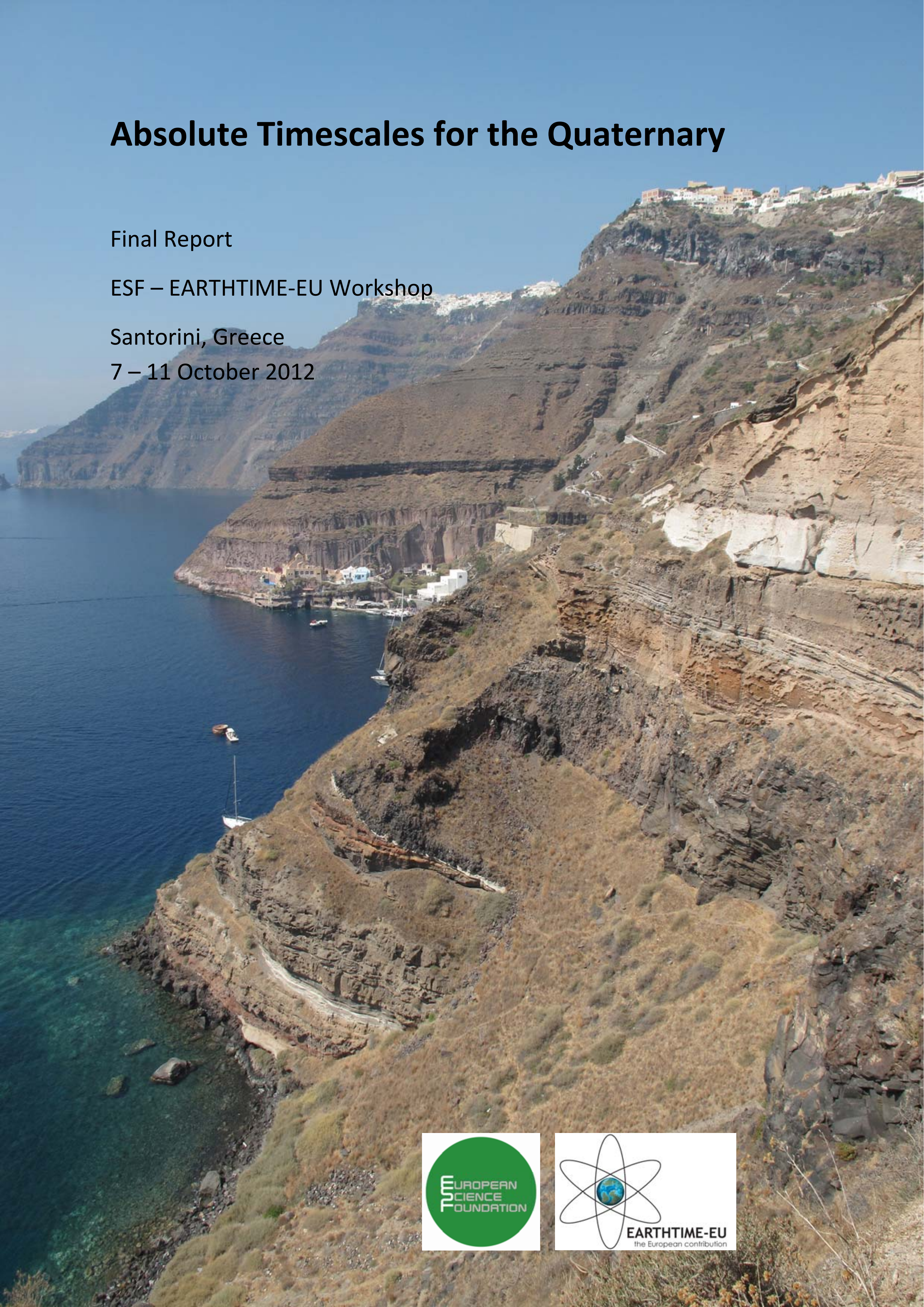

Absolute Timescales for the Quaternary

Final Report

ESF – EARTHTIME-EU Workshop

Santorini, Greece

7 – 11 October 2012

European Science Foundation

EARTHTIME-EU
the European contribution

Summary

During this meeting it was the first time that different communities working on Quaternary time scale calibration all were together. Some of the sub-communities had met in different settings, but never discussed their unresolved methodological issues as a "Quaternary Time Scale Community". All communities introduced the state-of–the art of their method, and presented their challenges for the next couple of years. The sub-communities are at the moment in different phases of internal organisation. The OSL community e.g. is starting inter-laboratory experiments, where the radiocarbon community is already checking the inter-laboratory measurements at a regular basis.

Although on individual basis inter-methodological comparisons are already performed, this isn't done in a systematic way. As follow up of this meeting, funding source will be sought in e.g. the Marie Curie Programme of Horizon 2020. However, methodological developments as such will not be the main aim of follow-up proposals. They should contribute to key scientific questions in the Quaternary.

Scientific content of and discussion at the event

The meeting was structured such, that key European representatives of the respective fields introduced their method followed by more focussed discussion. Below a summary is given of all sub-communities.

Radiocarbon group report

Five experts in the field of radiocarbon dating and its applications participated in the event. They presented the state of the art of ^{14}C dating in connection with the EARTHTIME program. Collaboration with other dating methods is explored, now possible by refinements in various methods during the last decade. Age modelling and intercomparison of methods will be pursued. Specific topics discussed/presented during the workshop are 1) Intcal (P. Reimer); 2) age modelling (C. Bronk Ramsey); 3) sample integrity matters; (I. Hajdas), and 4) archaeological connections in particular connected with the Minoan Thera eruption (H. Bruins).

