

Give or take 10 million years

Bands in rock can mark changes in Earth's orbit. Cretaceous-Palaeogene boundary section as exposed during construction of the Denver International Airport, Concourse B.

Astounding new techniques are allowing geologists to pinpoint the timing of events which occurred hundreds of millions of years ago to within 100,000 years. **Dan Condon** discusses how the Earthtime initiative will change our understanding of the history of this planet.

For geologists, it's all about timing. Questions we often ask when trying to understand geological processes or events that occurred millions of years ago are quite simple: when did it happen, how fast and in what order? The answer can be straightforward if you are only interested in rough estimates, say within the nearest million, or ten million years. But, if we need to piece together the order of events to recreate past climates then rough estimates aren't good enough. Researchers are using increasingly sophisticated models to simulate past climates as well as to explore how the Earth system will change in response to increasing CO₂ levels. Testing these models requires equally sophisticated calibration of the geologic record to assess that the models accurately simulate the various components of the Earth system. A new international initiative is helping with this calibration.

Quantifying geological time has been central to understanding the Earth system and its evolution. Knowing the age of certain

Our aim is to develop tools for high precision sequencing of Earth's history.

rocks, be it a thick accumulation of volcanic lava or an extinction layer, allows us to say something about causality. The extinction of the dinosaurs at the end of the Cretaceous period, 'about' 66 million years ago, is a good example of such cause-and-effect arguments. At 'about' the same time a large asteroid struck what is now the Gulf of Mexico, however a series of voluminous volcanic eruptions in India are also 'about' the same age. Both are viable kill mechanisms, and both are closely correlated in time with the extinction, but knowing they are 'about' the same age is not good enough. To evaluate the cause of the extinction we need to know the sequence of events at the highest possible precision.

Isotopes: different forms of an element with different numbers of neutrons in the nucleus.

Radioisotopes: unstable isotopes of an element that decay, emitting radiation.

The target interval is the extinction of the dinosaurs.

Geologists now possess an impressive toolbox for quantifying geological time, ranging from radioisotopic dating of minerals and rocks, to the astronomical dating of cyclically deposited sedimentary rocks (the Earth's tilt and position relative to the sun, which varies periodically, is linked to sedimentary layers deep beneath our feet – see page 15). While identifying 'age-specific' fossils has always been central to geologic time, we can only use this technique to date rocks in a relative sense. We are now attempting to address problems that require knowledge of the exact sequencing and tempo of events, such as mountain building and erosion, and their relationship, if any, to climate. This involves integrating records of ocean chemistry and climate change with geochronology tools.

Advances in mass spectrometry, an analytical technique used to determine the amount of a given isotope such as ^{238}U or its daughter product ^{206}Pb , means we can date certain rock types, for example, volcanic ash, with a precision of 0.1 percent or better. At 50 million years, this is an error of just plus or minus 50,000 years. These techniques can be used on rocks of nearly any age, from corals a few thousand years old to meteorites created during the early years of our solar system.

Astronomical dating, on the other hand, is based on recognising successive cyclically deposited sediments, which often reflect climate oscillations that depend on where Earth is in its orbital cycle. We can compare the sedimentary deposits to mathematical models of the solar system for at least the last 100 million years. The models tell us exactly the Earth's position and orientation in the solar system at any given point in time. These parameters influence Earth's climate and are reflected in the sedimentary record. For cyclical successions younger than about 23 million years the models work very well. As we go further back in time, uncertainty in the models increases. The most useful cycle occurs about every 405,000 years and is related to the eccentricity in Earth's orbit around the sun. This cycle is very stable. If a researcher can recognise it in the rock record it can provide a relative sense of time. However, if we can date such successions using radioisotopic techniques, the cyclicity can be pinned down and used to tell time with unprecedented precision and accuracy.

Combined, these techniques offer the potential for constraining many different types of geological records, from the seafloor records collected during ocean drilling expeditions, or the sediments eroded from large mountain chains such as the Himalayas. However, there is a catch. About a decade ago, the error on age determinations was largely dominated by the precision of the mass spectrometer measurement. Whilst there has been a great increase in the level of precision, little has changed in terms of accuracy. In other words, while spectrometers may repeatedly reproduce the same or similar dates, the accuracy of these dates is still an issue. This can cause problems when trying to compare one date with another.



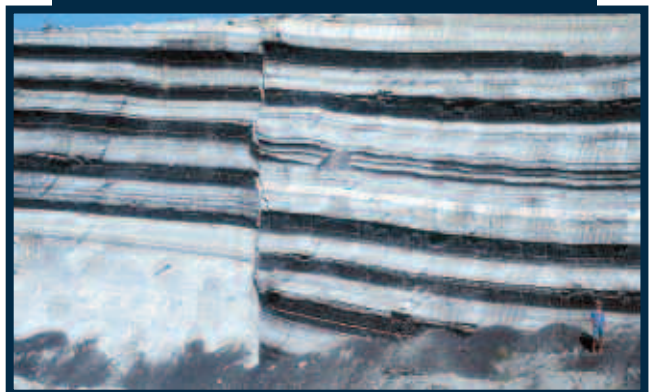
A Lower Pliocene (around 5 million years ago) section along the south coast of Sicily which shows precession, obliquity and eccentricity related patterns in the deep marine carbonate cycles.



