

## **EARTHTIME: A community-based effort towards high-precision calibration of earth history**

SAMUEL A. BOWRING<sup>1</sup>, DOUGLAS ERWIN<sup>2</sup>,  
RANDALL PARRISH<sup>3</sup> AND PAUL RENNE<sup>4</sup>

<sup>1</sup>EAPS, MIT, Ma 02319, USA (sbowring@mit.edu)

<sup>2</sup>NMNH, Smithsonian Institution, Washington, DC, USA

<sup>3</sup>NIGL, Keyworth, Nottinghamshire, UK

<sup>4</sup>BGC, 2455 Ridge Road, Berkeley, Ca 94709, USA

Geological time is customarily treated as an "independent variable"; deductions and conclusions are made assuming that the geological timescale as given is precise and accurate. Current geological timescales are based on data of variable quality, commonly averaging dates obtained by different techniques, with differing (though often ignored) absolute uncertainties. Consequently, the greatest uncertainty in most analyses of geologic and evolutionary rates is the timescale itself. Recent advances in geochronology and correlation methods now allow us to reframe research into the timing and rates of geological and biological processes in deep time, producing a newly calibrated geological timescale with significantly improved accuracy and precision standards commensurate with new and emerging geochronologic and chronostratigraphic methodologies. To address these issues the EARTHTIME initiative has been proposed as a new community-based effort to focus attention on the calibration of at least the last 800 million years of earth history. This will allow earth scientists to address a whole new series of questions that rely on knowledge of precise rates of biological, geological, and climatic change. Two EARTHTIME workshops have been held, the first to discuss the need for better integration of geochronology and paleontology and the second, on intercalibration of the U-Pb and Ar-Ar chronometers. As an outgrowth of these two meetings we have proposed the production of a mixed <sup>202</sup>Pb-<sup>205</sup>Pb-<sup>235</sup>U-<sup>238</sup>U spike for distribution to the international community and the sponsorship of a community wide intercalibration experiment using standard material (see Heizler et al., and Condon et al., this session). Community support is growing and we expect that this effort will fundamentally change our knowledge of the distribution of time in the rock record and give us unprecedented insight into the rates of geological, biological, and climatic processes in deep time. The EARTHTIME concept has wide application to all parts of the geological record and the Earth Sciences.

## **Intercalibration of astronomical and radioisotopic time**

K. KUIPER<sup>1,3</sup>, A. DEINO<sup>2</sup>, F. HILGEN<sup>1</sup>, W. KRIJGSMAN<sup>1</sup>,  
P. RENNE<sup>2</sup> AND J. WIJBRANS<sup>3</sup>

<sup>1</sup>Utrecht University, Faculty of Geosciences, The Netherlands  
(kkuiper@geo.uu.nl, fhilgen@geo.uu.nl,  
krijgsma@geo.uu.nl)

<sup>2</sup>Berkeley Geochronology Center, Berkeley, USA  
(adeino@bgc.org, prene@bgc.org)

<sup>3</sup>Vrije Universiteit Amsterdam, Isotope Geochemistry, The Netherlands (Jan.Wijbrans@falw.vu.nl)

Geological time scales (GTS) may be chronometrically calibrated using a variety of absolute dating techniques. In a recent version of the GTS (Gradstein, 2004), the entire Neogene is calibrated on the basis of astronomical ages, while the older part of this timescale relies on radioisotopic <sup>40</sup>Ar/<sup>39</sup>Ar and U/Pb methods. In order for the timescale to remain accurate and consistent throughout, it is crucial that astronomical and radioisotope dating methods produce identical results when the same geological event is evaluated.

The Mediterranean Neogene provides an excellent opportunity to compare these different dating methods through direct isotopic dating (<sup>40</sup>Ar/<sup>39</sup>Ar, U/Pb) of volcanic ash layers intercalated in astronomically tuned marine successions. We will present <sup>40</sup>Ar/<sup>39</sup>Ar ages for many of these tephra from parallel determinations in two laboratories (BGC and VU). These results allow the calculation of an astronomically calibrated age for the widely used FCT sanidine standard. A major advantage of an astronomically calibrated FCT age against a K/Ar calibrated standard is twofold: 1) consistency with Neogene timescales which increasingly are based on astronomical ages, and 2) a much smaller error in the absolute age due to absence of uncertainties in absolute <sup>40</sup>K and radiogenic <sup>40</sup>Ar content or <sup>40</sup>K/K in the primary standard, and a smaller error contribution of the decay constants because the branching ratio of decay to <sup>40</sup>Ca and <sup>40</sup>Ar is not required. A next step would be the introduction of a directly astronomically dated standard, eliminating the ca. 0.1% typical intercalibration error for unknown samples within the appropriate age range of the standard.

We will discuss all potential uncertainties in the astronomical ages of ash layers, as we have determined for ash layers in astronomically calibrated Mediterranean sections. This approach may be extended to other (U/Pb, U/Th) techniques and to older time intervals.

### **Reference**

Gradstein, F., Ogg, J., and Smith, A. (2004) A Geological Timescale 2004. Cambridge Univ. Press.

## Dating erosion events using $^4\text{He}/^3\text{He}$ thermochronometry

K.A. FARLEY, D.L. SHUSTER, M. CLARK  
AND G. MAHEO

Division of Geological and Planetary Sciences, Caltech,  
Pasadena, CA 91125; (farley@gps.caltech.edu,  
dshuster@gps.caltech.edu, mclark@gps.caltech.edu,  
maheo@gps.caltech.edu)

The timing of rapid erosion events, e.g., induced by river incision or by glaciation, can be determined using chronometric systems sensitive to low temperatures provided that a sample was cooled from above the system's bulk  $T_c$  to the point of quantitative retention. Even in the case of apatite He ages this requires cooling by more than 60 C, or more than a few km of erosion. Thus for all but large magnitude erosional events, traditional thermochronometry is not useful.

Determination of the  $^4\text{He}$  spatial distribution by the  $^4\text{He}/^3\text{He}$  method may provide an alternative approach. An apatite residing at a temperature where significant diffusion occurs will develop a diffusive  $^4\text{He}$  distribution decreasing to zero at the grain edge. If this apatite then rapidly cools to Earth's surface temperatures and thereafter remains cold, the concentration profile increases uniformly across the grain and the concentration *at the edge* is a direct reflection of the age of the event, the U+Th concentration, and  $\alpha$  ejection. The local "age" at the edge of the grain constrains the timing of the cooling event. Depending on timescale, the temperature at which these outermost few microns have a zero effective concentration is in most cases  $\sim 30^\circ\text{C}$ , i.e., the "edge age" can be measured and constrains the timing of an erosion event provided the sample was cooled rapidly from  $>30^\circ\text{C}$ . In reality, cooling histories must be more complex than this, but the full  $^4\text{He}$  concentration distribution is a remarkably sensitive indicator of cooling over the range  $\sim 80^\circ\text{C}$  to  $\sim 20^\circ\text{C}$ .

Preliminary results and challenges with this technique will be discussed with reference to ongoing studies in the Sierra Nevada. Additional results will be presented by Shuster et al. (this volume).

## Calibration of a Pleistocene geomagnetic instability time scale (GITS) using $^{40}\text{Ar}/^{39}\text{Ar}$ -dated lavas

B.S. SINGER

Department of Geology & Geophysics, University of  
Wisconsin-Madison, USA (bsinger@geology.wisc.edu)

Advances in the measurement of paleomagnetic intensity recorded by marine sediments, as well as  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of paleomagnetic directional recordings in Pleistocene lava flows, offer a powerful means of calibrating a global magnetostratigraphy for the last 2 myr. This involves moving beyond the classic geomagnetic polarity time scale (GPTS) and resolving temporally not only the undisputed polarity reversals, but also the many short-lived geomagnetic "events," or cryptochrons that are thought to signal periods of instability in the geodynamo. Some cryptochrons may be best described as geomagnetic excursions, others aborted reversals, and still others, rapid successions of back-to-back reversals. Even the shortest events are now revealed as distinct paleointensity minima in global stacked sediment records (e.g., SINT-800; GLOPIS-75). When the degree of stability of the geodynamo is considered, rather than lengths of polarity intervals, an alternative approach to the study of the GPTS is appropriate.

