



Arc Magmatism I: Relationship Between Subduction  
and Magma Genesis

Review - A Geologic Time Scale 2004

Terrestrial Analogues to Mars and the Moon:  
Canada's Role

Reviews

**Editor/Rédacteur en chef**

Sonya A. Dehler  
 Geological Survey of Canada  
 Bedford Institute of Oceanography  
 1 Challenger Drive, P.O. Box 1006  
 Dartmouth NS Canada B2Y 4A2  
 Tel: (902) 426-4289  
 Fax: (902) 426-6152  
 E-mail: sdehler@nrcan.gc.ca

**Editor/Rédacteur en chef**

Steve R. McCutcheon  
 Geological Surveys Branch - DNR  
 495 Riverside Drive  
 P.O. Box 50  
 Bathurst NB Canada E2A 3Z1  
 Tel: (506) 547-2070  
 Fax: (506) 547-7694  
 E-mail: Steve.McCutcheon@gnb.ca

**Advertising/Publicité**

Karen Dawe  
 Geological Association of Canada  
 St. John's NL Canada A1B 3X5  
 Tel: (709)737-2151  
 kfm dawe@esd.mun.ca

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**Publisher/Éditeur**

Geological Association of Canada  
 c/o Department of Earth Sciences  
 Memorial University of Newfoundland  
 St. John's NL Canada A1B 3X5  
 Tel: (709) 737-7660  
 Fax: (709) 737-2532  
 gac@esd.mun.ca  
 www.gac.ca

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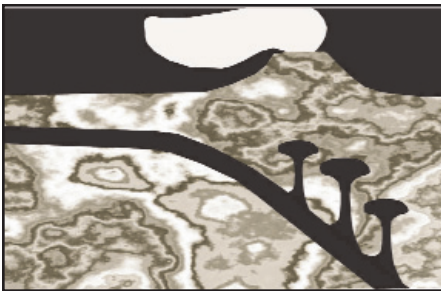
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**Cover.** Photograph from the Houghton Impact Structure, Devon Island. Shown is an erosional remnant of the allochthonous impact breccia formation, a rubble deposit resulting from the launching, airborne mixing, fallback and weak re-welding of impact-shattered fragments derived from the entire stack of excavated rocks. The breccia is cemented by hydrothermal veining. The hammer is 30 cm in length. Courtesy Marie-Claude Williamson, Geological Survey of Canada.

# SERIES



## Igneous Rock Associations 7.

### Arc Magmatism I: Relationship Between Subduction and Magma Genesis

**J. Brendan Murphy**

*Dept of Earth Sciences, St. Francis Xavier University, Antigonish, NS, Canada, B2G 2W5, e-mail: bmurphy@stfx.ca*

#### SUMMARY

Dehydration of subducted oceanic lithosphere releases fluid into the overlying mantle wedge and initiates a chain of events culminating in the generation of magma that rises to form volcanic arcs. Arc magmas are distinct from magmas in other settings because of the different geothermal regimes at destructive plate margins, the presence of fluids/volatiles derived from dehydration of the subducted slab and the generally compressive tectonic regime that inhibits the ascent of magma, thereby promoting extensive interaction with the adjacent wall rocks. As a result, most arc magmas solidify as intrusive bodies, ranging from sills and


dykes to large plutonic complexes. Several mechanisms facilitate the rise of arc magmas. Diapirs rising from a larger pool of buoyant magma are important in the ductile lower crust. The rapid rise and the expansion of magma results in the propagation of fractures, that facilitate stopping and assimilation in the brittle upper crust. Fracture zones are repeatedly exploited, and the net result may be formation of a composite batholith.

Water plays an important role in all stages of arc-magma evolution. Water lowers the temperatures that are required for the partial melting in the mantle wedge, which produces mafic magma, and in the crust, produces felsic magma. Arc magmatism is intimately related to metamorphism, although this relationship is complicated largely because maximum pressures and temperatures are attained at different times. Arcs under compression undergo rapid thickening, followed by erosional or tectonic exhumation. Crustal melting is triggered by a variety of processes, including relaxation following crustal thickening. Melting initiates at the base of the crust, but eventually occurs at shallower crustal levels. Arcs under extension have a steep geothermal gradient and underplating of the crust by mafic magma may transfer sufficient heat to induce anatexis. During a prolonged history of subduction, the dip and location of the subduction zone may vary causing the locus of arc magmatism to migrate and causing intermittent switching from compressional to extensional environments.

#### SOMMAIRE

Le phénomène de déshydratation qui accompagnent la subduction de la lithosphère océanique relâche des fluides dans le prisme mantélique sus-jacent et initie une suite d'événements qui conduit à la génération de magmas qui forment des structures d'îles en arc. Les magmas d'îles en arc diffèrent des magmas d'autres contextes parce que les régimes géothermaux aux lieux de destruction de marges tectoniques sont différents, étant donné la présence de fluides et/ou de volatiles issus de la déshydratation de la plaque en subduction, et du régime tectonique généralement compressif qui inhibe l'ascension du magma, d'où l'importance de l'interaction avec la roche encaissante. En conséquence, la plupart des magmas d'îles en arc forment des intrusifs, variant des filons-couches, aux dykes aux complexes plutoniques. Plusieurs mécanismes favorisent l'ascension des magmas d'îles en arc. Ainsi, l'ascension de diapirs à partir d'une grande accumulation de magma moins dense que l'encaissant est-il un phénomène important dans la croûte inférieure ductile. Cette ascension rapide jointe à l'expansion du magma provoque la propagation de fractures, ce qui facilite l'agrégation et l'assimilation de l'encaissant dans la portion supérieure cassante de la croûte. Fréquemment, le magma injecte ces zones de fractures, ce qui conduit parfois à la formation d'un batholite composite.

