

Uranium-Uranium Dating

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Uranium-uranium dating is a radiometric dating technique utilizing the comparison of two isotopes of uranium (U) in a sample: ^{234}U and ^{238}U . $^{234}\text{U}/^{238}\text{U}$ dating is one of several radiometric dating techniques exploiting the uranium radioactive decay series, in which ^{238}U undergoes 14 alpha and beta decay events while decaying to the stable isotope ^{206}Pb . Other dating techniques using this decay series include uranium-thorium (using $^{230}\text{Th}/^{238}\text{U}$) and uranium-lead dating.

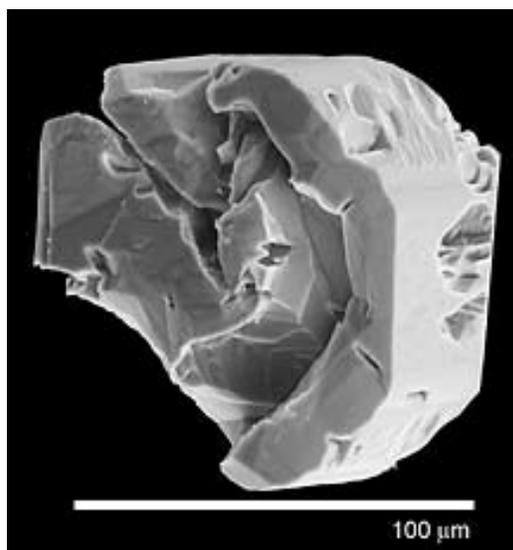
^{238}U , with a half-life of about 4.5 billion years, decays to ^{234}U through emission of an alpha particle to an isotope of thorium (^{234}Th), which is comparatively unstable with a half-life of just 24 days. ^{234}Th then decays through beta particle emission to an isotope of protactinium, ^{234}Pa . ^{234}Pa decays with a half-life of 6.7 hours, again through emission of a beta particle, to ^{234}U . This isotope has a half-life of about 245,000 years. The next decay product, ^{230}Th , has a half-life of about 75,000 years and is used for the related $^{230}\text{Th}/^{238}\text{U}$ technique. Although analytically simpler than $^{230}\text{Th}/^{238}\text{U}$ dating, in practice $^{234}\text{U}/^{238}\text{U}$ dating is almost never used as unlike $^{230}\text{Th}/^{238}\text{U}$ dating it requires prior knowledge of the $^{234}\text{U}/^{238}\text{U}$ ratio at the time the material under study was formed. For those materials (principally marine carbonates) for which the initial ratio is known, $^{230}\text{Th}/^{238}\text{U}$ remains a superior technique. This restricts the application of $^{234}\text{U}/^{238}\text{U}$ to extremely rare cases where the initial $^{234}\text{U}/^{238}\text{U}$ is well-constrained and the sample is also beyond the ca. 450,000 year upper limit of the $^{230}\text{Th}/^{238}\text{U}$ technique.

Unlike other radiometric dating techniques, those using the uranium decay series (except for those using the stable final isotopes ^{206}Pb and ^{207}Pb) compare the ratios of two radioactive unstable isotopes. This complicates calculations as both the parent and daughter isotopes decay over time into other isotopes.

In theory, the $^{234}\text{U}/^{238}\text{U}$ technique can be useful in dating samples between about 10,000 and 2 million years Before Present (BP), or up to about eight times the half-life of ^{234}U . As such, it provides a useful bridge in radiometric dating techniques between the ranges of $^{230}\text{Th}/^{238}\text{U}$ (accurate up to ca. 450,000 years) and U-Pb dating (accurate up to the age of the solar

system, but problematic on samples younger than about 2 million years).

URANIUM/LEAD DATING PROVIDES MOST ACCURATE DATE YET FOR EARTH'S LARGEST EXTINCTION



A new study by geologists at the Berkeley Geochronology Center and the University of California, Berkeley, improves upon a widely used dating technique, opening the possibility of a vastly more accurate time scale for major geologic events in Earth's history.

In a paper published this week in *Science*, geochemist Roland Mundil of the Berkeley Geochronology Center (BGC) and his colleagues at BGC and UC Berkeley report that uranium/lead (U/Pb) dating can be extremely accurate - to within 250,000 years - but only if the zircons from volcanic ash used in the analysis are specially treated. To date, zircons - known to many as a semiprecious stone and December's birthstone - have often produced confusing and inaccurate results.

