

# SwRI: Mineralogic Studies of The Pena Blanca Natural Analog Project

## Uranium Mineralogy

Primary uranium mineralization (i.e., uraninite) is preserved in highly silicified portions of the Nopal I deposit. The occurrence of uraninite at Nopal I is a fortuitous analogy in relation to a Yucca Mountain HLW repository because natural uraninite is a close structural and compositional analog to spent nuclear fuel. The presence of uraninite at Nopal I allows its alteration to secondary uranium minerals to be examined and compared to the results of oxidation experiments conducted using unirradiated  $\text{UO}_2$  or spent fuel.

*Rock thin section of uranium ore from Nopal I. Silicified breccia fragments are cemented by a black-colored, fine-crystalline matrix composed of uraninite intergrown with kaolinite. Oxidation of the uraninite has led to formation of yellow-colored uranyl minerals. Field of view is 18 mm across.*



Information on uranium minerals found at Nopal I, their paragenesis, the composition of Nopal I uraninite, and a comparison of Nopal I uranium mineralogy to nuclear fuel corrosion experiments was published in *Applied Geochemistry*. The abstract for this article follows.

*Applied Geochemistry*, Vol. 9, pp. 713-732, 1994

### **Alteration of uraninite from the Nopal I deposit, Peña Blanca District, Chihuahua, Mexico, compared to degradation of spent nuclear fuel in the proposed U.S. high-level nuclear waste repository at Yucca Mountain, Nevada**

English C. Pearcy, James D. Prikryl, William M. Murphy,  
and Bret W. Leslie

Center for Nuclear Waste Regulatory Analyses  
Southwest Research Institute  
San Antonio, TX 78228-0510, U.S.A.

#### **Abstract**

At the Nopal I uranium deposit, primary uraninite (nominally  $\text{UO}_{2+x}$ ) has altered almost completely to a suite of secondary uranyl minerals. The deposit is located in a Basin and Range horst composed of welded silicic tuff; uranium mineralization presently occurs in a chemically oxidizing and hydrologically unsaturated zone of the structural block. These characteristics are similar to those of the proposed U.S. high-level nuclear waste (HLW) repository at Yucca Mountain, Nevada. Petrographic analyses indicate that residual Nopal I uraninite is fine grained (5-10 microns) and has a low trace element content (average about 3 weight percent). These characteristics compare well with spent nuclear fuel. The oxidation and formation of secondary minerals from the uraninite have occurred in an environment dominated by components common in host rocks of the Nopal I system (e.g. Si, Ca, K, Na and  $\text{H}_2\text{O}$ ) and also common to Yucca Mountain. In contrast, secondary phases in most other uranium deposit form from elements largely absent from spent fuel and from the Yucca Mountain environment (e.g. Pb, P and V). The oxidation of Nopal I uraninite and the sequence of alteration products, their intergrowths and morphologies are remarkably similar to those observed in reported corrosion experiments using spent fuel and unirradiated  $\text{UO}_2$  under conditions intended to approximate those anticipated for the proposed Yucca Mountain repository. The end products of these reported laboratory experiments and the natural alteration of Nopal I uraninite are dominated by uranophane [nominally  $\text{Ca}(\text{UO}_2)_2\text{SiO}_7 \cdot 6\text{H}_2\text{O}$ ] with lesser amounts of soddyite [nominally  $(\text{UO}_2)_2\text{SiO}_4 \cdot 2\text{H}_2\text{O}$ ] and other

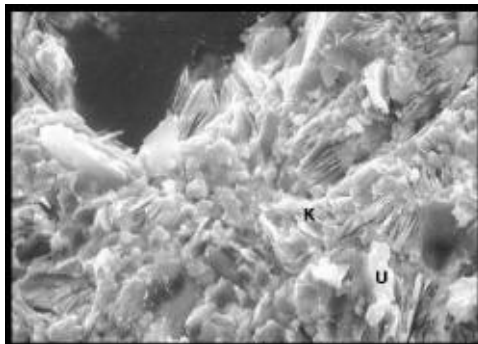
uranyl minerals. These similarities in reaction product occurrence developed despite the differences in time and physical-chemical environment between Yucca Mountain-approximate laboratory experiments and Yucca Mountain-approximate uraninite alteration at Nopal I, suggesting that the results may reasonably represent phases likely to form during long-term alteration of spent fuel in a Yucca Mountain repository. From this analogy, it may be concluded that the likely compositional ranges of dominant spent fuel alteration phases in the Yucca Mountain environment may be relatively limited and may be insensitive to small variations in system condition.

