EarthChem/EARTHTIME/BGS Workshop on Geochronology – U-series

British Geological Survey – Nottingham UK, June 21 and 22, 2010

Conveners:

Daniel Condon (BGS)

William Thompson (WHOI)

J. Douglas Walker (University of Kansas)

Report of September 21, 2010

1.0 Framing Statement

A significant fraction of our knowledge of Pleistocene chronology, particularly in areas related to climate and environmental change, relies on U-series dating of corals, speleothems, and other carbonates and the proxy records they preserve. This dating method also allows researchers to address magmatic process (duration of crystal growth, timing of crystallization vs. eruption) in ways not possible by other methods. Advances in analytical protocols (i.e., mass spectrometry, more precise estimates of λ^{234}U and λ^{230}Th) means that it is now possible to routinely obtain high-precision U-Th dates and the plethora of U-Th chronology papers in the peer reviewed literature reflects this. The accuracy of these dates, however, is often less well quantified (with respect to precision), thus limiting the usefulness of the data. In addition, many of the basic data are not captured in current data reporting schemes and methods reported in journals.

In light of the importance of U-series dating technique to the geochronology and paleoclimate communities, some discussion of the issues and pitfalls in the subject is warranted with a view to producing guidelines on the acquisition, interpretation, reporting, and archiving of U-series data. For this reason, a small, focused workshop was held to address certain aspects of data reporting and best practices for the U-series method. The conveners were from the US-NSF EarthChem and EARTHTIME projects, Woods Hole Oceanographic Institution, and the British Geological Survey.

2.0 Starting Goals for the Workshop

The conveners, in consultation with experts in U-series dating, identified several important subjects to investigate during the workshop. From these we developed specific goals, and targeted discussions and presentations to address them. These include the following:

2.1 Establish essential items for data reporting. The specific items, units, and general manner in which U-series results are reported are quite heterogeneous from application to application and even variable within specific specialties. It is clear that the use of more uniform formats, data items, and sample and laboratory metadata in data reporting would benefit the U-series community and make comparison of data easier and re-evaluation of published data possible. For this reason, the workshop had a focus on more clearly defining data reporting for U-series method.

2.2 Discuss more transparent and uniform approaches to data reduction and error reporting. As for the analytical methods, there is no uniform approach to data reduction, error analysis, or computation of final ages. Borrowing from the U-Pb and Ar-Ar communities, the workshop explored the flow of data from machine to interpretation to determine whether a more uniform approach or even a common reduction scheme/program would benefit the community. In addition, we identified the types of items and algorithms that should be handled in such a scheme, and initiated a discussion of approaches for rigorous error analysis.

2.3 Determine how U-series data can best be incorporated into the EarthChem Geochron database. Because U-series data and ages are so important to the late Pleistocene climate record as well as the understanding of many petrological and general geological processes, they need to be discoverable and documented online. A natural place is the Geochron website. To the goal of bringing the data into that system, the workshop discussed whether the new data reporting requirements would allow this, and if so how the data is best searched. Interactions with other systems such as the NOAA paleoclimate website was also discussed.

2.4 Explore aspects of best practices for the method. There is currently a great diversity of analytical methods, standards and tracers, and data handling algorithms used for the U-series method. The workshop attempted to determine whether a more uniform approach to reference standards could improve the comparison of data and interpretations between different laboratories or even within a single lab. This was a minor component of our discussions.

The group assembled at this workshop represents a small, but representative subset of the U-series community including experts in U-series analyses of both carbonate and silicates. The organizers attempted to invite a group to cover the depth and breadth of U-series applications and geographic distribution, and the limited size helped assure smoother and more rapid progress toward meeting the workshop goals. To ensure that the results are acceptable to the larger community, a series of outreach steps are described in a latter section of the report to fully revise and vet this report. This will ultimately conclude with a town hall meeting at the AGU 2010 fall meeting.

3.0 Presentations – Finding common ground on a diversely applied method

The applications of the U-series method to geochronology are broad and varied, and range from establishing ages of fossils and geomorphic surfaces to understanding the evolution of magmatic systems. For this reason, a series to talks were given to expose the whole group to aspects of each application. This is especially pertinent in that some of the participants have backgrounds outside of the Geosciences (computer programming/engineering) or are not expert in the technique. Summaries of these presentations are given in sections 3.1 to 3.4 below. Because the EARTHTIME initiative has been very successful at mitigating interlaboratory bias and expanding to aspects of data reduction and management in collaboration with the EarthChem project, a series of talks on standards/comparisons, EarthChem/Geochron data management, EARTHTIME U-Pb_Redux data reduction, and current practices in U-series were given. Brief recaps of these are in sections 3.5 to 3.9. Finally, the group heard about the current approach to error analysis and propagation in the U-Pb-ID-TIMS method (section 3.10).

