Report on the Calibration of the Geological Timescale Workshop

National Museum of Natural History
Washington, DC
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INTRODUCTION

In the geosciences, the study of many fundamental problems relies on precise knowledge of geological time. For example, in paleontology, information on the rates of origination vs. extinction of fossil taxa is essential to understanding what drives biological evolution and knowledge of the precise timings of major fossil extinctions, or series of extinctions, is crucial for pinpointing probable causes (climate change, bolide impacts, etc.). Interactions and/or interdependence among Earth's major biogeochemical cycles can be examined only through space-time correlations of multiple extended, uninterrupted, and high-resolution geochemical time series collected from different components of the global environment. Similarly, Earth's paleoclimatic conditions can be effectively evaluated only with a common geological timescale to quantify synchrony, lags and leads among climate proxy records. In geophysics, knowledge of Earth's crustal and deep mantle/core processes relies on modeling changes in physico-chemical parameters that can be observed only over geological timescales. In all cases, geological time is treated as the "independent variable"; deductions and conclusions are made assuming that the geological timescale as given is basically precise and accurate.

The time is ripe to reframe these research areas with a new geological timescale with significantly improved accuracy and precision standards commensurate with new and emerging geochronologic and chronostratigraphic methodologies.

High-precision geochronology is revolutionizing our understanding of how time is recorded in the rock record. In particular, the unification of paleontological and geochronological records has driven the development of a new field best described as *quantitative biogeochronology*. For much of the Paleozoic, however, this approach is in its infancy, and it is widely acknowledged that the definition of a comprehensive absolute timescale at an appropriate level of resolution for much of the Paleozoic and Mesozoic, which includes some of the major extinctions, is far from complete.

Current geological timescales generally have low temporal resolutions and are based on data of highly variable quality. Most, if not all of these compilations of available geochronological constraints are tied to paleontologically defined stratigraphic boundaries. Unfortunately, in an attempt to focus on the age of boundaries and to include all available data, many of these timescales have averaged dates obtained by different techniques and are often of highly variable quality. Inconsistent calibrations between different geochronometers are becoming increasingly evident and must be reconciled before a seamless timescale can be contemplated. Recent high-precision dates are often combined with older, less reliable results. Other compilations use unpublished data or ignore controversies over high-precision analyses of the same ash horizons. In many places, reliable geochronology is not available near major boundaries, so the compilers may interpolate from other data, yet rarely report error estimates. Since time is not linearly distributed in the rock record, interpolation is inherently inaccurate. The result, which is propagated into subsequent publications, is a timescale that is poorly calibrated in absolute terms. Indeed timescales of the same vintage report vastly different numerical values for the same boundaries. Consequently, the greatest uncertainty in most analyses of geologic and evolutionary rates is the timescale itself.

Many geoscientists are unaware of the problems with such estimates and use them to calculate rates of geological and evolutionary processes, for correlation with reliable calibrated events, or for other purposes. Although the number of calibration studies and their geochronological resolution has increased significantly in the past decade, it is being done in such an uncoordinated fashion it will take many decades to complete the calibration of the Phanerozoic. It is clear that a new and highly focused effort to calibrate at least the last 800 million years of earth history would benefit much research in the Earth sciences and remove the impediment of a poorly calibrated timescale. Such an effort can be envisioned as requiring a decade or more, depending availability of funding support, of highly focused, coordinated effort.

Recent developments in geochronology and stratigraphic correlation suggest that it is conceivable to calibrate the entire geologic timescale to better than 0.1 percent back at least to the beginning of the Phanerozoic, 542 million years ago (in other words, the accuracy of calibrated dates will be 0.1 percent or better). This effort will require about a decade of focused work; unprecedented cooperation among geochronological laboratories to resolve inter-laboratory calibration practices, sample handling and data-analysis issues; and community-wide involvement of stratigraphers, geochronologists, geochemists, and paleontologists. It is envisaged that the allocation of new funding to new and existing labs will be essential so that dedicated personnel and equipment can be brought to bear on the project. The payoff of this effort is enormous, for when combined with CHRONOS and other ongoing initiatives such as EARTHSCOPE that require geochronological data, it will provide a new and greatly improved temporal framework for geoscience research. This will allow us to address a new level of increasingly sophisticated questions related to the evolution of the Earth. Naturally, this effort will require the training of a new generation of students and researchers that can interact with multiple sub-disciplines and be equally comfortable dealing with geochronological and stratigraphic data.

