Scientific Report ESF LESC Exploratory Workshop

Earthtime: The European Contribution - Integration of High-Precision Geochronology and Astronomical Tuning for Calibration of the Cenozoic and Mesozoic Timescales

Amsterdam, Netherlands, 22 - 24 April 2007

convened by
**Klaudia Kuiper, Dan Condon, Frits Hilgen,
Lucas Lourens, Urs Schaltegger and Jan Wijbrans**

1. Executive summary

The workshop was held from Sunday April 22 till Tuesday April 24, 2007 at the Vrije Universiteit Amsterdam, the Netherlands. 25 participants from 9 European countries (Denmark, France, Germany, Italy, Netherlands, Slovakia, Spain, Switzerland, United Kingdom) and 1 participant from the United States attended the meeting and discussed key issues related to (the determination of) geological time. As time is a fundamental quantity in the Earth Sciences, geological time scales are critical for integrating geographically disparate records and determining rates of change. Techniques involved in time scale calibration are continuously developing and are approaching a position where precision exceeds accuracy. This limits the integration of time scale datasets generated through the application of different techniques and/or laboratories. At the same time, the scientific issues driving time scale calibration are becoming increasingly sophisticated (due mainly to the development of high resolution datasets from marine records recovered through ocean drilling programs) requiring unprecedented accuracy and precision. This workshop brought together key researchers mainly based in Europe from different communities involved in time scale calibration techniques (primarily astronomical tuning and radioisotopic geochronology) to discuss key issues related to achieving the aims of (1) the intercalibration of techniques employed in geological time scale calibration, and (2) the application of these techniques to the rock record to provide the next generation of geological time scales for Cenozoic and Mesozoic systems.

The workshop has increased communication with and between the different communities and marked the start of a coordinated European effort to time scale calibration issues that will have widespread implications for the Earth and Astronomical Sciences. The outcome of the workshop is an agreement to work closely together and a strategy to form a network as the European contribution to the international EARTHTIME initiative by:

- The development of a Marie Curie Initial Training Network (ITN) under the 7th Framework Programme of the European Union (a proposal submitted May 7, 2007). This network – called GTSnext - will bring together known expertise in fundamentally different time scale calibration techniques spread throughout Europe for the first time. Communication and cooperation between the different communities will be enhanced and the combined expertise will be employed to train a new generation geochronologists fully capable of integrating state-of-the-art numerical dating techniques required for constructing the next generation of the Geological Time Scale.
- A parallel application for an ESF Research Networking Program (RNP; call expected July 2007) to further broaden the community involvement and fully integrate Earth Science communities (magneto-, chemo-, bio-, sequence stratigraphy and IODP)

that either contribute to the development of the Geological Time Scale and/or its application to understanding the Earth Sciences.

- Organization of an international workshop in Europe through the ESF research conference scheme in 2013 focussing on the results of the ITN and RNP and consequent follow-up programmes.

Critical to the development of the next generation of geological time scales is the increased cooperation and communication between stratigraphers and chronologers. Our efforts will provide a basis for enhanced collaboration and breaking down barriers between the different communities.

2. Scientific content of the event

The workshop started on Monday April 23 with introductory talks on the organization of ESF (A. Strasser) and expectations of the workshop (K. Kuiper), followed by an review of the history of EARTHTIME and an overview of the ongoing efforts within EARTHTIME (S. Bowring). The morning session was finished by the current status of and issues in the different time scale calibration techniques. Dan Condon gave a general overview of the radio-isotope techniques with emphasis on precision versus accuracy, random versus systematic errors, and areas with potential for improvement (tracer calibration, standards, decay constants). Jan Wijbrans presented the results of the EARTHTIME $^{40}Ar/^{39}Ar$ interlaboratory standard comparison experiment (with thanks to Matt Heizler, New Mexico Tech, for providing the compilations), the issues of decay constant uncertainties and the intercalibration of the $^{40}Ar/^{39}Ar$ method with the astronomical method. Luc Lourens gave a general introduction to the principles and application of astronomical dating in constructing geological time scales. Jacques Laskar ended the more formal part of the workshop with a clear overview of the current status of astronomical solutions and the potential for future improvements of the solutions. A full orbital solution over ~60 Ma requires improvement of the current accuracy of input parameters by two orders of magnitude!