A marine upper Miocene (around 7 million years ago) section on Sicily, which shows precession and eccentricity related patterns in the dark, organic-rich layers.

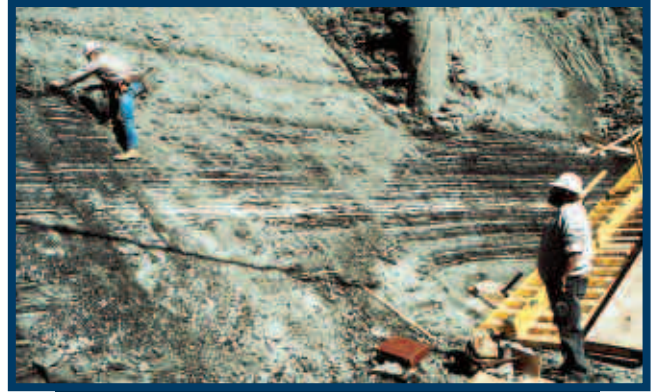


A Miocene continental section in Spain: the light and dark couplets reflect 23,000 year precession cycles.



A Pliocene continental section in Greece, the light and dark couplets reflect 23,000 year precession cycles

Nearly all research carried out on the geological record will benefit from a greatly improved calibration of Earth's history.



Volcanic ash beds (white) within late Cretaceous coal exposed during construction of the Denver International Airport, Concourse B. Such ash beds are the target of the Earthtime proof-of-concept project.

Kirk Johnson, Denver Museum of Science and Nature.

The accuracy of radioisotopic dating depends on both our ability to determine the ratio of parent isotope to daughter isotope and how well we know the rate of decay for these radioactive particles, which depends on the decay constant. For uranium-lead decay these constants are known to a little over 0.1 percent, however for others, such as those based on the decay of potassium to argon (known as the argon-argon technique), the uncertainty is much higher, approaching one percent. We can see this effect when we date samples using the two techniques, uranium-lead and argon-argon. There is often a systematic bias, uranium-lead dates are always older by 0.5-1 percent. Geologists have started to talk about argon years and uranium-lead years. The situation becomes even more cloudy when we begin to think about interlaboratory effects. At a workshop in 2004, most of the established uranium-lead and argon-argon labs presented data on a number of standard samples. In theory all labs should obtain the same age for the same samples within acceptable boundaries, and most labs did, however the degree of dispersion was significant and not all labs results overlapped within acceptable boundaries. This indicates that while each lab can make precise measurements, differences between different techniques and labs are bigger than the precision of the measurements.

A way forward? We want to unify the various chronometers without losing resolving power. The Earthtime initiative, which began in 2003, has been developed to sort this out. Earthtime is an

international, community-based effort. It has more than 200 participants in over 30 countries, and is funded by several research councils including the US National Science Foundation, the European Science Foundation and, of course, the Natural Environment Research Council.

Earthtime's overarching aim is to develop tools for high-precision sequencing of Earth history. But it's also about a philosophical change in the way we tackle such enormous projects. The bottom line is we have to do a better job of working together. There is great consensus in the community that there is a lot to gain from a more holistic understanding of the issues at hand. This means stratigraphers, geochronologists, palaeontologists, climate modellers, and many others, really working together, not just sending one another data. It also means geochronology labs must share expertise and collaborate on large projects, which will require some standardisation of techniques and results. This technical phase is already well under way. For example, at NIGL we have been working with colleagues from the US and Switzerland preparing and calibrating synthetic uranium-lead tracers which will be used by all Earthtime labs carrying out uranium-lead dating. This should eliminate the uranium-lead interlaboratory bias. In the next few years, we plan an intensive effort focusing on intercalibrating different chronometers so they can be integrated without losing resolving power.

In the next phase we will apply this improved toolkit to calibrating Earth's history. So, where do we start? Although many research projects are already

established, the Earthtime community has decided to choose a very specific project to demonstrate to ourselves and others that we can actually do it. The target interval is the extinction of the dinosaurs at the end of the Cretaceous. In addition to the high publicity of studying this geological time slice, it is an interval which has a diverse geological record, which means we can apply all our techniques and compare results directly.

NERC science has a lot to gain from Earthtime. Nearly all research carried out on the geological record will benefit from a greatly improved calibration of Earth's history. This is not only the university-based efforts but also research carried out by centres such as the British Geological Survey, the British Antarctic Survey and the National Oceanography Centre, Southampton. Perhaps the greatest beneficiary will be the Integrated Ocean Drilling Program, an international research initiative (UK funding comes from NERC). Although Earthtime focuses on Earth's history, the constraints it provides will be critical for verifying global climate models used to predict future climate. ■

Dr Dan Condon is a NERC Postdoctoral Fellow based at the NERC Isotope Geosciences Laboratory, British Geological Survey, Keyworth, Nottinghamshire. Email: dcondon@bgs.ac.uk

More information: www.bgs.ac.uk/nigl and www.earth-time.org