Radiocarbon (^{14}C) is a well established dating method for carbon containing materials for both organic (e.g., wood, seeds, plant tissues, fossil bones, shells) as well as for inorganic (e.g., carbonates, atmospheric trace gases) samples. Such samples can be dated with precisions of 0.5% or better from the present back to 50.000 years ago. The natural ^{14}C content is not constant, depending on the strength of the geomagnetic field, solar fluctuations and global carbon cycle reorganizations. This means that the ^{14}C timescale is "elastic" and requires calibration into calibrated ages in order to obtain absolute dates. This can be established by paired dating, i.e. dating by ^{14}C and by another, independent method. Traditionally this is done by means of dendrochronologically dated wood. Such records are available back to ca. 12.500 years ago. Beyond this date range, calibration has been established by marine records mainly during the last decade. The data consist predominantly of Pacific corals dated by both the U/Th disequilibrium method and by ^{14}C, and by foraminifera dated by ^{14}C linked to climatic events by ^{18}O isotopic signals (ice cores, speleothems). This constitutes the calibration curve Intcal09, released in 2009, the first curve covering the complete dating range of 50 ka. Note that this curve is marine derived. Marine samples are subject to so-called reservoir effects, requiring corrections to derive a terrestrial calibration curve, and introducing uncertainties.

A major upgrade (published in Science, 19 October 2012) is obtained by means of a laminated sediment core from Lake Suigetsu, Japan. This archive provides terrestrial samples for calibration purposes for the complete dating range. The laminations provide the absolute timescale, and can be connected to the dendrochronological curve. The calibration dataset is obtained from precise AMS dating of samples, and age modelling by comparing with climatic events from independent archives like speleothems and ice cores. The data will be implemented in the next calibration curve for general use, Intcal13. This establishes major improvement in precision towards "absolute dating" ^{14}C all the way, from the present to around 50 ka.

The ^{14}C community is internally well organised. There are specific conferences on AMS, on ^{14}C and Archaeology, and the traditional International Radiocarbon Conferences, each with a 3 year cycle. The laboratories organize mutual intercomparisons (blind tests), and those contributing to calibration are represented in the INTCAL group which recommends the calibration curve to the International Radiocarbon Conference for approval. The now absolute ^{14}C timescale is of obvious importance because this provides a basis for intercomparisons with other dating methods.

On the Quaternary timescale, "young time-range" methods (like ^{14}C) and "old time-range" methods (U-based, $^{40}Ar/^{39}Ar$) approach each other at their limits which now show a good overlapping time-range. The most common method in this respect is U/Th disequilibrium dating which covers the range of ca. 5-300 ka. Speleothems and corals can be dated by both ^{14}C and U/Th disequilibrium; many such data are used in the work on calibration. For other methods, possibilities are not very common since the methods are mutually exclusive, ^{14}C being based on organic materials, and geological isotopic methods on inorganic materials like rock and tephra.

On individual laboratory basis, intercomparisons with other methods are presently used in Quaternary dating, when possible. One example is a ^{14}C/OSL comparison from Eerbeek (Yssel river deposits, the Netherlands) in the ca. 10-70 ka age range (Wallinga & van der Plicht). Another is ^{14}C and $^{40}Ar/^{39}Ar$ dating tephra from the same Lake Suigetsu mentioned above. Age modelling is a topic that has a clear potential to be developed further by comparing ^{14}C and various geological methods.

U-series group report

Richards lead the U-series discussion. In principle the U/Pb systems allows for 4.5 Ga to "play with", but now focussing on Quaternary, with issues such as 1) hominin, faunal evolution and migration; 2) phasing relationships in Earth system with shift to 100 ka cyclicity and 'Middle Pleistocene Revolution' and 3) landscape evolution (and link with cosmogenic burial dating). Technological advances continue to be made, but increasing demands are made on inter-laboratory standards (Condon), common tools (McLean) and understanding of initial conditions. U-Pb by-passes the U-Th secular equilibrium threshold, but sufficient in-growth of radiogenic ^{206}Pb and ^{207}Pb to distinguish from common Pb is an issue. Further, closed system decay scheme for all intermediate daughters from ^{230}Th and ^{231}Pa to ^{206}Pb and ^{207}Pb is required and the U-Pb methods needs measured or 'a priori' information about state of disequilibrium.

Condon/McLean reported back on the U/Pb EARTHTIME experiment. The main lessons from the U-Pb EARTHTIME experiment is that 1) inter-laboratory exercises should initially start simple; 2) over-interpreation should be avoided; 3) over-interpreting scatter if many labs are involved should be resisted and 4) participating laboratories should be motivated to improve protocols/calibration if needed. Synthetic (U/Pb) solutions were largely useful first order assessment of tracer and mass-spectrometry. These solutions are matrix free, so that no chemistry is needed and made in large quantities for wide distribution. To assess the accuracy based calibration and isotope reference materials in combination with careful mass spectrometry is used. This traceability, comparability, statistical, and archiving advances made recently in U-Pb should be expanded to the U-Th system, which has many parallel problems. Eventually, assumptions, measurements, and models required to transform isotope ratio measurements into dates should be codified in a freely-available open-source software package.

Hoffman discussed the current status of U-series dating with its analytical challenges such as dynamic range of mass spectrometer, instrumental bias corrections, spike calibration, highly variable U concentrations, detrital components, open / closed system, etc.

The outlook for U/Pb and U-series is that speleothems (and other secondary calcites) offer excellent 'closed system' options to push back longitudinal records towards the Pliocene and beyond. Also tighter constraints on human/faunal evolution, landscape change should be possible. The key issue to be tackled is common tools (and half-lifes) required for U-Th-Pb disequilibrium with communty effort (sensu EARTHTIME, Cronus-Earth).

^{40}Ar/^{39}Ar group report

^{40}Ar/^{39}Ar participants gave an update on the current state-of-the-art of argon geochronology. Key themes in this community are precision and accuracy of obtained dates (presentation Kuiper). Under the EARTHTIME flag inter-laboratory calibration experiments were already initiated. The results initiated two new routes to track inter-laboratory differences. An EARTHTIME-US team constructed a pipette system with different argon compositions in different bottles. These were measured in >5 laboratories yield results with <0.1% precision (Turrin, pers. comm.). In Europe, a pipette system is build to measure absolute amounts of argon, thereby addressing accuracy issues (presentation Morgan). The ultimate aim is to be able to directly link the ^{40}Ar/^{39}Ar system to SI units, which is currently not the case.