The Monday afternoon session was based on two separate panel discussions of the two (radio-isotope and astronomical) communities. The radio-isotope community discussed a number of issues which will be briefly summarized. First, an inventory was made of people already involved in EARTHTIME efforts. Most of the U/Pb people (but this is a small group) and few of the Ar/Ar people were already involved having attended previous workshops (in the US) and participated in ongoing interlaboratory bias experiments. In fact, most European laboratories should commit to the international effort to keep the quality of the laboratories guaranteed and all attendees agreed to this. Several issues which will be (partly) incorporated in the ITN or RNP are focused on standardizing and streamlining chemical-analytical and mathematical procedures and protocols in order to improve interlaboratory comparison of results. These issues are in part being dealt with as part of the international initiative of which European labs are already playing a key role. Specific issues discussed centered around (1) sources of systemic bias between laboratories and between different chronometers and (2) assessing the levels of precision and accuracy that can be achieved and are required for intercalibration with, and feedback into, astronomically based time scales.

Systematic uncertainties in radio-isotope techniques have to be addressed. Inter-decay scheme calibration (i.e., U-Pb and Ar/Ar) might be improved via standard materials requiring more U-Pb and $^{40}Ar/^{39}Ar$ age pairs throughout Earth history (varying in age over ca. 3 Gyr, obtained on rapidly cooled on robust minerals such as zircon and sanidine). Intercalibration of dated material with astronomical time scales (on sections < 30 Ma) is another approach we should follow. Primary calibration of standards via K-Ar seems limited to a precision of ~1%. Furthermore, it was discussed how a series of standard materials for different users should be established for, 1) to ensure the long term reproducibility of dates from different laboratories, which asks for a homogenous standard and in large supply; 2) for interlaboratory comparison (homogenous and moderate supply), 3) for intercalibration of geochronological (U/Pb and $^{40}Ar/^{39}Ar$) with astronomical dating techniques (standards varying in age, well defined, rapidly cooled and fresh rocks, containing sanidine and zircon with undisturbed isotopic systems). For U-Pb it is possible to produce synthetic U-Pb solutions of varying ages from isotopically pure spikes. For Ar/Ar it was discussed that some large gem quality minerals might be suitable for such experiments.

Discussion then turned to what level of precision and accuracy could be achieved and what assumptions would underpin it. Questions related to culling of mass spectrometry data and the complexity of natural samples and related assumptions on a normal distribution should be addressed. To assess different data reduction software packages, a real and/or synthetic raw dataset should be developed and distributed to test the output. Criteria for data culling for arriving at weighted mean dates should be established. No community wide consensus exists, culling is mainly subjective. For the Ar/Ar community there is interest in a European led $^{40}Ar/^{39}Ar$ interlaboratory experiment under highly specified conditions. The last EARTHTIME experiment will be reviewed and new guidelines will be set for a next experiment, now attempting to explore single variables. This experiment will be fed into an ESF Research Networking Program.

The astronomical community discussed on how to extend the astronomical tuning back in time now that the entire Neogene has been astronomically dated in GTS2004. The next aim is the astronomical tuning of the Paleogene (back to 65 Ma), and the youngest part of the Mesozoic (back to 100 Ma). The 405 kyr cycle should be used for first order tuning of this time interval because of its long-term stability.

For the Neogene one has to look at obliquity - precession interference patterns in the tuning in detail to establish a time scale that can reliably be used to determine phase relations between astronomical forcing and climate response. For this purpose one has to take Earth parameters (tidal dissipation, dynamical ellipticity) into account. For older time intervals, astronomical time-scale work probably can proceed in two steps: 1) overall time scale back to Mesozoic based especially on the tuning to 400-kyr eccentricity, and 2) higher resolution time scales and improvements of existing time scales for the Neogene/late Paleogene by looking at more detail into climatic and "Earth system" processes. From the astronomy perspective it would be interesting and important to determine frequency ratios of for instance precession and 400-kyr eccentricity in the Mesozoic. The uncertainty of the 400-kyr cycle is now ±70 kyr over 100 Myr and ±250 kyr over 250 Myr. Shorter cycles are not very stable (though they will be present). In addition the timing of the shift of 2.4 Myr to 1.2 Myr eccentricity will help to constrain the chaotic behaviour of the Solar System.