Hence, a challenge is to calibrate a Geomagnetic Instability Time Scale (GITS) via  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of transitionally-magnetized lava flows. As an example, the Laschamp event—expressed as a sharp paleointensity minimum in the GLOPIS-75 marine sediment stack—was dated by matching O-isotope variations in North Atlantic sediments to those recorded in annually counted layers of the GISP2 ice core. By matching a few  $^{14}\text{C}$  ages from the sediments to specific varves in the ice core, the paleointensity minimum was found to span  $\sim 1500$  years between 41 and 39 ka.  $^{40}\text{Ar}/^{39}\text{Ar}$  incremental heating and unspiked K-Ar dating of two lavas that record the event at Laschamps, France yield an age of  $40.4 \pm 1.1$  ka ( $2\sigma$ , analytical uncertainty). Thus, despite systematic uncertainty in the  $^{40}\text{K}$  decay constant, both the accuracy and precision of the K-Ar clock—carefully applied to basaltic lava flows—can be remarkably good, i.e., better than 2% for the entire Pleistocene. A GITS based on intercomparison of several  $^{40}\text{Ar}/^{39}\text{Ar}$ -dated geomagnetic events will contribute further to quantifying: (1) astrochronologic age models based on O isotopes and orbital tuning, (2) long-term correlations of marine sequences, (3) the long-term behavior of earth's geomagnetic vector field, (4) production of cosmogenic isotopes, including  $^{14}\text{C}$ , and (5) paleoclimate records at sub-orbital time scales.

## Evaluating intercomparability amongst several $^{40}\text{Ar}/^{39}\text{Ar}$ laboratories

M.T. HEIZLER<sup>1</sup> AND EARTHTIME WORKING GROUP<sup>2</sup>

<sup>1</sup>New Mexico Tech, New Mexico Bureau of Geology, 801  
Leroy Place, Socorro, NM, 87801, USA (matt@nmt.edu)  
<sup>2</sup>Earthtime working group (<http://www.earth-time.org>)

The Earthtime initiative seeks to achieve a highly precise (ca.  $\pm 0.1\%$ ) geologic timescale as a basis for reaching a heretofore-unavailable record of several geological and biological processes. To reach this goal, calibration of standards within individual geochronological methods and amongst different methods must be improved. As an outgrowth from the Earthtime I meeting, fifteen  $^{40}\text{Ar}/^{39}\text{Ar}$  laboratories organized an effort to each analyze five common fluence monitors in a blind, full disclosure, experiment. A list of participating laboratories can be found at <http://www.earth-time.org>. No specific protocol was mandated except that each laboratory would run a split of the sample provided using Fish Canyon Tuff sanidine (FC-2) as the base neutron fluence monitor. The samples chosen include Alder Creek sanidine (~1.1 Ma); Taylor Creek sanidine (~28 Ma); GA1550 biotite (~99 Ma); and PP20 (equivalent to Hb3gr) hornblende (~1071 Ma). In addition, a sanidine separate from a Mid-Tertiary ignimbrite (TS-1a) was provided as a voluntarily unknown. Thus far 8 labs have contributed and until all data are received no rigorous compilation will be presented. The present results confirm that the standards are homogeneous and  $^{40}\text{Ar}/^{39}\text{Ar}_K$  values relative to FC-2 at 0.05-0.2% ( $1\sigma$ ) precision was achieved. Perhaps somewhat surprising, but gratifying, is that intercomparability between labs (with minor filtering) was at better than 0.2% for all samples. As expected, each laboratory fought various instrument problems throughout the year and anomalous data could generally be attributed to poor analysis conditions. These experiments indicate that the  $^{40}\text{Ar}/^{39}\text{Ar}$  community is well positioned to produce data that will be intercomparable at a level that corresponds to the goals of the Earthtime initiative. Further refinement and standardizing of protocol for Earthtime research should be considered. For instance, narrowing the number of reactors used for Earthtime samples would allow a concentrated characterization effort. Also, using the standards characterized in this effort would help eliminate errors involved with calibration of in-house standards. Continuing communication efforts and open sharing of ideas and data that have begun through the Earthtime workshops is essential to success.

## The role of U-Pb TIMS dating in resolving the causes of mass extinction events

S. KAMO

Department of Geology, University of Toronto, Toronto,  
Canada (skamo@geology.utoronto.ca)

The P-Tr and K-T boundaries mark the two largest mass extinction events in the rock record. While there is widespread acceptance of a meteorite impact origin for the K-T extinctions, the trigger for the P-Tr extinctions is considerably less certain, but with Siberian flood basalt volcanism generally regarded as a leading suspect, and the case for meteorite impact recently gaining momentum. A new U-Pb TIMS zircon age of  $251.7\pm 0.4$  Ma for a volcanic bed immediately below the P-Tr boundary, near Heshan, S. China, provides a robust maximum estimate of the boundary age that is identical to previously published U-Pb ages from Siberian flood volcanic rocks ( $251.1\pm 0.3$  and  $251.7\pm 0.4$  Ma; [1]) and the Noril'sk I intrusion ( $251.2\pm 0.3$  Ma; [2]). These ages provide a rigorous temporal link between the time of the most devastating mass extinction event and the largest Phanerozoic volcanic event.

The resolving power of the U-Pb dating method is widely accepted as unsurpassed, but to maximize its potential requires rigorous assessment of geological and analytical details that can potentially bias data. Small but significant age discrepancies reported by different U-Pb labs for the P-Tr boundary [3-5] emphasize the need for the EARTHTIME inter-laboratory calibration project, which seeks to understand and minimize sources of bias. Our data for the P-Tr boundary and Siberian flood volcanic events have been obtained from the same laboratory, thus circumventing any inter-laboratory calibration biases.

Meteorite impact has also been suggested as the primary trigger to the P-Tr event [e.g. 6], but the evidence presented is controversial [e.g. 7-9]. As in the case of the Deccan volcanism and the Chicxulub impact at the K-T boundary, precise time relations are essential for establishing the feasibility of such theories as large impacts initiating a chain of events leading to massive volcanism, rapid atmospheric-environmental changes, and mass extinction.

### References

- [1] Kamo et al. (1996) *Geochim. Cosmochim. Acta* **60**
- [2] Kamo et al. (2003) *Earth and Planet. Sci. Lett.* **214**
- [3] Bowring et al. (1998) *Science* **280**; [4] Mundil et al. (2004) *Science* **305**
- [5] Mundil et al. (2001) *Earth and Planet. Sci. Lett.* **187**
- [6] Becker et al. (2004) *Science* **304**
- [7] Glikson (2004) *Science* **306**
- [8] Wignall et al. (2004) *Science* **306**
- [9] Renne et al. (2004) *Science* **306**.

## U-Pb inter-laboratory calibrations using zircon samples: Application of the new CA-TIMS technique

JAMES M. MATTINSON

Department of Geological Sciences, University of California,  
Santa Barbara, CA 93106-9630, USA  
(mattinson@geol.ucsb.edu)

U-Pb inter-laboratory calibrations using natural zircon standards are perhaps the most useful and meaningful type of inter-calibration, but also the most demanding: they test not only isotopic tracer calibrations, but also sample homogeneity and analytical techniques, especially complete removal of all zircon domains with Pb loss.

A new zircon U-Pb geochronology method, CA-TIMS, combines pre-dissolution high-temperature annealing of natural radiation damage followed by multi-step dissolution. Early partial dissolution steps preferentially remove domains that have lost Pb. Later partial dissolution steps sample zircon that has behaved as a perfect closed system with respect to U and Pb. This yields highly precise and accurate crystallization ages for zircons that lack any inheritance, and also is very sensitive to detecting the presence of inheritance or any other isotopic complexities.