At the same time the argon community faces a transformation from the common single collector mass spectrometer to different types of multi-collector machines equipped with Faraday cups, and/or ion counters (presentation Hamilton). One of the main advantages for the Quaternary community is the promise of more accurate ^{36}Ar measurements that directly translates in more accurate ages. To test the accuracy of the new high resolution machines, direct comparison with other –accurate- methods is required. Dr. Victoria Smith, dr. Mike Storey and prof. dr. Jan Wijbrans discussed applications of ^{40}Ar/^{39}Ar geochronology of Quaternary tephra and basalts.

OSL group report

The luminescence-community participants were inspired and energized by this meeting. Four main aspects are briefly described below.

1) Network expansion: The workshop allowed us to meet specialists working on other dating methods and on linking glacial, marine and terrestrial records (INTIMATE group). Existing contacts were deepened, and new contacts were made. As a direct consequence of the workshop Murray and Wallinga will join the INTIMATE group.

2) Knowledge dissemination: We have deepened our understanding of other Quaternary dating methods, and have informed other participants about (new) possibilities of luminescence dating methods. This has led to improved mutual understanding of possibilities and limitations of methods, and increased awareness of opportunities for cross-validation and intercomparison.

3) *Quality control:* Recent efforts in other communities (in particular U-series and Ar-Ar) for laboratory intercomparison, quality control (flow charts linking to basic units and calibrations) as well as standardisation of methods has inspired us to increase our efforts in these fields (action Guralnik).

4) Opportunities for cross validation: Several ongoing efforts for cross validation were presented at the conference. New opportunities will be investigated with respect to the Suigetsu core (Murray & Buylaert with Bronk-Ramsey), and a lake core from Russia (Ankjaergaard & Dunai). Also we have become more aware of the possibilities of using (distal) tephras as marker horizons and a correlation tool.

Results and impact of the workshop for OSL community: 1) During the meeting, the luminescence dating participants agreed to expand a recently completed *laboratory intercomparison* with a check of the age calculations of participating labs. A publication based on the results will be written within the next 6 months (action Murray & Buylaert). In addition, we will initiate a second cycle of laboratory intercomparison (action Buylaert, Duller, Murray, Preusser, Wallinga); the first cycle started 6 years ago, and it is important to determine whether lessons have been learned from the first attempt. Some support will be sought to initiate this effort (about 5 k€ to be requested from EarthTime and/or INTIMATE; action Wallinga). 2) We will prepare a manuscript on *standards for reporting* luminescence ages, to be published in Quaternary Geochronology. We will agree on a set of minimum requirements, to guide editors and reviewers (action Preusser, with involvement Duller, Murray, Wallinga). 3) We will develop an improved age-calculation spreadsheet, and distribute it to promote the use of *standardized age calculations* by different labs (action Murray & NLL colleagues). Possibilities for translating this sheet to an (open source) package will be investigated (action Guralnik & Wallinga).

TCN group report

Dunai introduced the principles of cosmic ray produced radio-nuclides used as exposure age dating tool. The main challenges for this tool are 1) reconstructions of past geomagnetic field-strength (relevant for mid to low latitudes); 2) response functions for nuclide production (proxy measurements, nuclide x-calibration); 3) scaling at high-altitude (and/or low latitude); 4) production rate calibrations pre-YD and 5) laboratory cross calibrations!

Codilean focused on the issues and application of the ^{10}Be radio-nuclide. The majority of cosmogenic nuclide applications have used ^{10}Be in quartz. ^{10}Be is used alone or in combination with ^{26}Al, ^{21}Ne, and ^{14}C. One application is exposure age dating (see CRONUS-Earth online calculator exposure-age calculation). Further erosion rates and depositional features can be constrained (such as river terraces).

Ochs discussed methodological concerns of cosmogenic geochronology. According to Ochs the measured atoms per gram quartz is absolutely fixed by the AMS measurement and re-measurement of a given rock sample (also re-sampled) always agrees within the quoted measurement uncertainties (at best 3%). For the Alps the production rates are pretty well known given the measurement and 'scaling' uncertainties. Uniformity, at least in method of calculation, has been achieved through the CRONUS-Earth calculation website (^{10}Be & ^{26}Al). Problems with method are outside the method (e.g. geological issues). Cosmogenic nuclides have broad application in Quaternary Geology because of the different characteristic of the available nuclides and their combinations. We use cosmogenic nuclides to date boulders →→landforms (depth, burial for deposits). So we measure time since 'abandonment or stabilization' of the landform. Interpretation of obtained ages always proceeds in light of morpho- and lithostratigraphic relationships and other age or historical data. Boulders are moved during extreme, high energy events (rockfall, rock avalanche, debris flow) or by glaciers. We are still building up local chronologies in the search for patterns in time and space across the Alps with respect to glacier advances, and periods of high rock avalanche or debris flow activity.

Schimmelpfennig discussed the possibilities of ^{36}Cl dating. This cosmogenic nuclide is mostly applied in limestone: ^{36}Cl is the only cosmogenic nuclide that is suitable for limestone and can e.g. be used for dating rockfalls in limestone areas or dating of seismic events on normal fault scarps. ^{36}Cl applications in silicate rocks: 1) Moraines/Erratic boulders; 2) Channel incision and uplift rates in silicate bedrock; 3) Lava flows (whole rocks; 4) Potentially: combination with longer-lived nuclides e.g. in subglacial bedrock ➔ exposure/burial histories – extents of large ice sheets.

Stuart discussed ^{3}He exposure age dating. Uncertainties in production rate are currently ± 3% at best, since 1) the effect of fluctuation in geomagnetic field strength is not quantified; 2) reluctance to discard old (wrong) determinations; 3) He production mechanisms are not fully understood; 4) no standard protocol for calculation. Further, the effect of altitude and latitude (scaling factors) on production rates remain a significant source of uncertainty and no ^{3}He standard exist and one aborted international laboratory inter-calibration.

In summary, TCN dating is very application oriented where the relatively large uncertainties apparently do not interfere with scientific issues that are solved. Some community members are now striving towards better standards and initiate inter-laboratory experiments.

