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In geology, radioactivity has many beneficial spin-offs. It has given the Earth a heat engine to drive tectonics and provided tools for scientists to unravel the Earth’s dynamic history. Perhaps the most important of these are radioactive chronometers allowing us to date minerals and rocks. By using a variety of materials with a suitable dating method we know a great deal about the chronology of geological events — rates of sedimentation, erosion, and biological evolution — and the geological timescale has been numerically calibrated.

The two main high-precision methods of dating ancient (and indeed quite young as well) materials are the potassium–argon (and its widely used variant the argon–argon) method on potassium-bearing minerals and the uranium–thorium–lead (U–Th–Pb) method on accessory minerals such as zircon, monazite, titanite and others.

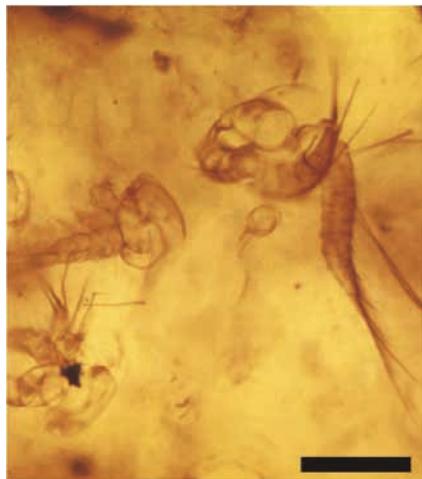
Within the NERC Isotope Geoscience Laboratories (NIGL) of the BGS, the U–Th–Pb dating facility is undertaken using a number of different instrumental methodologies. The U–Th–Pb dating scheme is unique amongst all dating methods: three radioactive isotopes uranium-238, uranium-235, and thorium-232 decay to different isotopes of lead (lead-206, lead-207, and lead-208, respectively). The fact that there are two uranium–lead decay systems endows several unique and extremely powerful attributes — an internal method for assessing disturbance and an extremely precise method for dating very old rocks based on the rapidly changing ratio of lead-207 to lead-206 with time. The latter of these allows uncertainties to be determined to as little as plus or minus 400 thousand years for minerals more than 3 000 million years old. This system of decay has ensured that the isotopic composition of lead has changed

A question of time — geologically speaking

Radiometric dating studies at the NERC Isotope Geosciences Laboratory

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Cluster of branchiopod larvae or nauplii in a thin section of the Windyfield chert (scale bar = 200 micrometres).

continuously with time, enabling a wide variety of applications of lead isotopes as geological and anthropogenic tracers.

The BGS and the NIGL facility support U–Th–Pb dating projects worldwide in collaboration with the UK scientific community. These have included studies of Himalayan erosion and tectonics, absolute calibration of the geological time scale, the dating of pressure–temperature–time paths of metamorphism, and the determination of rates of evolutionary processes.

For example the world-famous Rhynie cherts of north-east Scotland preserve amazing detail of flora and fauna living more than 400 million years ago. In conjunction with Ph.D. student Steve

Parry and Drs Clive Rice and Nigel Trewin, we have determined the age of the hot-spring sinters that encased these delicate fossils (*below left*) to be 409.6 ± 1.1 million years old using zircon and titanite. Studies like these have helped to quantify the precise age of biostratigraphical boundaries and assist in the correlation of rocks worldwide.

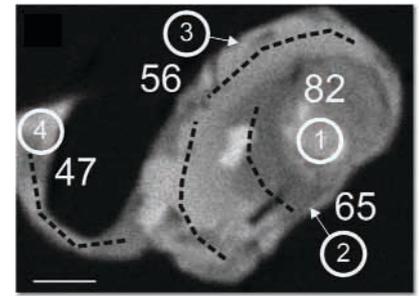
At the NIGL, there are two U–Th–Pb dating methods used in solving problems. The most precise is a technique called isotope dilution thermal ionisation mass spectrometry where minerals (often single crystals) are dissolved in the processing. The second, laser ablation plasma ionisation multicollector mass spectrometry (LA-PIMMS), involves intra-crystal analysis. A laser ablates the surface of a sample in a tiny (about 10–40 micron) region and transfers the mineral fragments into an inductively coupled plasma ionisation mass spectrometer. There is a trade-off in these methods between measurement precision and spatial resolution — we use them in a complementary fashion to solve problems in the most cost-effective manner possible.

An example of the use of LA-PIMMS is shown (*top right*) where chemically distinct yttrium zonation within tiny monazite crystals from a pelitic metamorphic rock are sampled and dated. In this work, conducted at NIGL, Drs Gavin Foster and Matt Horstwood in association with the University of Leicester, worked out a relative chronology of mineral growth and pressure–temperature conditions via detailed chemical study using electron microscopy. Then they dated the oldest-to-youngest zones. They were able to clearly separate the ages of growth from

four distinct chemical zones, ranging from 82 ± 3 million years for the oldest zone to 47 ± 3 million years for the youngest. This advanced technique has allowed a new area of research to be exploited that integrates high precision accessory mineral dating with pressure–temperature–time histories of metamorphic rocks. This, in turn, places robust constraints on the rates of burial and exhumation in metamorphism.

The U–Th–Pb method is unrivalled and indispensable for the unravelling of the history of the Precambrian Earth but, amazingly, can also be applied to date minerals of essentially Quaternary age. During the Ph.D. work of Oxford student Andy Thow, a beautiful aquamarine-tourmaline pegmatite (*below*) was dated to be just 3.5 ± 0.2 million years old. This rock was collected from an area of Pakistan cut by gorges more than three kilometres deep in an area north of Nanga Parbat that is rising faster than almost anywhere else on Earth at present. Here the U–Th–Pb dates have shed light on the rates of erosional processes.

With the timely rejuvenation of capital equipment from the NERC and the BGS, and the innovative development of better ways to date minerals using the radioactive decay of uranium and thorium, the NIGL laboratories offer world-class tools to better understand active tectonic processes and address other globally important earth science problems. This facility thereby provides not only essential support for the BGS and UK universities, but excellent student training and international leadership in method development and knowledge transfer. ■



X-ray map of Y content of monazite crystal from a pelitic schist from Pakistan, showing Y zones (numbers 1–4) and the ages of these zones in million years as determined by LA-PIMMS; scale bar is $20\mu\text{m}$.

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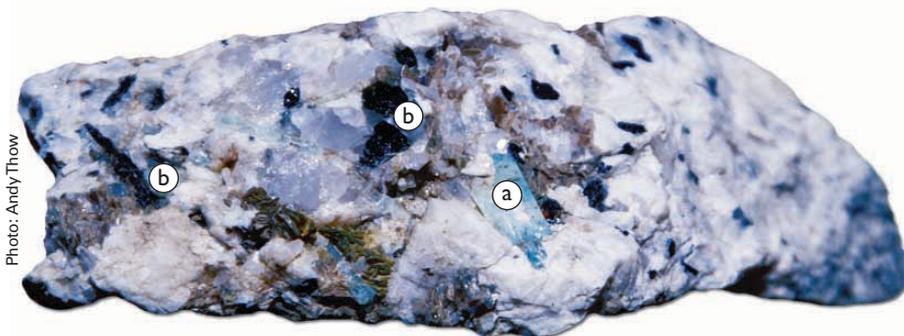


Photo: Andy Thow

Aquamarine-bearing pegmatite from the Karakoram mountains, Pakistan dated at 3.5 million years by U–Th–Pb methods; a = aquamarine, b = tourmaline.

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