3.1 Bill Thompson – Dating corals and open system behavior in the U-Th system. The use of corals to track sea level changes and to understand paleoclimate is a fundamental application of the U-series method. Unfortunately, somewhat open system behavior can compromise its precision and accuracy. The open-system behavior results from U and Th gain or loss via diagenesis and gain or loss via alpha-recoil processes. These effects can cause age variations of up to 100 ka for late Pleistocene samples. Two methods are commonly used to mitigate the impact of open system behavior: 1) screening of samples to pick those that are closest to the ideal closed system; 2) methods to correct ages for alpha-recoil artifacts by modeling recoil or to project samples back to the closed system U/Th evolution curve. Both screening and correction methods are currently used, but neither fully accounts for all possible combinations of loss and gain. At present, there is no standard data reporting format for corals; metadata and methodology presentations are also inconsistent.

3.2 David Richards – **Best and bad practices for working with speleothems**. Speleothems have emerged as the primary chronological constraint on the Quaternary. There are several aspects of the method that must be recognized in its applications. First, all U-series ages for speleothems are model ages and involve potentially complex assumption of such factors as decay constants, initial ^{230}Th, constant growth rates, and various ways of handing error analysis and reporting. In addition, the last major interlaboratory comparison was done in 1978, over 30 years ago.

3.3 Ken Rubin – Th-U dating of volcanic rocks. The method of U-series dating on volcanic rocks involves both internal and external isochrons. An internal isochron assumes that the magma had uniform initial U-Th composition. Because an array of minerals will have uniform ^{230}Th/^{232}Th but variable U/Th, they ingrow disequilibrium products to create an isochron. External isochrones are commonly used for basalts and rocks with difficult to handle minerals. This can give a rough age for a sample, but deviations in assumptions are not easily translated into errors on ages, and are sometimes ignored. On potential problem is the very low ^{230}Th/^{232}Th: this makes it critical to evaluate baselines and abundance sensitivity. Another issue is that there is an uneven reporting of data. Some authors give measured data, other derived. This difference must be documented in the reporting. Lastly, development and use of a synthetic standard would greatly aid the application of the method.

3.4 Mary Reid – *Zircon and SIMS.* In general, it is appropriate to assumed closed system behavior and that the crystals are in secular equilibrium with respect to ^{234}U/^{238}U when applying the U-series method to dating of zircons and other U-bearing minerals. This can give information on the crystallization history of zircons primarily by ^{230}Th/^{238}U dating, although some workers have explored the potential of ^{231}Pa/^{238}U dating. ^{230}Th/^{238}U dating can provide better resolution on ages from 300 ka to present than U-Pb dating. The uncertainties tend to be large, but useful problems are still addressed. Besides the basic analytical data collected to create model ages, extensive metadata are also needed. This includes relative sensitivity, mass fractionation on Th, masses analyzed, mass resolution, decay constants, reference standards, spot size, and location of spots within an image.

3.5 Doug Walker – EarthChem Geochron and collaboration with EARTHTIME. EarthChem is an NSF funded project aimed at being a one-stop-shop for discovery, download, and eventually archiving of geochemical data of all types. The Geochron database run by EarthChem is aimed at serving these purposes for geochronological and thermochronological data. The group has collaborated extensively with the EARTHTIME effort. The collaboration between the two groups has attempted to make age data easy to upload and search. The main goal is to make data reporting part of the scientist's workflow. This appears to be most easily accomplished by adding functionally in data reduction programs to interact directly with the Geochron database.

3.6 Dan Condon – Insights from the U-Pb EARTHTIME initiative. The EARTHTIME goal is to bring much higher precision and reproducibility to geochronological ages. One of the important activities undertaken was the preparation and analysis of reference standards to quantify and help mitigate interlaboratory biases. Tracer calibration exercise made the U-Pb group take up almost every aspect of the system, including all aspects of constants and standards. Communication between different laboratories using the same and even different systems (e.g., U-Pb, Ar-Ar) has increased greatly. It is likely that a similar approach of preparing standards and doing comparisons would greatly benefit the U-series community. In general, funding agencies have been very supportive of the effort.