INTIMATE group report

The INTIMATE (INTegration of Icecore, Marine and Terrestrial records) group is already organized in a COST Action programme (COST Action ES0907 - http://cost-es0907.geoenvi.org). INTIMATE aims to INTegrate Ice core, MArine, and TErrestrial palaeoclimate records over 60-8 ka by consistent **dating** or synchronization and robust **calibration** of the records so that we can analyse the combined data, e.g. with the help of climate **modeling** to better understand the mechanisms and **impacts** of past, and future changes. A wish list from a users point of view includes 1) need for integration of dating methods; 2) calibration; 3) increased precision; 4) more correlation tools; 5) cooperation; 6) multi-datable archives; 7) project funding beyond COST-Action like e.g. Global INQUA and the CELL-50k project.

Svensson provided an update on ice core time scales. INTIMATE implications are 1) the Dansgaard Oeschger (DO) or DO-like onsets observed in many northern hemisphere records during marine isotope stage 2+3 are synchronous within a few hundred years. 2) Ice core and C-14 time scales are currently offset by about 1 ka around 29 ka BP and 3) northern and southern hemisphere records can potentially be even more tightly linked via ice cores.

Results and impact on the future directions (up to 1 page)

It was for the first time the scientists using/developing Quaternary dating tools met in this setting. Smaller sub-groups met be before in different settings (e.g. EARTHTIME, INTIMATE, CRONUS-EU, GTSnext). The size of ~34 persons attending over 3 days allowed for lots of informal discussion and seting-up news collaboration on individual basis. For the Quaternary dating community as a whole, there is interest to look for site where as many of the tools can be applied to check for precision and accuracy of different methods. We will never be able to apply all techniques on a single site, due to the underlying methodological and geological principles, but can strive to several sites where all methods can be tackled.

The main point of discussion was where to find the funding for persons to actual do the research. The network possibilities seem to be covered by e.g INTIMATE and EARTHTIME-EU, but project funding is more difficult to find. The idea is to look for funding in e.g. the People Programme of Horizon 2020 in an Initial Training Network where research and training is combined. Experience with this type of funding (Chronos-EU by Dunai/Struart and GTSnext by uiper/Wijbrans) already exists in the network.

In summary, the future direction is to look for funding in a more systematic way to tackle issues described above.

Jan Wijbrans and Klaudia Kuiper, Amsterdam, December 2012

FINAL PROGRAMME OF WORKSHOP

Welcome to the workshop

Chairperson organizing team:
dr. Klaudia Kuiper (VU – Utrecht Universities)

Organizing team:

Professor J. van der Plicht	^{14}C	Groningen University, NL
Dr. W. Hoek	Tephrochronology, INTIMATE	Utrecht University, NL
Dr. D. Condon	U/Pb	NIGL – BGS, Keyworth, UK
Dr. D. Richards	U-series	University of Bristol, UK
Dr. J. Wallinga	OSL	Delft technical University, NL
Dr. F. Stuart	TCN, SUERC	University of Glasgow, UK
Professor J. R. Wijbrans	$^{40}Ar/^{39}Ar$	VU University, Amsterdam, NL.

Excursion leader:

Dr. R. Gertisser,	volcanology	Keele University

Established techniques for dating the Late Quaternary (^{14}C and U-series) have recently been complemented by several exciting developments including cosmogenic nuclides, optically-stimulated luminescence and $^{40}Ar/^{39}Ar$ dating. Concomitantly, age models based on climate records and tephrochronology have improved. Initiatives are proposed to inter-calibrate these techniques and for metrological calibration. In the proposed Science Meeting we will bring together specialists to coordinate this research effort at a European level.

Perhaps surprisingly, time scales of the youngest period of the Geological Time Scale are amongst the most difficult to constrain accurately. This time period is important as it covers the period from archaeological interests to the spreading of humans into Europe and climatology of the ice-age period. On the one hand the ^{14}C method, the radio-isotopic dating method of choice for the youngest part of this time period, rapidly loses precision in the range between 5 and 10 half-lives (ca. 25,000 – 50,000 years) and effectively is extinct in material older then *ca*. 60,000 years. On the other hand the classic isotope geochronometers such as the K/Ar and U/Pb methods struggle in this time period because of the low in-growth rate of radiogenic daughter isotopes.

Alternative approaches use climate records in sediments or ice cores that can be linked via the insolation curve to accurate absolute time using the orbital parameters of the Earth: precession, obliquity and eccentricity are now well established. However, intercalibration with the K/Ar system is not resolved and the method requires continuous sediment (climate) records. Other techniques such as Optically Stimulated Luminescence dating (OSL) and Terrestrial Cosmogenic Nuclides (TCN) have sufficient precision but lack accuracy. In summary, there is at this moment no dating technique that covers the Late Quaternary with sufficient accuracy and precision.

Radiocarbon is a well established dating method for carbon containing samples, both for organic remains (e.g., wood, seeds, plant tissue, bones, shells) as well as for inorganic (e.g., carbonates). Calibration using dendrochronology provides an accurate timescale for the last 12,500 years. Further back in time, the calibration curve is based on marine records subject to ^{14}C-reservoir uncertainties. For the oldest part of the dating range, say 30-50 ka, methodological problems are identified which need to be better addressed. Going back in time towards the 50 ka limit, calibration, contamination, sample integrity and laboratory issues become increasingly important. Intercalibration of ^{14}C dating with other dating methods is essential. Initiatives for intercalibration with OSL, U-Th series and $^{40}Ar/^{39}Ar$ are underway.

U-Th(-Pb) methods are used for carbonate materials of late Quaternary age such as corals, speleothems, where stratigraphic control and additional proxy records such as stable isotopes add confidence. There is full overlap and comparable resolution when compared with ^{14}C. In fact, the extension of ^{14}C calibration greater than 26 ka relies on U-Th data. There is potential for ^{231}Pa-^{235}U for improving the robustness of U-series ages, and inclusion of U-Th/Pb potentially widens the range of applications to early Pleistocene and older. At the older limit of the technique with higher precision analysis, the precision of the accepted half-life determination becomes limiting. Confidence is also reduced through lack of widely accepted standard values and inter-laboratory comparison similar to that in ^{14}C, TCN, U-Pb and $^{40}Ar/^{39}Ar$ and other communities.

