SPECIAL REPORT

Telling the time

Geochronologists can pin down dates in deep time more accurately than ever before. **Rex Dalton** talks to the researchers who are rewriting the details of Earth's history.

By fine-tuning their techniques, researchers are refining their ability to measure ever more precisely the ticking of Earth's geological clock.

For decades, geologists and palaeontologists have had only ball-park estimates for when major events happened in the history of life on Earth. Now a series of new methods has radically improved their understanding of time long gone[1]. With unprecedented precision, researchers are now arguing over whether date estimates are off by as little as 100,000 years — remarkably accurate for events that may have occurred hundreds of millions of years ago.

Leading the quest for increasing accuracy is the international EARTHTIME project, the brainchild of Sam Bowring, a geologist at the Massachusetts Institute of Technology (MIT) in Cambridge. Its goal is nothing less than a complete restructuring of the chronology of deep time[2]. "In a decade, we hope to radically recalibrate Earth's history back to the origin of animals," Bowring says.

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Researchers involved in the effort gathered in Philadelphia last month at a meeting of the Geological Society of America to plan out their strategy. Yet as they try to standardize their complex dating procedures, they must accept a re-evaluation of dates that they themselves may have determined.

Last year, Bowring won a US$1-million grant for research with about 225 collaborators for three years from the National Science Foundation. In January, team members plan to apply for another grant to undertake 'a proof of concept' experiment — seeing whether they can standardize geological dates for the Cretaceous–Tertiary (K/T) mass extinction about 65 million years ago.

The group hopes to date the K/T boundary in a series of sediments in eastern Colorado, and use that date as a benchmark for studies in other geographical regions. They will also target another geologic interval from the Cretaceous period, about 90 million to 100 million years ago, to further cross-check dates and develop a precise chronology.

Douglas Erwin, a palaeobiologist at the Smithsonian Institution in Washington DC and co-organizer of EARTHTIME, notes that major extinctions are often followed by a burst of speciation. "I think these new dating methods will be a powerful spur to new work on evolutionary rates," he says.

One of EARTHTIME's major thrusts will involve 'astronomical tuning', as Earth's orbital motion affects the geological record. Earth's changing movements — the angle of the globe's spin axis, the path of its orbit and the orientation of its axis relative to the Sun — change cyclically, and in turn influence climate. These climatic changes appear in the sedimentary record as changes in the thickness of sediment layers, in the ratio of carbon or oxygen isotopes, and in the abundance of tiny fossils, for example.

Scientists have already calculated this astronomical record as far back as nearly 40 million years. Now they plan to push it back even further.

Traditional techniques to date rocks include identifying fossils that were known to exist during particular eras; counting the ratios of different isotopes of radioactive elements, such as uranium, argon or lead, as these change over time; or relying on the intermittent reversals of Earth's magnetic field, recorded in rocks.

Fossils known to exist at a certain time can help researchers put a date to rocks.

J. GEHLING/SOUTH AUSTRALIAN MUSEUM

At the rock face: researchers study sediments dating from the Cretaceous–Tertiary boundary.

K. JOHNSON

But although such methods can estimate the age and conditions under which a particular rock was formed, they cannot reveal how long those conditions lasted. That's where astronomical tuning comes in, by providing a long-running sequence of climatic events, such as ice ages, that are recorded in seafloor cores.

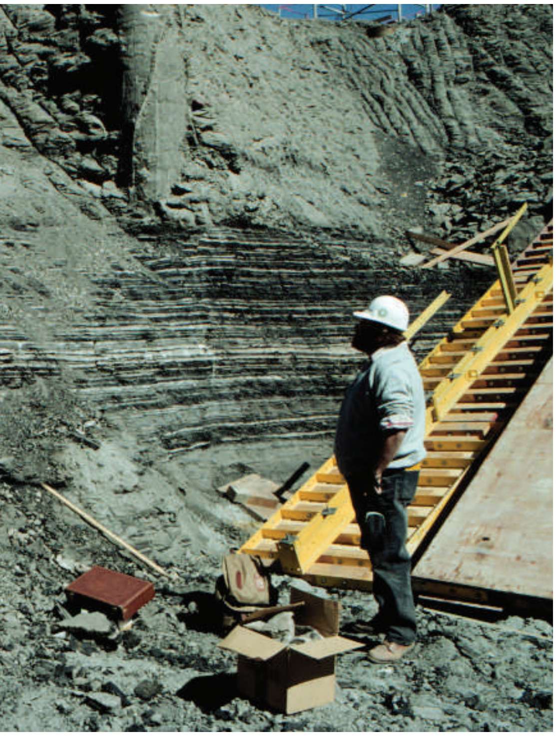
"You see variations of colour and lightness in the cores," says Heiko Palike, a geologist at the National Oceanography Centre in Southampton, UK. "It is like counting tree rings, then analysing the isotopic composition of the microfossil shells in the layers."

Deep time

To expand this astronomical record, researchers are designing ocean drilling expeditions primarily to examine these time-specific sedimentary cores[3]. The drill ship *JOIDES Resolution* is set to travel to the Pacific Ocean in November 2007, to drill a core dating between 35 million to 55 million years ago, to help pin down the chronology of events during that time period.