L'eau joue un rôle important à toutes les étapes de l'évolution des magmas d'îles en arc. La présence



d'eau abaisse les températures de fusion partielle dans le prisme mantélique, ce qui conduit à la formation de magmas mafiques, et de magmas felsiques dans la croûte. Le magmatisme d'île en arc est intimement lié au métamorphisme, bien que cette relation soit compliquée, surtout parce que les pressions et les températures maximales sont atteintes à des moments différents. Les magmas d'îles en arc en situation de compression s'épaississent rapidement, puis sont érodés ou exhumés tectoniquement. La fusion de la croûte est déclenchée par une variété de processus, dont la détente accompagnant l'épaississement crustal. La fusion se produit d'abord à la base de la croûte, mais elle atteint éventuellement des niveaux moins profonds de la croûte. Les magmas d'île en arc en situation d'extension ont un gradient géothermal très pentu, et le placage de la croûte par un magma mafique peut y apporter assez de chaleur pour provoquer l'anatexie. Si l'histoire de la subduction se prolonge, le contexte d'un système d'îles en arc peut alterner épisodiquement d'un régime en compression à un régime en extension.

# REVIEW

## A Geologic Time Scale 2004

Edited by Felix M. Gradstein,  
James G. Ogg and Alan G. Smith

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Reviewed by Rob Fensome

Natural Resources Canada, Earth Sciences  
Sector

Geological Survey of Canada (Atlantic)

P.O. Box 1006, Dartmouth, Nova Scotia  
B2Y 4A2

There are many elements of science that invoke wonderment: as a professional biostratigrapher whose livelihood is based on the reality of evolution, it is not unusual for me to think about the amazing achievement represented by our understanding of the history of life. Advances such as plate tectonics and particle physics also come to mind. However, one achievement not so widely appreciated is the geological time scale. Born of the great work of people such as Nicolaus Steno (1638-1686; Cutler 2003), James Hutton (1726-1797; Repcheck 2003), William Smith (1769-1839; Winchester 2001) and Arthur Holmes (1890-1965; Lewis 2000), time scales to the middle of the 20<sup>th</sup> Century became based on a three-way foundation of the rock record, the fossil record, and radiometric dating. The most significant development since then has been the addi-

tion of new tools that provide additional help in calibrating our planet's history. These new tools include magnetostratigraphy, cycle stratigraphy, chemostratigraphy and sequence stratigraphy. No sub-discipline has a complete answer ... the art of time-scale construction lies in collaboration.

Several authoritative time scales have appeared over the last 25 years. These include the "Decade of North American Geology" or "DNAG" time scale (Palmer 1983); the Haq et al. (1988) scale for the Mesozoic and Cenozoic; and, in Canada, the time scale compiled by Andy Okulitch and distributed as a GSC Open File (Okulitch 1999, 2004). Perhaps the most influential was that produced by Brian Harland and colleagues (Harland et al. 1982) and called, *A Geological Time Scale*. Harland et al. (1990) produced a revised version, *A Geological Time Scale 1989*. The volume under review here is the third version of this initiative: *A Geological Time Scale 2004* (GTS 2004; Gradstein et al. 2005). The publisher has been Cambridge University Press for all three editions and there are familiar aspects such as the detailed charts and tables. But this third edition – under the editorial stewardship of Felix Gradstein, James Ogg and Alan Smith (the only lead author/editor involved in all GTS editions so far) – is clearly the most ambitious venture yet; not just an update of previous editions. Moreover, it seems to have the blessing of the International Commission on Stratigraphy, and the schemes presented for parts of the geological

column appear to be those supported, for the most part, by the respective working groups of the authoritative International Union of Geological Sciences.

GTS 2004 is arranged in four parts: Introduction (chapters 1-2), Concepts and Methods (chapters 3-8), Geologic Periods (chapters 9-22) and Summary (Chapter 23). Part 2 on concepts and methods is a largely new and welcome innovation in this edition. The chapters/contributions are individually authored, in contrast to the first two editions. And although charts are still a prominent feature, there is much more background text, which expands the book significantly, but in many ways makes it more approachable. In addition to the chapters, there is an interesting Preface that describes the drawn out process of producing the book and hints at the tribulations of making the contributions of 40 scientists conform seamlessly, with no time warps between intervals. One item that I found a little odd in the Preface (p. xv) was the statement that the aim of the new edition was to "... present a balanced overview designed to be educational and useful for advanced university students": surely a current and detailed time scale is more fundamental than that.

In Chapter 1, Felix Gradstein discusses the nature and evolution of time scales, especially in the context of new and evolving methodologies. In apparent contrast to the preface statement, Gradstein (p. 3) acknowledges that, "All earth scientists should under-

stand how the evolving time scales are constructed and calibrated, rather than merely using the numbers in them.” Gradstein points out that the calibration of the stratigraphic record to “absolute” or linear time involves: 1) the relative correlation (chronostratigraphy) of the global rock record using internationally agreed stratigraphic divisions (e.g. “Jurassic”, “Maastrichtian” “*Harporceras falciferum* ammonite zone” or “polarity Chron C24r”); 2) the (chronometric) measurement of linear time (through, for example, radiometric dating) or elapsed durations (e.g. through astronomical cyclicity as reflected in sediments); and 3) the means of joining chronostratigraphic and chronometric schemes. The chronostratigraphic scale is an agreed convention based on (actual or potential) defined boundary stratotypes and reference points, whereas the chronometric scale is “a matter for discovery or estimation”.

