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GAC NUNA CONFERENCE Mont Tremblant, Quebec 15-18 March 2003

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Aller au sommaire du numéro

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CONFERENCE REPORTS

New Frontiers in the Fourth Dimension: Generation, Calibration, and Application of Geological Time Scales

GAC NUNA CONFERENCE
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15–18 March 2003

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INTRODUCTION

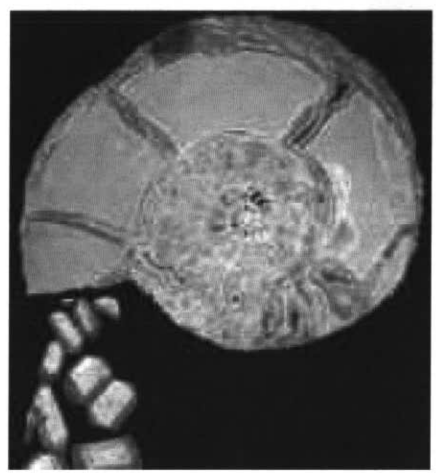
Biostratigraphers don't normally have much to do with geochronologists (and vice versa) in the everyday scheme of things, but at a recent Geological Association of Canada NUNA conference, they found plenty of common ground on which to share ideas and coordinate future research efforts. This common ground was, of course, the Geological Time Scale, and as geological time scales are based on two fundamental types of data – geochronological data and stratigraphic data, geochronologists and "stratigraphers" (*sensu lato*) from around the globe were brought together *en masse* for perhaps the very first time under the auspices of a research conference entitled "*New Frontiers in the Fourth Dimension: Generation, Calibration and Application of Geological Time Scales*". Held from March 15-18, 2003, in the beautiful ski resort of Mt. Tremblant, Québec, this meeting was organized by Mike Villeneuve, Godfrey Nowlan, Andy Okulitch (Geological Survey of Canada – GSC), and John Westgate (University of Toronto) to generate interaction and discussion between stratigraphers and chronometrists concerning the key issues faced by both groups in the construction of a unified, global geological time scale.

CONFERENCE THEMES

The conference was subdivided into five thematic sessions for talks and one session for posters. The opening talk by A. Okulitch (GSC) gave a broad overview of the various challenges in building a geological time scale and introduced all of the issues to be discussed in the remainder of the talks – in particular the division of Precambrian time, acceptable units of time, nomenclature, the definition of time scale boundaries, the importance of age uncertainties in such definitions, and improving the precision and accuracy of time scales.

The Precambrian

The first session on "Precambrian Time" highlighted the several problems associated with trying to subdivide 88% of earth's history. Conference delegates heard that the current subdivisions of the Precambrian are significantly flawed (Bleeker, GSC) for several reasons including the use of gaps in the stratigraphic record to mark boundaries, the lack of a globally consistent nomenclature, and the use of arbitrary defined numerical ages (e.g. 2500 Ma) as boundaries; instead a strong case was put forward to develop a "natural" Precambrian time scale fundamentally based on key events as recorded in the extant rock record. This "golden spike" approach was in marked contrast, however, to an alternatively proposed numerical time scale (Hofmann, McGill University) consisting of intervals of equal duration (in numerical units of 100 Ma, known as "geons") that were chosen to encompass the vast tracts of time spanned by major geological events, and earth and solar system evolution. Although the golden-spike concept [formalized as the Global Standard Stratotype Section and Point (GSSP)] has been used extensively to



Ammonoid ingesting (excreting?) zircon crystals. Although this occurrence has rarely been recorded in the past, the recent NUNA conference bringing together biostratigraphers and geochronologists for the first time makes this phenomenon far more likely in the future. Ammonoid and zircons imaged in reflected light. Use scale bars at your own risk. Photo courtesy of M. Villeneuve.

define Phanerozoic global chronostratigraphic boundaries, Precambrian chronostratigraphic boundaries are formally defined in terms of absolute ages using a different kind of stratotype known as the Global Standard Stratigraphic Age (GSSA), presumably due to the lack of biostratigraphic control (Rainbird, GSC; for more information, see the International Commission on Stratigraphy WWW site at *http://www.micropress.org/stratigraphy*). From all of the talks, it became evident that there are two major challenges in developing a Precambrian time scale based on the extant rock record. The first challenge is to decide on what globally significant geological events should be used to define the chronostratigraphic units. Several potential candidates were highlighted including the onset of giant iron formations, the intrusion of regionally extensive dyke swarms, the first appearance of supracrustal rocks, and the onset/demise of global ice ages. Implicit in this endeavour, of course, is testing whether or not the selected events were globally synchronous. The second challenge is the need for accurate and precise isotopic dating of key stratigraphic horizons in these old rocks; although U-Pb zircon dating is most commonly used at present, new developments in the dating of U-bearing authigenic phosphate cements and overgrowths (Annell, UBC) may soon enable Precambrian clastic sediments to be radiometrically dated.