The relatively simple chemistry of the Nopal I system (predominantly rhyolitic tuffs) and the youth of the deposit has resulted in the formation of fewer uranium minerals when compared to most other uranium deposits that have undergone oxidative alteration. A listing of the uranium minerals found at Nopal I are shown in the accompanying table.

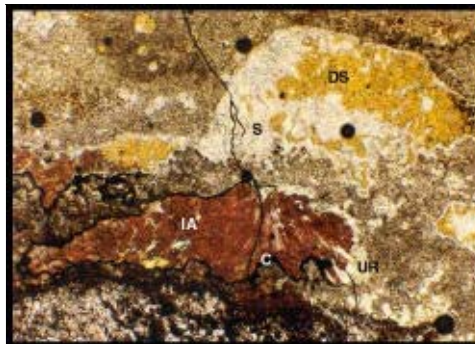
Uranium minerals at Nopal I	
Minerals	Nominal Chemical Formula
Uraninite	$UO_{2+x}$
Soddyite	$(UO_2)_2SiO_4 \cdot 2H_2O$
Uranophane	$Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$
Beta-uranophane	$Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$
Haiweeite	$Ca(UO_2)_2Si_6O_{15} \cdot 5H_2O$
Weeksite	$K_2(UO_2)_2Si_6O_{15} \cdot 4H_2O$
Boltwoodite	$KH(UO_2)SiO_4 \cdot 1.5H_2O$
Becquerelite	$Ca(UO_2)_6O_4(OH)_6 \cdot 8H_2O$
Ianthinite	$U^{4+}(U^{6+}O_2)_8(OH)_{14} \cdot 3H_2O$
Schoepite	$UO_3 \cdot 2H_2O$
Dehydrated Schoepite	$UO_3 \cdot nH_2O (n < 2)$

*Modified from Percy et al., 1994*

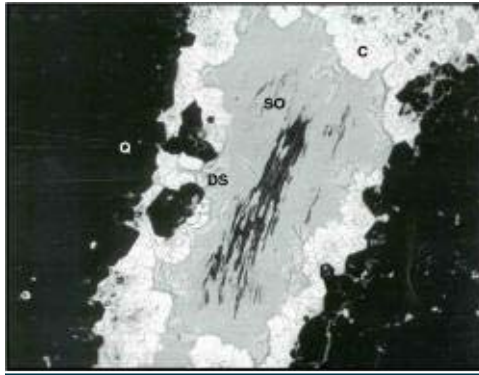
The paragenesis of uranium minerals at Nopal I is relatively simple consisting of primary uraninite followed by uranyl oxide hydrates followed by uranyl silicates. Paragenetic relationships between the uranium phases at Nopal I are illustrated in the following photos:



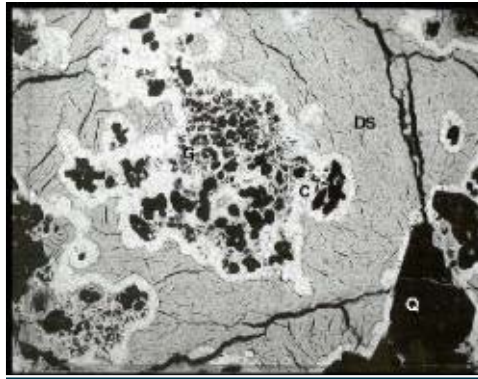
Scanning electron photomicrograph of uraninite (U) intergrown with kaolinite (K). The primary mineralization at Nopal I consists of a uraninite-kaolinite-pyrite-quartz assemblage. Texturally the assemblage consists of a matrix of fine crystalline uraninite-kaolinite which cements silicified breccia fragments. The dark colored material at the top left is the border of a breccia fragment. Pyrite crystals of varying size and concentration occur within the uraninite-kaolinite matrix. Scale - 0.045 mm across



