

# Stable Isotope Geochemistry

## What is stable isotope geochemistry?

Stable isotope geochemistry is an interdisciplinary science that uses the natural abundance patterns of different forms of elements, called stable isotopes, to determine how earth materials are formed and modified in environmental settings. Of the elements that have multiple stable isotopes, there is usually one isotope that is most common while all others are relatively rare. It is the natural distribution of these rare and common isotopes that provides insights into the origin and flow of elements in environments and ecosystems. Stable isotope distributions are not random, but rather are a consequence of reactions governed by the laws of physics. Consequently, stable isotope distributions can be predicted in nature, providing researchers with a powerful tool that allows the isotopic ratios characteristic of environmental compounds to be used to determine their origins.

The most important stable isotopes to display natural abundance variations are those of relatively low atomic mass ( $\text{amu} < \sim 40$ ). Hydrogen, carbon, nitrogen, oxygen, and sulfur are biogeochemically active elements that commonly display relatively wide ranges in natural abundance patterns. These

elements also participate in almost all of the important physicochemical and biological reactions that occur in nature.

## Environmental research at the SRS that utilizes stable isotope geochemistry

The Savannah River Site (SRS) contains polluted areas that must be remediated to levels that pose negligible human and ecological health risks. Since cleanup can be expensive, it is important to determine which sites represent the greatest health risk. Remediation costs can be lowered by demonstrating that natural processes are reducing the level of contamination in any specific site. This process, called natural attenuation, occurs at almost all contaminated sites, but it is a viable alternative only for those sites where contaminants are converted to nontoxic forms in a realistic time frame.

Harmless by-products of natural attenuation reactions may not be readily distinguished from natural environmental compounds. For example, chloride may occur naturally or from degraded trichloroethylene (TCE). Even when it is clear that components are derived from pollutants, the rates



Aerial view of the D-Area Coal Pile Runoff Basin (CPRB), one of the sites on the SRS where stable isotope geochemistry is providing information important to remediation efforts.

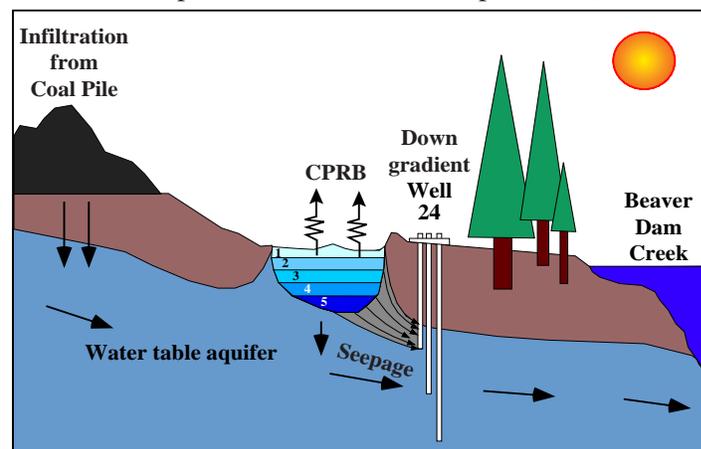


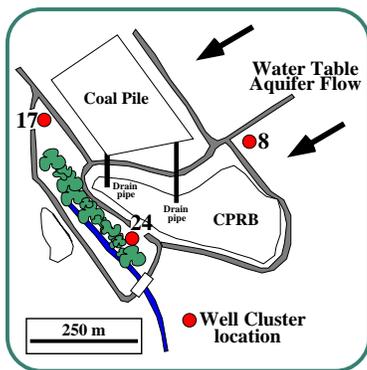
Illustration of groundwater contamination at D-Area as a result of metal-rich waters leaching from a coal pile and a nearby catchment basin.

at which by-products are formed are often difficult to determine.

Stable isotopic analyses of environmental pollutants and their by-products provide an unambiguous measure of natural attenuation. The unique isotopic fingerprint of many compounds allows for the source and fate of contaminants to be traced and transformation rates to be determined.

