



In 1789, uranium oxide was first recognized as the mineral pitchblende (now considered as a variety of uraninite). The mineral was recovered from a silver mine in Joachimsthal, Bohemia, now a part of the Czech Republic, by an amateur chemist, Martin Klaproth. Klaproth named the compound uranium in a tribute to his friend, William Herschel, a famous composer and astronomer, who had discovered the planet Uranus (Uranus is the Greek god of the Heavens). However, it was not until 1841 that the true metal, uranium, was isolated from its oxide form by a French chemist, Eugene Peligot. In 1896, another French scientist, Henri Bequerel, left some uranium in a drawer with a photographic plate for a few days and to his surprise found the photographic plate to be exposed. This lucky “experiment” was the beginning of atomic research and the understanding of radioactivity. Marie Curie and her husband Pierre conducted various experiments on uranium ore, some of which came from Colorado, from 1898 through the 1920s in their lab in Paris. They recognized the process of radioactivity and discovered two of uranium’s daughter products, polonium and radium. In the 1930s and early 1940s, scientists discovered that one isotope of uranium,  $^{235}\text{U}$ , was fissionable—that is when an atom of  $^{235}\text{U}$  is bombarded by neutrons its nucleus splits into two equal parts, usually an atom of barium and krypton, at the same time releasing substantial energy in the form of heat and two or several more neutrons. The released neutrons then collide with other atoms of  $^{235}\text{U}$ , releasing more energy and neutrons, a process known as a chain reaction. The chain reaction released such large amounts of energy that it led to the development of nuclear weapons, ending World War II. After the end of the war scientists put the energy released by fission to work to heat water, create steam, turn a turbine to generate electricity—the major use of uranium today.

Uranium is a widespread and ubiquitous element. It has a crustal abundance of 2.8 parts per million, slightly more than tin. Primary deposits of uranium tend to concentrate in granitic or alkalic volcanic rocks, hydrothermal veins, marine black shales, and early Precambrian age placer deposits. Secondary (or epigenetic) deposits of uranium are



*A uranium roll in the Salt Wash Member, Spring Creek Mesa Mine. Hammer for scale.*

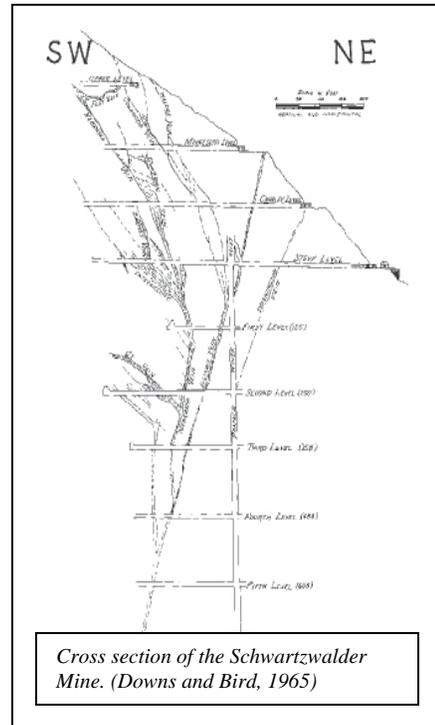
formed later than the surrounding rocks that host the mineral deposit. Uranium is soluble in oxidizing aqueous solutions, especially the  $\text{U}^{+6}$  valence state, and can be redistributed from primary source rocks into porous sedimentary rocks and structures by groundwater and form secondary (epigenetic) uranium mineral deposits. Examples of epigenetic deposits of uranium in sedimentary rocks form the bulk of uranium deposits in Colorado. These include the many mines of the Uravan, Cochetopa, Maybell, and Rifle districts, and other scattered places including the Front Range and Denver Basin. Primary uranium

deposits in Colorado occur in hydrothermal veins, especially in the Front Range.

**Epigenetic Uranium Deposits in Colorado** Epigenetic uranium deposits in the sandstones of the Salt Wash Member of the Jurassic-age Morrison Formation are widespread in the Uravan district of southwestern Colorado. The sandstones of the Salt Wash Member were deposited by meandering streams and were later covered by shales, siltstones, and volcanic ash beds of the Brushy Basin Member of the Morrison Formation. Later, near shore marine sands of the Dakota Formation and marine muds, silts, and sands of the Mancos Shale covered the rocks of the Morrison Formation. The Salt Wash sandstones are porous, permeable, and locally contain abundant fossil plant material. Sometime after the deposition of the sandstones, uranium- and vanadium-bearing waters, probably derived from the overlying volcanic ash beds, flowed through the sandstones. The uranium- and vanadium-bearing water met changing physicochemical conditions, such as a reducing zone occupied by fossil organic material or changes in the acidity of the water, and the uranium precipitated as the minerals uraninite or coffinite and vanadium precipitated with clay minerals. Uranium and vanadium minerals formed irregularly shaped ore deposits, commonly referred to as uranium rolls. Typical roll deposits from the Spring Creek Mesa Mine near Uravan are shown in Figure 12. Ore deposits in the Uravan district range in size from a few tons to over a million tons. The average uranium grade is about 0.25 percent and the average vanadium grade is about 2 percent. The Cochetopa uranium district also contains uranium mineralization in the Upper Jurassic Morrison Formation. In the Thornburg Mine, the silicified and brecciated sandstone and mudstone of the Brushy Basin Member of the Morrison Formation contain black, sooty, finegrained uraninite in veinlets and as finely disseminated grains. Not all epigenetic uranium deposits in Colorado are located in the much favored Morrison Formation. The Jurassic-age Entrada and Navajo sandstones in the Rifle Creek district, Garfield County host typical vanadium-uranium minerals. The grade of these deposits ranges from 1 to 3 percent  $V_2O_5$ , and generally less than 0.10 percent  $U_3O_8$ . Epigenetic uranium deposits also occur in carbonate rocks in the Marshall Pass district, Saguache County. In the 1970s, Homestake Mining Company geologists working on the Pitch Mine recognized that they had discovered a previously unrecognized type of uranium ore deposit in brecciated dolomite of the Mississippian-age Leadville Limestone. Most of the uranium deposits and prospects of the district occur along the north-trending Chester fault. Large uranium deposits were formed where the fault intersected the Leadville Limestone.