3.7 Jim Bowring – Machine to interpretation workflow for U-Pb ID-TIMS. A rigorous software engineering approach should make reporting, archiving, and interpreting data a seamless and effortless part of the researchers workflow. This has been accomplished using Tripoli and U-Pb_Redux for the ID-TIMS method. Tripoli interacts directly with the machine-produced data (i.e., measured ratios) to provide tools for user checks on quality control and assurance. It outputs the data in real time to U-Pb_Redux, a program to compute dates and interpret ages. Calculations in both are transparent, and U-Pb_Redux is open source. More information and downloads are available at www.cirdles.org.

Tripoli reads output files from most types of mass spectrometer. It manipulates data using both rigorous tests as well as manual and interactive tools. U-Pb_Redux is a powerful program for reducing the data and interacts seamlessly with Tripoli. Upload to Geochron implemented in the program. In addition, the program will search Geochron and download data for compilation or further visualization.

3.8 Dirk Hoffmann – Report on Regular European Inter-laboratory Measurement Evaluation Program. There is a program for interlaboratory measurement of U isotopic ratios in nitric solution. This consists of 4 samples of depleted to low-enriched U. Seventy labs received the solution. In general, the $^{234}U/^{238}U$ had large variations; the $^{236}U/^{238}U$ had a very large range, and many laboratories did not report this ratio. Setup of the instrument is important, and includes reporting/documenting such aspects as: machine and spray chamber, sample uptake rate, peak intensities, presence of an energy filter, scheme for sample and standard bracketing, and type and calibration of spike. Common biases can result from: background, memory, mass fractions, gain factors, linearity, peak tailing, interferences, chemistry blanks, and tracer purity. Ken Sims published an interlaboratory comparison similar comparison for laboratories analyzing the Th/U ratio in 2008. It is concluded that the use of synthetic standards could greatly help the method.

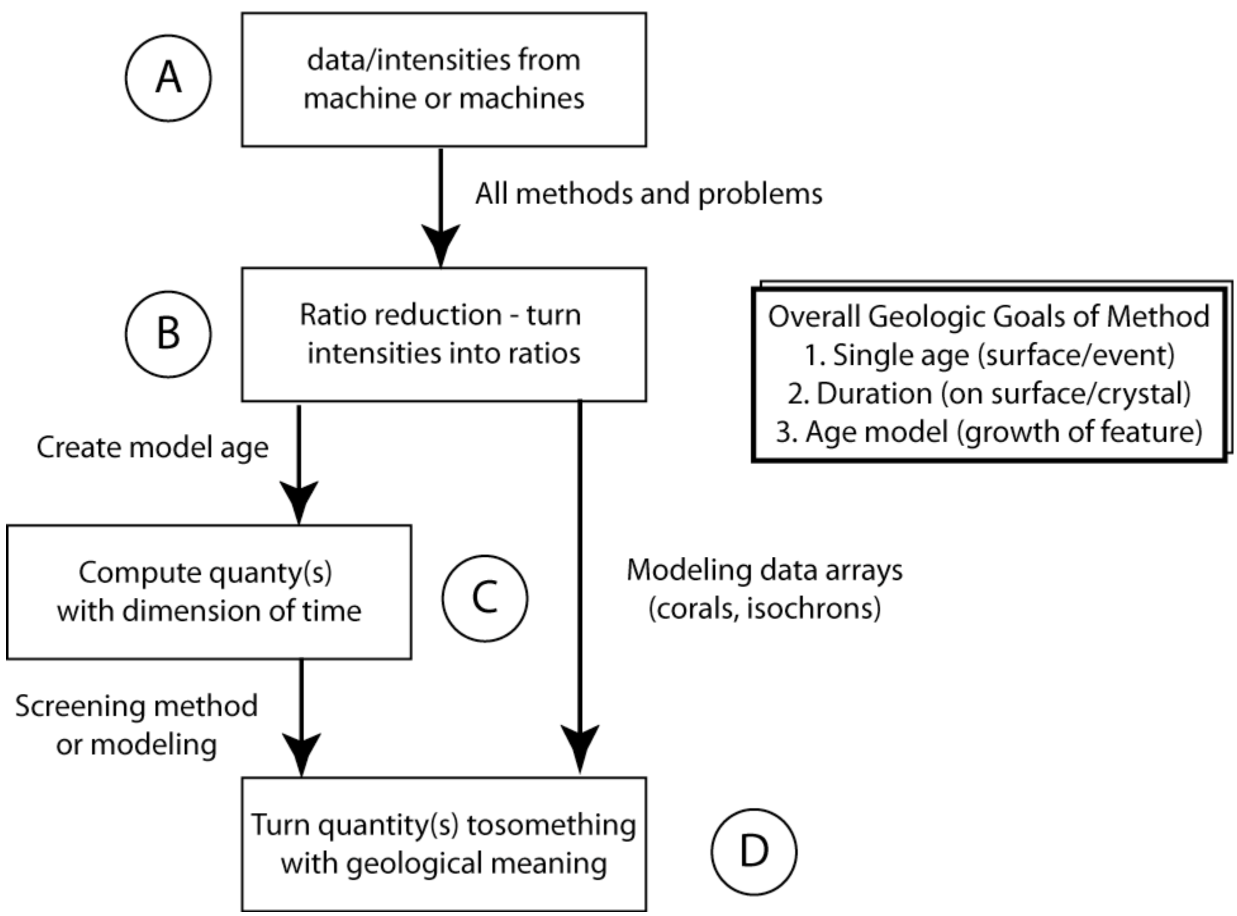
3.9 Morton Anderson and Alex Thomas – current state of data reduction in U-series. Data acquisition for U-Th data is diverse and varies greatly from lab to lab. Any more general data reduction program or algorithm must accommodate this variability. One stand-alone program exists and is being used by the Oxford group.