CA-TIMS was applied to two recent, but widely used zircon standards: R33 and TEMORA-2. An aliquot of each zircon standard was annealed in air at 1,000°C for 48 hrs, then digested in 16 partial digestion steps of gradually increasing intensity. In each case, the first 4 steps removed disturbed zircon. Both samples showed perfect closed-system behavior for the remaining 12 steps, each yielding a set of statistically identical  $^{206}\text{Pb}^*/^{238}\text{U}$  ages and defining a plateau on a plot of age versus  $^{238}\text{U}$  released. The plateau for R33 yields an age of  $419.96 \pm 0.15$  (MSWD = 0.96); TEMORA-2 yields an age of  $417.82 \pm 0.06$  (MSWD = 0.52).

In terms of mass balance, the plateau for R33 was reached after removal of 15% of the total U, but only 5% of the zircon mass. The plateau for TEMORA-2 was reached after removal of 31% of the total U, but only 3.4% of the zircon mass, reflecting the strong U zoning of the zircons, and also demonstrating the high selectivity of the CA-TIMS steps.

Both samples yielded  $^{207}\text{Pb}^*/^{206}\text{Pb}^*$  ages for the plateau steps that are concordant with the  $^{206}\text{Pb}^*/^{238}\text{U}$  ages within analytical and decay constant uncertainties.

The CA-TIMS analyses demonstrate that both R33 and TEMORA-2 have “clean” isotopic systematics, and that only a very small volume of high-U rim material has Pb loss; both are excellent standards for U-Pb calibration purposes.

## Progress report on the U-Pb interlaboratory experiment

DANIEL J. CONDON<sup>1</sup> AND MEMBERS OF THE  
EARTHTIME U-Pb WORKING GROUP

<sup>1</sup>EAPS, MIT, Cambridge, Ma 02319, USA  
(dcondon@mit.edu)

Uncertainty in the Pb/U ratio of tracer solutions utilized in U-Pb isotope-dilution thermal ionization mass-spectrometry (ID-TIMS) geochronology, typically estimated at 0.1 to 0.25%, is one of the largest sources of uncertainty in the comparison of data from different laboratories. In order to better assess the degree of agreement among the various ID-TIMS U-Pb laboratories, an interlaboratory experiment involving natural zircon standards (R33 and TEMORA) and common mixed U-Pb gravimetric solution(s) is now underway as an outgrowth of the EARTHTIME project (<http://www.earth-time.org/>). Published ID-TIMS data sets for these two standards indicate that concordant and equivalent clusters of data can be obtained with uncertainties in the  $^{206}\text{Pb}/^{238}\text{U}$  date of ca. 0.1-0.2% [1]. These studies also demonstrate that techniques employed to minimize Pb-loss (e.g., air abrasion) are critical for producing equivalent datasets. Initial datasets from TEMORA and R33 zircons that were presented at the EARTHTIME II workshop indicate up to 1% scatter in the U-Pb dates between various laboratories. However, given variation in pre-treatment techniques (i.e., degree of air-abrasion etc.) and variability in blank contribution, it is impossible to assess how much of the variation is attributable to tracer solution calibration. In order to minimize such effects, batches of uniformly pre-treated zircons (both air-abraded and annealed/leached) were prepared and distributed. Such high-*n* ID-TIMS data sets, combined with tracer solution calibrations against multiple mixed U-Pb gravimetric solutions, offers the potential for interlaboratory calibration at the 0.1% level or better. Data on these standards and solutions will be presented. Elimination of interlaboratory biases is a crucial first step before the geochronology community will be able to systematically (1) compare and/or integrate U-Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$  data sets from multiple labs and, (2) assess systematic variation between  $^{206}\text{Pb}/^{238}\text{U}$  and  $^{207}\text{Pb}/^{235}\text{U}$  dates and uncertainties in the  $^{235}\text{U}$  and  $^{238}\text{U}$  decay constants.

### Reference

- [1] L. P. Black *et al.*, *Chemical Geology* **205**, 115-140 (APR 30, 2004).

## High-precision Re-Os shale geochronology

R.A. CREASER, D. SELBY AND B.S. KENDALL

Dept Earth & Atmospheric Sciences, University of Alberta,  
126ESB Edmonton AB Canada T6G2E3  
(robert.creaser@ualberta.ca, dselby@ualberta.ca,  
bkendall@ualberta.ca.)

The  $^{187}\text{Re}$ - $^{187}\text{Os}$  system has been known to yield depositional ages for organic-rich clastic sedimentary rocks like black shales for some time. However, only with improved analytical method-ologies for digestion and optimal sampling strategies have "high-precision" Re-Os ages (precision better than  $\pm 1\%$   $2\sigma$ ) been routinely attained. In addition, we have shown that the Re-Os geochronometer in shales remains undisturbed through hydrocarbon maturation and in some cases chlorite-grade metamorphism, which together with "organic-selective" dissolution techniques, allows precise depositional ages to be determined from a greater range of shales than previously thought possible, even with TOC contents as low as  $\sim 0.5\%$ . Accuracy of our Re-Os shale dates is best illustrated by comparison to units or boundaries for which precise U-Pb age determinations also exist. For example, our recent study of directly dating black shale at the Devonian-Carboniferous boundary in Western Canada, has yielded a Re-Os age of  $361.3 \pm 2.4$  Ma ( $2\sigma$ , including  $\lambda$  uncertainty), in accord with the most recent interpolations of the DC boundary age using U-Pb zircon age determinations. This result, and other high-precision results for Jurassic units, demonstrate that the Re-Os shale geochronometer has a role to play in timescale calibration research, especially in sections with limited potential for ashbed dating. In another application, precise ( $< \pm 1\%$   $2\sigma$ ) Re-Os shale dates have been determined for several shale units associated with Neoproterozoic glaciations which have resulted in a more detailed understanding of the timing of these glacial event(s). Limitations of the method include the restriction to  $<$  chlorite-grade metamorphism, and accuracy, intercalibration and decay constant issues related to uncertainties in Os standard compound stoichiometry.

## Triassic-Jurassic time scale and mass extinction: Current status and new constraints

ROLAND MUNDIL<sup>1</sup> AND JOZSEF PALFY<sup>2</sup>

<sup>1</sup>Berkeley Geochronology Center, 2455 Ridge Rd., Berkeley, CA 94709, USA (rmundil@bgc.org)  
<sup>2</sup>Hungarian Academy of Sciences-Hungarian Natural History Museum, POB 137 Budapest, H-1431 Hungary (palfy@nhmus.hu)

The Triassic-Jurassic (Tr-J) boundary coincides with one of the most profound mass extinctions known in the history of life on Earth. A number of potential causes for the biotic crisis have been proposed but most constraints for the timing are restricted to terrestrial sequences which have been studied in detail in eastern N America as well as NW Africa. Recent research presented geochronological evidence supporting a link between the Tr-J biotic crisis and the CAMP (Central Atlantic Magmatic Province) volcanism.  $^{40}\text{Ar}/^{39}\text{Ar}$  ages from CAMP magmas cluster around 199.9 Ma and have been documented to coincide with an abrupt change of both fauna and flora on land.

In contrast, the preserved marine geologic record is scarce. The only recent radio-isotopic age, a U/Pb zircon date of  $199.6 \pm 0.3$  Ma (Palfy et al., 2000), was obtained from a volcanic ash predating the Tr-J boundary. Although in apparent agreement with the  $^{40}\text{Ar}/^{39}\text{Ar}$  age for the CAMP volcanism, recent results from several studies applying U/Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$  analyses to minerals from the same rocks show that there is a systematic bias between the two isotopic systems, with  $^{40}\text{Ar}/^{39}\text{Ar}$  ages being ca 1% younger than U/Pb ages. Accounting for this discrepancy consequently shifts the expected U/Pb age for the main pulse of the CAMP volcanism to 202 Ma and therefore predates the U/Pb age for the marine extinction by more than 2 Ma. Additional constraints come from a preliminary age of  $198.0 \pm 0.6$  Ma (single-crystal IDTIMS U/Pb analyses) applied to a volcanic layer within early Sinemurian marine sediments in S Hungary, which suggests that the Tr-J boundary is older than 199.6 Ma, unless the lowermost stage of the Jurassic (Hettangian) is extremely short.