Ore mined from 1959 to 1963 was probably also from the Leadville Limestone though the host rock was unrecognized. Uranium ore in the Tallahassee Creek district occurs in two early Oligocene to Eocene age formations, the Tallahassee Creek Conglomerate and the Echo Park Alluvium. The Echo Park Alluvium consists of sandstone, shale, and conglomerate. The Wall Mountain Tuff, a rhyolite ash flow tuff, overlies the Echo Park Alluvium. The Tallahassee Creek Conglomerate overlies the Wall Mountain Tuff and is mostly composed of boulders derived from the erosion of volcanic rocks and Precambrian igneous and metamorphic rocks. Uranium was dissolved from the Wall Mountain Tuff by groundwater leaching and then deposited as uraninite in favorable zones in the Echo Park Alluvium and Tallahassee Creek Conglomerate.

**Hydrothermal vein deposits** Vein deposits containing uranium minerals are widespread throughout the Precambrian terrain of Colorado. The central Front Range contains numerous uranium occurrences; most of which were not very productive. However, the largest and most productive uranium mine in Colorado was the hydrothermal vein deposit at the Schwartzwalder Mine located in the Ralston Buttes district of Jefferson County. The hydrothermal veins of the Schwartzwalder Mine are hosted in Precambrian age metamorphic rocks, schists, gneisses, and quartzite. Most of the uranium-bearing veins are located in garnet biotite gneiss and quartzite. The veins fill north- to northwest-trending, mostly steeply dipping, Laramide age (about 70 million years ago) fractures in the garnet biotite gneiss, quartzite, and other rocks. The ore minerals in the veins consist of uraninite (variety pitchblende), some coffinite, copper sulfides, and other base metal sulfides. Quartz and carbonate minerals form the gangue (non-ore) minerals.



**What is enriched uranium, and depleted uranium?** In order to make a nuclear reaction occur there has to be a greater percentage of the more fissionable  $^{235}\text{U}$  in the fuel than occurs in nature. The enrichment process converts  $\text{U}_3\text{O}_8$  into a gas, uranium hexafluoride ( $\text{UF}_6$ ), which enables the uranium to be enriched from a  $^{235}\text{U}$  content of 0.7 percent to about three to four percent. The enriched  $\text{UF}_6$  is converted back into  $\text{UO}_2$  and formed into fuel pellets. So-called weapons grade uranium is enriched to much higher levels of  $^{235}\text{U}$ , generally greater than 90 percent.

Depleted uranium is created by the process of making enriched uranium and contains 0.25 to 0.30 percent  $^{235}\text{U}$ . Every ton of natural uranium enriched for nuclear energy purposes contains about 260 pounds of enriched uranium and the remaining 1,740 pounds is depleted uranium. Depleted uranium is very dense (about 1.7 times lead) and is used as counterweights in aircraft, keels of boats, and as military projectiles.

### **Uranium Minerals**

**Uraninite** (pitchblende):  $\text{UO}_2$ , often containing thorium, lead, and other metals of the lanthanum and yttrium group. Uraninite is very dense, black to brown, has a greasy luster, and is radioactive.

**Coffinite**:  $\text{U}(\text{SiO}_4)_{1-x}(\text{OH})_{4x}$ , a black hydrated aluminum silicate is named after R.C. Coffin, a Colorado Geological Survey geologist who wrote one of the first monographs on the Uravan district.

**Carnotite**:  $\text{K}_2(\text{UO}_2)_2(\text{VO}_4)_2 \cdot 3\text{H}_2\text{O}$ , a secondary mineral of uranium with a bright yellow color.

**Autunite:**  $\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 10\text{--}12\text{H}_2\text{O}$ , a common secondary mineral after uraninite. It has a yellow to yellowgreen color and a prominent yellow-green fluorescence.

**Tyuyamunite:**  $\text{Ca}(\text{UO}_2)_2(\text{VO}_4)_2 \cdot 5\text{--}8\text{H}_2\text{O}$ , similar to carnotite with Ca substituting for K. Often associated with carnotite and very similar in appearance.