The ***cosmogenic isotopes*** (^{3}He, ^{10}Be, ^{21}Ne, ^{26}Al and ^{36}Cl) are used routinely in a vast array of Earth Science disciplines, including geomorphology, tectonics, paleoclimatology, paleoseismology and volcanology. In particular the method has been successfully applied to determining the age, extension and dynamics of glaciers and ice-sheets, the timing of response of river systems to climate change or tectonic movements and process rates and ages of landscapes. Additionally they can be used to determine long-term rates of bedrock and soil erosion that are valuable natural background values with which to compare with modern values to quantify the importance of man's effect on erosion. Most applications demand age accuracy that is better than ~5%. Analytical uncertainties are usually low (2-3%). However, a theoretical and empirical foundation to consistently calculate production rates of *in situ* produced TCN to better than 10-20% is lacking. Production rates are governed by several inter-dependent factors; latitude, altitude, and the energy spectrum of cosmic ray neutrons in the Earth's atmosphere. These controls must be quantified in order to accurately establish spatial and temporal variation in production.

Argon geochronology has been widely used for decades for dating of the early Pleistocene and older rocks (~750 – 1800 ka), but struggles increasingly in the late Pleistocene. Several pioneering studies have demonstrated that in favourable instances age signals as young as 2 – 4 ka can be measured, but is this time interval the enrichment of radiogenic ^{40}Ar with respect to the ubiquitous atmospheric ^{40}Ar component is challenging. New instrumentation allowing the precise detection of very smaller amounts of argon holds a promise for improved age resolution in the late Pleistocene tephra records. Calibrated against orbital solutions and U/Pb, $^{40}Ar/^{39}Ar$ could develop as one of the benchmarks for calibrating Quaternary dating techniques.

Optically stimulated luminescence (***OSL***) dating allows the dating of deposition and burial of sand and silt-sized minerals of quartz and feldspar. OSL dating holds great promise due to its broad range of applicability 1) in range (~10 years - >150.000 years), 2) in wide occurrence of quartz or feldspar bearing sediments, and 3) in diversity of processes in e.g. aeolian, fluvial, coastal settings. OSL dating as a relatively young technique is still under development. The main challenges include: 1) the relatively large uncertainty (at least 5%); 2) signal saturation, preventing reliable dating of older Quaternary deposits; 3) age bias caused by inadequate light exposure in e.g. young fluvial, glacial deposits. Mechanisms underlying OSL in natural minerals at the atomic scale are still largely unknown.

Each dating techniques for the late Quaternary has strengths and weaknesses and none is universally applicable. Relatively new techniques such as TCN and OSL significantly broaden our range of datable material. We propose to bring together specialists from these dating communities in an Earthtime-EU Science Meeting that will focus on the individual challenges facing each of these dating techniques. The meeting aims present an overview of where the field stands and to start new initiatives to arrive at a fully intercalibrated set of dating techniques that can be applied in different environments in this time slice. By bringing together active scientists from each of these fields we aim to foster future collaborations in the field of intercalibration of methods leading ultimately to a single accepted time standard in the Quaternary.

Meeting Programme

Sunday 7 October 2012

18.00h	Welcoming reception and buffet	

Monday 8 October 2012

8.30h	Welcome by organizing team	
	INTIMATE	**Chair:** Wim Hoek
8.45-9.15h	INTegration of Icecore, MArine and TErrestrial records (INTIMATE): the importance of dating and correlation.	Wim Hoek
9.15-9.30h	An update on ice-core chronologies and synchronizations	Anders Svensson
9.30-9.45h	Tephrochronology, the INTIMATE 60ka and beyond	Simon Blockley
9.45 – 10.15h	**discussion**	
10.15 – 10.45h	Coffee break	
	Radiocarbon dating	**Chair:** Hans van der Plicht
10.45-11.15h	Timescales: a radiocarbon perspective	Christopher Bronk Ramsey
11.15-11.30h	Radiocarbon timescale calibration archives	Paula Reimer
11.30 -11.45h	Reliable chronologies: from sample treatment to calendar timescales	Irka Hajdas
11.45 – 12.15	**discussion**	
12.15– 13.15h	Lunch break	
	OSL dating	**Chair:** Andrew Murray / Jakob Wallinga
13.30 - 14.00h	Shedding light on the Quaternary through luminescence dating	Jakob Wallinga
14.00 -14.15h	Some suggestions towards quality management and reporting of luminescence ages	Frank Preusser
14.15 - 14.30h	Luminescence dating of the Middle and Late Pleistocene using feldspar	Jan Pieter Buylaart & Andrew Murray
14.30 -14.45h	TT-OSL - A new luminescence signal from quartz to date further back in time	Geoff Duller
14.45 -15.00h	VSL - Extending optical dating to cover the full Quaternary?	Christina Ankjaergaard
15.00 – 15.30h	Coffee break	
15.30 - 15.45h	Luminescence thermochronology	Benny Guralnik
15.45 – 16.00h	Amino acid dating	Kirsty Penkman
16.00 -18.00h	**Discussion**	**Chair:** Jan Wijbrans
20.30 – 24.00h	discussion in break-out groups	

