projected completion of a revised GTS89 at the turn of the Millennium. Slightly after, F.M.G. and J.G.O. became executive officers of ICS for the 2000–2004 term, and the GTS project was incorporated in ICS's formal objectives.

Creating a new GTS in 2000, 2001, or even 2002, turned out to be rather optimistic. The more we involved ourselves in the myriad of challenges in stratigraphy and the Phanerozoic geologic time scale the more we realized that a major overhaul was in order. Rather than updating and revising chapters of GTS89 we set out to re-write the book from scratch and expand geologic period chapters along a "fixed," and ambitious format of text and figures. Advances in time scale methodology involving cycle stratigraphy, mathematics and statistics, stable isotope stratigraphy, and the formidable progress in high-resolution age dating all demanded close attention with data integration and specialists chapters.

The vast progress in Precambrian and Phanerozoic stratigraphy achieved during the last decade required intense involvement of many more geoscientists than initially envisioned. Although the more ambitious scope and bigger team did push back completion deadlines, we are confident it has enhanced the consensus value of the new geologic time scale, named GTS2004. Had we known beforehand that a total of 18 senior and 22 contributing authors, for a total of 40 geoscience specialists from 15 different countries, would work on the book and deal with the new time scale, we might have had second thoughts about our undertaking. The number of e-mails sent "criss-cross" over the globe as part of GTS2004 is in the tens of thousands. A fundamental difference between multidisciplinary studies and geologic time scale studies is that all chapters must align along the arrow of time. To put it simply: the Carboniferous cannot end at 291 Ma with the Permian starting at 299 Ma. Close agreement on type of data and standards admitted in actual time scale building is also vital. Hence, the actual data standardization and time scale calculation for each chapter was kept to a small team in which Mike Villeneuve, Frits Agterberg, F.M.G., and J.G.O. played key roles, with other senior authors as advisors. The new Neogene time scale was developed by Luc Lourens and his team of tuning specialists.

The fascination in creating a new geologic time scale is that it evokes images of creating a beautiful carpet, using many skilled hands. All stitches must conform to a pre-determined pattern, in this case the pattern of physical, chemical, and biological events on Earth aligned along the arrow of time. It is thus that this new scale is a tribute to the truly close cooperation achieved by this slate of outstanding co-authors. We also consider the new time scale a tribute to the scientific competence harbored and fostered by ICS.

We are deeply grateful to all co-authors who without reservation accepted the challenge to be part of this dedicated team, slowly (!) stitching and weaving this carpet of time and its events that are Earth's unique and splendid history.

It is with deep regret that we learned in mid 2002 that one of our most valuable scholars in Paleozoic stratigraphy, Professor Michael House, had passed away, very shortly after submission of his draft chapter on Devonian stratigraphy. It has been an honor to complete the task he set himself to create this erudite chapter of expansive and dramatic Earth history between 416 and 359 Ma. Vascular plants and forests established on Earth, exceptional high global sea level occurred, ice caps formed in the south polar region in late Devonian time, and present continents and shelves assembled on one hemisphere. Old Red Sandstone is one of the Devonian's great continental remnants.

Through the NUNA Conference in Canada in March 2003 on "New Frontiers in the Fourth Dimension: Generation, Calibration and Application of Geologic Timescales" the essay "Toward a natural Precambrian time scale" by Wouter Bleeker came to this book. Hence, this period of over 88% of Earth history is getting some more urgent attention. We thank Mike Villeneuve and his team for organizing this timely geochronology conference.

We are pleased to acknowledge the financial contribution of ExxonMobil, Statoil, ChevronTexaco, and BP. With these vital donations the elaborate graphics became possible. J. G. O. acknowledges partial support by the US National Science Foundation under Grant No. 0313524. The Geological Survey of Canada and the Network of Offshore Records in Geology and Stratigraphy (NORGES) project at the Geology Museum of the University of Oslo assisted with design and printing of the time scale wall chart.