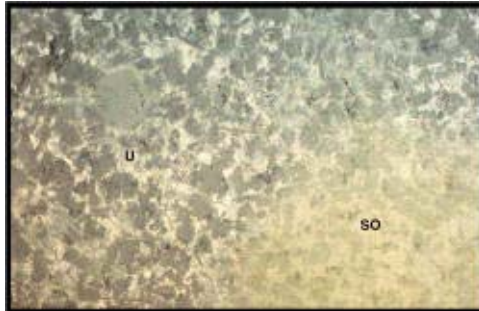
Plane light photomicrograph of uranium phases filling open space. Open space is filled by uranyl oxide hydrates: ianthinite (IA) followed by schoepite (S) and dehydrated schoepite (DS). Uranophane (UR) replaces all three uranyl oxide hydrates. Note the thin black rim of colloform uraninite (C) preserved along the margin of the granular material. Scale - 0.8 mm across



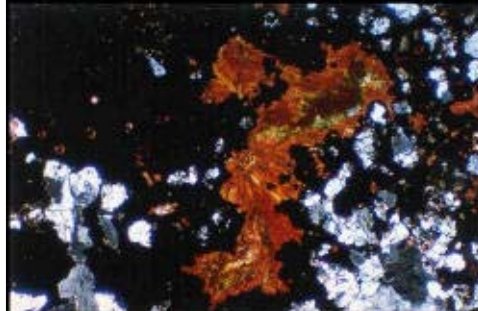
*Backscattered electron photomicrograph of uraninite with a colloform texture (C) lining open space between silicified breccia fragments. Note the euhedral quartz substrates (Q). The remaining open space is filled by uranyl oxide hydrates [dehydrated schoepite (DS)] and uranyl silicates [soddyite (SO)]. Scale - 0.4 mm across*



*Backscattered electron photomicrograph of uranium phases filling open space between breccia fragments. Granular uraninite (G) composed of fine crystalline uraninite intergrown with kaolinite is followed by colloform uraninite (C). The remaining open space is filled by dehydrated schoepite (DS). Euhedral quartz crystals (Q) act as substrates for uraninite formation. Scale - 0.4 mm across*



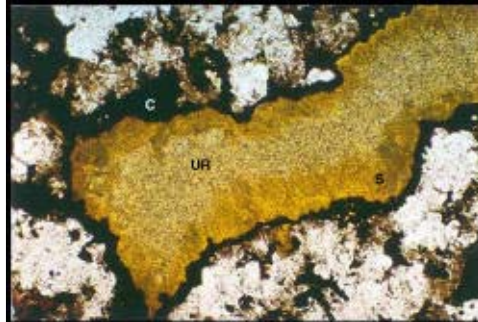
*Reflected light photomicrograph showing an oxidation front in a sample of Nopal I uranium ore. Uraninite (U) intergrown with kaolinite (dark colored mineral) is being oxidized to the uranyl silicate soddyite (SO). Kaolinite is unaffected by the alteration. Scale - 0.1 mm across*



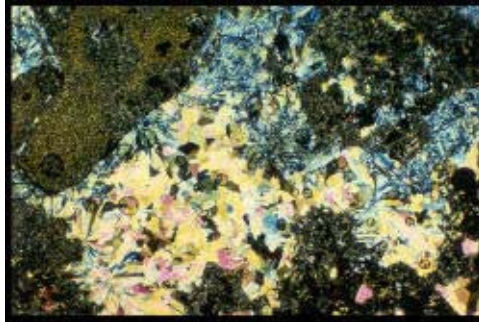
*Transmitted light photomicrograph of red-colored ianthinite filling open space within a breccia fragment. The ianthinite is being replaced by yellow-colored schoepite and uranophane. Scale - 0.8 mm across*



