

Peña Blanca (Mexico)

Description: The Nopal I uranium deposit in the Sierra Peña Blanca of northern Mexico provides a natural analogue for high-level radioactive waste (HLW) repositories, especially for the proposed Yucca Mountain repository in Nevada, USA (see Figure 1). Uraninite, analogous chemically to spent nuclear fuel, has been oxidized at Nopal I, where the geological, geochemical, and hydrological conditions closely resemble those at Yucca Mountain. Issues of contaminant source and transport over long periods of time and under conditions relevant to geological isolation of nuclear waste at Yucca Mountain have been studied at Peña Blanca.

Research activities conducted by the Center for Nuclear Waste Regulatory Analyses (CNWRA) at the Nopal I uranium deposit include evaluation of the mechanisms of uraninite alteration, controls on groundwater and mineral compositions, and processes affecting elemental migration.

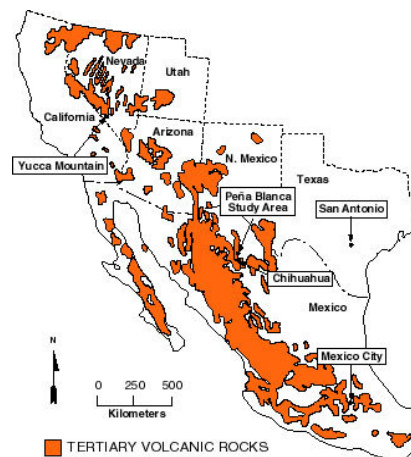


Figure 1: A map of the Tertiary volcanic domain of Mexico and southwest USA (from <http://www.swri.edu/4org/d20/ghs/PBlanca/overview.html>)

Geology and Stratigraphy

The Sierra Peña Blanca of northern Mexico is a geological terrain in the Basin and Range province of western North America with physical similarities to the Yucca Mountain geological system. The geological terrains are large rotational fault blocks composed of silicic volcanic rocks of Tertiary age.

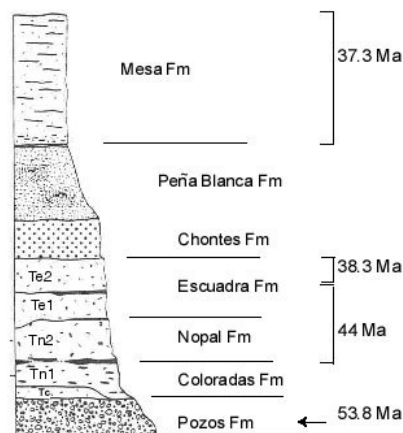


Figure 2: The stratigraphy at Peña Blanca (from <http://www.swri.edu/4org/d20/ghs/PBlanca/overview.html>)

The Sierra Peña Blanca is a west-dipping horst block with a superimposed set of parallel northwest-striking normal (extensional) faults (Goodell, 1981). The regional structural province is bounded to the east by the Trans-Pecos Range and to the west by the Sierra Madre Occidental (George-Aniel et al., 1985).

Peña Blanca stratigraphy consists of a sequence of Cretaceous limestones and mudstones on which a series of Tertiary silicic volcanics has been deposited (Stege et al., 1981). The preserved total thickness of the volcanic units varies over the Sierra Peña Blanca area from 106 to 538 m, and rock ages range from 35 to 44 Ma (Alba and Chavez, 1974). Host rocks for most of the uranium deposits in the district are the Escuadra, Nopal, and Coloradas Formations which are composed of variably welded tuffs with air-fall, ignimbrite, vitrophyre, lahar, and water-worked units (Figure 2).

Uranium Deposits

The Sierra Peña Blanca hosts the Peña Blanca mining district, which is located about 50 km north of Chihuahua City. Many of the uranium deposits in this district were drilled and/or developed by underground or open pit mining over a period of 20 years. However, there has been no mining activity at Peña Blanca since 1983. Combined, the Peña Blanca deposits include more than 2000 tonnes of U_3O_8 and constitute the bulk of Mexican uranium reserves (Goodell, 1981).