Chronometric Calibration

The second thematic session focused on a variety of chronometric issues involving the geological time scale. The U-Pb and $^{40}Ar/^{39}Ar$ geochronometers are two of the most important radioisotopic systems that have been used to successfully calibrate the time scale. Because of its high precision and shorter half-life, the $^{40}Ar/^{39}Ar$ system is the method of choice from the Cenozoic to the Mesozoic, whereas the exceptional accuracy of the decay constants and the internal concordancy check makes the U-Pb system the preferred method in the Paleozoic and beyond. Some of the outstanding issues facing geochronologists, however, involve the recognition and incorporation of various uncertainties which can be classified under four broad categories (Renne, Berkeley Geochronology Center): 1) systematic errors (especially those associated with the decay constants and calibrating standards), 2) interpretation errors (in which open-system behaviour may not have been recognized), 3) inappropriate analytical strategies, and 4) geological complexities (including diachronous boundaries, the use of provincial taxa, interpolation between chronostratigraphic units, and the use of independent chronometers on the same rocks that may date different events, e.g. magma residence times). The U-Pb system is generally accepted as the benchmark for time-scale calibration (Schmitz, Carnegie; Bowring, MIT) and elucidating the formation of the solar system (Amelin, GSC), although some outstanding issues still remain such as the lack of global zircon standards for the ID-TIMS and SHRIMP (Compston, Australian National University) techniques and the potential to improve U decay constant errors which appears to be limited ultimately by the systematic errors of the tracer calibration and how well we know $^{238}U/^{235}U$. New U-Pb data were presented supporting a Cambrian-Precambrian boundary age of 542–543 Ma (Bowring, MIT) and further refining the Devonian time scale (Kaufmann, University of Tübingen). Two major issues facing $^{40}Ar/^{39}Ar$ geochronologists (Lee, Queen's University; Renne, Berkeley Geochronology Center) are apparent discrepancies between the absolute values of the ^{40}K decay constants used in the earth science vs. nuclear physics communities (1–2% difference) and their corresponding uncertainties (200–500% difference); studies are currently under way to address this issue. A promising application of the Re-Os geochronometer to time-scale work is the potential to date the deposition of organic-rich sedimentary rocks such as black shales (Creaser, University of Alberta). Like U-Pb ID-TIMS ages, the precision of Re-Os ages is ultimately limited by the accuracy and precision of the tracer or spike calibration; however, the currently favoured value of the ^{187}Re decay constant is ultimately calibrated against the U decay constants (through the use of a 4.5578 Ga (Pb-Pb) meteorite "standard"), requiring the propagation of additional errors to obtain a complete description of uncertainties in a Re-Os date (Selby, University of Alberta). In contrast to the radioisotopic methods discussed above, the application of the Earth's orbital fluctuations (i.e., in eccentricity, obliquity, precession) as the basis of an independent, astronomical clock (orbital "tuning" or "forcing") has led to its use as a geochronological tool; however, several fundamental complications inherent in the nature of the methodology lead to the conclusion that orbital forcing theory (Milankovitch cyclicity) can be used to estimate elapsed time within rock sequences and has the potential to assist in geological time-scale calibration, but only in younger rock sequences where an extrapolation of present-day (and well-known) orbital periodicities backwards through time can provide tight constraints (Giles, GSC). A pertinent example highlighting the problems inherent in extrapolating Milankovitch cyclicity further back through time was presented in the thematic session on *Biostratigraphic Calibration* (Pálfy, Hungarian Academy of Sciences – see below). Another example highlighting complications in determining the age of Chron M0r resulting from integrating geochronological, cyclostratigraphic, and magnetostratigraphic data was also presented (Pringle, Scottish Universities Environmental Research Centre).