The workshop at the National Museum of Natural History was held 3-4 October 2003 to gauge community support for such a coordinated effort, identify the opportunities and challenges in producing a highly calibrated geologic timescale, and to discuss the community needs to deliver on this ambitious project. In preparing for the workshop, the conveners developed the name EARTHTIME and a webpage for this initiative (see http://eaps.mit.edu/earthtime/).

The workshop brought together a diverse group of geochronologists, paleontologists, physical-, chemo-, and magneto-stratigraphers, and paleoclimatologists. While the number of participants was limited due to financial constraints, it was a representative group of earth scientists, and there has since been growing community support from people who did not attend the workshop.

The response of the community at the workshop, including many participants from NSF, was overwhelmingly enthusiastic. There was strong agreement that the time was ripe for the development of an improved, highly resolved timescale and that the research that would be generated by such a timescale would be highly beneficial to a variety of disciplines. A number of members of the press were present for the meeting and articles were published in both Science and Nature within weeks of the meeting (see: http://eaps.mit.edu/earthtime/articles.html). Moreover, the development of a highly resolved timescale has important connections to the CHRONOS geo-informatics initiative and the Paleobiology Database (PBDB) project, both of which require more finely resolved databases than are currently available.

The earliest discussions at the workshop made it clear that there is an enormous demand for high-precision geochronology. Many earth scientists do not include geochronology in their research because of a perception that there are not enough laboratories with interest and/or capacity to meet their needs. The clear message from this discussion that developing and strengthening geochronological techniques and capacity must be a major part of this initiative, and that active and aggressive integration of geochronology with all the geosciences is the key to making major progress in understanding the evolution of our planet.

OPPORTUNITIES

As discussed in detail above, the first and foremost aim of this initiative will be to develop a precise and accurate temporal record of earth history. There was considerable discussion of the utility of developing a calibrated geological timescale that would be "unbinned" or unconstrained by sometime arbitrary subdivisions of stratigraphic nomenclature. Rather than binning data into stages, series and other chronostratigraphic units of variable duration, Peter Sadler's CONOP-9 program and John Alroy's appearance event ordination method implemented in CONJUNCT rely on the simultaneous consideration of the order of events at multiple localities. These are examples of new approaches to stratigraphic and paleontological data that promise the development of an *interval-free* fossil record. While the geological community will doubtless continue to rely on chronostratigraphic subdivisions for years to come, there was consensus that geochronological investigations of stage-boundaries are not an appropriate focus and that science-driven projects that are focused on key intervals and specific problems is the best way to proceed.

The Workshop identified a number of important opportunities, or science drivers, outlined below that are highly dependent upon, and intrinsically related to the development of, a highly resolved geological timescale. The nature of the science drivers investigated will determine the resolution of the timeframe developed for specific geological intervals and in certain cases it may be necessary to move beyond a geologically defined (i.e., binned) timescale and develop goechronologically defined timeframes in which paleobiological and stratigraphic data can be integrated.

1) *To evaluate how evolutionary rates vary through time, in different systems (e.g., terrestrial versus marine) and in different clades.* Calibrating rates of evolutionary, primarily morphological, change in the fossil record is hampered by the absence of a sufficiently high-resolution record, which effectively averages different rates over long time spans. The rates of mass extinctions, post-extinction recoveries, evolutionary radiations, paleoecological transitions and bursts of diversification are all difficult or impossible to evaluate, or even effectively compare, without a higher-quality temporal constraints. Such constraints are also needed to compare the timing of biologic events with possible physical drivers, ranging from volcanic eruptions to bolide impacts. Moreover, a highly calibrated timescale can provide far more robust dates for divergence nodes

important to the application of a molecular clock and to evaluate the accuracy of divergence times as calculated with molecular approaches. Geochronology sits at the foundation for the kind of integration that is a cornerstone of programs such as biocomplexity. Finally, paleontologists are in need of a highly resolved timescale for both long-term global studies as well as problems of narrower intervals of time.

