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Measuring the March of Geologic Time

Highly sensitive devices such as the SHRIMP IIe/MC ion microprobe help scientists to make precise measurements of past time-scales, paleoclimatic temperatures, and much more.

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Geology is, above all, the science of the Earth's history. Until the mid-twentieth century, however, there was no known way to directly determine the age of rocks. The time-frame when rocks, mountains, or other formations were actually formed could only be estimated. Scientists made educated guesses using a relative time scale, based on the order in which characteristic organisms appeared in the Earth's history in the form of fossils. Precise measurement of geologic time only became possible after the discovery of sensitive methods of chemical isotope analysis, which use the process of natural radioactive decay as a direct "yardstick" of geologic time. Such chemical analyses were also not easy, requiring a lot of meticulous preparations as well as numerous instruments and devices, and so they came to be replaced with much more convenient and efficient physical methods. These not only shorten the time needed to perform analyses but are also able to test smaller amounts of material. State-of-the-art analytical devices cost millions of dollars, and they can be found in just a handful of the world's best research centers.

Sensitivity

One such instrument is the sensitive high-resolution ion microprobe, known as SHRIMP IIe/MC, which is used in the Ion Microprobe Facility of the Micro-Area Analysis Laboratory at the Polish Geological Institute – National Research Institute in Warsaw. SHRIMP is a secondary ion mass spectrometer (SIMS) with two

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The super-sensitive high-resolution ion microprobe SHRIMP IIe/MC weighs over 13 tonnes, and the ion beam path, from the sample to the detector, extends over seven meters. The curvature results from the use of very large analyzer sectors: an electrostatic sector with a radius of 1,272 mm (the energy analyzer) and a magnetic sector with a radius of 1,000 mm (the momentum analyzer)

analyzer sectors. The most important characteristic of this microprobe is its amazing sensitivity, coupled with a very high resolution – it is close to being able to measure a single point. It precisely analyzes isotopic composition in a field that is 20 microns in diameter without destroying the sample, which makes it possible to determine the age of even individual sub-zones within tiny mineral grains, invisible to the naked eye.

Radioactive elements are commonly found in rocks and minerals. They decay at a constant, unchanging rate (referred to as their "half-life"), turning into other elements. Geochronological analyses most commonly make use of zircon, a mineral that incorporates uranium and thorium atoms into its crystalline structure and strongly rejects lead. This means that any lead atom found in zircon is radiogenic, having ultimately come from a uranium atom. Since we know the exact rate at which uranium decays into lead, the current ratio of lead to uranium in a sample of the mineral can be used to determine its age in a reliable way. SHRIMP measures geologic time based on such decay, using uranium isotopes, which turn into lead isotopes (and also into thorium, which likewise turns into a lead isotope). If we measure the proportion of the parent product, which is uranium, to the daughter product, which is lead, based on uranium's half-life of 4.47 billion years we can establish the absolute age of a given sample.

While this is one of the best methods for determining the age of rocks and minerals, the measurements of the proportions of elements have to be very accurate, because the isotopes are present in tiny trace quantities and the differences in their mass are unimaginably small. Despite this challenge, SHRIMP makes it possible to measure different isotopic indicators. The SHRIMP microprobe is a mass spectrometer, so it works by the well-known principles of mass spectrometry. However, the device may be reconfigured for different uses by changing the polarities and sources to maximize its sensitivity.

Versatility

The ion microprobe is an instrument that can also be utilized for purposes other than establishing geologic time. Depending on how it is configured, it may be used to analyze the ions of different elements, from lithium to americium, with atomic weights from 6.94 to 248. Thanks to its amazing resolution and sensitivity, the microprobe can be used to analyze the content of sulfur, carbon, and oxygen isotopes in solid samples. Stable isotopes of sulfur, oxygen, and carbon are used in geology, biology, archaeology, paleoclimatology, and geoenvironmental research. For instance, the microprobe can help us identify places where we should prospect for new mineral deposits, thus reducing the investment risk in the raw materials industry.

Oxygen isotopes, in turn, are commonly studied to answer the question of how the climate once looked. The ratio of oxygen's heavy isotope to its light isotope is a basic indicator of the temperatures that prevailed millions of years ago. The microprobe thus makes it possible to better assess temperature variations in the Earth's ancient history and determine many other parameters of paleoclimate, including the content of carbon dioxide in the atmosphere. This brings scientists closer to understanding the regularities governing today's climate.

Stable isotopes are also used in studies of extraterrestrial materials, including meteorites. Ion microprobes have been used to analyze cosmic matter, moon rocks, and samples from Mars, as well as the course of processes in material engineering, nuclear fuel, and geochemical contamination. In fact, new applications keep emerging. The Australian geological agency (Geoscience Australia) is examining the potential use of such an instrument for doping tests. By measuring the oxygen isotopes in an athlete's blood, we can determine during a sports competition if he or she received a blood transfusion.

> Thanks to its amazing resolution and sensitivity, the SHRIMP IIe/MC ion microprobe can analyze the content of sulfur, carbon, or oxygen isotopes in solid samples.

Thanks to its analytical versatility and universality, the SHRIMP IIe/MC ion microprobe may be used successfully to resolve problems in many exact and engineering sciences, ranging from geology, Earth science, and natural resources science to cosmochemistry, paleontology, biology, archeology, environmental protection, nuclear energy, and materials engineering in the semiconductor industry. Research findings also provide new insight into timescales on Earth and in the cosmos and the origins of many mineral deposits; they also help develop effective methods of prospecting for potential deposits of natural resources and changing popular opinions on the prevailing conditions of the paleoenvironment and paleoclimate. ■

The ion microprobe used in the Polish Geological Institute – National Research Institute in Warsaw was made by the Australian company Australian Scientific Instruments, which collaborates with the Australian National University (ANU) in Canberra. The purchase was possible thanks to a subsidy from the Polish Ministry of Science and Higher Education.