Cenozoic Time

The third thematic session emphasized the various approaches needed to calibrate this unique slice of geological time – unique because it is the part of Earth history most "accessible" to earth scientists. As a result, researchers in Cenozoic time tend to use more integrated approaches in building a time-stratigraphic framework of this segment of the rock record. Tephra beds are extremely useful in stratigraphic correlation because of their large areal extent, short duration, and suitability for radiometric dating typically by $^{40}Ar/^{39}Ar$ or fission-track methods (Westgate, University of Toronto). By combining tephrostratigraphic studies with biostratigraphic (paleoecological) and paleomagnetic studies, this becomes a powerful integrated approach that not only provides chronometric calibration of the time scale potentially at decadal resolution but also ties the rock record directly to detailed interpretations of climate/environmental change (Froese, Simon Fraser University). Because of the extremely young ages involved, establishing a precise Quaternary chronology with traditional isotopic dating techniques is difficult. Again, a multidisciplinary approach utilizing tephrochronology, magnetostratigraphy, orbital tuning, biostratigraphy, luminescence, amino acid, and radiocarbon dating has proven to be the most effective (Pillans, Australian National University).

Biostratigraphic Calibration

The fourth thematic session marked a significant change in the focus of the meeting to biostratigraphic issues concerning the time scale. Geological time scales are based on two fundamental types of data – geochronological data and stratigraphic data. Stratigraphic data provide a "relative" time scale that is based on detailed, but empirical, observation and interpretation of the complex history of life as recorded in the rock record. The empirical nature of biostratigraphy results in a variety of challenges faced by workers in the field including taxonomy, the use of different kinds of fossil zones, and geographic significance of a biostratigraphic scheme (Nowlan and Poulton, GSC). A major source of uncertainty in any biostratigraphic scheme, and of the time scale derived from it, relates to definitions. Biostratigraphic age is dependent on taxonomic interpretation and definition, a point made by several speakers and illustrated with an example from the Triassic (Orchard, GSC). Sound taxonomy is thus an essential component of the Phanerozoic time scale. Ambiguous definition of time scale unit boundaries is being addressed by the International Commission on Stratigraphy; about 40 of the 100 or so stages of the Global Geochronological Scale are now "fixed" by GSSP's, greatly reducing scope for misinterpretation. One of these, at the base of the Silurian, is currently being revised (Melchin, St. Francis Xavier University).

A second major source of uncertainty arises from imprecise subdivision (coarse zonation), imprecise or incorrect correlation, and imprecise or incorrect interpolation (calibration). A new quantitative approach uses a computer-assisted optimization procedure (CONOP) to derive a scaled composite sequence and relative time scale of high precision (Cooper, New Zealand Institute of Geological and Nuclear Sciences) greatly improving the subdivision, correlation and interpolation procedures. The method: (a) finds the optimum correlation of sections with a corresponding measure of the "goodness-of-fit", (b) produces a finely scaled composite free from inferences about biozones, and (c) uses high-precision radiometric dates to calibrate the scaled composite and to test its accuracy, estimating interpolation errors on uncertainties from the optimum fit.

More detailed discussions of a variety of biostratigraphic issues involved in refining the Mesozoic and Paleozoic time scales were presented in the remainder of the session talks. Key issues here included correlation of lower Paleozoic bentonites using geochemical signatures (Pearce, University of Wales), the application of U-Pb dating and ammonoid biostratigraphy to resolve an apparent conflict with time scales predicted from orbital tuning in the mid-Triassic (Pálfy, Hungarian Academy of Sciences), recalibration of the Cretaceous time scale based on microfossils (Sikora, University of Utah), and integration of palynological and magnetostratigraphic chronologies in the Late Cretaceous/Paleocene for western Canada (Sweet, GSC). The session ended with a discussion of how rapid sedimentation rates in a Proterozoic basin can be deduced by interpreting the sedimentary succession (the Belt Supergroup) as a faithful "seismograph" of synsedimentary tectonic activity through a careful examination of earthquake-affiliated and tsunami-generated deposits (seismites and tsunamites) and the application of high-precision geochronology (Pratt, University of Saskatchewan).