2) *To determine the rates of change associated with major climatic events and perturbations to global geochemical cycles in deep time.* The record of deep time climate is rich, but is poorly explored because the timescale is so poorly resolved. Periods of extended and extreme global warming such as the mid-Cretaceous as well as abrupt, brief intervals of climate change (e.g., the Late Paleocene Thermal Maximum) have no parallels in the recent and Quaternary record. Thus, the deep time geologic record is the only archive available for understanding the full range of variability in Earth's climate system dynamics. A highly calibrated timescale is critical to reconstructing proxy records of these events and for evaluating forcing factors and developing process based models. In particular, the development of well-calibrated, marine and terrestrial paleoclimate archives at equal spatial and temporal resolution is critical to documenting the global nature of large-scale environmental perturbations, to fully delineating the mechanistic links, feedbacks and thresholds, and in constraining the origin of the forcing mechanisms.

3) *To determine whether cyclical patterns in deep time are controlled by astronomical cycles; whether the forcing cycles can be identified; and how astronomically controlled cyclostratigraphy can be integrated with other techniques to improve the temporal resolution of the geologic timescale*. The astronomically tuned timescale is currently the most highly resolved record in deep time, but there is considerable uncertainty over whether cyclical patterns in rocks represent astronomical control. A major goal of this project should be to evaluate proposed astronomically tuned cycles using high-precision geochronology. Particular attention needs to be paid to identifying the astronomical cycles most likely to remain stable over long time spans (hundreds of millions of years).

4) *To improve the calibration of the magnetostratigraphic and chemostratigraphic records.* A major effort at intercalibration of the magneto- and chemo-stratigraphic records is essential for more robust interpretation of the record. This should include a major effort to evaluate the existing calibrations of both records. For the late Mesozoic and Cenozoic, existing sea-floor magnetic compilations offer magnetostratigraphy that can be calibrated to nearly arbitrary accuracy through judicious choice of tie-points.

Addressing these science drivers will require the development of the geochronologic techniques required to produce temporal constraints with uncertainties approaching 0.1 percent. The development and refinement of existing geochronological techniques will be essential as well as implementing novel approaches. In particular, there needs to be an unprecedented effort at inter-laboratory collaboration, sharing of techniques, data, and standards. This is beginning to happen with the Ar-Ar community and will soon begin within the U-Pb community. There are abundant scientific questions, many not yet conceived, that can be addressed by pushing geochronological technique to its ultimate resolving power.

Meeting participants also pointed out that there is an enormous unmet demand for even relatively low-precision geochronology as well and that dates with uncertainties of 1-2 percent for many rocks would be welcome. At present U-Pb and Ar-Ar dating of volcanic rocks and minerals dominates calibration of the geological timescale, however there have been recent developments of other techniques that can provide powerful temporal constraints for rocks not amenable to more traditional methods. These include U-Pb dating of synsedimentary (e.g. pedogenic, lacustrine and marine) carbonates, Re-Os dating of black shales and Lu-Hf dating of inorganic and biogenic phosphate. These have not been fully exploited for timescale issues and warrant further exploration and development.

CHALLENGES

The challenges in addressing these science drivers were another important focus of discussion.

Analytical Capacity:
Inadequate throughput in existing geochronology laboratories was consistently identified as one of the major existing stumbling blocks to rapid progress. Many participants reported waiting years for analyses. This demand was also reported by geoscientists residing in existing labs who reported that they were swamped with requests for analyses. These reports demonstrate that the current national capacity for high-resolution geochronologic analyses is insufficient. Additional laboratory capacity, both equipment (largely mass spectrometers), and personnel is urgently needed to meet this demand. This seems to be more of an issue for the U-Pb community than the Ar community, but there is no question that additional capacity is needed to make rapid progress.

There has been an increase in the development of rapid throughput U-Pb geochronology using ion microprobes and laser ablation ICPMS, but the precision available with these techniques is not sufficient for a highly-resolved timescale. However, these approaches can be very useful for screening detrital zircon populations. Scientists to some extent use these techniques for timescale work out of an apparent frustration at their lack of access to existing high-precision laboratories, coupled with inadequate understanding of the ultimate capabilities of various techniques. Many scientists who run labs point to the difficulty in maintaining a skilled and trained staff when funding commitments are commonly only one to two years duration.