Tuesday 9 October 2012

	$^{40}Ar/^{39}Ar$ geochronology	**Chair:** Jan Wijbrans / Klaudia Kuiper
8.30 - 9.00h	Quaternary time scales: an argon perspective	Klaudia Kuiper
9.00 - 9.15h	Metrological Traceability in $^{40}Ar/^{39}Ar$ geochronology	Leah Morgan
9.15 - 9.30h	Using $^{40}Ar/^{39}Ar$ ages of volcanic units to reliably date Late Pleistocene palaeoclimate records	Victoria Smith
9.30 -10.00h	Examples of Quaternary dating projects problems and solutions	Jan Wijbrans, Fin Stuart, Michael Storey
10.00 -10.15h	New noble gas mass spectrometers for ^{3}He, ^{21}Ne and $^{40}Ar/^{39}Ar$ studies	Doug Hamilton
10.15 – 10.45h	coffee break	
	Terrestrial Cosmogenic Nuclides	**Chair:** Fin Stuart
10.45-11.15h	Terrestrial cosmogenic nuclides - fundamental controls on their production on Earth	Tibor Dunai
11.15 -11.30h	Cosmogenic ^{3}He - issues and applications	Fin Stuart
11.30 - 11.45h	Cosmogenic ^{10}Be - issues and applications	Tibi Codilean
11.45 - 12.00h	Cosmogenic ^{36}Cl - issues and applications	Irene Schimmelpfennig
12.00 - 12.15h	Absolute chronology using terrestrial cosmogenic nuclides	Susan Ivy-Ochs
12.15 – 12.45h	**discussion**	
12.45 – 13.45h	Lunch break	
	U Series	**Chair:** David Richards
13.45 - 14.15h	U-series dating: state-of-the-art and future challenges	Dirk Hoffmann
14.15 - 14.30h	Combining stratigraphy, U-series and ^{10}Be ages in a neotectonic setting	Alex Thomas
14.30 -14.45h	U-Th disequilibrium methods beyond 500 ka	David Richards
14.45 -15.00h	Sharpening the U-series chronometer	Dan Condon
15.00 -15.15h	Community tools for U-series age determination	Noah McLean
15.15 – 15.45h	coffee break	
15.45 -18.00h	**Discussion** Discussion on today's topics Break-out groups Reporting back	
19.00 – 20.00h	The Minoan Santorini eruption as the key Earthtime light in the Archaeological and Historical correlation problems of the mid-2nd millennium BCE	Hendrik Bruins
20.00 – late	Conference dinner Restaurant Fanari	

Wednesday 10 October 2012

9.00-18.00h Excursion (Quaternary volcanics) lead by Ralf Gertisser, Keele University

18.00 – 21.00h dinner at El Greco

21.00 – late discussion and planning future initiatives.

Thursday 11 October 2012

Departures

Participants EARTHIME-EU workshop – Absolute timescales for the Quaternary

^{14}C community

- ✓ Prof. Dr. Chris Bronk Ramsey - Research Laboratory for Archaeology and the History of Art, Dyson Perrins Building, South Parks Rd, Oxford, OX1 3QY, United Kingdom
- ✓ Prof. Dr. Hendrik Bruins - Ben-Gurion University of the Negev, Jacob Blaustein Institutes for Desert Research, Swiss Institute for Dryland Environmental and Energy Research, Sede Boker Campus 84990, Israel
- ✓ Dr. Irka Hajdas - ETH, Institute for Particle Physics, Schafmattstrasse 20, 8093, Zürich, Switzerland
- ✓ Prof. Dr. Paula Reimer - 14CHRONO Centre, School of Geography, Archaeology and Palaeoecology, Queen's University, Belfast, BT7 1NN, Northern Ireland, United Kingdom
- ✓ Prof. Dr. Hans van der Plicht* - Center for Isotope Research, Groningen University, Nijenborgh 4, 9747 AG Groningen, Netherlands

OSL community

- ✓ Dr. Christina Ankjaergaard - Delft University of Technology, Faculty of Applied Sciences Reactor Institute Delft, Mekelweg 15, 2629 JB, Delft, Netherlands
- ✓ Dr. Jan-Pieter Buylaert, DTU Nutech, Center for Nuclear Technologies, utech Radiation Physics, Technical University of Denmark, Frederiksborgvei 399, 4000 Roskilde, Denmark
- ✓ Prof. Dr. Geoff Duller - Institute of Geography & Earth Sciences, Aberystwyth University, Llandinam Building, Penglais Campus, Aberystwyth, SY23 3DB, United Kingdom
- ✓ Dr. Benny Guralnik, ETH Zürich, Geologisches Institut, Sonneggstrasse 5, 8092 Zürich, Switzerland
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- ✓ Prof. Dr. Frank Preusser - Department of Physical Geography and Quaternary Geology, Stockholm University, SE-106 91 Stockholm, Sweden
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The European Science Foundation

The European Science Foundation (ESF) is an independent, non-governmental organisation, the members of which are 79 national funding agencies, research-performing agencies, academies and learned societies from 30 countries.

The strength of ESF lies in the influential membership and in its ability to bring together the different domains of European science in order to meet the challenges of the future.

Since its establishment in 1974, ESF, which has its headquarters in Strasbourg with offices in Brussels and Ostend, has assembled a host of organisations that span all disciplines of science, to create a common platform for cross-border cooperation in Europe.

ESF is dedicated to promote collaboration in scientific research, funding of research and science policy across Europe. Through its activities and instruments ESF has made major contributions to science in a global context. The ESF covers the following scientific domains:

- Humanities
- Life, Earth and Environmental Sciences
- Medical Sciences
- Physical and Engineering Sciences
- Social Sciences
- Marine Sciences
- Materials Science
- Nuclear Physics
- Polar Sciences
- Radio Astronomy Frequencies
- Space Sciences

EARTHTIME-EU OBJECTIVES

The EARTHTIME-EU Research Networking Programme (RNP) is part of a broader international initiative "EARTHTIME: a community-based scientific effort aimed at sequencing Earth history through an integrated geochronologic and stratigraphic approach". The ambition is to broaden the EARTHTIME platform in Europe with this RNP, which combined with a proposed FP7 Marie-Curie Initial Training Network ("GTSnext"), will also serve as the basis for wider outreach towards the Earth Science community, and allow crucial construction of databases and teaching activities with a global dimension.

The Geological Time Scale (GTS) is the fundamental measurement yardstick and the key to reconstruct Earth history. We want to (1) develop a next generation fully integrated GTS for the last 100 million years, and (2) exploit the scientific predictions arising from this improvement. This time scale, with unprecedented accuracy, precision, resolution and stability, can be achieved by integrating independent dating techniques. The numerical calibration of the GTS is the main focus of the GTSnext-ITN. With the RNP we specifically aim to link the much improved numerically calibrated time scale with other stratigraphic disciplines to arrive at a fully integrated GTS.

