New Tools for Isotopic Analysis
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The isotopic compositions of natural materials are affected by a variety of processes. On Earth, radiogenic decay and physiochemical fractionation are the two dominant mechanisms. Radiogenic decay generally proceeds at a specific rate, allowing geochronologists to date rocks by measuring the ratio of parent to daughter atoms. Physiochemical fractionation results from the mass-dependence of certain chemical reaction rates and produces a systematic bias (with mass) in isotopic abundance. Extraterrestrial samples show effects of spallation, that is, the break-down of nuclei from impacting cosmic rays, and may show large isotopic anomalies as a result of incorporation of nucleosynthetic material, whose isotopic composition differs substantially from terrestrial abundances.

Isotopic differences produced by these processes can vary widely in magnitude. More importantly, isotopic compositions can either be homogeneous over relatively large volumes or inhomogeneous on smaller scales. This has led to two fundamentally different approaches to isotopic measurement. So-called conventional analysis involves the chemical separation of an element, which is then mixed with material of known anomalous composition (isotope dilution), followed by analysis to high precision. In contrast, in situ analysis by ion microprobe involves direct analysis of very small amounts of material; precision is typically limited by the number of ions counted in the analysis. These two approaches have often produced conflicting results because of the differences in the volume of the material analyzed and of questions concerning precision, accuracy, and reproducibility.

Recently, major advances have been made in laser ablation-inductively coupled mass spectrometry (LA-ICPMS), a technique that bridges the gap in sample size between isotope dilution mass spectrometry or to account for the possible presence of heterogeneities in that volume by choosing a technique that samples a smaller amount. The choice is dictated by the nature of the expected effect; a uniform but small variation is best measured on a large volume at high precision, whereas small, isotopically distinct objects require more selective analysis.

For problems requiring high-precision analysis (Fig. 1A), modern thermal ionization mass spectrometers can achieve extremely high levels of precision through sustained analysis and statistical reduction in the error of the mean. The internal statistics can be improved further through multiple collection, where individual ion beams are measured in separate detectors.