### Ground water contamination at D-Area

Ground water at D-Area on the SRS is being contaminated by metal-rich waters leaching from a coal pile and a nearby catchment called the Coal Pile Runoff Basin (CPRB). Rain water percolating through the coal pile infiltrates directly into the water table while runoff that is directed to the CPRB also seeps into the underlying water table.



Effective cleanup strategies and pollution prevention can benefit from a fundamental knowledge of the pathways that contribute to ground water contamination at D-Area. Chemical analyses of contaminated water have been ineffective in discriminating between direct infiltration and basin seepage because both water masses receive contamination from a common source. However, stable isotope geochemistry has been effective in discriminating contamination pathways because these waters undergo different processes prior to their mixing in the local water table. The natural process of evaporation imparts a unique stable isotopic fingerprint on CPRB water that permits it to be distinguished from water infiltrating from the coal pile.

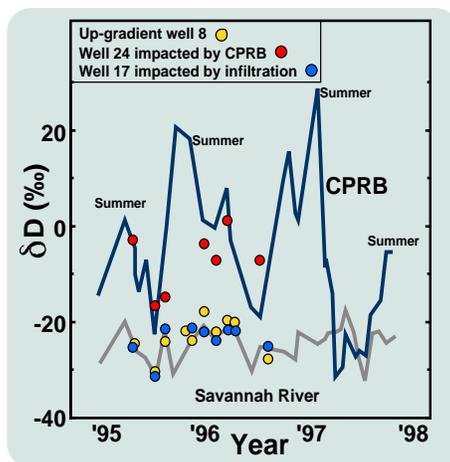
Varying contributions of infiltration from the coal pile and seepage from the CPRB were determined using distinct isotopic ratios ( $^2\text{H}/^1\text{H}$ ,  $^{18}\text{O}/^{16}\text{O}$ ) for each water mass. The unique isotopic signature of CPRB waters was traced into the subsurface, permitting ground water flow velocities to be calculated independent of expensive well drilling. With knowledge of the chemical composition of contaminated ground water, natural attenuation reactions may be defined and the buffering capacity of CPRB sediments determined.

### Tracing contaminant pathways through ecosystem food webs

The stable isotope signature of organisms may be used to trace the flow of contaminants through food webs of terrestrial and aquatic ecosystems. In particular, the process of contaminant “biomagnification” can be documented and this information can be used to identify target species that are especially sensitive to particular contaminants in polluted environments.



Contaminant exposure and biomagnification were documented for Wood Storks that forage near the SRS by characterizing the stable isotope ( $^{15}\text{N}$ ) and mercury (Hg) content of down feathers. Storks that foraged in upland environments grew down feathers that were preferentially enriched in  $^{15}\text{N}$  and Hg compared with down from storks that foraged in coastal environments. The low concentration of mercury in down from coastal storks is likely due to lower levels of dietary mercury exposure in coastal and estuarine waters. This probably reflects lower rates of methylmercury production in coastal systems, or binding of mercury in sulfide-rich sediments. A better understanding of the process(es) that minimize contaminant bioavailability will enable environmental scientists at the SRS to develop new and innovative technologies for the remediation of pollutants.



### On-going stable isotope research at SREL:

- Characterizing natural attenuation reaction mechanisms and rates
  - “ Sequestering contaminants in solid phases (oxides, carbonates, sulfides)
- Stable isotopes as classical environmental tracers
  - “ Deuterated water and noble gas tracers
- Discriminating contaminant by-products from natural environmental compounds
  - “ Chloride from TCE degradation vs. ambient chloride
  - “  $\text{CO}_2$  from organic solvent (BTEX) oxidation vs. ambient  $\text{CO}_2$
- Identifying pathways that concentrate contaminants in biota
  - “ Bioaccumulation and biomagnification