A major problem is that many do not understand, or at least under-appreciate, that high-precision geochronology requires a large number of analyses per sample to insure that open system behavior or other complexities such as inheritance can be recognized and avoided. This is true for U-Pb zircon, Ar-Ar, U-Pb in carbonates, Re-Os in black shales, and Lu-Hf in phosphates. For example, in high-precision U-Pb geochronology it is common for 10-20 single grains of zircon per sample to be analyzed, which requires a major expenditure of resources. Geochronologists must do a better job of educating the geoscience community as to the difficulty and expense, both in dollars and person-hours, required for high-precision geochronology.

Pilot Studies:
Many scientists who attended the workshop expressed frustration at their inability to conduct pilot studies on rocks that show promise for radiometric dating. Geochronology labs do not often have

the flexibility in resources to take on these projects, especially since the process of conceiving, writing and submitting a proposal typically takes 1-2 years before it is funded. Furthermore, some geochronologists expressed frustration at a lack of follow-through by their collaborators, i.e., having expended precious time and resources to do pilot analyses with fruitful results. Many scientists suggested that funds should be available for small pilot projects that could link geochronologists with stratigraphers/paleontologists and allow the development of working relationships and the ability to test samples with a potential for high-precision geochronology.

Accuracy:
Geochronologists reported a series of issues that limit the accuracy of radiometric dating. These include a lack of sufficient inter-laboratory comparisons, different spikes and standards, a lack of standardized data reporting and a need for common, generally accepted protocols. Success in this initiative will require unprecedented levels of cooperation between laboratories and agreement on many analytical protocols.

As analytical precision for both Ar-Ar and U-Pb geochronology has improved, it has been recognized that new geological uncertainties at the 1-200K year level must be considered. These include: (1) the possibility that "volcanic" ashes are re-sedimented deposits that may have been erupted at some resolvable time before deposition; and (2) the issue of magmatic residence time. The latter is of special concern for U-Pb geochronology as zircons may reside in magma chambers below the closure temperature for Pb diffusion for up to 300K years prior to eruption. Increased precision has also led scientists to scrutinize existing decay constants. There is no question that there appears to be a bias of 0.7-1 percent between U-Pb zircon and Ar-Ar dates, and that this must be resolved. The discrepancy is most likely due to imprecision in the K–Ar decay constants and/or the age of neutron fluence monitors such as the Fish Canyon tuff, but it could conceivably reside in the U decay constants themselves. We envision an effort to calibrate the timescale that will naturally lead to many comparisons between high-precision U-Pb and Ar-Ar dates and hopefully an effort to recalibrate decay constants. In addition, there is ongoing discussion of the robustness of the Lu and Re decay constants. There is no question that a major new effort at evaluating all the decay constants used for radiogenic isotope geochronology must be undertaken immediately.

Communication:
A fundamental conclusion of the workshop was that there was a need for much greater communication between groups of people involved in geochronology, paleontology, and stratigraphy. Participants decided that both groups need to better understand each others' needs, and that interactions between groups, especially in the training of the next generation of students, needs to be encouraged.

IMPLEMENTATION

There is no question that there is a high demand for more precise and accurate geochronological constraints for studies on the evolution of the planet. We generally agreed that a major, community-based initiative is needed to make rapid, organized progress and to increase capacity. Such an initiative should encourage the participation and innovations of individual investigators, but build on an underlying and encompassing structure to foster collaboration and assure "quality control". Two different models of implementation were discussed. The first, best termed a centralized model, would involve the designation of a national geochronological facility. This could be comprised of, for example, two large, well-equipped facilities. Each facility would be able to produce a high throughput of samples and apply a *full suite* of geochronological techniques. The center would be staffed with technicians and research scientists and would encourage new and innovative analytical protocols, technique development, and perhaps even instrument design and construction. This model has apparently served the mass spectrometric needs of the cosmogenic nuclide and ^{14}C communities well where the biggest stumbling block seems to be the time and effort put into sample preparation. In fact, both centralized sample preparation and analytical facilities have been developed for these techniques. For radiogenic isotope geochronology, there is continuous feedback between sample preparation, mineral separation and characterization, irradiation, chemical separations, and analysis. The second model was termed the distributed model and involves developing two to five centers of excellence, or nodes, by upgrading and expanding existing labs and creation of one or more new labs, each with a strong emphasis on timescale calibration. These labs would devote a significant amount of their analytical capacity to timescale issues. In both cases significant resources will be required from NSF to build and upgrade facilities as well as to add and support personnel.