Among the several uranium deposits in the Peña Blanca district, the Nopal I deposit is the most studied as an analogue relevant to a HLW repository. Information on the geology, mineralogy, and geochemistry of Nopal I is available from previous research at the deposit (e.g. Cardenas-Flores, 1985; George-Aniel et al., 1985; Goodell, 1981; Ildefonse et al., 1990; Ildefonse et al., 1991; Leroy and George-Aniel, 1992). Analogous aspects of the Nopal I deposit include the silicic, tuffaceous host rocks, the semi-arid climate, the unsaturated hydrological regime and the presence of reduced and oxidized uranium mineralization.



Figure 3: The Nopal I uranium ore body, Peña Blanca. The uranium mineralization is in the darker area of the foreground (from Miller et al., 2000).

The Nopal I deposit consists of a near vertical breccia pipe some 40 m in diameter which extends over a vertical interval of at least 100 m. Nopal I is hosted by tuffaceous rocks of the Nopal and Coloradas Formations, which are separated by a basal argillaceous zone, interpreted to be a vitrophyre. At depth the Nopal I orebody extends into the Pozos Formation which is largely a limestone conglomerate that formed on the surface of the Cretaceous limestone. The lowest level of the deposit is about 50 m above the local water table (Figure 3).

The Nopal Formation is a rhyolitic tuff, densely welded and hematitic in unaltered zones. The Coloradas Formation is a densely welded, reddish-coloured, lithic-crystal rhyolitic tuff. Removal of hematite and alteration of phenocrysts to clays and calcite are characteristic of Nopal and Coloradas tuffs altered by hydrothermal solutions associated with the ore body. Comparison of the chemical composition

(major oxide abundances) of the Nopal and Coloradas Formations with that of the Topopah Spring Member of the Paintbrush Tuff Formation (the proposed repository horizon at Yucca Mountain) illustrates chemical similarity between the units.

The uranium mineralization at Nopal I is presently exposed on broad excavated benches at the +00 and +10 m levels, which together provide surface access to a horizontal section across the entire width of the deposit. Unmaintained shafts and adits also penetrate the deposit. Adits at the +00 and -40 m levels provided access to the interior of the orebody. The breccia pipe contains high grade uranium mineralization in the form of uraninite, uranyl oxide hydrates, and uranyl silicates.

Uranium Mineralogy

The Nopal I deposit is exposed at the surface in both the walls and the floor of the mine, allowing a three-dimensional investigation to be performed of the distribution of primary and secondary mineralization. Uranium-lead dating of the ore at Nopal I suggested that the primary uraninite had been formed about 8 Ma ago. Approximately 3 Ma ago, the deposit was largely oxidised and, as a result, the mineralization is now in the form of secondary uranyl minerals such as uranophane, weeksite, soddyite and schoepite. A few centimetre-sized remnant pods of primary uraninite still remain, and detailed mineralogical observation of these has shown a characteristic pattern of alteration on mineral surfaces and at grain boundaries (Miller et al., 2000).

Information on uranium minerals found at Nopal I, their paragenesis, the composition of Nopal I uraninite, and a comparison of Nopal I uranium mineralogy with nuclear fuel corrosion experiments has been presented by Percy et al., 1994. 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 with most other uranium deposits that have undergone oxidative alteration.

Uranium Transport Studies

Uranium transport at the Nopal I deposit has been studied to evaluate the mechanisms by which high-level waste nuclides could be transported through silicic tuff over long time periods. Transport of uranium from areas of primary mineralization was determined by radiometric surveying and analysis of uranium concentrations and distributions in bulk rock samples and minerals both within and outside the ore deposit. The rate-limiting step for migration appears to be advective transport in groundwaters (Murphy and Percy, 1993).

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 54,000 years ago (Percy et al., 1994).