3.10 Noah McLean – Error analysis and uncertainty in U-Pb ID-TIMS and possible extensions to U-Th. The current efforts on revising the U-Pb data reduction scheme and program began in 2004 with the advent of EARTHTIME II. It was an attempt to correct the errors and simplifications present in earlier approaches and to establish and international standard for data reduction protocols. In essence, there was a need to move beyond the restrictions presented by Pedant and Isoplot as applied to ID-TIMS data (although it is recognized that these pioneering efforts propelled the community to be able to undertake this effort). The principal advance has been an attempt to rigorously propagate errors especially the numerous covariance terms. This has been greatly aided by using a matrix math approach. The approach is general, and can be used for any system that can be thoroughly described.

4.0 Results of the Breakout Sessions

To meet the goals of the workshop, we held several breakout sessions. Discussions lead us to focus on two of the main goals – data reporting and data reduction (Goals 1 and 2). The third goal was discussed briefly. The last goal, a review of best practices in the method, was a subject initially discussed at the WHOI/PALSEA workshop and thought to be a subject mostly for an additional workshop.

In conducting the breakout sessions, the group quickly realized that there are a variety of perspectives about how to use the method and how to discuss the results. For that reason, we prepared an organizational flow chart that corresponds to the workflow and purpose of each processing and/or interpretation step. This is shown in the figure below. One of the more important realizations was that the U-series method is applicable to a limited range of geological goals: 1) obtain a single age that can be interpreted to correspond to the time of development of a geological surface or some other geological event (e.g. crystallization from a magma); 2) obtain several ages that related to the duration of a geological event (e.g., coral growth on a terrace or length of crystallization); or 3) give an age model for the growth of a feature (e.g., speleothem).



The first task, A, is to collect peak and background intensity data from the machine or machines (e.g., mass spectrometers). This involves a variety of tasks in collecting information for backgrounds, interferences, etc. This task is common for all goals and applications. The next step, B, is to apply a series of algorithms to turn the intensity data into isotopic and/or elemental ratios. This step formed much of the discussion of the first breakout group. This is followed in some applications by step C, computing quantities that have dimensions of time, but may not actually correspond to a geologically meaningful result (this corresponds to a "date" in the EARTHTIME parlance). An example of this are analysis of samples of corals that may be subject to open system behavior to compute age arrays so such behavior can be modeled or results screened. Lastly, in step D, an interpretation is made to create a time value that has some geological significance (the "age" in EARTHTIME). This may result from using previously derived values (C) or may be computed directly from ratios (e.g., an isochron).