Chapter 2, by Felix Gradstein, James Ogg and Alan Smith, is about linking time and rock. The authors note that the chronostratigraphic scale (i.e. the geological column in more popular parlance) was originally established from a combination of the correlation of regional lithologic units (e.g. the western European Chalk, in part, defining the Cretaceous) and the unique, non-recurring events provided by biological evolution. Classically based on the largely marginal marine and pelagic rock record in Europe, the chronostratigraphic units (systems, stages, etc.) that developed are an incomplete record of geological time. The authors provide a striking demonstration of this in Fig. 2.1, where traditional stratotypes of stages for the Paleocene and Oligocene are shown to represent only about a quarter to a third of the actual time interval represented; the Eocene is only slightly better off. As a result (p. 20) “... a distinction between a hierarchy of material chronostratigraphic units (rock-time) and abstract geochronologic units

(Earth time) units was required, and a dual nomenclatural system was codified...” Hence, we can refer to the Maastrichtian Stage of the Cretaceous System of the Mesozoic Erathem in a chronostratigraphic sense or to the Maastrichtian Age of the Cretaceous Period of the Mesozoic Era in a geochronologic sense; similarly, chronostratigraphic units can be subdivided into lower, middle and upper subunits; geochronologic units can be subdivided into early, mid and late subunits. I will return to this matter of terminology later in this review.

In recent decades, under the auspices of the International Commission on Stratigraphy (ICS), the designation of Global Stratotype Sections and Points (GSSPs) has helped (arguably to some) to clarify and stabilize the link between rocks and time. As the authors of Chapter 2 point out, the basal boundary of each chronostratigraphic unit (effectively stages because the base of a system will be the base of its lowest stage) is standardized at a point (“golden spike”) in a reference section within an interval exhibiting continuous sedimentation. Careful study and extensive international discussion takes place before each GSSP is ratified, in contrast to the somewhat individual and *ad hoc* process that went into the development of the systems and stages in the 19<sup>th</sup> and early 20<sup>th</sup> centuries. Gradstein et al. note that it is over 25 years since the first “golden spike” was “hammered” in place – at the base of the Devonian at a place called, appropriately, Klonk in the Czech Republic. The base of the Devonian (actually the base of the Lochkovian stage) coincides with the first occurrence of the graptolite *Monograptus uniformis* in bed No. 20 of the Klonk section. The authors (p.23) note, however, that “... once the golden spike has been agreed, the discovery ... of *Monograptus uniformis* below the GSSP does not require a re-definition ..., but simply an acknowledgement that the ... level chosen was not ... the

lowest occurrence of the ... [species].”

At the time of writing, 46 “golden spikes” had been defined, and updates are reported on the ICP website. Most are biostratigraphically based, but other criteria have been used, such as the iridium spike at the base Cenozoic, the carbon isotope anomaly at the base of the Eocene, and a specific Milankovitch cycle at the base of the Pleistocene.

Returning to the matter of terminology, there seems to me to have been much confusion in recent decades over the application of the terms chronostratigraphy and geochronology themselves, as well as extensive misuse of the related terminologies, e.g. system versus period or lower versus early. Such items are perennial “bones of contention” for manuscript editors and reviewers. By way of a section header, the authors (p. 41) ask “Do GSSP boundary stratotypes simplify stratigraphic classification?” They note that, given GSSPs, the limits of chronostratigraphic units (stages) are (actually or potentially) “fully defined in time.” They note that Harland et al. (1990) realized that the GSSP concept leads to a redundancy of separate “time-rock” (meaning chronostratigraphic) terms. The authors (p. 41) cite Harland et al. (1990): “The use of time-rock terms (e.g. Lower Cambrian) predates the standardization of time terms, so it is an understandable perpetuation of an old habit that it is now nevertheless timely to replace. By referring to Early Cambrian rather than Lower Cambrian, the definition (and concept) is more direct. Early Cambrian rocks are any rocks formed in early Cambrian time.” Gradstein et al. hint that they are sympathetic with this point of view but had some resistance to it from other authors contributing to the volume. I am inclined to agree with Harland et al. (1990).

Part 2 of the book focuses on concepts and methods. There are chapters on biostratigraphy 3), orbital

parameters and cycle stratigraphy 4), geomagnetic polarity 5), radiogenic isotopes 6), strontium isotopes 7), and geomathematics 8). Even though it was identified in Chapter 2 as a cornerstone of time scale building, “stratigraphic reasoning” (i.e. the rock record itself) does not merit a chapter, perhaps because it is considered “old hat” or “understood”. However, a short review chapter, in my view, would not have been out of place, and would serve to remind readers how important the fundamentals are still.

One aspect that comes across strongly in this suite of chapters is how the various methodologies are working together to refine the time scale. For example, although magnetic polarity unit boundaries are globally simultaneous, in contrast to some of the other correlation tools, the authors of Chapter 5 (James Ogg and Alan Smith; p. 64) leave no doubt that magnetostratigraphy needs biostratigraphy to corroborate general stratigraphic position. They state, “It is essential to have some biostratigraphic constraints on the polarity zone pattern resolved from any given section in order to propose a non-ambiguous ... correlation to the ... geomagnetic polarity time scale.” The oldest (magnetic or polarity) units (chrons) identifiable from the ocean floor are Middle Jurassic. Radiometric dates from drilled seafloor basalts from this age forward allow not only for dating of the magnetic units, but also for dating of biostratigraphic events (Williams et al. 2004). A problem, however, is the current dearth of reliable dates from the Middle Jurassic Oxfordian Stage to the Early Cretaceous Barremian Stage, a span of some 35 million years. Ogg and Smith explain how seafloor spreading rates and, to a lesser extent, cycle stratigraphy have been used to develop a provisional time scale for this interval. Regarding the youngest chrons, the authors note how, initially, potassium-argon radiometric ages were used, but have been superseded by “absolute

orbital-cycle ages with very high precision.” They further comment (p. 73) that “Cycle stratigraphy will eventually ... assign absolute durations to polarity chrons throughout the Phanerozoic.” This statement seems optimistic perhaps given the statement (p. 60) in Chapter 4 on cycle stratigraphy by Linda Hinnov that “... cycle stratigraphy much older than ~20 Ma may never successfully be correlated directly to the orbital cycles, but only indirectly through comparison of average signal characteristics between data and orbital theory.”