A number of potential scenarios arise, none of which can be unambiguously accepted from the currently available database, and therefore await a rigorous test. Among them is the possibility that the extinction on land and in the ocean was diachronous, or that the biotic crisis was synchronous in both environments and the geochronology, particularly in marine environments, needs significant improvement.

### Reference

Palfy J. et al., (2000), *Geology* **28**, 39-42.

## The Manicouagan impact melt rock: A proposed standard for the intercalibration of U-Pb and $^{40}\text{Ar}/^{39}\text{Ar}$ isotopic systems

J. RAMEZANI<sup>1</sup>, S.A. BOWRING<sup>1</sup>, M.S. PRINGLE<sup>1</sup>,  
F.D. WINSLOW III<sup>2</sup> AND E.T. RASBURY<sup>2</sup>

<sup>1</sup>EAPS, MIT, Cambridge, MA 02139. (ramezani@mit.edu,  
sbowring@mit.edu, mpringle@mit.edu)

<sup>2</sup>Dept. of Geosciences, SUNY, Stony Brook, NY 11794.  
(fwinslow@ic.sunysb.edu, troy.rasbury@sunysb.edu)

A source of uncertainty in the high-precision intercalibration of U-Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$  geochronology using magmatic minerals is protracted crystallization in complex magma chambers. This has been demonstrated in felsic plutonic and pyroclastic rocks, where magma chamber residence times of >0.3 Myr have been documented. One approach is to find rapidly formed and cooled, homogeneous, magmatic rocks, for which impact melt rocks appear to be an ideal candidate.

The central island of the 65-km-diameter Manicouagan crater in east-central Quebec, Canada is underlain by a sheet of melt rock with an apparent thickness of 230 m. The melt sheet overlies, and is locally mixed with, brecciated basement lithologies of Proterozoic age. The texturally stratified, upward coarsening, melt sheet is marked by an upward reduction in impact-derived clast content. Its chemistry is suggestive of extensive homogenization prior to solidification [1]. Thermal modelling indicates a maximum crystallization duration of about 1600 yr at the core of the melt sheet [2].

Single, 160 to 300  $\mu\text{m}$ -size, zircons from the highest levels of the melt sheet analysed so far by ID-TIMS have consistently produced  $^{206}\text{Pb}/^{238}\text{U}$  dates of ca. 215.5 Ma. No indications of inheritance from older zircon have been detected. These results are in agreement with previously reported U-Pb zircon dates of Hodych and Dunning [3]. Ar systematics are complex but a preliminary  $^{40}\text{Ar}/^{39}\text{Ar}$  sanidine plateau age of ca. 213 Ma by Shepard [4] is encouraging. We propose the demonstrably melt-derived zircon and sanidine in Manicouagan as new potential standards for the high-precision intercalibration of the U-Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$  isotopic systems. In addition, this study confirms the conclusions of Hodych and Dunning [3] that the impact does not coincide with the Triassic-Jurassic extinction at ca. 200 Ma.

### References

- [1] Grieve, R.A.F. and Floran R.J., (1978), *J. Geophys. Res.* **83**(B6), 2761-2771
- [2] Onorato P.I.K. and Uhlmann D.R., (1978), *J. Geophys. Res.* **83**(B6), 2789-2798
- [3] Hodych J.P. and Dunning G.R., (1992), *Geology* **20**, 51-54
- [4] Shepard, J.B., (1986), *unpub. B.A. thesis.*

## Intercalibration of the U-Pb and $^{40}\text{Ar}/^{39}\text{Ar}$ geochronometers: Status, prognosis, and proscription

PAUL R. RENNE<sup>1,2</sup>, ROLAND MUNDIL<sup>1</sup>,  
KYOUNGWON MIN<sup>3</sup> AND KENNETH R. LUDWIG<sup>1</sup>

<sup>1</sup>Berkeley Geochronology Center, 2455 Ridge Rd., Berkeley,  
CA 94709, USA (prenne@bgc.org)

<sup>2</sup>UC Berkeley, EPS, Berkeley CA 94720, USA

<sup>3</sup>Yale, Geology/Geophysics, New Haven, CT 06511, USA

The  $^{40}\text{Ar}/^{39}\text{Ar}$  method is comparable to U-Pb in terms of precision and possession of internal reliability criteria. Intrinsic limitations favor U-Pb in the pre-Mesozoic, and  $^{40}\text{Ar}/^{39}\text{Ar}$  for the Cenozoic. Nonetheless, the substantial overlap in routine applicability dictates that these two geochronometers be well intercalibrated in order to achieve an accurate and highly resolved time scale. Existing uncertainties (e.g. in decay constants and  $^{40}\text{K}/^{40}\text{Ar}$  data for standards) in calibration of the  $^{40}\text{Ar}/^{39}\text{Ar}$  method yield absolute age uncertainties of approximately 2%, roughly an order of magnitude worse than for U-Pb. While independent improved calibration of the  $^{40}\text{Ar}/^{39}\text{Ar}$  method is worth-while, it is equally valid and in some ways more desirable to effectively normalize the  $^{40}\text{Ar}/^{39}\text{Ar}$  to the U-Pb system. Such a program has been ongoing at BGC for 7 years, and has produced 15 data pairs for volcanic rocks of Cenozoic-Proterozoic age. Volcanic rocks are critical to avoiding decoupled isotopic systems due to slow cooling. From this data set, complemented by several U-Pb data from MIT, approximately -1% bias ( $^{40}\text{Ar}/^{39}\text{Ar}$  relative to U-Pb) is evident. Under the stimulus of EARTHTIME, more such data are likely to be generated in the future. The statistical methods of Kwon et al. (2002) permit simultaneous derivation of both the  $^{40}\text{K}$  total decay constant and the age of a standard. Values determined by this approach are already better than 0.5% in  $1\sigma$  precision and will improve with increased data input. It will be critical in going forward that data used for this purpose be of the highest possible quality for both systems. Obviously, both systems must be applied to minerals separated from the exact same rock. Data from intrusive rocks, though perhaps illustrative, are inappropriate for quantitative use.  $^{40}\text{Ar}/^{39}\text{Ar}$  data must have rigorously controlled neutron fluence relative to a well-intercalibrated standard (e.g., FCs) and be demonstrably free of effects due to alteration, secondary degassing, recoil, and excess argon. U-Pb data must be free of Pb-loss and inheritance effects, as best deduced from ID-TIMS analysis of single zircons using the annealing/chemical abrasion technique.

### Reference

- Kwon et al. (2002) *Math. Geol.* 34: 457-474

## U-Th/He dating of basalt

S. ACIEGO<sup>1,2</sup>, D. DEPAOLO<sup>1,2</sup>, B. KENNEDY<sup>2</sup>  
AND J. CHRISTENSEN<sup>2</sup>

<sup>1</sup>Department of Earth and Planetary Science, UC Berkeley,  
Berkeley, CA 94720, USA (aciego@eps.berkeley.edu)

<sup>2</sup>Lawrence Berkeley National Lab, Berkeley, CA 94720, USA

Determining ages and/or time scales for Quaternary (<1.8 my) basaltic eruptions still remains a challenge. Despite considerable progress in the fields of C-14, Ar-Ar, and cosmogenic nuclide dating, no single method with wide applicability has emerged and those methods that have been used often do not overlap in time or type of applicable material. We have investigated the use of the U-Th/He system as a method for dating the eruption age of volcanic rocks. Our first step was to assess the viability of using this dating technique on young samples (Aciego et al, 2003). The second step is to apply this technique to a system that has some age constraints, but that could benefit from direct age measurements. For this purpose we have chosen to focus on two areas: (1) a set of basalt samples from the Snake River Plain of Idaho and (2) a suite of post-shield alkalic basalts from the Big Island of Hawaii. Both sets of samples have upper and lower bounded age constraints, but individual flows have not been dated.