4.1 Data flow start to finish

This breakout session discussed the aspects of data acquisition and reduction, focusing on (1) mass spectrometry, (2) corrections made to measured ratios in order to get a best approximation of the sample isotopic composition, and (3) interpretation of the sample isotope ratios in order to determine a U-series date. These topics were discussed in light of the broader aims of the workshop, data reporting, and potential future efforts for data reduction efforts (i.e., a U-series version of U-Pb redux) and long-term archiving of U-series data.

Many aspects of mass spectrometry were discussed (e.g., mass resolution, criteria used for data rejection, collectors and measurement protocols, calibration of ion counting detectors, use and calibration of energy filters). In particular the analytical protocol specific to many U-series determinations were discussed, the use of internal and/or external normalization for both Th and U, and the assumptions (and uncertainties) related to the various different approaches. Even though a limited number of platforms (TIMS, MC-ICP-MS, SIMS) exist it was clear that numerous permutations are being employed in U-series mass spectrometry and this will likely continue to be the case in the future. Following on from this the group discussed the various corrections (background, abundance sensitivity, isobaric interferences - hydride, oxide, etc.): Again many different permutations are currently employed.

Much of this discussion was conducted with the possible development of open-source data reduction software for use in U-series geochronology in mind. In the U-Pb ID-TIMS community two open-source software units have been developed: *Tripoli* which is charged with transforming raw mass spectrometer data (ratios and/or intensities) into isotope ratios that are thought to reflect the true composition of the sample (i.e., corrections are made for interferences, beam drift, and/or mass fractionation). The second package, *Redux*, take the output from *Triopli* (or any other set of corrected mass spectrometry data) and is responsible for all of the steps required for calculating a date (i.e., spike stripping, correction for blank, initial disequilibria, isotope dilution, date calculation etc.), sensitivity testing of data and assessment of multiple analyses (i.e., weighted mean determinations, calculation of MSWD etc.). Many aspects of data acquisition and reduction specific to U-series geochronology were discussed and based upon the design of *Redux* and *Tripoli* it was suggested that developing a U-series 'toolbox' to encompass the various permutations would be tractable. Examples of tools for carbonate U-series applications that were discussed: (1) calculation of open-system model ages, (2) development of development of age models for speleothems (similar to OxCal – http://c14.arch.ox.ac.uk/embed.php?File=oxcal.html), and (3) consideration of the uncertainty of seawater $\delta^{234}U$ using a range of 'acceptable' values/uncertainties.

Redux also serves as an interface with the EARTHCHEM Geochron database (see above) which is important as it makes data archiving a 'seamless' part of the data reduction – making data archiving a separate step is a major impediment to people routinely using these types of databases. This lead on to discussion of other possible functionality that may be desirable: (1) recalculation of published data held in a GEOCHRON-type database will be required if/when different constant parameters are used (e.g., decay ^{230}Th and ^{234}U constants); and (2) capturing data obtained on widely distributed standard materials that can be used to assess long-term reproducibility and accuracy of data produced in different labs and/or different analytical protocols.

A major point of agreement was that the present wide variety of approaches to data acquisition and data reduction that are current in the U-Th community are generally valid and there is no desire to develop tools that are prescriptive with regards to mass spectrometry and elements of data reduction such as interference corrections.

4.2 Reporting of data

The other breakout sessions focused mainly on aspects of data reporting. To this end, we attempted to identify all the data and metadata that would be needed to fully document an age interpretation. This is given in the table below, and is broken into four general groupings. First is information about the sample. This includes location as well as a detailed description of the material. It also should include the overall goal of the dating effort. The second category is the analytical information that details what equipment was used and how the data were collected. The third category is the data and derived dates. Last is the age interpretation made by the scientist(s).

Table for Data Reporting Requirements and Guidelines

Quantity Type	Explanation/Sample Values
Sample Information	
Sample/geologic setting	Sample name and location type – terrace, cave
Specific sample selection criteria	Clean/dirty carbonate coating
Associated proxy/process	Stable isotope, trace elements, radiogenic tracers (Sr, Nd, Pb, Hf), radiocarbon, etc.; magma residence time, eruption ages, etc.
Goal	Age, duration, age model
Chemical and/or mineralogical characterization	XRD, CL
Elevation	Error and reference datum
Location GPS/coordinates	Projection/datum
Cross-reference to other databases	NOAA repository, Smithsonian volcano list
Sub-sampling	Type and method
Photos	If taken
Archival information	Location of sample, IGSN if available
Prior studies?	List of publications
Corals	Species and genus
	Uplift rate
	Paleo-depth estimate (interpretation)
	Facies for sampling (interpretation)
	Stratigraphy/map/diagram
	In Growth position (?)
Terrestrial carbonates/sediments	Carbonate petrology (tufas, cements, soils etc.)
	Stratigraphy/map/diagram
	Facies for sampling (interpretation)