Zircons have produced complicated data that are hard to interpret, though people have pulled dates out," said Mundil, a former UC Berkeley postdoctoral fellow now at the BGC, a non-profit scientific research



institute dedicated to perfecting dating techniques for establishing the history of Earth and life on Earth.

"Many of these studies will now have to be redone."

The U/Pb isotopic dating technique has been critical in dating geologic events more than 100 million years old, including volcanic eruptions, continental movements and mass extinctions.

"The beauty of this new technique is that we now can analyze samples we previously could not get an accurate date for," Mundil said. "This will have a big impact on radio-isotopic dating in general."

Mundil and his colleagues, including BGC director Paul Renne, adjunct professor of earth and planetary science at UC Berkeley, used this improved U/Pb technique to establish a more accurate date for the end of the Permian period and the beginning of the Triassic period - 252.6 million years ago, plus or minus 200,000 years. This boundary coincides with the largest extinction of life on Earth, when most marine invertebrates died out, including the well-known flat, segmented trilobites.

Based on the improved U/Pb technique, the team also established that the argon/argon (Ar/Ar) isotopic dating technique that Renne employed for an earlier study of the Permian-Triassic boundary consistently gives younger dates, by about 1 percent. Renne ascribes this to a lack of a precise measurement of the decay constant of potassium. The technique is based on the fact that the naturally occurring isotope potassium-40 decays to argon-40 with a 1.25 billion year half-life. Comparison of the amount of argon-39 Produced in a nuclear reactor to the amount of argon-40 gives a measure of the age of the rocks.

Uranium, on the other hand, is so well studied that its decay constant is much better known, making the U/Pb dating technique more accurate, Mundil noted. U/Pb dating relies upon the decay of naturally occurring uranium and different isotopes of lead.

"Further application of Mundil's approach will make the geologic time scale more accurate, letting us calibrate extinctions and important events in Earth's history, ranging from 100 million to several billion years ago, with unparalleled accuracy," Renne added. The new U/Pb date, though about 2.5 million years older than Renne reported nine years ago based on Ar/Ar dating, nevertheless confirms his conclusion that the Permian extinction occurred at the same time as a major series of volcanic eruptions in Siberia. This is

strong evidence that these eruptions caused, at least in part, the global die-off, which some scientists have ascribed to a meteor impact.

Mundil noted that in 1998, one group used U/Pb dating to assign a date of 251.4 million years ago for the main pulse of the Permian extinction, in apparent conflict with the new U/Pb age. That 'age,' however, "is based on interpretation of a very complicated data set," Mundil said.

Mundil and his colleagues set out to resolve the issue, using a new zircon pretreatment invented by UC Santa Barbara isotope geologist James M. Mattinson. The problem with using microscopic zircons, which are prevalent in volcanic ash, is that the decay of uranium to lead is so energetic that the lead atoms smash through and destroy the zircon crystal structure, which apparently allows some lead to leak out of the crystal, throwing off the analysis. Geologists have tried various zircon treatments, including abrading the outer surfaces of the crystals, which are typically a tenth of a millimeter across, or leaching the crystals with strong acid. Despite these treatments, the U/Pb method still produced a wide range of dates for zircons from the same layer of ash.

Mattinson's idea was to first heat or anneal the zircons, sealing off the least damaged areas of the crystal, then using a strong reagent, hydrofluoric acid, to eat away the heavily damaged areas.

When Mundil used this treatment, the zircon dates were much more consistent, requiring no selective interpretation of the data. The calculated uncertainty is about a quarter of a million years, which means the extinction took place over a very short time, the researchers concluded.

The zircons were obtained from ash layers located in central and southeastern China. The Meishan section in the latter region is accepted as the type locality for the Permian/Triassic boundary.

- Whereas the U/Pb method yields ages which are more accurate, "Ar/Ar is still king in dating rocks younger than 100 million years and is about as precise as U/Pb methods, though we need to get better data for the decay constants to establish an absolute calibration," Renne said. "As soon as that calibration is put in place, the Ar/Ar method could become as accurate as U/Pb."