While good arguments can be made for both models, the majority of participants favored the "distributed model" as a way of getting maximum throughput, allowing healthy competition between laboratories, fostering innovation, and making facilities accessible to a substantial number of scientists. There was the strong opinion that while centralized facilities can be appropriate in this case a greater number of smaller facilities would better serve the community than one or two national facilities. In particular, concern was voiced by many participants about the tendency of central facilities to become "ossified".

The EARTHTIME initiative could be organized either by focusing on dating boundaries between geological units (whether systems, series, stages or finer levels) or by focusing on critical research questions. The participants in the workshop unanimously agreed that a research-driven approach would yield more useful science and involve a larger spectrum of the geoscience community.

Data synthesis and direction of research will be coordinated by collaborative interactions between the geochronology labs and a full complement of stratigraphers and paleontologists. We envision that these scientists will be part of multidisciplinary study teams that target particular time slices. Because horizons amenable to radiometric dating are randomly distributed both geographically and through geologic time, considerable emphasis will be placed on both biostratigraphy and physical means of high-resolution correlation including chemical and magnetic signals. We will work with the emerging CHRONOS database project to ensure that the data are widely available. Examples of key intervals that need considerable geochronological control were discussed at the meeting and in the Forum on the Earthtime website. These include:

Vendian/Cambrian
Mid-Late Cambrian: biomere events and trilobite evolution and extinction
Ordovician radiation/extinction/Silurian recovery
Devonian mass extinction/recovery
Late Paleozoic ecosystem dynamics and global change during the Gondwanan glaciation

Permo/Triassic extinction and recovery
Triassic/Jurassic extinction and recovery
Late Triassic (Carnian) basal radiation of dinosaurs
Early/Middle Jurassic radiation of tetrapods
Cretaceous radiation of angiosperms
Paleocene mammalian radiation

A POSSIBLE ORGANIZATIONAL STRUCTURE

Calibrating the geological timescale to a precision of < 0.1 percent through the Phanerozoic is an attainable task within the next decade, but only through a community-wide effort involving geochronologists, stratigraphers, paleontologists and database specialists. Feedback from participants at the workshop and from other members of the geoscience community indicates that there is widespread support for such a plan, as well as a willingness to commit the effort that will be required to see it through to completion. Indeed, since the workshop several geochronologists have taken the initiative to begin planning a workshop on inter-laboratory calibration, and a separate plan has been developed for workshops for paleontologists and others on the potential of geochronology. Further, all groups have access to the latest database and other information technology resources through organizations such as CHRONOS.

Operationally, responding to the challenge and opportunities outlined above requires four immediate integrated steps: (1) development of an organizational structure for this initiative; (2) funding for three to five geochronological "centers of excellence" including both instrumentation and personnel to serve as models for eventual expansion; (3) establishment and ongoing funding for the integrative activities incorporating community involvement; and (4) development of an aggressive program of education and public outreach focused on both earth scientists as well as the general public. Below we discuss each of these steps in more detail.