	Total thickness of soil and thickness of each layer (organic soil, mineral soil, sapropel) Sampling method/sub-sampling (pore-water filtering size, soil sieving size, sequential extraction used) Date sample collected (and details of seasonality of precipitation and temperature)
Marine carbonates/sediments	Carbonate petrology Stratigraphy/map/diagram Host lithology Sample size and homogenization procedure Dissolution protocol If calculating authigenic or excess components: State assumptions in detrital composition, and associated uncertainties. (U/Th$_{detrital}$ (^{230}Th/^{238}U)$_{detrital}$). State (or reference) equations used for correction, ie. are authigenic and detrital components treated separately for correction of excess State (or reference) how age model used for corrections has been established Water depth core was taken in. (used for calculating 230Th normalized sedimentation. Mineralogy (some measure of opal content of sediment), may only be relevant for ^{231}Pa/^{230}Th
Speleothems	Stratigraphy/map/diagram In Growth position (?) Morphology (flowstone/stalagmite/stalagtite) Sampling position (axial/non-axial, cm from base) Trace/REE elements Paleo-elevation estimate (interpretation)
Silicates	Rock type and mineral assemblage Minerals analysed Trace/REE elements
U-bearing accessory minerals	Rock and mineral type (zircon, allanite etc) CL images Inclusions Trace/REE elements

Other materials	(Bones, egg shells, teeth, phospate precipitates etc.)
	Material (e.g. calcite vs. aragonite)
	Assumptions on initial ^{230}Th
	Age model assumptions
	Stratigraphic context
	Stratigraphy Position (e.g. axial/non-axial, cm from base)
	Sample heterogeneity (e.g. inclusions, inner vs. outer part)

Analytical Information

Standards used and other quality control measures	Names. Description, and reference values if appropriate
Laboratory	Name and affiliation
Instrumentation and manufacturer	TIMS, SF-ICP-MS, Q-ICP-MS, MC-ICP-MS, Laser microprobe
Sample dissolution	Total or partial dissolution. Ra, Pa measured on aliquot of whole sample or separate dissolution?
Sample introduction	Filament (Re with graphite, double Re, W or Re with TaO), nebulizer system (type, uptake rate µl/min, laser ablation conditions), ICP gas conditions (N2 or He added to Ar carrier).
Measurement protocol	Standard bracketing, internal normalization, ^{229}Th-^{230}Th-^{232}Th in-house Th standard
Method reference paper	
Tailing and hydride correction procedure, ion beam size, energy filter	
Mass bias correction	
^{235}U/^{238}U assumptions	Assumed or measured ratio, and where applied in scheme
Other corrections	Non-linear collectors
Relative sensitivity	For SIMS
Pretreatment and preparation of samples before chemistry/analysis	Mount in In vs epoxy, leaching, physical abrasion
Tracer/spike composition and calibration	Calibration against secular equilibrium materials, natural standards or gravimetric solutions
Tracer/spike creation method	Daughter isotope milking (i.e., ^{228}Ra from ^{232}Th; ^{233}Pa from ^{237}Np, or neutron activation for ^{233}Pa
Chemical separation techniques	Column chemistry and post chemistry treatment (e.g. HNO_3-H_2O_2 or AG-1 clean-up column for organics)
Th, U blank masses and isotope composition	
Data reduction tools	Isoplot, U-Pb redux, Open system model (type)
How uncertainty calculated	Mass Spectrometer, blank, half life – other sources of error
Component parts to systematic and random errors	