From Chapter 6 by Mike Villeneuve, it was interesting to discover that generally only results from the U-Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$  methodologies are now considered reliable. Moreover, as Felix Gradstein notes in the book’s Introduction, high precision does not always imply accuracy. For example, Villeneuve reports the example of two high-precision studies of the same horizon around the Permian-Triassic boundary: one yielded a date of  $251.4 \pm 0.3$  Ma and the other  $253 \pm 0.3$  Ma. The author uses this example to stress the importance of understanding the geological processes and avoiding samples with, for example, thermal overprinting; in the above example, the second date is inaccurate because of unrecognized Pb loss. Of course, radiometric dating is especially important for the Precambrian, for which most or all of the other methodologies are unavailable.

Chapter 7 by John McArthur and Richard Howarth covers strontium isotope stratigraphy, a methodology based on the observation that the  $^{87}\text{Sr}/^{86}\text{Sr}$  value of Sr, dissolved in the world’s oceans, has varied through time. It is disappointing that there are no similar contributions in the volume on isotopes of oxygen and carbon; these are becoming increasingly important in stratigraphy: for example, as mentioned above, a dramatic spike in carbon isotope values is now used to define the Paleocene/Eocene bound-

ary. Part 2 wraps up with a chapter on Geomathematics by Fritz Agterberg, a vital aspect in modern time construction.

Chapters 9 through 22 then work their way through the geological intervals, mainly periods, each written by one to eleven experts. The chapters covering Cambrian to Neogene follow a similar internal structure. However, the Precambrian and Quaternary/Pleistocene have their own special problems and/or character, and so demand special treatment.

There are two chapters on the Precambrian, expressing different philosophical approaches - and it is to the editors’ credit that they have included both. The first paper, by Laurence Robb and others, emphasizes the chronometric (not to be confused ... as it sometimes is ... with geochronologic) nature of the Precambrian time scale, although it points out the increasing utility and promise of isotope stratigraphy in that interval. The authors acknowledge that the Neoproterozoic shows promise for a chronostratigraphic scale, but note (p. 129) that “It will be a long time before such developments can be applied to the whole of the Proterozoic, or to the Archaean, and the present chapter should, therefore, be regarded as an interim report on a challenging topic.” The chronometric subdivision of the Precambrian, ratified by IUGS in 1990, thus involves the familiar break down into the Archean and Proterozoic eons, further subdivided respectively into Eo-, Paleo-, Meso and Neoproterozoic eras, and Paleoproterozoic, Mesoproterozoic, and Neoproterozoic eras. Less familiar to most geologists are the periods of the Proterozoic. These are, from oldest to youngest (with age and “typical, but not necessarily diagnostic” features from which the names are derived): Siderian (2500-2300 Ma; banded iron formations), Rhyacian (2300-2050 Ma; injection of layered complexes), Orosirian (2050-1800 Ma; global orogenic period), Stratherian (1800-1600

Ma; stabilization of cratons), Calymmian (1600-1400 Ma; platform covers), Ectasian (1400-1200 Ma; continued expansion of platform covers), Stenian (1200-1000 Ma; narrow belts of metamorphism and deformation), Tonian (1000-850 Ma; apparently an interval of stretching), Cryogenian (850-630 Ma; global glaciation), and the chronostratigraphically defined Ediacaran (630-542 Ma). All of these units except for the Ediacaran are defined chronometrically.

The alternative Precambrian chapter by Wouter Bleeker is one of the most interesting in the book. Bleeker (p. 141) states that “Definition of boundaries [in the Precambrian] in terms of arbitrary, round, absolute ages, although superficially appealing, is ... naïve.” The author discusses problems with reliance on radiometric dates, noting that “As new [data] ... become available, rocks that had previously been assigned to the Archean might become Proterozoic or vice versa.” He also casts serious doubt on the value of the IUGS-ratified period system for the Proterozoic; his search of the Georef database for “Ectasian” or “Calymmian” yielded zero results; as Bleeker comments, “Precambrian stratigraphers are simply ignoring the formal terminology for ... [periods].” The author recommends retention of the Archean and Proterozoic eons and the 7 eras (Neoproterozoic, etc); but proposes that the boundaries be based on natural events tied to interpretations of rocks. For example, the base of the Archean (Eoarchean) would be defined by the base of the oldest (preserved) supracrustal rocks at about 3850 Ma. The author also proposes an interval between the Archean and Proterozoic termed the “Transition” from about 2600 to 2300 Ma. This interval reflects the diachronous nature of the transition between the granite-greenstone tectonic style of the Archean and the incipient plate-tectonic style of the Proterozoic. In promoting these ideas, Bleeker is following a trend set by ear-

lier Canadian authors (Stockwell 1973; Douglas 1982 and Okulitch 1987); Andy Okulitch (personal communication, 2007) notes that, “since arguments continue about when plate tectonics began, this transition zone is merely a complex portion of Earth history whose timing may be better defined by mafic dyke swarms than orogenic events.”

Chapters 11 through 21 cover the periods from Cambrian to Neogene and encompass a wealth of information. As well as detailed tables and figures that present the evidence for the time scale for that interval, each chapter has sections on History and Subdivisions, Stratigraphy, Time Scale, with occasional extra sections where necessary (for example Previous Standard Divisions in the Ordovician). For those not interested in stratigraphic details like the basal conodont zone of the Eifelian, a useful overview for each period (plate tectonics, life, extinctions, climate, environments, stages in global history, and more) can be plucked out without too much sieving. And if you are into the history of the time scale and its units (the Sedgwick-Murchison debate for example), each of these chapters provides an overview.