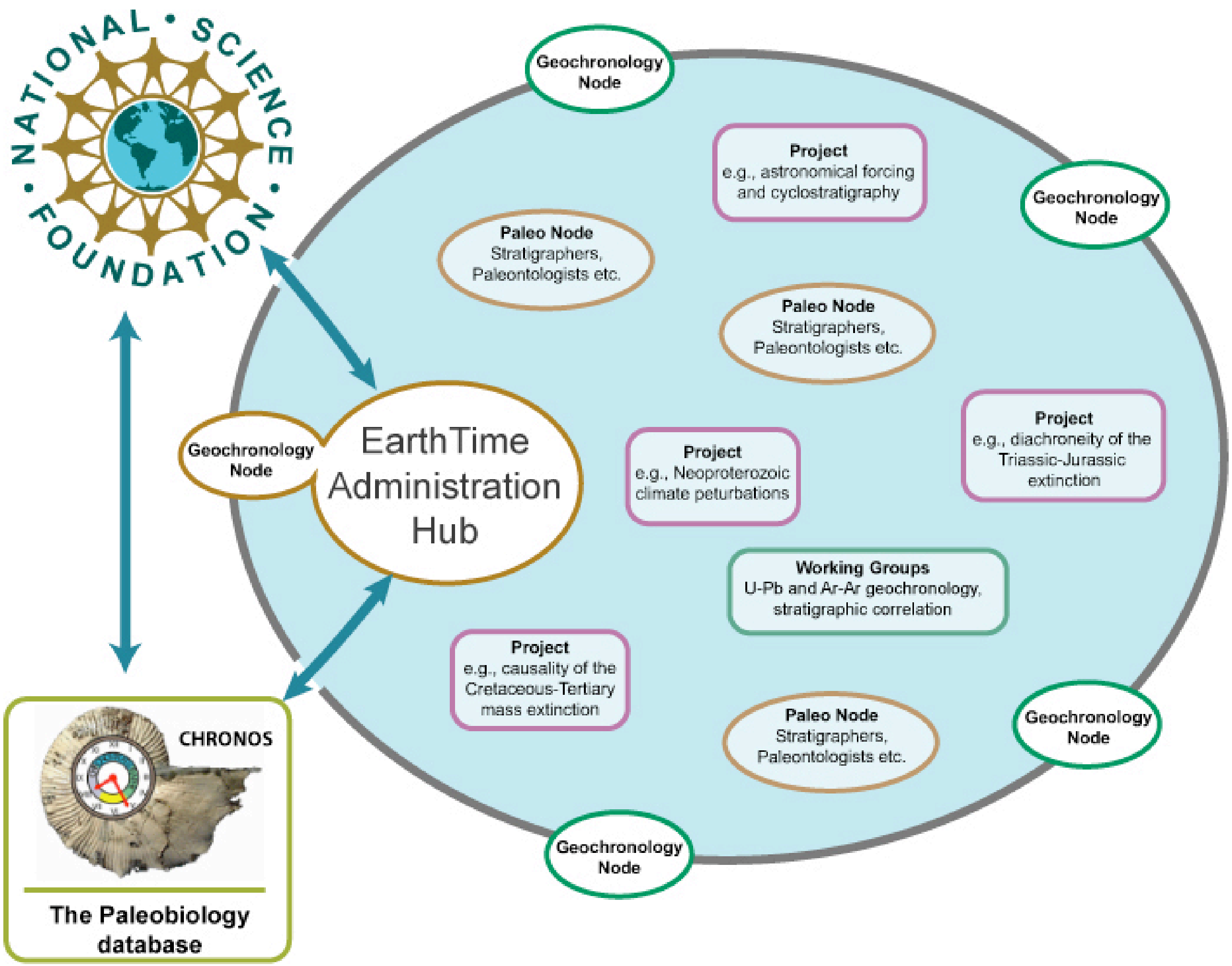
1) The proposed initiative will require a highly organized structure that will be responsible for planning and implementation of the EARTHTIME initiative. A possible model for this structure is discussed below and a core group of researchers and administrators will be responsible for coordinating interactions between various labs and groups, planning different strategies, organizing workshops and meetings, and developing outreach programs.

2) The workshop participants agreed unanimously that current timescale focused geochronology labs have insufficient capacity, both in equipment and personnel, to meet current demand for high-resolution U/Pb and Ar/Ar geochronology, as well as newer techniques such as U-Pb carbonate dating, Re-Os, and Lu-Hf. It was the general consensus of the workshop participants that the establishment of three to five national centers with support for both mass spectrometers dedicated to timescale work, and the personnel and running costs needed for this initiative would be most beneficial to the community as a whole. However, to achieve the desired outcome, a host of technical issues must be resolved that will require a centralized organization (EARTHTIME steering committee) to facilitate collaborations, maintain quality control and to interface with NSF, CHRONOS etc.

3) Workshop participants unanimously rejected an approach based simply on time periods in favor of one focused on compelling scientific questions that require a high-resolution timescale to resolve. There is a strong need for interdisciplinary workshops and ongoing working groups that will bring together geochronologists, paleontologists, physical-, chemo- and magneto-stratigraphers, and other geologists to address such problems. It is clear from our two-day workshop that much progress could be made in producing a highly calibrated timescale if interactions between a broad cross-section of the communities and integration of different data sets are actively encouraged. As the project develops, gaps in the coverage will develop and we must establish a means to bridge them, even in the absence of an immediate, compelling science driver.