One of the drawbacks associated with using the U-Th/He technique on olivine has been the different sources of error. First, the olivine typically has low U,Th concentrations, making measurement of U,Th and He difficult. In the absence of improvements in mass spectrometer sensitivity, one way to overcome this is to measure larger amounts. The low concentrations of parent and daughter products also necessitates measuring the parent and daughter on the same aliquot, as small variations in parent or daughter between separate aliquots would produce large errors in the calculated age. For this purpose, a furnace was designed capable of heating 1-2 g of sample then retrieving the melted sample for U, Th determination. Second, the basalt matrix has more U and Th than the phenocrysts leading to a He implantation effect. Modeling of the injection-ejection effects indicate that the corrections are small. Ages have been measured for several basaltic lavas ranging from 100 to 350 kyr. The ages are consistent with geological constraints and have 1-sigma errors of  $\pm 6\%$ .

### Reference

[1] Aciego et al. (2003) *EPSL* **216**, 209-219

## Study of the <sup>40</sup>Ar/<sup>39</sup>Ar age and Ar isotope distribution of phengite in high pressure orthogneiss (the surrounding rock of the Qinglong-shan eclogite, East China)

J.J. CAI<sup>1</sup>, W. CHEN<sup>1,2</sup> AND Y. ZHANG<sup>1</sup>

<sup>1</sup>Laboratory of Isotope Geology, Institute of Geology, Chinese Academy of Geological Science, Beijing  
(chenwenf@public3.bta.net.cn)

<sup>2</sup>Institute of Geology and Geophysics, Chinese Academy, Beijing (chenwenf@vip.sina.com)

The conventional <sup>40</sup>Ar/<sup>39</sup>Ar ages of phengite in high pressure metamorphic orthogneiss, the surrounding rock of the Qinglongshan eclogite, East China, are from 211.4Ma to 219.5Ma. This ages range is not only in concordance with the <sup>40</sup>Ar/<sup>39</sup>Ar age (217.9Ma) of K-feldspar which is extracted from the same rock sample, but also identical with the Rb-Sr age (219Ma) and Sm-Nd (224Ma) of eclogite [1].

We use laser spot-fusion technique to analyze the <sup>40</sup>Ar/<sup>39</sup>Ar age in a single grain of phengite. The minimum age is 218.2 $\pm$ 2.3Ma and the biggest one is 220.4 $\pm$ 4.3Ma. These ages are concordant with the classical <sup>40</sup>Ar/<sup>39</sup>Ar ages of bulk-sample of phengite, which shows that the argon isotope has been fairly well-distributed in the phengite.

Therefore the fundamental conclusion is: (1) phengite in the high pressure metamorphic orthogneiss does not contain excess argon and can be used as the object of <sup>40</sup>Ar/<sup>39</sup>Ar dating. (2) phengite in Qinglongshan eclogite contains large amounts of excess argon [1] while phengite in its surrounding rock, high pressure orthogneiss, does not contain excess argon. This fact proves that the excess argon of phengite in the eclogite does not come from its country rock but from its inheritance.

### Acknowledgements

This work was supported by the National Natural Science Foundation of China (49973003, 40473005) and Science Project of China Geological Survey (200020190118-2).

### Reference

[1] Li, S., Wang, S., Chen, Y.. (1994) *Chem. Geol.*, **112**, 343~350.

## Precessional climatic signal in the Plio-Pleistocene Chemeron Formation, Central Kenya Rift

A.L. DEINO<sup>1</sup>, J.M. GLEN<sup>1,2</sup>, J. KINGSTON<sup>3</sup>  
AND A. HILL<sup>4</sup>

<sup>1</sup>Berkeley Geochronology Center, 2455 Ridge Rd., Berkeley, CA 94709

<sup>2</sup>USGS, MS 989, 345 Middlefield Rd., Menlo Park, CA 94035

<sup>3</sup>Dept. Anthropology, Emory University, 1557 Pierce Drive, Atlanta, GA 30322

<sup>4</sup>Dept. Anthropology, Yale University, PO Box 208277, New Haven, CT 06520

The Chemeron Formation (4.5–1.6 Ma) is exposed within the Tugen Hills, a tilted horst block within the central Kenya Rift. The formation typically consists of fluviolacustrine and alluvial fan sediments, with volcanoclastic interbeds. Near the Barsemoi River, the formation includes a series of five prominent diatomite beds (2.7–2.5 Ma) intercalated in the terrigenous sequence. The diatomite units, up to 12m thick, document intermittent, significant lake systems within the axial portion of the rift.

<sup>40</sup>Ar/<sup>39</sup>Ar dating of anorthoclase-bearing tephra horizons within the section permit precise determination of chronometric tie points to evaluate the sedimentation history of the sequence. Sedimentation rates are remarkably linear through the sequence that includes the diatomite horizons. By interpolation, we are able to estimate the absolute ages of the individual lakes (as represented by the diatomites). The regular temporal spacing of the lake sequence (ca. 25 ka periodicity) matches very well with the periodicity of the Earth's precessional curve for this interval. Given that there is a 1:1 match of diatomites to precessional peaks for five successive precessional cycles, we deem it highly probable that the lake systems are a climatic response to changes in insolation accompanying precession of the Earth, rather than a response to tectonism.

The Gauss/Matuyama paleomagnetic transition occurs just above one of the diatomites of this precessional sequence. This relationship to a paleomagnetic boundary allows us to compare the phase relationship of a wet period in the central Kenya Rift to the Mediterranean sapropel record; they appear to be in phase to within one quarter of a precessional cycle, if published astronomical ages for paleomagnetic boundaries can be relied upon.

## Quartz hydration dating: A new mineral geochronological technique

J.E. ERICSON<sup>1</sup>, F. RAUCH<sup>2</sup> AND O. DERSCH<sup>2</sup>

<sup>1</sup>Environmental Health, Science and Policy, UC Irvine, Irvine, CA, U.S.A. 92697-7070 (jeericso@uci.edu)

<sup>2</sup>Institute für Kernphysik, J.W. Goethe Universität, Frankfurt, Germany (f.rauch@em.uni-frankfurt.de, o.dersch@em.uni-frankfurt.de)

### New Geochronological Technique for Direct Dating of Minerals

The new Quartz Hydration Dating (QHD) technique relies on the phenomenon of water diffusion into quartz leading to the formation of a hydration layer that can be measured by a hydrogen profiling technique, based on the resonant reaction  $^1\text{H}(^{15}\text{N}, \alpha\gamma)^{12}\text{C}$ , and diffusivity data connecting the layer thickness with the hydration time.

We have obtained such data by induced-hydration experiments in the temperature range 60 to 200 °C and derived a general equation for calculating diffusion coefficients which was validated by results from dated artifacts. The main factors influencing the diffusivity are temperature, the crystallographic orientation, measured as the angle between surface of hydration and crystal c-axis, and initial H content of the quartz.

The effective time range of QHD is 100 ya to over 100 kya. The error of age determination is 35%, but may be reduced to 20% by controlling for material variability. QHD is applicable to single-crystal specimens and aggregates of single crystals. QHD serves as an example of silicate mineral dating. A range of geological applications is discussed.

### Reference

J.E. Ericson, O. Dersch, F. Rauch. (2004). Quartz Hydration Dating. *J. Arch. Sci.*, **31**, 883-902.

## Estimating $\lambda(^{40}\text{K})$ by U-Pb and $^{39}\text{Ar}$ - $^{40}\text{Ar}$ dating of the peralkaline Ilímaussaq complex, Greenland

T. KRUMREI<sup>1</sup>, I. VILLA<sup>2,3</sup>, M. MARKS<sup>1</sup> AND G. MARKL<sup>1</sup>

<sup>1</sup>Geowissenschaften, Uni Tübingen, Germany

<sup>2</sup>Isotopengeologie, Uni Bern, CH (igor@geo.unibe.ch)

<sup>3</sup>Università Milano Bicocca, Italy

The Mesoproterozoic Ilímaussaq igneous complex comprises an extraordinary diversity of peralkaline rock types formed in three distinct magmatic events. The first one, augite syenite, was followed by alkali granite and, finally, nepheline syenites. Such extreme differentiates require a fast (< 0.1 Ma) differentiation process. Solidus temperatures reach down to 450 °C; intrusion depths were 3-4 km. Water activity was very low and no metamorphic overprint occurred. Therefore, all mineral ages are magmatic crystallization ages.