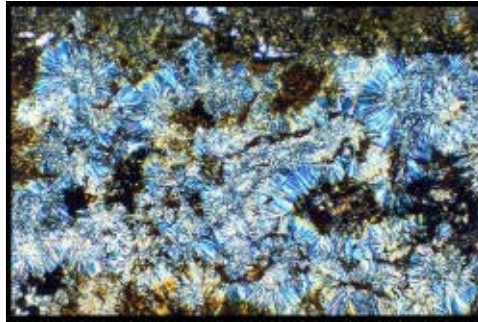
*Transmitted light photomicrograph of radiating clusters of intergrown schoepite and uranophane. This is a replacement texture after colloform uraninite. Scale - 2.6 mm across*



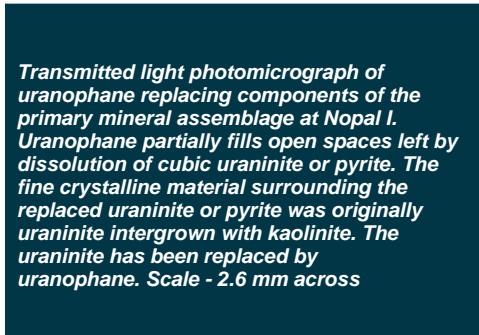
*Transmitted light photomicrograph of schoepite (S) and uranophane (UR) filling an open void. Schoepite occurs at the margin of the void and follows colloform uraninite (C). Uranophane occurs in the middle of the void and replaces schoepite. Scale - 0.8 mm across*



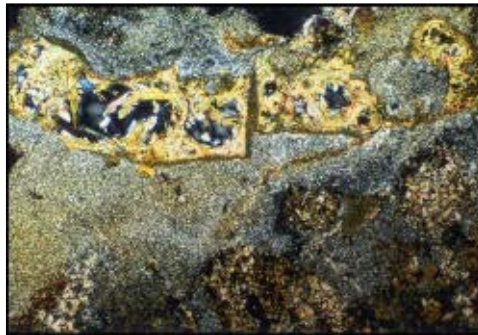
*Transmitted light photomicrograph of uranophane and beta-uranophane filling open space in fractured breccia. Beta-uranophane consists of the coarser, yellow-colored crystals, whereas uranophane is composed of finer, blue-green crystals. Scale - 2.6 mm across*



*Transmitted light photomicrograph of clusters of acicular weeksite crystals within a fracture in brecciated tuff. Scale - 1.3 mm across*



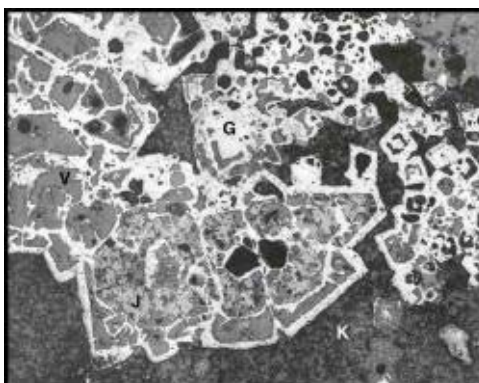
*Transmitted light photomicrograph of uranophane replacing components of the primary mineral assemblage at Nopal I. Uranophane partially fills open spaces left by dissolution of cubic uraninite or pyrite. The fine crystalline material surrounding the replaced uraninite or pyrite was originally uraninite intergrown with kaolinite. The uraninite has been replaced by uranophane. Scale - 2.6 mm across*



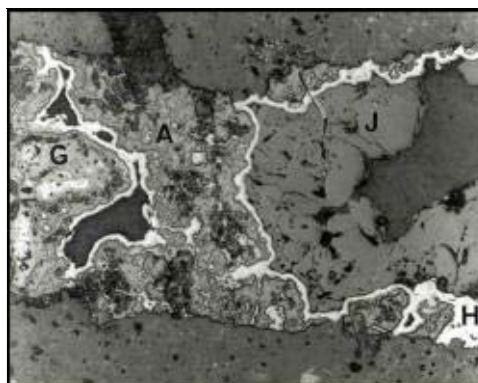
## Non-Uranium Mineralogy

Studies of non-uranium minerals at Nopal I have been utilized to evaluate mechanisms and timing of U transport at the deposit. For example, dating of U-rich opal and calcite precipitated on and adjacent to the uranium deposit has documented water movement and U mobilization at 54 ka (Pearcy et al., 1994).