4) Educational issues were also discussed throughout the workshop and all agreed that they must play a significant role in the EARTHTIME initiative. Educational initiatives must be focused, both within the geoscience community, and with the general public. For the geoscience community, there was much interest in implementing an aggressive program of short courses that would deal with such basic topics as limitations and applications of different geochronological techniques, data evaluation and interpretation, recognition and collection of volcanic ash beds, and on the dating of non-volcanic geological materials. Much of the geoscience community is unaware of the tremendous advances made recently by geochronologists. Similarly, many geochronologists under-appreciate the necessary level of detailed paleontologic, stratigraphic, and geochemical data that must be gathered along with the geochronological samples to produce a reproducible data set that can be properly assessed and validated. A concerted educational and outreach effort will be required through short courses (which could be made more widely available through video-conferences, on-line guides and other means to reach a wide cross-section of geoscientists). In addition, outreach to other scientists and the general public must be included, perhaps in cooperation with CHRONOS, to provide an up-to-date and reliable geologic timescale, including clear distinction between interpolated and calibrated dates. There must be a parallel effort at educating the general public about geological time, how it is determined, reliability issues and usefulness in understanding problems with societal relevance. This effort should involve workshops and preparation of educational materials for high-school teachers, and visits by students to laboratories. We must seek public support because much misinformation persists in the public domain about basic geochronological issues. A measure of the interest in this topic is the fact that articles about this workshop appeared in both Science and Nature and are available at the website (http://eaps.mit.edu/earthtime/articles.html)

A schematic of one model for the EARTHTIME network discussed during the workshop is shown in the figure below.



An endeavor of the sort we are proposing will require a formal organizational structure that can maintain oversight and foster communication. This figure shows one possible organizational structure that emphasizes integration and interaction between communities under the umbrella of NSF. At the top EARTHTIME interacts with the National Science Foundation as the principle funding source and with related geoinformatics initiatives sponsored by NSF, including CHRONOS and the Paleobiology Database. EARTHTIME will also include a database of geochronologic information, both historical and developed by the project, and a geochronology working group to facilitate interlaboratory calibration and standardization.

We envision a central EARTHTIME steering committee that would coordinate activities between nodes. A management hub would be centered at a single institution and have administrative support and a budget for bringing groups together.

The functions of the central EARTHTIME steering committee will be:

- To meet once or twice a year to: 1) develop and implement a comprehensive management plan with community approval; 2) discuss priorities and facilitate collaboration between geologists needing geochronology and the correct technique and an available labs; 3) provide a source for community input into the direction of the program.

- To allocate small amounts of starter funds for exploratory dating to produce the data needed to justify larger, collaborative proposals that would be submitted to regular Geoscience core programs.
- To manage and conduct outreach activities including meeting and workshop organization, and develop ties with international colleagues and similar efforts
- To coordinate technique intercalibration, instrument and technique development;
- To identifying new research directions, ensure close collaboration with database netwoking projects such as CHRONOS, and to identify gaps in coverage and develop plans to fill them to achieve the overall goals of the project.

In closing, we must emphasize that our proposed model for the time calibration of the stratigraphic record could easily be expanded to serve the equally pressing demands of the rest of the geoscience community for high-precision geochronology. In addition, all of the standardization of laboratory protocols and collaborative networks that will be established as part of our initiative are equally applicable to all geochronological techniques and applications.

WORKSHOP DETAILS

The workshop was organized by Sam Bowring (MIT), Doug Erwin (NMNH). A web page located at http://eaps.mit.edu/earthtime was prepared before the meeting and since the meeting served as a way to promote discussion and inform the community of post-workshop activities.

Presentations on the potential of a highly refined timescale for significantly impacting geological research occupied the first morning, followed by breakout sessions during lunch, which identified the significant challenges and opportunities for this project. The afternoon included presentations on the new ICS 2004 geologic timescale, and allied projects. The second day was largely occupied with breakout sessions on identifying the science drivers for such a project, and the means of integrating the research effort, and on appropriate managements structures and outreach efforts. The group was split into four groups for each breakout session to maximize the number of different ideas produced. Integrating sessions at the end of the morning and afternoon allowed all participants to hear and respond to the ideas of each breakout group.

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