Colorado's Uranium Deposits

Jim Burnell, Ph.D., P.G.
Senior Minerals Geologist
Colorado Geological Survey

Uranium Geochemistry and the Mechanics of Uranium Deposits

Uranium is a scarce element in the earth's crust, occurring at an abundance of about 2 to 4 parts per million. The element is not evenly distributed throughout the crust, however, being concentrated in some types of rocks and depleted in others. The uneven distribution is a function of factors involving the nature of the uranium atom and the characteristics of different types of rocks.

The most important factor in uranium's behavior in the crust is its sensitivity to *redox* conditions. Redox refers to the abundance of oxygen present, controlling the "reducing-oxidizing" conditions, hence the term "redox." In an oxidizing environment, where abundant oxygen is available, uranium assumes its oxidized state. Where oxygen is scarce – reducing conditions – uranium tends to transform to its reduced state. In its oxidized form, uranium is very soluble, and hence highly mobile, and able to dissolve in water, often traveling coupled with carbonate ions (CO_3 ions).

In an oxygen-starved environment, uranium's solubility is greatly reduced and it can't remain dissolved, dropping out of solution to form solids – commonly the mineral uraninite (UO_2). So what does this mean for uranium deposits?

Introduction of Uranium to the Earth's Surface

Magmas of granitic composition – those low in magnesium, iron and calcium, high in silica, sodium, and potassium – contain more uranium than other types. These magmas, when nearing the surface, are likely to erupt explosively because of their high viscosity and water content. Explosive eruptions of granitic magma fall back to earth as ash-fall deposits or volcanic *tuff*.

Landscape during an eruption of volcanic ash.

The high viscosity of granitic magmas results in tuffs that crystallize as glass –magma that froze before it had time to form into mineral crystals. Because glass is not stable, it is susceptible to leaching by water - losing atoms from the glass into surrounding water. Groundwater encountering a tuff deposit on the surface is oxygen-rich, having dissolved oxygen from the atmosphere. Uranium diffuses out of the glassy tuff particles, dissolves in its oxidized form, and heads off in the groundwater.

The glass also may spontaneously crystallize at some point by the process of *devitrification*. (*Vitric* is the root referring to "glass," so to *"devitrify"* means essentially the process of "un-glassifying." In the process, large, unwieldy atoms that don't fit readily into the structure of the forming minerals are expelled. So devitrified glass contains a lot of uranium atoms, just sitting around unattached -an easy pick-up for oxygenated groundwater trickling through the now-devitrified tuff.

Transport of Uranium

Groundwater containing uranium gradually works its way through the sediments beneath the tuff, sinking deeper beneath the surface. If that groundwater at some point encounters a permeable zone, though which it can flow more easily, it will move along that preferred zone.

Sometimes those permeable zones may contain areas where oxygen is depleted. They could be sulfur-rich areas, zones through which petroleum or methane has flowed, or zones containing organic matter. In a reducing zone, oxygen is stripped from the solution and the uranium becomes reduced, losing its ability to remain in solution. That is where it precipitates, or settles out of the solution in solid form, like salt precipitating in a salt pan. This is a uranium deposit. If large and rich enough, it is a candidate for mining.

A list of factors needed for a uranium deposit includes three things: (1) a source of uranium; (2) oxidizing fluid to dissolve and transport the uranium and (3) reducing conditions to precipitate and concentrate the uranium.

A uranium-rich zone in a sandstone of the Morrison Formation, Carnation Mine, San Miguel County, Colorado.

The Situation in Colorado

In its geologic past, Colorado was blessed with all three of the factors necessary for economic uranium deposits. One time and place that all the factors began to come together was in the Jurassic Period – the age of dinosaurs, 150 to 200 million years ago – across much of our State. A land of interspersed lakes, swamps, lowlands with braided streams and meandering streams, characterized the Jurassic time in which a sequence of sediments were deposited that are now referred to as the Salt Wash sequence.

An active meandering stream system. This is probably how Colorado looked during the deposition of the Morrison Formation.

The environment was warm and wet, with abundant flora and fauna. Slow-moving streams wandered through the area, transporting sediment toward the Jurassic sea to the East. Mud and clay formed in the swamps, but in the deeper stream channels, coarse sand was deposited in long sinuous zones following the twisted stream course. Because the environment was rich in life, organic material floated down the streams, often coming to rest in the channel and being buried by successive waves of sediment.

As time and water flowed on, these coarse sand channels were covered with finer sediments, as the streams meandered back and forth. After a time, the Salt Wash layer of rocks consisted of inter-fingered layers of coarse and fine sand, silt, and mud, in places several hundred feet thick.

River-lain sandstones ("fluvial" sandstones) in the Morrison Formation.

Over much of the Jurassic landscape, the rivers slowed and were replaced by slower-moving streams, and greater areas of swamp and marsh. At the same time, volcanoes to the west were erupting, sending clouds of volcanic tuff that deposited in the muds forming at the time, muds that later became known as the Brushy Basin sequence of rocks. These tuffs are believed to have been the source of large quantities of uranium, along with vanadium and other important metals.

The sequences described above formed the thickness of sediments we know as the Morrison Formation. While dinosaurs were tramping around on the mud, groundwater was dissolving uranium from the tuffs and carrying it deeper into the sedimentary layers. When the coarse sand channels were encountered in the underlying sequence of layers, the uranium-rich water began moving sideways down the old channels. There it encountered reducing zones caused by accumulations of oxygen-consuming organic matter. Maybe these zones were old log jams, now buried under 200 feet of sediment; maybe they were just accumulations of decaying leaves or algae. We know that within the Morrison Formation, we find dinosaur bones with a layer of uraninite on the outside, where it was precipitated by the reducing conditions around the bone. Whatever the nature of the original organic material, these zones created large deposits of uranium-rich material along these old stream channels.

On the Colorado Plateau of southwest Colorado more than 1200 uranium mines were punched into the Salt Wash member of the Morrison Formation in the 20th century. The mines wind around underground, as the miners attempted to follow the river channels containing the uranium. Many of the same mines being reentered today, moving further along the channels, breaking loose more of the uranium that got there through a series of processes that we see around the world and through time.