Combining the RNP with GTSnext, the expected scientific contributions and breakthroughs are 1) new insights into key geological processes including climate change, catastrophic impacts, and volcanic hazards, 2) a stable time scale that is beneficial for academia and industry, 3) full integration and intercalibration of different numerical dating and stratigraphic techniques, leading to 4) significant improvement in the consistency of these techniques; 5) progress towards a fully astronomically-tuned and stratigraphically integrated GTS over the last 100 million years.

A fundamental comprehension of geological time and the time scales at which key processes occur is appropriate in view of the impact we have on System Earth.

The running period of the ESF EARTHTIME-EU Research Networking Programme is for 5 years from June 2010 to May 2015.

SCIENTIFIC BACKGROUND

RESEARCH FIELD

This ESF Research Networking Programme aims to bring together the European and pan-European specialists to develop and improve the Geological Timescale. Knowledge and understanding of detailed ages and durations of events, and therefore rates of processes, are the fundamental basis for Earth System Science in general, and crucial for tackling current challenges such as driving forces and feedbacks at the global scale and understanding abrupt or extreme changes in the Earth System in particular.

SCIENTIFIC CONTEXT

The need for much improved knowledge of the durations and ages of climatic and geological events, such as the Palaeocene-Eocene Thermal Maximum (~55 million years ago), has become urgent within the Earth science and climate modelling communities. The exact dating and timing of fluxes into and out of the marine carbon reservoir can differentiate between competing hypotheses of climatic change. Highly detailed reconstructions of Earth history allow us to assess whether past climatic change can be used as an analogue for the current and future change of ocean acidification and climate. The EARTHTIME project, and this RNP, are an international effort with the goal to further this quest for a well calibrated and stable time scale that will allow more precise dating of rock layers and minerals.

Radioisotopic dating methods have a small but significant error that hinders our ability to assess geologically short-lived climate events. For instance, the most widely used method for the Cenozoic era is 40Ar/39Ar, which has an error of up to 2.5% and few tie points of known age (see fig. 2). Yet, over the last two decades much progress has been made in exploiting the imprint of Earth's orbital variations in palaeoclimatic records. This has dramatically increased the potential age resolution of approaches like cycle counting and pattern matching, to less than 40,000 years throughout much of Cenozoic time (the past ~66 million years, Pälike & Hilgen, 2008, see fig. 4).

Unfortunately, there have been a number of inconsistencies and discrepancies between ages and durations derived from radioisotopic and astronomical dating. What is now needed is a more systematic and co-ordinated approach to provide a detailed intercalibration of radioisotopic clocks (U-Pb, Ar-Ar methods), the rock standards that are used for these methods, and geological tie-points with astronomical ages. At the same time, Cenozoic palaeoclimatic compilations need to be improved by closing existing gaps, verifying data from single sites, and supplementing the database of magneto- and biostratigraphy so we can improve the accuracy of existing age calibrations.

For all Earth Science applications time is a fundamental parameter, essential for the integration of disparate datasets, for unravelling cause and effect relationships (not only in the climate context), and for the quantification of rates and durations of geological processes. Temporal relationships are often the key to causality arguments in Earth Sciences, for example between environmental and biological change during mass extinction events. The Geological Time Scale (GTS) is instrumental for the quantification of geological time. However, published time scales are commonly based upon a limited number of geochronological tie-points of variable quality, and derivative age models that are of different and widely disparate quality. The accuracy and resolution of such time scales are also variable, generally in the order of 1 to 0.5% at best. Large uncertainties, on the order of several millions of years, still exist in our estimates for the age and duration of key geological intervals. The integration of revised numerical ages with key stratigraphic information requires a concerted and coordinated approach at the European level to tackle these important research questions, and we thus seek a broad collaborative effort through workshops, outreach and scientific exchange activities.

OBJECTIVES AND ENVISAGED ACHIEVEMENTS

The principal scientific objective of the network is to link the much improved numerical calibration of the GTS that comes out of the numerical dating part of the programme to other stratigraphic disciplines (bio-, magneto-, chemo-, and cyclostratigraphy) in order to arrive at a fully integrated Geological Timescale for the last 100 million years. Such a time scale, with its stratigraphic underpinning, underlies all fields in the Earth Sciences. The broader stratigraphic community that will work on the integration can also directly start to apply the new time scale. Thus biostratigraphers can have a much more precise look at evolution and the influence of environmental changes, magnetostratigraphers are interested in reversal history and frequency, sequence stratigraphers in the potential link to eccentricity, cyclostratigraphers at the possible orbital control on sequence stratigraphy and long period hyperthermals and ocean anoxic events, astronomers are eager to find out about the expression of the chaotic behaviour of the Solar System. To achieve both objectives, EARTHTIME-EU will bring together acknowledged expertise in all subdisciplines of time scale calibration techniques found within the European Earth Science community, with a strong cross-disciplinary character including astronomers, the radioisotopic dating community, the wider stratigraphic community as well as climate scientists, industry, and the Integrated Ocean Drilling Program (IODP) and similar initiatives. This European-centred effort (http://www.earthtime-eu.eu), which will be closely linked to a broader international initiative EARTHTIME (www.earth-time.org), focuses on (1) the integration and intercalibration of these techniques in order to exploit both their strengths and to address their weaknesses, and specifically (2) a major effort to intercalibrate different bio-, magneto- and cyclostratigraphic efforts under a strategic umbrella.

Increased communication and cooperation between the different communities will result in a fundamental change in the approach Earth scientists take in quantifying geological time. The achievements are planned to be supported through several different strands:

1. Training of a new generation of PhDs and PostDocs is envisaged within the framework of a Marie Curie ITN (FP7-PEOPLE-2007-1-1-ITN, “GTSnext”)

2. A broader networking component of stratigraphers is envisaged under this RNP, involving principal investigators, key collaborators, and the PhD and Postdoc cohort, all from the wider science community (open calls). This will provide integration and synthesis of the results from (1), and result in applications such as better understanding of climatic changes for the past and future. This proposed effort will be made wholly in concert with the continuously ongoing work by IUGS/ICS to improve the GTS.