One of the most striking realizations for me was how few radiometric dates the authors found acceptable in the Phanerozoic: only 11 reliable dates for the entire Cambrian, for example. This means that much of the time scale is controlled by graphic and/or statistical methodology based on biostratigraphic analyses and tied by these relatively few radiometric dates; assumptions about evolutionary or depositional rates play significant roles in these calculations. The comment in Chapter 11 (p. 164) states that, “our estimates of stage durations become correspondingly intuitive and the age of stage boundaries in the Early Cambrian ... should be regarded as highly approximate.” The Early Cambrian is an extreme example, but there are many sections through the Phanero-

zoic where similar, if milder cautions would not be amiss. There is no implied criticism in this observation: this is just the way it is (see Okulitch 2004), although it does underscore the fact that there is still much work to do.

In spite of the problems surrounding radiometric dates, there is no doubt of the value that they bring to understanding our geological past – largely because of them, there can be no serious doubt about the general temporal framework of our planet’s evolution. However, it is my impression that the public perception of the way that rocks are dated solely involves people in white lab coats with shiny multi-computer-linked machines: specimens are collected and prepared, buttons are pressed, widgets whir, and, hey presto, a number comes up: eureka – the rock is 197.223 million years old. The corollary is a general impression that palaeontology (with biostratigraphy as one of its main contributions) is nowadays redundant. That this impression is wrong is compellingly brought home in the Devonian chapter, where the late Michael House and Felix Gradstein (p. 215) note that “The detailed and high-resolution conodont-ammonoid zonation ..., with over 35 zones ..., is in stark contrast to the handful of [reliable] radiometric dates employed in Devonian time scale building.” An almost identical statement is made in the Carboniferous chapter, this time citing 35-40 zones and 21 radiometric dates.

Ordovician aficionados will be interested, and some probably dismayed, to know that the historical series/epoch terms Arenig, Llanvirn, Llandeilo, Caradoc and Ashgill have been dropped. To an outsider like me, it is a little perplexing to read (p. 169) that, although these terms are formally discarded, “... it is likely that they will continue to be widely used ...”: yet they are not included in most of the figures and tables as a regional option. This is even more perplexing when one reads, under the general heading of “Evolu-

tionary Events” (p. 174), that “Two spectacular bursts in diversity took place [in the broad Ordovician context], one in the late Arenig and the other in the late Llanvirnian to early Caradocian ....” One gets the impression of conflict within the Ordovician establishment.

In my own work, I focus on Mesozoic-Cenozoic (especially Jurassic through Paleogene) material, so chapters 18-20 were of special interest. In recent years, there has been an increasing trend in dinoflagellate biostratigraphy to use events (first and last appearances) rather than zones. Based on methods and techniques discussed above, the chronostratigraphic age for each event is established and, either directly or indirectly, the chronometric age is determined. This is a complex process, but any chronometric ages thus determined must be related to a particular time scale. The scale used by many Mesozoic-Cenozoic micropaleontologists in recent years is that by Hardenbol et al. (1998). These authors incorporated a detailed event stratigraphy associated with their time scale. The problem with a changing time scale is that somewhat complicated conversions need to be made, and users have to get used to a new set of numbers: it would be very trying to have to do this more often than every 5-10 years.

Like the bottom (Precambrian) part of the time scale, the top part is also highly contentious. And strangely enough there is a similar reason: for both, fossils have not been as prominent in the process of determining units. Unlike the other Phanerozoic intervals, which the GTS treats mainly, if not exclusively, from a marine biochronological context, stratigraphy for the most recent geological past has tended to emphasize climatically controlled continental lithostratigraphy (Van Couvering 2006). At least, the basis for the definition and subdivision of the Quaternary has been the recognition and

interpretation of climatically driven glacial and interglacial sedimentary sequences. On the other hand, the Pleistocene and its subdivisions are based on largely fossil and paleomagnetic criteria, while the Holocene base is defined at 10 000 radiocarbon years (about 11 500 real years). The view represented by GTS 2004 is thus, that the Pleistocene-Holocene terminology conceptually fits the top of the GTS, whereas the Tertiary-Quaternary terminology is a quaint throwback, and at odds with current philosophy. Thus, although keeping the term Quaternary as an option, GTS 2004 decoupled it from the Pliocene-Pleistocene-Holocene terminology; the term Tertiary is dropped altogether. This is a new issue: until recently, the base of the Quaternary was assumed to correspond to the base of the Pleistocene. The problem has been made real (rather than semantic) by the designation of a golden spike at the base of the Pleistocene, estimated at 1.806 Ma; those who favour a Quaternary terminology (including it seems most of those working on rocks at the top of the geological column) consider the base of the Quaternary as the onset of oscillating glacial and non-glacial episodes, at about 2.6 Ma, as calibrated loosely by geomagnetics.

To this point, I have carefully avoided naming the authors of Chapter 22 on “The Pleistocene and Holocene Epochs”: they are Phil Gibbard and Thijs van Kolfschoten. The chapter and youngest part of GTS 2004 have set off a heated debate: according to Bowen and Gibbard (2007), its publication “... surprised one of its co-authors, who published a swift rebuttal on the omission [sic] of the term Quaternary...” The rebuttal appeared in Gibbard et al. (2005). For an alternate perspective, see Van Couvering (2006).

Despite its problems, this book represents a tremendous achievement: insofar as a compendious book can be, it represents a state of the art of the geological time scale up to 2005.