But ocean cores only can reveal sediments going back about 180 million years; any older sediments have been recycled into Earth's interior. When it comes to exploring further back in time, geochemical analyses are the gold standard — specifically, isotopic analyses of radioactive elements as they decay.

Methods include argon/argon dating, which



compares the amount of radioactive argon-40 and argon-39, and uranium/lead dating, which does the same with isotopes of uranium and lead. Argon/argon dating can date materials from 2,000 years ago back to Earth's birth, some 4.5 billion years ago. The uranium/lead technique's usefulness ranges backwards in time from about 10 million years ago.

There are some 50 labs worldwide doing argon/argon dating, but of 20 in the United States, only about five will be able to obtain EARTHTIME's desired degree of precision, says Paul Renne, director of the Berkeley Geochronology Center in California.

Researchers use radioactive reagents, typically argon, uranium or lead, to correct for material lost in analysis. But these 'spikes' tend to vary between labs, increasing the margin of error. In a bid to enforce standardization, Bowring bought up all the available spikes, and EARTHTIME investigators now obtain them from Bowring's lab at MIT.

The techniques for uranium/lead dating have also improved. For instance, the Arizona LaserChron Center at the University of Arizona combines a laser with a mass spectrometer to produce uranium/lead dates on zircons — microscopic crystals found in sediments. In the 1990s, multiple zircons often were used for dating analyses, but now a single zircon can be dated accurately, reducing the error from averaging the dates from several zircons.

But the most important development in uranium/lead dating has been the ability to treat zircons to compensate for the loss of lead from radiation. James Mattinson of the University of California, Santa Barbara, revolutionized the field with a high-temperature technique[4] for removing zircon surfaces that may have lost lead over geologic time, introducing errors.

The date debate

Mattinson's technique prompted others to reanalyse material from hotly debated points in time, such as the Permian–Triassic boundary (P/Tr), a mass extinction of terrestrial and marine life that occurred some 250 million years ago. The ebb and flow of this dispute — which involves key EARTHTIME members — shows the personal investment researchers have in their dates, and shows how hard it can be for them to jettison their published views.

In 1998, Bowring and colleagues reported uranium/lead zircon dates for the P/Tr boundary of 251.4 million years ago, plus or minus 300,000 years[5]. But in 2001, Roland Mundil of the Berkeley geochronology lab questioned Bowring's date, suggesting that the MIT group had not sufficiently accounted for lead loss in its analysis of multiple zircon batches[6]. After learning of Mattinson's technique, Mundil applied it to P/Tr zircons — and placed the mass extinction at 252.6 million years ago, plus or minus 200,000 years[7].

The difference between the two figures might not seem much, but both sides clung on to their view — just as the presses were set to roll for the new edition of a major reference text, *A Geological Time Scale 2004* (ref. 8). The book used MIT's dates, prompting "a great deal of criticism", says James Ogg, a geologist at Purdue University in West Lafayette, Indiana, who co-edited the book. Now, Ogg says, the prevailing view is that Mundil was correct. "We should have listened to Mundil more," he says, and an earlier date for the P/Tr boundary will probably be used in the next edition of the book, scheduled for 2008.

"The philosophy of EARTHTIME is to resolve dating debates to the highest level."

At a conference two months ago in Melbourne, Australia, Bowring reported his team's latest date for the same event: 252 million years, plus or minus 100,000 years. "The philosophy of EARTHTIME is to resolve these kinds of debates to the highest level," he says.

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3. Cyranoski, D. *Nature* **426**, 492–494 (2003).
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SIDELINES

SCORECARD

Property rights
'Air rights' above land have a value to high-rise developers separate from the plot itself. So conceptual artist Jonathon Keats has bought the rights to the higher dimensions predicted in string theory associated with six properties in San Francisco. Although the cost was very reasonable, development opportunities will be limited if the extra dimensions are, as currently predicted, subatomic in scale.

Rewarding virtue
Having been fined in May for despoiling a beautiful lake while making a film, Chinese director Chen Kaige has been nominated for a 'Green Chinese' award. Nominators felt that the fuss over *The Promise* — which is up for a Golden Globe — raised awareness of environmental concerns.

NUMBER CRUNCH

12% of Americans see the environment as one of the three most important issues facing the United States today.

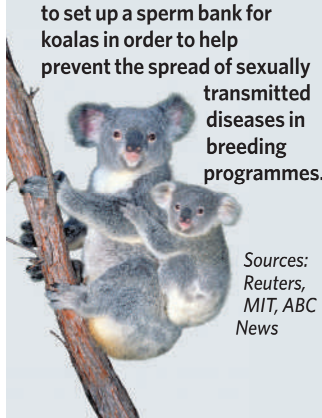
48% see global warming as the most important environmental problem facing the United States, up from 22% in 2003.

45% think there is a lot of disagreement among scientists on global warming, but 61% feel that there is enough evidence to justify action.

60% of Americans would be willing to pay at least $10 more a month for electricity to solve the global warming problem.

ZOO NEWS

Steve Johnston, of the University of Queensland, Australia, wants to set up a sperm bank for koalas in order to help prevent the spread of sexually transmitted diseases in breeding programmes.



Sources: Reuters, MIT, ABC News