Baddeleyite is an early phase in the augite syenite: it occurs as euhedral inclusions in olivine, cpx, feldspar and Fe-Ti-oxides. U-Pb dating on 4 replicate baddeleyite fractions from stage 1 augite syenites gave  $1160 \pm 5$  Ma. This agrees with the zircon age of  $1166 \pm 9$  Ma from stage 2 alkali granite [6].

Seven amphiboles were dated by  $^{39}\text{Ar}$ - $^{40}\text{Ar}$ : Ca-rich members from early augite syenites (ferro-edenite, ferro-pargasite) and Na-dominated arfvedsonite and nyböite from late agpaitic rocks. Very importantly, the Ar mass spectrometry was performed with the Faraday cup only, avoiding potential problems with multiplier nonlinearity. K-Ar ages calculated ages with the  $^{40}\text{K}$  decay constant of Steiger & Jäger [5],  $\lambda = 5.543 \times 10^{-10} \text{ a}^{-1}$ , and relative to an MMhb-1 age of 523.1 Ma (i.e. an FCT age of 28.02 Ma [4]), are ca. 1145 Ma. In this case, one has to postulate a differentiation history with a gap of 15 Ma between the augite syenite and the other agpaitic rocks, which is unreasonable. This indicates that the  $\lambda$  used so far has to be re-examined (see also [1]).

Simultaneous optimization of the K-Ar monitor age with  $\lambda$  was proposed by [3]. Calculating the ages of our amphiboles using the values in [3],  $28.27 \pm 0.13$  Ma and  $5.476 \pm 0.034 \times 10^{-10} \text{ a}^{-1}$ , respectively, makes them ca. 7 Ma older than the U-Pb ages. However, most of our samples show no indications for excess Ar or other disturbances of the Ar isotopic system.

The best agreement between K-Ar and U-Pb ages is obtained by reducing the FCT age to 28.15 Ma and increasing  $\lambda$  to  $5.490 \times 10^{-10} \text{ a}^{-1}$ , in marginal agreement with those proposed by [3]. If one considers the FCT age as fixed at  $28.24 \pm 0.01$  Ma [2], then the resulting  $\lambda$  is  $5.503 \times 10^{-10} \text{ a}^{-1}$ .

### References

- [1] Begemann et al, GCA 65 (2001) 111-121.
- [2] Kuiper et al, IGC abstract (2004) 172-11.
- [3] Kwon et al, Math Geol 34 (2002) 457-474.
- [4] Renne et al, Chem Geol 145 (1998) 117-152.
- [5] Steiger & Jäger, EPSL 36 (1977) 359-362.
- [6] Upton, Lithos 68 (2003) 43-65.

## Calibration of the early Triassic biotic recovery: New U/Pb zircon ages from South China

M. OVTCHAROVA<sup>1</sup>, H. BUCHER<sup>2</sup> AND U. SCHALTEGGER<sup>1</sup>

<sup>1</sup>Earth Sciences, University of Geneva, Geneva, Switzerland  
(maria.ovtcharova@terre.unige.ch,  
urs.schaltegger@terre.unige.ch)

<sup>2</sup>Institute and Museum of Paleontology, University of Zürich, Switzerland (Hugo.FR.Bucher@pim.unizh.ch)

Calibration of the Early Triassic biotic recovery is presently only constrained by two zircon ages obtained for the Permian-Triassic boundary ( $252.6 \pm 0.2$  Ma, Mundil et al., 2004) and the Anisian-Ladinian boundary ( $\approx 241$  Ma, Mundil et al. 1996, Palfy et al. 2003). The respective durations of the four Early Triassic stages (Griesbachian, Dienerian, Smithian, Spathian) and of the Anisian remain to be established. Preliminary new zircon ages obtained from ash beds intercalated with ammonoid faunas in the Luolo Fm (Early Triassic) and the overlying Baifeng Fm. (Anisian) in northwestern Guangxi (South China) lead to first estimates of the durations of the Spathian and of the Anisian.

Zircons were dated by precise isotope-dilution U-Pb techniques of mechanically abraded single-grains. In the upper carbonate unit of the Luolo Fm., zircons from the lower ash bed (basal Spathian) yield a crystallization age of 250.7 Ma, whereas those from the upper ash bed (Haugi Zone, latest Spathian) yield an age of 247.1 Ma. Zircons from an ash bed at the very base of the Baifeng Fm. (early Anisian) point to an approximate age of 246.4 Ma. Increased precision will be achieved by applying annealing-leaching procedures.

Hence, the Spathian/Anisian boundary is bracketed between 247.1 Ma and 246.4 Ma, which leads to a duration of the Early Triassic comprised between 5.5 and 6.2 my if adopting a P/T boundary age of 252.6 Ma. As the duration of the Spathian is no less than 3.6 my, this stage accounts for at least half of the duration of the Early Triassic. The duration of the Anisian is comprised between 5.4 my and 6.1 my when taking a 241 Ma Anisian/Ladinian boundary. Our new ages constrain the very high recovery rate of ammonoids, which had a first diversity peak during the Spathian.

### References

- Mundil R., Brack P. Meier M., Rieber H. and Oberli F. (1996). EPSL 141, 137-151.
- Mundil R., Ludwig K.R., Metcalfe I. and Renne (2004). Science 305, 1760-1763.
- Palfy J., Parrish R.R., David K. and Vörös A. (2003). J. Geol. Soc. London, 160, 271-284.

## New high precision zircon ages from the Carboniferous of Scotland and their implications for the systematic bias between U-Pb and $^{40}\text{Ar}/^{39}\text{Ar}$ dating techniques

R.R. PARRISH<sup>1</sup>, A.A. MONAGHAN<sup>2</sup>, AND M.S. PRINGLE<sup>3</sup>

<sup>1</sup>Dept of Geology, University of Leicester & NERC Isotope Geosciences Laboratory, British Geological Survey, Keyworth, Notts, NG12 5GG, UK

(r.parrish@nigl.nerc.ac.uk)

<sup>2</sup>British Geological Survey, Murchison House, West Mains Road, Edinburgh, EH9 3LA, UK (als@bgs.ac.uk)

<sup>3</sup>Department of Earth Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA (m.pringle@mit.edu)

Several samples have been precisely dated by using either U-Pb or  $^{40}\text{Ar}/^{39}\text{Ar}$  methods in the Midland Valley of Scotland. While high quality sanidine and zircon have not yet been dated from the same sample, we have dated samples in close proximity where the stratigraphic relationships are well established. The U-Pb results on concordant abraded zircons range in age from 335 to 344 Ma with  $2\sigma$  uncertainties of  $\pm 0.7$  to  $\pm 0.9$  Ma.  $^{40}\text{Ar}/^{39}\text{Ar}$  ages from related samples have uncertainties of approximately  $\pm 1.5$  Ma but are systematically younger. The minimum bias between the dating techniques can be quantified because the U-Pb ages from stratigraphically higher samples are between  $0.50 \pm 0.33\%$  and  $1.34 \pm 0.48\%$  older at the 95 % confidence level than  $^{40}\text{Ar}/^{39}\text{Ar}$  ages from samples lower down in the same succession. The U-Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$  ages are relative to ages of 418.2 Ma for Temora zircon and 98.79 Ma for GA1550 biotite using well characterised mineral standards and U-Th-Pb metal reference solutions. Magma chamber residence time between dated crystal separates is unlikely to explain a bias of this size, given the Carboniferous absolute age. The amount of systematic bias is smaller than that documented from some other studies yet important when using the dates for numerical timescales or regional correlations. Together the data suggest that the minimum bias between the two methods is between 0.5%-1.0%. The results support the need for further work on fundamental argon concentration measurements that underpin K-Ar and  $^{40}\text{Ar}/^{39}\text{Ar}$  age determinations and/or the  $^{40}\text{K}$  decay constant, and to a lesser extent refinements in the U decay constants and U-Pb intercalibration experiments.