The discussion continues on the global stratigraphy and existing coverage of data. Questions which are addressed are how astronomically tuned ages are exported from reference section to other sites. Should the magnetostratigraphy and biostratigraphy already be included at this stage or should the initial focus be on numerical dating of sections using existing lower resolution magnetobiostratigraphies. The existing tuned sections and cores are another point of concern, since even for the Neogene, the total coverage with high quality records is still very limited (first $\delta^{18}O$ "patched" (not composite) records only exists for a very few sites). The Oligocene/Miocene boundary is now covered 3 times; for the Oligocene only one single record (ODP 1218) exists; for the Eocene no complete record is yet available and new climatic events are still being discovered. Existing tuned cyclostratigraphies further need to be validated (more, longer records that overlap).

Further, the importance of databases in the astronomical community is suggested. Following the "meta-database" approach of the geochronology community, the astronomical community should also set-up a database to incorporate information of the underlying basis of tuned time scales, such as which models are used, which assumptions are made, overview of whole "workflows", age-models and tie-points, raw data, output data etc. These databases MUST have a certain amount of minimum information and should be linked to other databases (to assess e.g. whether radio-isotope ages are consistent with astronomical ages).

Apart from improvement of the time scale itself (the tool), we should also exploit its the applications and e.g., use geological data to constrain astronomical calculations and establish a link to the industry with its high interest in integrated high-resolution stable time scale including the interesting link to sequence stratigraphy.

On Tuesday 24 April focus was on the set-up and contents of a Marie Curie Initial Training Network (ITN) and a broader strategy to provide (and fund) a European platform contributing to EARTHTIME. The ITN is structured according to 4 tasks (the Neogene, Paleogene, Cretaceous and Fundamental Issues) in which all three techniques are represented. The morning was spent on panel discussions of the three time slices and final projects in the ITN focus on:

For the ***Neogene*** deep marine successions are successfully employed to establish an astronomical tuning, resulting in a standard Geological Time Scale with an accuracy and resolution that was previously only possible for the late Pleistocene. However this time scale still needs to be fine-tuned before it can be reliably used to determine phase relations between astronomical (insolation) forcing and climate response in the Neogene and possibly also the Oligocene. Radio-isotopic dating of Neogene ash layers is challenging (due primarily to the limited time for in-growth of radiogenic daughter isotopes), but it also offers excellent opportunities for gaining insight into isotope systematics via their independent dating by astronomical tuning. An example of this synergy is the development of astronomically tuned standards for $^{40}Ar/^{39}Ar$ geochronology.

In contrast to the Neogene, the ***Paleogene*** Time Scale is still in a state of flux with significant revisions being regularly published, preventing us to exploit the rich and diverse Paleogene record. Further, the resolution of the time scale is low caused by the limited number of calibration points although floating astrochronologies start to be incorporated. Extension of the astronomical time scale into the Paleogene seems limited to ca. 40 Ma due to the accuracy of the current astronomical solution. A new numerical solution will supposedly be accurate over 50-60 Ma. However, the 405 kyr eccentricity component is very stable, permitting its use in time scale calibrations back to 250 Ma using only this frequency. Phase relations between cyclic paleo-climate records and the 405 kyr eccentricity cycle are usually straightforward and unambiguous. Therefore, a first-order tuning to ~405 kyr eccentricity can only be revised by shifting the tuning with (multiples of) ~405 kyr. Isotopic age constraints can 'anchor' floating astronomical tunings as long as absolute uncertainties in isotopic ages are less than ± 200 kyr, which are readily achievable even at present. We will integrate the astronomical tuning with the $^{40}Ar/^{39}Ar$ and U/Pb techniques in order to arrive at a high resolution and stable time scale for most of the Paleogene.

The ***Cretaceous*** is famous for its remarkable cyclic successions of marine pelagic sediments which bear the unmistakable imprint of astronomical climate forcing. As a consequence floating astrochronologies which are based on number of cycles have been developed for significant portions of the Cretaceous, covering a number of geological stages. Unfortunately, such floating time scales provide us only with the duration of stages but not with their age. However, due to significant improvements in the astronomical solutions for the Solar System and in the accuracy of radio-isotopic dating (also through its intercalibration with the astronomical dating method), time is ripe now to make a serious attempt to establish a tuned time scale for the Late Cretaceous. Unfortunately, no datable ashbeds are found in the cyclic successions selected for tuning. As a consequence classical cyclic sections in Europe will be used for the tuning, while the radio-isotopic age constraints necessary for the tuning will come from dating ashbeds in the western Interior Basin in North America.

