Precise and accurate intercalibration of biostratigraphic and radioisotopic timescales

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In the Earth Sciences, the study of many fundamental problems relies on precise knowledge of geological time. Paleontology provides information on appearance vs. extinction of fossil taxa, essential for the understanding of the processes that drive biological evolution, and also allows relative dating of sedimentary rocks. The interaction between the Earth's biogeochemical cycles can only be examined through correlations in time and space, using multiple stratigraphic cross-sections, which allow high-resolution sampling of uninterrupted time-series from different fossil environments in different places. Paleontology also defines periods of dramatic biotic changes, i.e. mass extinction events; knowing the precise timing of such events is crucial for pinpointing their possible causes. Since causality in the geological past can very often only be demonstrated by contemporaneity, we need age determinations, which are highly precise and accurate. In the case of major biotic events these areo applied to possible causes (volcanic eruptions, meteorite impacts, climatic overturns), as well as to the global (marine) stratigraphic record. The "absolute" calibration of biostratigraphic sections will eventually allow quantitative assessments on the rates of biotic changes, such as the rates of extinction and post-extinction recovery.
For a so-called quantitative biochronology we therefore need to calibrate high-resolution paleontological ages with radio-isotopic ages of the highest precision and accuracy. The dating techniques that provide the most precise and accurate ages are 39Ar-40Ar (using micas, feldspars and amphiboles) and ID-TIMS U-Pb (using zircon and monazite), which are based on the radioactive decay of 40K, 235U and 238U, respectively. These minerals can be found in volcanic ash beds that are interlayered with well-preserved fossiliferous sedimentary strata in marine sections.

However, to achieve precise and accurate age data we have to overcome a series of obstacles and problems.

- We need biostratigraphically well-documented and uninterrupted marine stratigraphic sections that allow global biostratigraphic correlation.
- Furthermore, these sections must contain numerous volcanic ash layers that allow precise and accurate calibration of the biostratigraphic zones with radio-isotopic dating techniques.
- The sample material for isotopic dating needs to show ideal behaviour: no open-system behaviour leading to partial loss of radiogenic daughter isotopes (due to thermal overprinting, triclinisation of sanidine feldspars, or decay damage of the zircon lattice), otherwise the resulting age may be precise but inaccurate (yielding too young ages through Argon or Lead loss).
- We have to ensure that age determinations produced by the different decay systems (K-Ar and U-Pb) yield equivalent results. This requires that the two

systems close at the same time in geological history, and that the decay systems give an equivalent answer – which is often not the case.…
- We have to make sure that age values being published by two different laboratories are equivalent – which is often not the case….

The talk will demonstrate which parameters need to be controlled in order to achieve the highest degree of confidence in both the precision and accuracy of U-Pb zircon ages from ash beds. Data from the Permian/Triassic boundary and the early Triassic of southern and southeastern China are used as an example. There is a debate about the correct age of the P/T boundary, since two age determinations differ by 1 m.y.: 251.4 ± 0.3 Ma (Bowring et al. 1998) vs. 252.6 ± 0.2 Ma (Mundil et al. 2004). This discrepancy points to a systematic inter-laboratory bias, which is due to systematic effects (differing tracer isotope calibrations in the two laboratories, differing non-linearity behaviour and subsequent correction procedures of different multiplier types in the two mass spectrometers) and/or different sample preparation procedures to minimize the effects of lead loss (mechanical surface abrasion by Bowring et al. vs. annealing-leaching technology in the case of Mundil et al.). Another discrepancy exists between the above mentioned U-Pb ages and sanidine 39Ar-40Ar age determinations of 249.9 ± 1.5 Ma (Renne et al., 1995). This may be explained by a systematic deviation of the Ar ages because we use a 40K decay constant, which is thought to be 0.8% too low (Schoene et al. 2006). Ultraprecise data are needed to trace these systematic and nonsystematic deviations before we can suggest remedies! Among the suggested efforts to improve accuracy are:

- Production and use of the same 202Pb-205Pb-233U-235U tracer solution by all laboratories implicated in time-scale research in order to minimize interlaboratory biases. Quality control by using international dating standards such as R33 and TEMORA-2 zircons.
- Minimization of mass spectrometer biases by better control of fractionation (by the above spikes) and production of more linear and more stable multiplier devices by the mass spectrometer companies.
- Re-determination of the 40K and U decay constants by counting experiments

Such effort will allow quantitative intercalibration of biochronologic, astronomical, cyclostratigraphic, magnetostratigraphic and isotopic timescales in future; this is the aim of the EARTHTIME/EARTHTIME-EUROPE initiatives (http://www.earth-time.org; http://www.earth-time.org/Eurotime_1.pdf).
A new data set from a well-documented early Triassic (Smithian-Spathian-Anisian) section in southern China (Ovtcharova et al. 2006) serves as an example how the new techniques lead to more precise and accurate age information on a selected time slice in the past: The data corroborate the 252.6 Ma Mundil et al. age for the P/T boundary and allow quantification of the early Triassic post-extinction biotic recovery:

- The Griesbachian and Dienerian substages are shown to have a maximal duration of 1 m.y.
- The Smithian substage is shown to have an equally short maximal duration of 1 m.y.

- The duration of the Spathian substage is equal to some 3 m.y.
- This implies a duration of some 6 m.y. for the Anisian, based on the Anisian/Ladinian boundary age of 241.2 Ma ± 0.8 Ma (Brack et al. 1996).

These data have important implications on the tempo of biotic recovery during the Griesbachian-Dienerian-Smithian substages, and on ammonoid recovery after the end-Smithian biotic crisis.

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