## Paleocene timescale miscalibration: Fact or fiction?

MALCOLM S PRINGLE<sup>1</sup> AND LYNNE M CHAMBERS<sup>2</sup>

<sup>1</sup>EAPS MIT, Cambridge MA 02139, USA

(mpringle@mit.edu)

<sup>2</sup>NIGL, BGS, Keyworth NG12 5GG, UK (lmch@bgs.ac.uk)

In the absence of an accepted global stratigraphic section, the Paleocene/Eocene (P/E) boundary is currently a c. 1 m.y. interval within magnetic polarity chron C24r which includes the NP9/NP10 nannofossil boundary, the planktonic foraminifera P5/P6a boundary, a seawater carbon isotope excursion, and the -17 through +19 ash layers in Denmark. Early, unpublished Ar/Ar ages suggested that the -17 ash was c. 55 Ma. The late Paleocene thermal maximum [LPTM] is older than the -17 ash, but younger than the base of C24r.

Based on a correlation of the palynoflora found within the base of the Mull Plateau Group lavas with the LPTM, Jolley et al [2002, 2003] suggested that there is a previously undetected problem with the Paleogene time scale, concluded that the LPTM is older than the Mull lavas, placed the LPTM within the early phase of widespread North Atlantic igneous province volcanism, and even suggested that the onset of this volcanism at 60 Ma was the cause of ocean-floor methane hydrate release thought to be responsible for the LPTM.

Below we present new Ar/Ar ages on the +19 and -17 ashes which, combined with our previous results constraining the duration of British Tertiary volcanism, conclusively show that the Danish ashes and P/E boundary are indeed 55-56 Ma, there is no general problem with P/E time as previously calibrated, and the LPTM is no older than 56-57 Ma. As the main extrusive phase of British Tertiary volcanism was complete by 59 Ma, the thermophilic palynoflora found within the base of the Mull lava pile simply cannot be correlated with late Paleocene thermal maximum time.

### *Paleocene/Eocene Ashes:*

+19, Denmark 55.26  $\pm 0.24$  Ma<sup>1</sup>

-17, Denmark 55.44  $\pm 0.08$  Ma<sup>1</sup>

### *Late Stage British Tertiary Volcanism:*

Mull, Late Stage dikes 58.99  $\pm 0.26$  Ma<sup>2</sup>

Mull, Loch Ba Ring dike 59.35  $\pm 0.36$  Ma<sup>2</sup>

Skye, Loch Ainort granite 59.45  $\pm 0.26$  Ma<sup>2</sup>

Eigg, Sgurr of Eigg rhyolite 59.61  $\pm 0.16$  Ma<sup>2</sup>

### *Early Stage British Tertiary Volcanism:*

Mull, basal lava 61.46  $\pm 0.58$  Ma<sup>2</sup>

Muck, basal tuff, zircon U-Pb 61.15  $\pm 0.26$  Ma<sup>2</sup>

Muck, basal tuff, sanidine 61.55  $\pm 0.14$  Ma<sup>2</sup>

### *Cretaceous/Tertiary Boundary*

Beloc, Haiti, tektite 65.78  $\pm 0.06$  Ma<sup>1</sup>

*Ages relative to FCs @ 28.02 Ma<sup>1</sup> or TCs @ 28.34 Ma<sup>2</sup>*

## Determination of the $^{87}\text{Rb}$ decay constant by $^{87}\text{Sr}$ accumulation

E. ROTENBERG<sup>1</sup>, D.W. DAVIS<sup>1</sup> AND Y. AMELIN<sup>2</sup>

<sup>1</sup>University of Toronto, Department of Geology, Toronto, ON Canada M5S 2B1 (ethanr@galena.geology.utoronto.ca)

<sup>2</sup>Geological Survey of Canada, Ottawa, ON Canada, K1A 0E8 (yamelin@nrcan.gc.ca)

We are currently re-determining the decay constant of  $^{87}\text{Rb}$  ( $\lambda_{87}$ ) with improved accuracy by measuring  $^{87}\text{Sr}$  accumulated in  $\text{RbClO}_4$  prepared by Davis in 1976 from a high purity salt with a known initial Sr isotopic composition. Results from 14 aliquots give a preliminary value of  $1.421 \pm 0.001$  (MSWD=0.88), and are shown in Figure 1.  $^{87}\text{Sr}^*$  accounts for between 82-97% of all  $^{87}\text{Sr}$ .

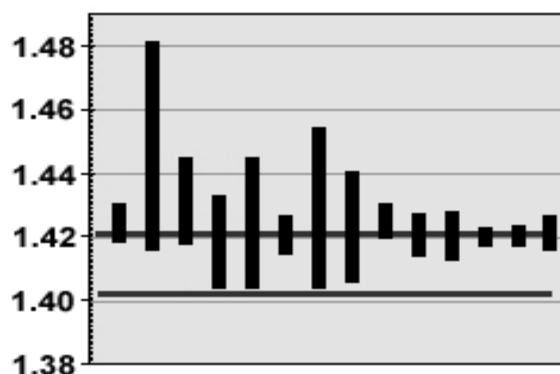


Figure 1 shows results of the Sr accumulation experiment and includes a reference line at 1.402. First eight measurements were taken on VG354, last six on Triton. (Error bars are  $2\sigma$ ).

This value agrees with that of Davis et al. (1977):  $1.419 \pm 0.012$ . However, it is higher than the age-comparison values suggested by Minster et al. (1982), Shih et al. (1985), and Amelin and Zaitsev (2002) of 1.402, Kossert's (2003) counting experiment value of  $1.395 \pm 0.009$  and the value recommended by Begemann et al. (2001). Six additional aliquots await isotopic analysis and we are undertaking duplicate spike calibrations on pure samples of  $\text{SrCO}_3$  (SRM-987) and  $\text{SrCl}_2$ .

### References

- Amelin and Zaitsev (2002) *GCA*, **66**: 2399-2419.  
Begemann et al. (2001) *GCA*, **65**: 111-121.  
Davis et al. (1977) *GCA*, **41**: 1745-1749.  
Kossert (2003) *Appl. Radiat. Isot.* **59**: 377-382.  
Minster et al. (1982) *Nature*, **300**: 414-419.  
Shih et al. (1985) *GCA*, **49**: 411-426.  
Steiger and Jager (1977) *EPSL*, **36**: 359-362.

## New ID-TIMS U-Pb zircon ages for the Carboniferous-Permian boundary sections of the southern Urals – Russia, Kazakhstan

M.D. SCHMITZ<sup>1</sup>, V.I. DAVYDOV<sup>1</sup>, W.S. SNYDER<sup>1</sup>,  
J. RAMEZANI<sup>2</sup> AND S.A. BOWRING<sup>2</sup>

<sup>1</sup>Department of Geosciences, Boise State University, 1910 University Drive, Boise, ID 83725, USA (markschmitz@boisestate.edu, vdavydov@boisestate.edu, wsnnyder@boisestate.edu)

<sup>2</sup>Department of Earth, Atmospheric and Planetary Sciences, M.I.T., 77 Mass. Ave., Cambridge, MA 02139, USA (ramezani@mit.edu, sbowring@mit.edu)

Abundant interstratified volcanic tuffs within a detailed multi-taxa biostratigraphic framework for Late Pennsylvanian-Cisuralian (Early Permian) stratotypic marine sections of the southern Urals provide the opportunity to calibrate the absolute ages and durations of the global stages and biozonal subdivisions of this geological transition, which holds one of the Phanerozoic's major climate regime changes.

New ID-TIMS U-Pb zircon ages (weighted mean  $^{206}\text{Pb}/^{238}\text{U}$  dates of equivalent annealed and chemically abraded single zircons with no rejected outliers) have been obtained for ash beds above and below the Pennsylvanian-Permian boundary at the Usolka and Dal'ny Tulkas sections, spanning the Upper Moscovian to Upper Sakmarian stages. Two ash beds separated by 2.3 meters in the Upper Moscovian at Dal'ny Tulkas yield ages of  $307.3 \pm 0.2$  Ma and  $305.4 \pm 0.2$  Ma, in stratigraphic order. At Usolka, an ash bed in the Lower Sakmarian yields an age of  $290.0 \pm 0.4$  Ma. In concert with refined bracketing ages for the Pennsylvanian-Permian boundary at Usolka, these data anticipate the fine scale to which an accurately correlated, composite reference section for the Pennsylvanian-Cisuralian can be constructed and calibrated.