Supported by these programmes, geochronologists will be fully capable to apply and evaluate the various state-of-the-art dating techniques for the first time.

EXPECTED BREAKTHROUGHS OF EARTHTIME-EU:

- Exchange of expertise, multi-disciplinary training, and teaching for the next generation of young multi-disciplinary geochronologists with established laboratories and key researchers in a pan-European context.
- Strengthening the ties between researchers across Europe (particularly new EU member countries) as stratigraphic data from Eastern European and circum-Mediterranean countries will be indispensable to reach the formulated targets
- Development of extensive outreach activities encompassing the direct network specific topics as well as highlighting the direct application of this science to societal challenges, including climatic change on different time scales. Outreach will be achieved through development of teaching materials (“e-learning”), workshops, Summer schools, production of displays and exhibits, and through a dedicated website, hosted at http://www.earthtime-eu.eu.
- Development of an integrated stratigraphic database that incorporates and converts between different astronomically and radioisotopically derived ages and age models.
- An accurate and precise intercalibration of the improved numerical dating techniques in the context of stratigraphic data
- Significant progress towards an integrated (astronomically-tuned and radioisotopically calibrated) Geological Time Scale (GTS) over the last 100 million years, in concert with GTSnext and EARTHTIME.
- A time scale that is robust and stable, and will be employed by academia and industry because the proliferation of new time scales will essentially be avoided.
- Increased appreciation of the potential for highly resolved time scales in addressing outstanding issues in Earth System science.

EARTHTIME-EU – Absolute timescales for the Quaternary

- An improved understanding of Earth history through the application of this timescale by gaining new insights into key geological processes, including climate change, catastrophic impacts and volcanic hazards.

We envisage several dedicated activities for the European EARTHTIME initiative. All activities will follow an open-call, either for participation of individual scientists, or for proposing dedicated workshop themes, and will be operated through the Steering Committee. Industry involvement and input is sought where possible.

Steering Committee Meetings

The Steering Committee will discuss overall strategy, organise open-calls for workshops, meetings and outreach activities, and provide interaction between members on scientific grounds. The Steering Committee will assess crucial targets and milestones each year. The first kick-off meeting took place in Strasbourg on 1 June 2010.

Science Workshops and Summer Schools

One of the main pillars of the Research Networking Programme will be a series of dedicated Workshops and Schools that bring together the EARTHTIME-EU science community, including researchers, students and PostDocs.

The first EARTHTIME-EU scientific meeting is planned in Barcelona, Spain, in February 2011. In this meeting, scientists will map out new strategies and state-of-the art techniques in the fields of astrochronology, marine biostratigraphy, radioisotopic dating, and regional correlation.

Later, we envisage several open-call workshops and one Summer School (both 15-20 participants each) during the first 48 months duration of the programme. Two of the yearly workshops will be under a theme agreed by the Steering Committee, with an open call for participation. These themes will fall under the four main strands of GTSnext effort ("Confirming the Neogene", "Calibrating the Paleogene", "Exploring the Cretaceous" and "Fundamental Aspects of Timescale calibration Tools"), and be significantly broadened with expected participation from the cyclostratigraphy, radioisotopic dating, and stratigraphic disciplines, closely aligned to the Marie-Curie GTSnext initiative, but with wider and open participation of stratigraphers. The other two workshops will follow open calls for more specific aspects of the GTS and its application. Examples could include "Integrated and revised chronologies for the Eocene / Oligocene greenhouse to ice-house transition", "Rates of change across the Paleocene Eocene Thermal Maximum" etc. The Steering Committee will administer open calls for topical and cutting edge workshops that contribute to the EARTHTIME-EU initiative. Each year (for 5 years) there will be a call for a Summer School geared towards current PhD students, and taught by EARTHTIME-EU researchers, that focuses on a specific technique of time scale development. This activity will link with outreach activities (developing teaching material and providing e-learning web material such as recorded lecture webcasts).

ESF Research Conference

One of the key targets of the RNP for its final year will be the organisation of a larger (~120 participants over 3 days) ESF Research Conference, synthesising the scientific objectives, producing a contribution for the next update of "The Geological Timescale" publication (together with the ICS), as well as formulating a strategy to continue the EARTHTIME-EU initiative through further Initiatives, and/or participation in other funding mechanisms. This Conference will focus on the major achievements of the EARTHTIME-EU and GTSnext initiative.

Grants for Short and Exchange Visits

A different pillar for the RNP will be provided by open-calls for short visits (1-2 weeks) and Exchange grants (2 weeks to 6 months) between European laboratories, ideally targeted at early career researchers and PhD students. These activities will provide crucial capacity building and knowledge exchange in the overall EARTHTIME-EU effort. Open-calls will be formulated by the Steering Committee, and selected candidates of Travel Grants will be expected to contribute to outreach and publication activities, as well as providing a report of scientific achievements (milestones).

Database development, maintenance + hosting

A major legacy of a network will be a web-enabled portal that integrates all new stratigraphic and radioisotopic ages and age models developed through the network, including facilities for easy access, conversion and integration with partner databases and their interfaces, for which joint standards have to be defined. Such a database will be a lasting tool for academia as well as industrial applications in the Earth Science Community. We envisage the development, set-up, maintenance, data-quality assurance, and archiving of a portal, which will be linked to the EARTHTIME-EU dedicated website. Rather than duplicating effort, this database will be a working document of the community and closely link with existing databases (such as the US CHRONOS initiative, the Integrated Ocean Drilling Program databases initiative (SEDIS), PALEOSTRAT, WDC-MARE PANGAEA, as well as the ICS website that hosts the current GTS2004 ages).

Publicity, dedicated website and Outreach:

All of the above activities will be closely coupled with a strong outreach activity. A dedicated website at: (http://www.earthtime-eu.eu) will host the exchange of scientific achievements.