As an active research tool, this type of book is probably becoming superseded by dynamic databases (e.g. the GeoWhen Database: [<http://www.stratigraphy.org/geowhen/>]). For those interested in gaining a sense of developments since 2004/2005, especially with regard to the seemingly increasing controversial nature of the GSSP approach, Berggren et al. (2006) is worth checking out. Nevertheless, GTS 2004 is a “must” for all institutional libraries that make any claim to cover the natural sciences. At US\$70 it is not cheap, but – given its almost 600 pages plus pull-out chart – good value nonetheless, and most geologists will want to at least have ready access to a copy. It is an excellent source of technical and non-technical information, and the bibliography alone makes it a great resource for many projects.

#### ACKNOWLEDGEMENTS

I am very grateful to Andy Okulitch and Graham Williams for cogent critiques of the first draft of this review, which was considerably improved as a consequence. Thanks are also due to Martin Head, who provided me with an insider’s perspective of, and recent information on, the Quaternary/Pleistocene debate; and to co-editor Sonya Dehler for the opportunity to delve into this big book.

#### REFERENCES

- Berggren, W.A., Van Couvering, J.A., Piller, W., Zalesiewicz, J.A., and McGowran, B., 2006, Penrose Conference report. Chronostratigraphy: beyond the GSSP: *GSA Today*, v. 16, no. 11, p. 22-24.
- Bowen, D.Q. and Gibbard, P.L., 2007, The Quaternary is here to stay: *Journal of Quaternary Science*, v. 22, p. 3-8.
- Cutler, A., 2003, *The Seashell on the Mountaintop: A Story of Science, Sainthood, and the Humble Genius who Discovered a New History of the Earth*: Dutton,

- New York, 228 p.
- Douglas, R.J.W., 1980, Proposals for time classification and correlation of Precambrian rocks and events in Canada and adjacent areas of the Canadian Shield. Part 2: a provisional standard for correlating Precambrian rocks: Geological Survey of Canada, Paper 80-24.
- Gibbard, P.L., Smith, A.G., Zalasiewicz, J.A., Barry, T.L., Cantrill, D., Coe, A.L., Cope, J.C.W., Gale, A.S., Gregory, F.J., Powell, J.H., Rawson, P.R., Stone, P., and Waters, C.N., 2005, What status for the Quaternary?: *Boreas*, v. 34, p. 1-12.
- Gradstein, F., Ogg, J., and Smith, A.G., 2005, *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge, 610 p. (Cover date 2004, published April 2005)
- Haq, B.U., Hardenbol, J., and Vail, P.R., 1988, Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change, *in* Sea-level changes – an integrated approach: SEPM Special Publication, no. 42, p. 71-108 + chart in pocket.
- Hardenbol, J., Thierry, J., Farley, M., and others, 1998, Mesozoic and Cenozoic chronostratigraphic framework of European basins, *in* de Graciansky, P.-C., Hardenbol, J., Jacquin, T. and Vail, P.R., *eds.*, Mesozoic-Cenozoic sequence stratigraphy of European basins: Society of Economic Paleontologists and Mineralogists, Special Publication, v. 60, p. 3-13, 763-781 + charts.
- Harland, W.B., Cox, A.V., Llewellyn, P.G., Pickton, C.A.G., Smith, A.G., and Walters, R., 1982, *A Geologic Time Scale*: Cambridge University Press, Cambridge, 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, Cambridge, 263 p.
- Holmes, A., 1913, *The Age of the Earth*: Harper, London.
- Holmes, A., 1937, *The Age of the Earth*: Second edition: Nelson, London.
- Lewis, C., 2000, *The Dating Game: One Man's Search for the Age of the Earth*: Cambridge University Press, Cambridge, 253 p.
- Okulitch, A.V., 1987, Proposals for time classification and correlation of Precambrian rocks and events in Canada and adjacent areas of the Canadian Shield. Part 3: a Precambrian time chart of the Geological Atlas of Canada: Geological Survey of Canada, Paper 87-23.
- Okulitch, A.V., 1999, *Geological Time Chart 1999*: Geological Survey of Canada, Open File 3040 (National Earth Science Series, Geological Atlas).
- Okulitch, A.V., 2004, *Geological Time Chart 2004*: Geological Survey of Canada, Open File 3040 (National Earth Science Series, Geological Atlas) - revision.
- Palmer, A.R., 1983, *Geologic Time Scale, Decade of North American Geology (DNAG)*. Geological Society of America, Boulder, Colorado.
- Repcheck, J., 2003, *The Man who Found Time: James Hutton and the Discovery of the Earth's Antiquity*: Simon and Schuster UK, London, 247 p.
- Stockwell, C.H., 1973, *Revised Precambrian Time Scale for the Canadian Shield*: Geological Survey of Canada, Paper 72-52.
- Van Couvering, J.A., 2006, Editorial: No Warming in the Quaternary: *Stratigraphy*, v. 2, p. 310. (Cover date 2005, issue date 2006)
- Williams, G.L., Brinkhuis, H., Pearce, M.A., Fensome, R.A., and Weegink, J.W., 2004, Southern Ocean and global dinoflagellate cyst events compared: index events for the Late Cretaceous-Neogene: *Proceedings of the Ocean Drilling Program, Scientific Results*, v.189, p.1-98. Available from World Wide Web: [[http://www.odp.tamu.edu/publications/189\\_SR/107/107.htm](http://www.odp.tamu.edu/publications/189_SR/107/107.htm)]. [Cited 2004-04-09]. College Station, Texas, U.S.A.
- Winchester, S., 2001, *The Map that Changed the World: William Smith and the Birth of Modern Geology*: HarperCollins, New York, 330 p.