Chronostratigraphic Calibration

The final thematic session re-emphasized the importance of various uncertainties in the construction of any time scale and the importance of integrating information from a variety of sources. Recognizing that cyclostratigraphy is often tied to radiometric ages that have their own uncertainties, a new mathematical-statistical methodology was presented that has the potential to extract high-resolution cyclostratigraphic time scales from laminated sedimentary records and can combine biostratigraphic and radiogenic time scales into a single consistent time scale (Prokoph, Speedstat). Stratigraphic uncertainty in correlations to international chronostratigraphic divisions is one main reason why a locally derived time scale based on local geological events and local rock successions is still favoured in New Zealand, although there is clearly a desire to move towards the use of a global time scale (Crampton, New Zealand Institute of Geological and Nuclear Sciences). Quantifying and melding stratigraphic uncertainty with geochronological uncertainty is not an easy task, but by applying a variety of statistical tests and tools, however, promising quantitative methods have been developed to estimate the ages of chronostratigraphic boundaries and their associated uncertainties and to calculate the error bars of stage or zone durations (Agterberg, GSC). The final talk of the session outlined a new international database network initiative (CHRONOS), which will attempt to assemble, integrate and distribute any data relevant to the Earth's history by providing a "dynamic" time scale to all interested researchers (Koppers, Scripps). The final presentation of the conference was given by F. Gradstein (University of Oslo), who summarized the various selection strategies and methods (orbital tuning, seafloor spreading, dating, scale composite standard, maximum likelihood methods, and spline-fitting) used to construct the latest version of the Geologic Time Scale (anticipated publication in 2004) as endorsed by the International Commission on Stratigraphy (ICS), working under the auspices of the International Union of Geological Sciences (IUGS).

DISCUSSION AND FUTURE PLANS

One major highlight of the meeting included the several discussion periods held at the end of each of the thematic sessions. The Precambrian time scale remains a subject of controversy (Easton, Ontario Geological Survey), but general agreement among meeting participants was found on several points including a strong desire to link the time scale with the rock record, the importance of tying boundaries to key geological events (where ideally such key events must be global, correlatable and of short duration), and the incorporation of uncertainties in the ages of the these boundaries. The chronometric session emphasized several issues which still need to be addressed by the geochronology community – analytical age uncertainties (is there a need for interlaboratory calibrations, standardized analytical protocols, and a standardized set of norms for reporting data?), decay constants and uncertainties and atomic-abundance uncertainties in the Ar-Ar, U-Pb, Re-Os and Lu-Hf systems, standard calibrations (e.g. Fish Canyon Tuff, SHRIMP, and a suitable rock which can be used as a "golden standard" to calibrate both the Ar-Ar and U-Pb systems), and the incorporation of geological and interpretation uncertainties. One positive outcome from this meeting was the idea of forming a working group at the 2004 IGC in Florence to provide a forum for addressing all of these issues. New, more reliable approaches to be taken in calibrating the Cenozoic time scale will involve applying Ar-Ar geochronology to key horizons such as ash beds in the stratigraphic section and precisely dating tephras as an independent check on the accuracy of the astronomical calibrations. In order to assess uncertainty in biostratigraphic events, it was concluded that a variety of approaches were required, including improvements in taxonomy, new sampling, the application of quantitative methods, and the integration of geochronology, magnetostratigraphy, and chronostratigraphy. Finally, many unresolved issues were discussed regarding the question of whether we can build a statistically sound, web-based time scale. How much raw data (e.g. mass spectrometer output, digital photos of GSSP's, etc.) is it necessary to store? How can regional stratigraphic sections/time scales be correlated with the database Time Scale, e.g. GSSP's? When and how do you publish data? How will unpublished data be handled? Should a peer-review system be implemented and who will enforce it? What kind of search functionality is required? Should databases be linked or stand-alone? On what time scale do we update the Time Scale?! Clearly there are several important issues that will require future consideration.

By bringing together researchers in geochronology and biostratigraphy for the very first time, the meeting was an ideal venue to illustrate and discuss fundamental problems faced by both groups as well as provide insights into some of their common problems in working towards a unified, global geological time scale. As beneficial as the meeting was for all involved, two other groups of time-scale researchers, with the exception of those working in the Quaternary, were notably absent – magnetostratigraphers and fission-track geochronologists; their input would certainly be welcome in the future. Although there has not been a great deal of active collaboration between the two scientific communities in the past, the outlook for a more coordinated research thrust in future time-scale work is promising and the groundwork is now laid. There is already discussion of future meetings and the possibility of initiating a list server for the timely discussion of current issues, so perhaps this is just the start of a beautiful friendship.

FURTHER INFORMATION

For more information about the meeting or meeting topics, interested readers can access *http://www.nunatime.ca/*, where the meeting program and abstracts are all online. If you are interested in becoming involved, please feel free to contact any one of the meeting organizers.

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