Cambridge University Press patiently awaited the fruits of our labor, and we are much obliged to Matt Lloyd, Sally Thomas, and Lesley Thomas for their thorough editorial advice and assistance.

Figure 1.4 in the Introduction chapter illustrates the 1960 geologic time scale by its pioneer, Arthur Holmes, who introduced period scaling from observed maximum thickness. The appearance datum of this new opus in mid 2004 is nearly 90 years after Arthur Holmes's first humble geologic time scale in 1913 in search of the age of the Earth and its remarkable historic components.

This publication on the International Geologic Time Scale was produced under the auspices of the International Commission on Stratigraphy (ICS). Information on ICS, its organization, its mandate, and its wide-ranging geoscience program can be obtained from www.stratigraphy.org.

Felix M. Gradstein
James G. Ogg
Alan G. Smith

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The Paleogene Period, Chapter 20, was authored by Hans-Peter Luterbacher and many contributors. Heiko Pälike reviewed and advised on the actual time scale, Jan Hardenbol advised on an early draft of the manuscript, and Frits Agterberg performed the scaling and uncertainty calculations.

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Abbreviations and acronyms

ORGANIZATIONS

CGMW	Commission for the Geological Map of the World
DNAG	Decade of North American Geology
DSDP	Deep Sea Drilling Project
GSC	Geological Survey of Canada
ICS	International Commission of Stratigraphy
IGC	International Geological Congress
IGCP	International Geological Correlation Project
INQUA	International Quaternary Association
IUGS	International Union of Geological Sciences
ODP	Ocean Drilling Project
SNS	Subcommision (of ICS) on Neogene Stratigraphy
SQS	Subcommission (of ICS) on Quaternary Stratigraphy
SOS	Subcommission (of ICS) on Ordovician Stratigraphy
UNESCO	United Nations Education, Scientific, and Cultural Organization
USGS	United States Geological Survey

TIME SCALE PUBLICATIONS (see References for details)

NDS82	*Numerical Dating in Stratigraphy* (Odin *et al.*, 1982)
GTS82	*A Geologic Time Scale* (Harland *et al.*, 1982)
DNAG83	*Geologic Time Scale, Decade of North American Geology* (Palmer, 1983)
KG85	Kent and Gradstein (1985)
EX88	Exxon 1988 (Haq *et al.*, 1988)
GTS89	*A Geologic Time Scale 1989* (Harland *et al.*, 1990)
OB93	Obradovich (1993)
JGR94	*Journal of Geophysical Research* 1994 (Gradstein *et al.*, 1994)
SEPM95	Society for Sedimentary Geology 1995 (Gradstein *et al.*, 1995)
GO96	Gradstein and Ogg (1996)

GEOSCIENTIFIC CONCEPTS

FAD	First appearance datum
FCT	Fish Canyon Tuff sanidine monitor standard (in Ar–Ar dating)
GPTS	Geomagnetic polarity time scale
GSSP	Global Stratotype Section and Point
GSSA	Global Standard Stratigraphic Age (in Precambrian)
HR–SIMS	High-resolution secondary ion mass spectrometry (in U–Pb dating)
LAD	Last appearance datum
LA2003	Laskar 2003 numerical solution of orbital periodicities
MMhb-1	McClure Mountain hornblende monitor standard (in Ar–Ar dating)
SL13	Sri Lanka 13 monitor zircon standard (in HR–SIMS dating)
TIMS	Thermal ionization mass spectrometry (in U–Pb dating)
TCR	Taylor Creek Rhyolite Sanidine monitor standard (in Ar–Ar dating)

SYMBOLS

ka	10^3 years ago (kilo annum)
kyr	10^3 years duration
Ga	10^9 years ago (giga annum)
Ma	10^6 years ago (mega annum)
myr	10^6 years duration
SI	Système Internationale d'Unités
yr	year duration