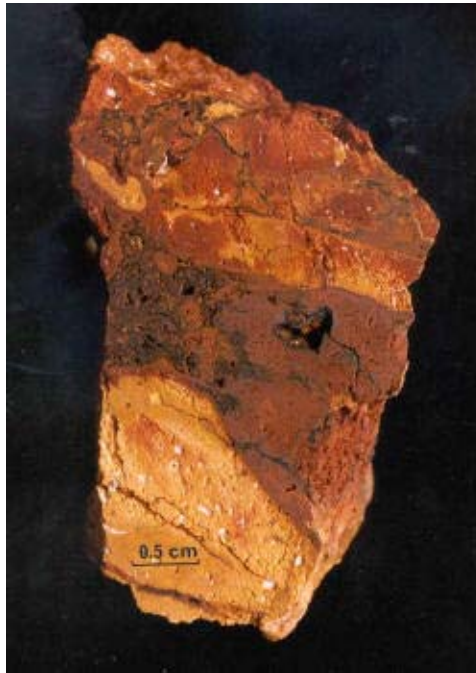
Oxidation of pyrite has led to the formation of iron oxides, iron hydroxides, and sulfates both within and outside the uranium deposit. A zone within the interior of the deposit is characterized by no observable U minerals and abundant alunite [ $KAl_3(SO_4)_2(OH)_6$ ]. The conditions under which alunite forms (oxidizing, low pH) are also conditions that tend to mobilize U. A major fracture set that crosscuts the deposit contains goethite, hematite, amorphous Fe-oxyhydroxides, and jarosite [ $KFe_3(SO_4)_2(OH)_6$ ] produced by chemical weathering of pyrite (Prikryl et al., 1997). The goethite, hematite, and amorphous Fe-oxyhydroxides within this fracture contain anomalous U concentrations (e.g., several hundred to several thousand ppm U). U concentrations in these minerals decreases with distance from the deposit which strongly suggests that U was mobilized and transported away from the deposit.



*Reflected light photomicrograph of fracture-infilling materials. Hematite (H) has a colloform texture and grows into open space from goethite (G) and amorphous Fe-oxyhydroxide (A) substrates. Jarosite (J) grows from hematite substrates into open voids. Field of view is 0.5 mm wide.*



*Reflected light photomicrograph of goethite (G) replacing cubic pyrite. Open voids (V) left by pyrite dissolution are partially filled by jarosite (J). Field of view is 0.5 mm wide.*



*Photograph of infilling material and host tuff from a major fracture which crosscuts the ore deposit. The fracture contains Fe-oxides (hematite and goethite) that often cement tuff fragments. Jarosite crystals line the large open void within the fracture.*

## References

**Pearcy, E.C., J.D. Prikryl, W.M. Murphy, and B.W. Leslie,** 1994, Alteration of uraninite from the Nopal I deposit, Peña Blanca district, Chihuahua, Mexico, compared to degradation of spent nuclear fuel in the proposed US high-level nuclear waste repository at Yucca Mountain, Nevada, *Applied Geochemistry*, Vol. 9, p. 713-732.

**Prikryl, J.D., D.A. Pickett, W.M. Murphy, and E.C. Pearcy,** 1997, Migration behavior of naturally-occurring radionuclides at the Nopal I uranium deposit, Chihuahua, Mexico, *Journal of Contaminant Hydrology*, Vol. 26, p. 61-69.

For more information about natural analog studies in the Sierra Peña Blanca or CNWRA research at Nopal I, contact [James D. Prikryl](mailto:jprikryl@swri.org) at [jprikryl@swri.org](mailto:jprikryl@swri.org) or call (210) 522-5667.

---

©1998-2011 Copyright Southwest Research Institute

Printed from:

<http://www.swri.org/4org/d20/ghs/PBlanca/mineral-new.htm>

---

Southwest Research Institute® (SwRI®) is an independent, nonprofit, applied engineering and physical sciences research and development organization with 11 technical divisions using multidisciplinary approaches to problem solving. The Institute occupies 1,200 acres and provides more than two million square feet of laboratories, test facilities, workshops, and offices for more than 3,000 employees who perform contract work for industry and government clients.