The approach to a European strategy is described in 3.

3. Assessment of the results, contribution to the future direction of the field

The EARTHTIME initiative is an organized, international, community-based scientific network aimed at sequencing Earth history primarily through the integration of high-precision geochronology and quantitative chronostratigraphy. The US NSF provided funds to establish an organizational hub, a series of ongoing workshops and initial research into issues such as interlaboratory bias, identified as a priority during the first workshop (www.earth-time.org). Several European scientists have been involved in the US-led effort to date and some European national funding agencies have supported efforts.

The outcome of the ESF Exploratory Workshop is that we intend to set-up a complementary European funding structure, where collaboration between the different sciences communities is essential (figure 1). As a first step a proposal has been submitted for a Marie Curie Initial Training Network (ITN, deadline May 7, 2007, status pending). The convenors of this workshop form the core group around which this ITN is organized. The proposed GTSnext ITN will add a central component to international EARTHTIME initiative by tackling the fundamental issues of the age calibration of the Geological Time Scale (GTS) and the consistency of radio-isotopic and astronomically derived time scales. We will build upon successful ongoing efforts in the international community (such as interlaboratory bias experiments, multi-disciplinary workshops) and continue to collaborate with, and contribute to the international initiative. The remarkably strong European expertise in the field of astrochronology, combined with established expertise in radio-isotopic dating, and integration of techniques already going on, offers a unique opportunity to intercalibrate the fundamentally different techniques used in time scale calibration and apply them to construct the next generation of the GTS. At the same time, a new generation of geochronologists, fully capable of integrating the widely different techniques that until recently belonged to separate scientific communities, will be trained, bearing the bright prospect of applying the much improved GTS to such important issues as climate change, evolution and geodynamics.

An application for an ESF Research Networking Program (call expected July 2007, deadline October 2007) will be made in parallel to further broaden the network and fully integrate Earth Science communities that either contribute to the development of the GTS and/or use it. Workshop participants Dr. Miguel Garcés (magnetostratigraphy), Prof. Dr. Andy Gale (biostratigraphy) and Dr. Heiko Pälike (IODP) will be actively involved in the preparation of this proposal representing links to their respective communities. It is our intention that we will continue to play a leading role in the ongoing international EARTHTIME initiative (see www.earth-time.org) through the development of a continuous research programme that aims to realize the overall goals of the initiative, more specifically by applying the new time scale to solve fundamental problems in Earth history.

Other outreach will take place by the organization of sessions at scientific conferences (e.g. European Geosciences Union 2008 – convened by B. Schoene, F. Hilgen and M. Heitzler; International Geological Congress 2008 – convened by S. Bowring, T. Torsvik and K. Kuiper).

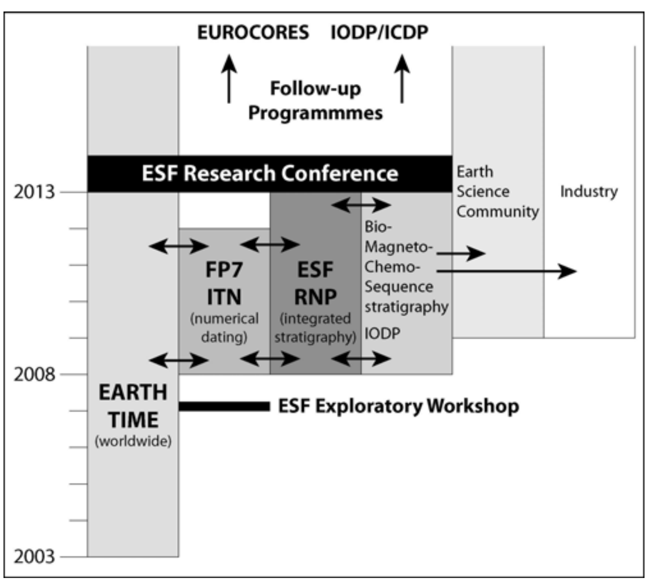

Figure 1: Proposed follow-up activities in the context of the international EARTHTIME initiative, including proposals for a Marie Curie Initial Trainings Network and an ESF Research Networking Programme, enhanced community involvement and other anticipated follow-ups.