# ARTICLE



## Terrestrial Analogues to Mars and the Moon: Canada's Role

Gordon R. Osinski, Richard Léveillé, Alain Berinstain, Martin Lebeuf and Matthew Bamsey

*Canadian Space Agency, Space Science,  
6767 Route de l'Aéroport, Saint-Hubert,  
QC J3Y 8Y9, e-mail:  
gordon.osinski@space.gc.ca*

### SUMMARY

Terrestrial analogues are places on Earth that approximate, in some respect, the geological, environmental and putative biological conditions on a particular planetary body, either at the present-day or sometime in the past. Analogue studies are driven by the need to understand processes on Earth in order to interpret and groundtruth data sent back from Mars and other planetary bodies by unmanned orbiters and rovers. This presents an ideal opportunity to further collaboration between the solid earth and planetary science communities in Canada and elsewhere. Analogue environments also provide a critical locale for optimizing

exploration requirements and strategies for future manned missions to the Moon and Mars. The ideal geography and climate, a wide diversity of analogues sites, and a history of analogue activities, ensures that Canada can play a leading role in the expanding international use of terrestrial analogues sites.

### SOMMAIRE

Les analogues terrestres sont ces endroits sur la Terre qui possède jusqu'à un certain point, les conditions géologiques, environnementales ou biologiques présumées d'un corps céleste, actuelles ou passées. Les études d'analogues terrestres sont nécessaires pour comprendre le fonctionnement de certains processus sur Terre afin de permettre l'interprétation et la validation sur site témoin de données reçues d'orbiteurs non-habités ou de robots mobiles d'exploration. C'est là une occasion idéale d'accentuer la collaboration entre les communautés des sciences planétaires et celles des géosciences au Canada et ailleurs. Les milieux d'analogues constituent aussi des endroits importants permettant d'optimiser les besoins et les stratégies d'exploration de missions habitées vers la lune et Mars. De par ses caractéristiques géographiques et climatiques idéales, sa grande diversité de sites d'analogues, et son histoire d'activités analogues, le Canada est assuré de jouer un rôle de chef de file dans l'utilisation internationale croissante de sites d'analogues terrestres.

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# REVIEWS

## **A World Inside: 150-year History of the Canadian Museum of Civilization**

By C. Vodden and I. Dyck

*Canadian Museum of Civilization, Hull, 2006*

ISBN 0-660-19558-5.

\$29.95, Paperback, 104 pages

Reviewed by Randall F. Miller

*Geology and Palaeontology Section*

*Natural Science Department*

*New Brunswick Museum*

*277 Douglas Avenue, Saint John, NB, E2K 1E5*

If you are a geologist in Canada and you do not know where our national museum system originated, here is your chance for enlightenment. I suspect it is one of those unknown stories of our profession. By its title, this book might not find its way into the hands of a geologist, but it should. I have the opportunity to work in a museum founded by a geologist, not an uncommon beginning for institutions of this kind. Geologists, by their profession, and probably by nature, are collectors. It seems that building a collection to document and represent what we see around us often leads to a museum.

Vodden and Dyck have put together a great book celebrating the 150-year history of the Canadian Museum of Civilization. Even though the focus of the book is about the Canadian Museum of Civilization, it touches on the other museums in our national

system, as they all have a common origin in the early work of the Geological Survey of Canada. I have picked up the book a number of times to write this review, but have found myself intrigued by the content and its connection to our museum, and off I go to explore some thread picked up in this book. I have already used it as a reference in a couple of manuscripts in progress and loaned the book out to a colleague in our Humanities department. My colleague is exploring 19<sup>th</sup> century collections in our museum and unexpectedly began reading about geologists and Sir William Logan. It was a treat for me to point out that geologists contributed in many ways to the development of museums and our knowledge of Canada. *A World Inside* turned out to be a valuable reference source for her work as well. Although the book includes suggested reading and illustration credits, there are unfortunately no references. While understandable for this kind of book, some might find this a little frustrating. I encountered a couple of stories while reading the book and I would love to know where the information came from.

*A World Inside* is an engaging story, easy to read, well illustrated with fabulous photographs from the Canadian Museum of Civilization collection. There are archival photographs including portraits, field work and museum exhibits. In twelve chapters, *A World Inside* follows the story of the birth of the National Museum of Canada, its progression through the early 20<sup>th</sup> cen-

tury and the two World Wars, Canada's centennial, and finally the opening of the Canadian Museum of Civilization in Hull, now Gatineau. It is a story of institutional and personal vision, accomplishment and disappointment, hard work and determination. The choice of illustrations nicely complements the story and includes images both familiar and new. One of the first images shows Sir William Logan in a pose familiar to most Canadian geologists, one of the last images is of Pierre Trudeau, dressed as a voyageur for the groundbreaking ceremony of the Canadian Museum of Civilization. The story is laid out in chronological order starting with the Survey's beginnings in Montreal and Logan's desire to develop a museum. Survey staff documented more than geology, they described the flora and fauna as they went. They also had an interest in the people and cultures they encountered. Not surprising, because field work brought Survey staff into contact with people across the country. Field geologists often lived and worked with indigenous peoples and may have been the first contact some of the native people had with Europeans. Anthropology became a natural and logical part of the Survey's interests. Geologists will find familiar names among the founders of Canada's national museums. George Dawson is described here as the 'Father of Canadian Anthropology'. Survey Directors Robert Bell, Albert Low, and Reginald Brock all worked to develop anthropology as part of the Survey's mandate.

I have only one complaint to offer about the book and that is the landscape format (20.5 x 33 cm). I admit it works well for the presentation of illustrations, but the soft cover binding makes this a difficult book to hold. The first time I read the book I wanted to slouch in a chair, put my feet up and enjoy the story. No matter how I tried I just could not hold the book and turn pages without it falling out of my hands. It is a small matter, but then again for me it is the kind of book that deserves a relaxed read, with time to ponder the connections to my own experiences. Otherwise the book is nicely produced with quality illustrations and offered at a very good price.