Data	
Material/mineral	(e.g., coral, zircon, aragonite)
Measured isotope ratios (corrected for analytical biases):	$^{234}U/^{238}U$, $^{230}Th/^{232}Th$, $^{228}Ra/^{226}Ra$, $^{231}Pa/^{233}Pa$ (suggested numerator/denominator, atom or activity) with total 2s uncertainties
Concentrations:	^{238}Uconc. (μg/g), ^{232}Thconc. (ng/g) (intensity as surrogate for SIMS) with total 2σ uncertainties, ^{228}Ra conc. (fg/g), ^{231}Pa conc. (fg/g) with total 2σ uncertainties
Element ratios:	$^{230}Th/^{238}U$, $^{226}Ra/^{230}Th$, $^{231}Pa/^{235}U$ (activity ratios) with total 2σ uncertainties
Isochron ratios	(e.g. $^{238}U/^{232}Th$ - and ^{230}Th/Ba, ^{226}Ra/Ba - tabulate the data used to make isochron ages including correlations and units)
Significant figures	2 significant figures in uncertainty – use same decimal place in data
Half lives used and reference	
Initial $\delta^{234}U$, 2σ error	

Interpreted Ages	
Ages, errors (2s), and how calculated Activity units must be stated if used	(e.g. uncorrected age, Th corrected age, isochron age etc)
For U/Th ages – should be quoted with radiocarbon reference (1950) as zero	
Or - for U/Th, U/Pa and Ra-Th ages >100 years – should be quoted with a standard reference date (e.g., 2000, or radiocarbon reference (1950)) as zero	
For U/Th, U/Pa and Ra-Th ages <100 years – provide ACTUAL calendar age	Use year, or year and Julian day (dictated by error)

4.3 Website Development

The group also discussed archiving and searching U-series data at the EarthChem Geochron site. This was considered an appropriate goal. Data can be submitted either using web-based forms or some sort of well-formatted table/file. In the future, the group hopes to use online submission through a data reduction program similar to the Tripoli and U-Pb_Redux workflow using in the U-Pb community.

Search criteria that would be helpful include several aspects of the sample and data. Sample type and location are obviously needed as well as the overall goal of the dating effort. Searching by interpreted age is also important. This would either attempt to match a sample age or determine if the age falls in the range of a growth for minerals or speleothems. Also in the case of speleothems, the cave name and location are important. Analytical parameters would also be searched.

5.0 Summary and Future Plans

Overall, the workshop was successful in meeting the goals of the organizers. A clear path to data archiving and submittal, including the items to be reported, was determined. Various aspects of data reduction and error analysis were also done. The group emphasized the need for inter-laboratory comparisons.

The participants and organizers will review this document and recommendations. In September, the document will be put online and sent to the community for comments. Once concluded, a subset of the group will prepare a paper on data reporting guidelines. A town hall meeting will be organized at the fall AGU meeting for further comment. In addition, a set of short movies on Tripoli and U-Pb_Redux will be assembled to show an example of workflow and data reporting to the U-series community. As a test case for the interaction with Geochron, the PALSEA dataset will be assembled and uploaded to the database.

Tentative Agenda of Workshop

Note: Schedule includes time for presentations and question/answer periods

Monday, June 21

8.30 am – pickup at Jurys Inn Hotel, travel to Keyworth.

UK participants travel to Keyworth for 9am arrival.

Morning session –Background on current efforts.

9:30 Introductions, goals of workshop, schedule, nature of final report – Walker, Thompson, Condon

9:40 Overview of method and current state of data reporting – William Thompson (corals), David Richards (speleothems), Ken Rubin (silicates), Mary Reid (zircon and SIMS).

10:30 Results of previous EarthChem workshops – Doug Walker

10:45 Break

11:00 EARTHTIME approach to standardization – Dan Condon/Noah McLean

11:30 Examples of data reduction and database approaches – James Bowring

12:00 Lunch

Afternoon sessions – Reporting and standardization/protocols I

1:15 Current state of U-Th data reduction - Morten Andersen/Gideon Henderson

1:45 Topics for breakout groups.

Group 1. Data reporting – developing required information items.

Group 2. Data reduction, standardization, best practices.

4:30 Plenary session on group results.

Workshop dinner

Tuesday, June 22

Morning session – Reporting and standardization/protocols II

9:00 Overview of error analysis in U-Pb dating – Noah McLean

9:30 Breakout groups.

Group 1. Data and uncertainty reporting/editorial guidelines.

Group 2. The future of data reduction for U-series.

11:30 Plenary session on group results.

12:00 Lunch

Afternoon session – Nature of a U-series website and conclusion

1:30 EarthChem and Geochron website – Doug Walker

2:00 Plenary session on website needs and interactions with other data types.

3:00 Break

3:15 Plenary session on strategic recommendations.

4:30 Adjourn, Start of final report.

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