Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.38453

The Vast Unexplored Landscape of Nature's Isotopic Structure - *V.M. Goldschmidt Award Lecture*

JOHN EILER

California Institute of Technology

Isotope geochemistry is an outgrowth of discoveries in nuclear and chemical physics and inventions for analytical chemistry. The field generally tries to mold those discoveries and inventions into a toolkit for answering questions in the earth, environmental and space sciences. However, there is also a role for isotope geochemistry to turn around and look in the other direction, seeking new frontiers in fundamental chemistry, physics and technology motivated by questions posed by the natural world.

Among the largest unresolved questions in natural chemistry concerns the properties and distributions of isotopic forms of molecules. This subject might seem to have been solved by our academic great, great grand advisors, but there are some details still to be settled: There exists a total of est.1020 unique isotopologues — isotopic versions of molecules — summed across all natural and common synthetic compounds. Up until a few years ago, an order of a hundred had been analyzed directly in natural materials at useful precision and sensitivity. However, the last several years of developments in isotope ratio mass spectrometry have made possible precise measurements of ~1011-12 of these species at natural isotope abundances and modest sample sizes. I.e., our capacity to explore the isotopic diversity of nature very recently expanded by something like a factor of a billion. How do these newly analyzable species behave? What controls their distributions? What new geochemical tools will emerge from their systematic study? This subject seems overwhelmingly complex, but might that complexity be turned to our advantage by way of the equally new tools of machine-learning-informed data science?

I will explore these questions by posing first-order problems in the origins, forms, distributions and effects of volatile elements in the early solar system, from nebular and disk history to prebiotic chemistry and detections of life. I will then detail how these problems motivated invention of new analytical technologies and exploration of chemical physics in new contexts, letting us use nature's vast landscape of molecular isotopic structures to address some of its most challenging problems.