For those with an interest in geoscience history in Canada this is a good introduction to a part of that history. If you have never seen the Canadian Museum of Civilization read this book and then go visit. A deeper understanding of the museum's origin gained from this book will make it all the more interesting.

## Beauty in the Rocks The Photography of David M. Baird

By David M. Baird

*TouchWood Editions*

ISBN 10: 1-894898-37-0 (Hardcover)

ISBN 13: 978-1-894898-37-9

144 pages \$44.95

Reviewed by E.R. Ward Neale

5108 Carney Rd. NW, Calgary AB T2L 1G2

David Baird is known to this reviewer and other geoscientists for his work as a geologist, historian, educator and photographer extraordinaire. But he is also known to a much wider segment of the public through his creativity as founding Director of the National Museum of Science and, later, as founding Director of the Royal Tyrrell Museum. In 2004, the latter mounted an exhibition of Baird's black-and-white photographs amassed over his years of world travel. Images from that exhibition along with others from his collection form the basis of this remarkable book.

The essence of "Beauty in the Rocks" is perhaps best captured by the first two lines of a lovely poem in the introductory section:

"Walk softly, lest in your haste  
You miss a thousand things of  
beauty"

The author explains what you can miss in a prose format: "...natural patterns and textures are all around us. Satisfaction may come from the grandeur of a mountain scene....Delight may come from the symmetry of microcrystals in a snowflake or in a tiny cavity in a rock. In some places, the elements are being formed as we watch. In others, what we see tell us of events and processes in times past..."

This is the ideal coffee table picture book. Pages are not numbered and the lucid explanations of the pictures are not marred by technical jar-

gon. The photographs are grouped in "chapters" with catchy, self-explanatory titles. Thus, "Fashioned by Time" includes photos of glacial erratics in Norway, weathered granite in South Africa, chunks of basaltic lava in the Galapagos Islands rounded by Pacific surf, almost spherical boulders on a Cape Breton Island beach, and wind-blown sand grains in an ancient Newfoundland limestone. Other "chapters" are entitled: Field of View; Free-Flowing Forms; StillLife (fossils of course!); Cracks and Tracks; Geometry in Nature (e.g. columnar joints of Giant's Causeway); Beauty Revealed (roadcuts or erosion revealing ancient patterns); From Mountain Top to Sea; Waves and Ripples; Silent Sentinels (e.g. sea stacks and hoodoos).

The final "chapter", Off the Road, is probably my favourite because it includes several exquisite photos of back country Rocky Mountain scenes that I have come to know in my retirement years. As well, it includes Arctic mountains and a Chilean stratovolcano. Lone, distant figures in two of these scenes emphasize the insignificance of humans in the vast grandeur of nature.

The explanations of the pictures are frequently accompanied by interesting and/or amusing comments on circumstances at the time of photography. Thus, as he attempted to capture a diamond pattern made by waves on a Hawaiian beach "...the stream of passersby....seemed constantly intrigued by the crouching photographer with his nose and camera almost on the wet sand." A road cut in jointed slates at the intersection of the T.C.H. and the Banff-Jasper Highway caused "...tourists on the busy road to slow down to see what on Earth that man was fussing about on a mere rock outcrop. I was meanwhile thinking that beauty is where you find it." On another occasion, accompanying a warden on patrol in back country near Jasper, our hero was assigned a "gentle horse". Unfortunately, the animal was fright-

ened by its own noisy flatulence which led to a wild and windy ride! Most dramatic was the circumstance under which the mountains of the South Fiord Dome were captured. Flying over the frozen Arctic Sea in an Otter, a blown gasket required a rapid, powerless glide to reach safety on a flat bouldery strip of shoreline on Axel Heiberg Island. There, our dauntless photographer went about his business while the pilot summoned help.

Many geoscientists, including your reviewer, have participated in field trips with David Baird. Most of us admit that our very best pictures of rocks were achieved by surreptitiously pointing our cameras over his shoulder when he had carefully selected the right angle to catch the shadows on a mountain range or on a row of ripple marks. Our printed products were good but never as good as the Master's. Why? ...because David Baird develops and prints his negatives using the technique of "dodging" to highlight texture and details and so produce the aesthetically pleasing results that have enchanted thousands. "Beauty in the Rocks" is a must for your coffee table and an ideal gift for nature-loving friends and colleagues (e.g. soon-to-be geoscientist retirees!).

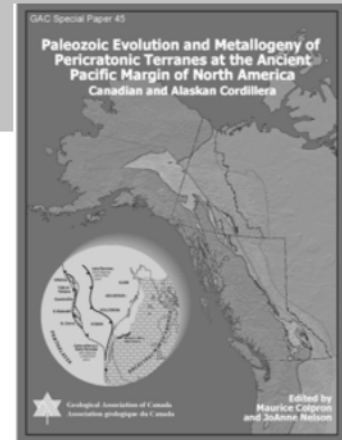
## New Publications From the Geological Association of Canada



### *Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of N. A.*

M. Colpron, J. Nelson, 2006,  
528 p. + CD, ISBN: 1-897095-22-8

This volume presents the results of a five year cooperative geoscience program, the Ancient Pacific Margin National Mapping Program. The eighteen papers in it address the pericratonic terranes, including the Kootenay, Yukon-Tanana and Slide Mountain/Seventy-mile terranes. New and previously published data are compiled in digital format on CD-ROM, along with published detailed geological maps.



### Impact Structures in Canada



**Impact Structures in Canada**  
R.A. Grieve, 2006, 219 p.,  
ISBN: 1-897095-11-2

This book compiles, synthesizes and distils the knowledge base from published and unpublished data and information from the extensive program of study of Canadian impact structures, the program's partners and from other researchers. It represents a time-slice of integrated knowledge on Canadian impact structures, as it stands today.

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