With this high-resolution framework we can anticipate unprecedented temporal constraints on: the rates of sedimentation and sea-level change in various locations around the world; accurate reconstructions of the full range of variability of the Late Paleozoic climate systems; the relations between marine and terrestrial geologic records; spatial and temporal patterns of extinction events and the rates of ecological recovery and biodiversification following such events; and the timing, duration, and synchronicity of tectonic activity associated with the final assembly and early modification of Pangaea.

## Characterising and U-series dating (TIMS) of travertine from Hungary

M. SIERRALTA<sup>1</sup>, F. MELCHER<sup>2</sup> AND M. FRECHEN<sup>1</sup>

<sup>1</sup>Leibniz Institute for Applied Geosciences (GGA), Stilleweg 2, 30655 Hannover, Germany  
(m.sierralta@gga-hannover.de)

<sup>2</sup>Federal Institute for Geosciences and Natural Resources, Stilleweg 2, 30655 Hannover, Germany

### Introduction

Terrestrial carbonate formations, such as travertine, speleotherm and lake sediments, are important archives of terrestrial climate forcing. At the sections at Süttö in Hungary, a complex sequence of travertine is covered by loess and palaeosols indicating at least an OIS 7 age for the travertine. The Süttö travertine is a high resolution continental archive of interglacial palaeoenvironmental change.

### Analytics

As the growth of travertine is a very complex mechanism and pore cements may cause serious problems for precise dating (e.g. Mallick and Frank 2002), we utilized microscopic, mineralogical and geochemical methods to determine the abundance of primary calcite phases. The state of alteration of primary spar and micrite was characterized by cathodoluminescence and microprobe analyses. Absolute ages were determined by TIMS <sup>230</sup>Th/U.

### Results and Discussion

In contrast to travertines from Weimar-Ehringsdorf, Germany, travertines from Süttö showed homogeneous phases of primary calcite, minor micropores and rare pore cements. For U-series dating the samples were prepared from areas with mainly micrite and spar, avoiding pores. We determined <sup>230</sup>Th/U isochron ages with an isochron approach using the leachate/leachate method (Kaufman 1992). Travertines from Süttö show Mid Pleistocene ages which are supported by results from luminescence dating of the overlying loess sequence.

### Conclusions

The absolute age determination of travertines at Süttö, Hungary yields a more reliable chronological frame to reconstruct both climate and environmental change for the time period of the Mid Pleistocene more precisely.

### References

- Mallick R. and Frank, N. (2002), *Geochim Cosmochim Acta*, **66**, 4261-4272.  
Kaufman, A. (1992), *Geochim Cosmochim Acta*, **57**, 2303-2317

## On the <sup>40</sup>Ar/<sup>39</sup>Ar age of biotite in Green River Formation ash: The advantages of incrementally heating single crystals with a laser

M. E. SMITH, B. S. SINGER, AND A. R. CARROLL

Department of Geology and Geophysics, University of Wisconsin-Madison (msmith@geology.wisc.edu)

Some distal ash fall tuffs in the Eocene Green River Formation either lack sanidine, or the small proportion of sanidine crystals yield heterogeneous ages unsuitable for precise <sup>40</sup>Ar/<sup>39</sup>Ar-based age stratigraphy. Thus, we have on occasion turned to biotite, mindful that it is far more prone to alteration, argon loss, and <sup>39</sup>Ar<sub>K</sub> recoil. For example, we determined the age of biotite in the 6<sup>th</sup> tuff using a CO<sub>2</sub> laser to fuse 26 small aliquots, each comprising three ~500 µm diameter crystals, to be 49.70 ± 0.17 Ma [1] based on 22 of the measurements [2]. A second laser fusion study<sup>3</sup> of biotite from the same tuff measured smaller (>354 µm) and fewer (1-2) crystals per aliquot, with the result that only 11 of 31 apparent ages were considered concordant and gave a mean age of 49.12 ± 0.39 Ma [1], ~580 kyr younger than our fusion age [3].

To resolve this age discrepancy, and investigate the problems presented by biotite, we incrementally heated large (~1000 µm), hand-screened, euhedral crystals, or groups of three such crystals together with a laser. Twenty-three of twenty-six such experiments yield reproducible, concordant plateau ages that give a grand weighted mean age of 49.62 ± 0.17 Ma [1] (MSWD = 1.02). The three excluded experiments exhibit discordant spectra with young initial steps, plateau ages ~500 kyr older than the mean age, and integrated ages both older and younger than the mean. This pattern suggests that microscopic alteration along crystal edges and internal cleavage planes promoted subtle <sup>40</sup>Ar\*-loss and <sup>39</sup>Ar<sub>K</sub> recoil from these domains in ~10% of studied grains. Such open-system behavior may explain much of the variance attributed to xenocrystic contamination in previous fusion-based studies, particularly given the smaller crystals used [2,3]. Our new age fits well into the sanidine-based <sup>40</sup>Ar/<sup>39</sup>Ar accumulation rate profile for the Green River Formation [2]. Should biotite be the only available chronometer for a distal ash, incremental heating of large crystals is recommended.

### References

- [1] ages relative to 28.34 Ma TCs standard; ±2σ intercalibration uncertainty.  
[2] Smith, M.E., Singer B.S. and Carroll, A.R., (2003), *GSA Bull.* **115**, 549-565.  
[3] Machlus, M., Hemming, S.R., Olsen, P.E. and Christie-Blick, N., (2004), *Geology* **32**, 137-140.

## **Ar-Ar and SHRIMP U-Pb age evidence of the Daohugou fossil-bearing beds in Ningcheng, Inner Mongolia, NE China**

Y. ZHANG<sup>1</sup>, W. CHEN<sup>1,2</sup>, D.Y. LIU<sup>3</sup>, Q. Ji<sup>1</sup>  
AND B. SONG<sup>3</sup>

<sup>1</sup>Laboratory of Isotope Geology, Institute of Geology, Chinese  
Academy of Geological Science, Beijing  
(yzhang737@sina.com)

<sup>2</sup>Institute of Geology and Geophysics, Chinese Academy,  
Beijing

<sup>3</sup>Beijing SHRIMP Center (liudunyi@public.bta.net.cn)

A new set of fossil-bearing beds, Daohugou fossil-bearing beds, was found in Daohugou area, Ningcheng, Inner Mongolia, NE China. This Biota is the key of researching the Yanliao Biota's extinction and the origin of the Jehol Biota. Before, there exist two representative opinions on the age of the Daohugou fossil-bearing beds. Some specialists suggest that it should belong to the Middle Jurassic and others believe that it should belong to the early Cretaceous. Their difference on the age is over 30 million years but both of them did not provide accurate isotope geochronological data. We dated the trachyte and trachytic welded tuff structurally overlying the Daohugou fossil-bearing beds using Ar-Ar and SHRIMP U-Pb method.

The plateau age of the sanidine from the trachytic welded tuff is  $164.2 \pm 2.5$ Ma and the mean  $^{206}\text{Pb}/^{238}\text{U}$  age of the zircon from the same sample is  $164.6 \pm 2.4$ Ma. The mean  $^{206}\text{Pb}/^{238}\text{U}$  age of the zircon from the trachyte is  $165.2 \pm 1.8$ Ma. Based on these data, we can draw the following conclusions: (1) the age of the intermediate-acid volcanic rocks overlying the Daohugou fossil-bearing beds is about 164-165Ma; and (2) the age of this fossil-bearing beds is over or equal to 165Ma. Therefore we suggest that the age of Daohugou Biota is tens of millions years earlier than that of the Jehol Biota and it should belong to the Yanliao Biota or belong to the Biota between the Yanliao and Jehol Biota.

### **Acknowledgement**

This work was supported by the Science Project of China Geological Survey (200020190118-2; 200413000033).