4. Final programme

PROGRAMME

Sunday 22 April 2007

Afternoon	*Arrival*
17.00-22.00	*Ice-breaker & Indonesian buffet at Vrije Universiteit Amsterdam*

Monday 23 April 2007

08.00	*Transport from Hotel to Venue location*
09.00	*Coffee*
09.10	**Welcome** (**K. Kuiper**)
09.15	**Presentation of the European Science Foundation (ESF)** **A. Strasser** (ESF Standing Committee for Life, Earth and Environmental Sciences)
09.35	**Introduction by Scientific Organisers** (**K. Kuiper**)
10.00	**Introduction of Earthtime** (**S. Bowring**)
10.30	*Coffee*
11.00	Status of radio-isotope techniques – **D. Condon et al.**
11.45	Status of astronomical time scale – **L. Lourens**
12.15	*Lunch (Atrium)*
13.00	Status of astronomical solutions – **J. Laskar**
13.30	**Discussion**
14.00	**Panel discussions:**
	Astronomical community – chair **F. Hilgen / L. Lourens**
	Radio-isotope community– chair **J. Wijbrans et al.**
14.45	*Tea break*
15.00	**Panel discussions continued**
16.00 – 17.30	**Reporting of panels and discussion**
19.00	*Dinner in Indian restaurant Balti House*

Tuesday 24 April 2007

08.00	*Transport from Hotel to Venue location*
08.30	*Coffee*
09.00	**Towards a strategy to form a Marie Curie Initial Trainings Network (ITN) under the EU 7th framework programme - U. Schaltegger**
09.15	**Panel discussions of task groups in EU Training Network** (Neogene / Paleogene / Cretaceous)
10.30	*Coffee*
11.00	**Panel discussions of task groups in EU Training Network** (Neogene / Paleogene / Cretaceous)
12.30	*Lunch (Panoramazaal MF)*
13.00 (F-647)	**Reporting of panels and discussion**
15.00	*Tea-break*
15.30	**Towards a broader European strategy/platform**
16.30	**Summary**
17.00	*End of workshop & departure*

5. Statistical information on participants

Names of participants:
A total number of 26 participants attended the meeting. There were two last minute cancellations. Four participants did not show up. A list of all attendees is given. The names of participants are listed in alphabetical order: Dr. Hayfaa AbdulAziz (Munich), Prof. Sam Bowring (Cambridge, USA), Dr. Peter Brack (Zurich), Dr. Dan Condon (Keyworth), Prof. Dr. Wolfgang Frank (Bratislava), Prof. Dr. Andy Gale (Portsmouth), Dr. Miguel Garcés (Barcelona), Dr. Frits Hilgen (Utrecht), Prof. Dr. Simon Kelley (Milton Keynes), Dr. Klaudia Kuiper (Utrecht), Prof. Dr. Jacques Laskar (Paris), Dr. Marinella Laurenzi (Pisa), Dr. Luc Lourens (Utrecht), Prof. Dr. Klaus Mezger (Munster), Dr. Oliver Nebel (Amsterdam), Dr. Heiko Pälike (Southampton), Prof. Dr. Xavier Quidelleur (Paris), Dr. Ursula Röhl (Bremen), Prof. Dr. Urs Schaltegger (Geneva), Dr. Blair Schoene (Geneva), Dr. Richard Spikings (Geneva), Dr. Mike Storey (Roskilde), Prof. Dr. Igor Villa (Bern), Dr. Thomas Westerhold (Bremen), Dr. Jan Wijbrans (Amsterdam) and the ESF representative Prof. Dr. Andreas Strasser (Fribourg).

Age structure:
No details collected, but roughly 40% was younger than 40 years.

Gender repartition:
Participants: 4 female, 22 male

Countries of origin:
Denmark: 1
France: 2
Germany: 4
Italy: 1
Netherlands: 5
Slovakia: 1
Spain: 1
Switzerland: 6
United Kingdom: 4
United States: 1

6. Final list of participants

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