The host volcanic tuffs at Peña Blanca are commonly fractured, particularly in the welded zones, and these fracture porosities were the key factor controlling unsaturated water flow through the rocks. The distribution of uranium in and around fractures at the Nopal I deposit, as described in Percy et al. (1995), was used to evaluate matrix diffusion and its significance as a retardation mechanism in performance modelling of radionuclide transport (CNWRA, 1997). Field studies clearly show that uranium transport and water flow had occurred predominantly through the fractures. These studies have also suggested that matrix diffusion is not an important retardation mechanism in the volcanic rocks at Peña Blanca. By analogy, matrix diffusion is not important for nuclide retardation at Yucca Mountain.

Mobilised uranium has been transported away from the ore into the surrounding tuffs and has been partly re-deposited. Association of the re-deposited uranium with minor phases such as iron oxyhydroxide in the fractures and the rock matrix is a significant retardation process. An important conclusion from the uranium isotopic measurements on fracture coating minerals is that uranium transport in the system at Peña Blanca was episodic rather than continuous, and assumed to relate to preferential mobilisation during periods of high groundwater flow (Pickett and Murphy,

2002). This observation has clear implications for modelling groundwater flow and nuclide transport at Yucca Mountain.

Relevance: Natural uraninite is a close structural and compositional analogue to spent nuclear fuel. The study is relevant to the understanding of long-term behaviour (migration and chemical composition) of uranium under non-saturated conditions, and is especially analogous to Yucca Mountain. Several past and present processes at Nopal I are analogous to those that could affect radionuclide migration at Yucca Mountain. Processes governing the oxidation of uraninite, the resulting dispersion of uranium from the sites of original mineralization, and the formation of secondary uranyl silicates are analogous to processes that may affect spent nuclear fuel and elemental migration. The analogue site is important for testing 3-D models of contaminant transport via groundwater flow.

Position(s) in the matrix tables: This natural analogue study belongs to the Spent fuel/Barrier Containment-Chemical Integrity box of the Near-field matrix table. It also belongs to the Spent fuel/Dissolution box of the same table.

The study also occupies the Advection (unsaturated flow)/Tuffs box under Nuclide migration in rock at low temperatures (<100 °C) in the Geosphere matrix table.

Limitations: The study is only relevant to an unsaturated geosphere for a deep spent fuel repository. The analogue does not apply to a deep repository in saturated rock in a wet climate. The composition of the natural uraninite does not match exactly the composition of spent fuel, which would contain a different suite of trace and radioactive elements.

Quantitative information: A matrix diffusion coefficient value for U can be derived ($D_a t = 0.3 \text{ m}^2$) based on the uranium contents in bulk rock samples collected across the western margin of the Nopal I deposit (modified from Percy et al., 1995).

The age of the primary and secondary mineralization at Peña Blanca, and information on its alteration were used to calculate a radionuclide release rate which has been applied in a performance assessment for Yucca Mountain to compare with an experimentally-derived base case value. The analogue-derived value gave lower calculated doses than the base case, providing confidence in the conservatism of the base case value (Pickett and Murphy, 2002; Murphy et al., 2002).

Uncertainties: The timings and exact compositions of the episodic groundwater pulses that have affected the tuffs and uranium mineral distributions at Peña Blanca are not known with any great certainty.

Time-scale: The relevant time-scale covered by the study is geological (>2Ma & <2Ma), involving the last 8 Ma.

PA/safety case applications: The use of Peña Blanca information in Yucca Mountain performance assessment is summarized in a number of articles e.g. Murphy (2000); Murphy et al., (2002); Pickett and Murphy (2002). There has been extensive application of the study in the recent NRC Total System Performance Assessment for the Yucca Mountain repository (CNWRA, 1998; NRC, 1999a; 1999b). The sensitivity of performance results was tested using an alternative source term model based on the maximum average oxidation rate of uraninite estimated for the Nopal I uranium deposit and scaled to the proposed repository inventory.

The measured correspondence between the mineral products formed by oxidation of natural uraninite from Peña Blanca and the oxidation products of un-irradiated UO_2 (simulating spent nuclear fuel) found in the laboratory has been used as a basis to include the secondary uranyl minerals schoepite, soddyite, uranophane, and Na-boltwoodite in reactive transport simulations for the Department of Energy (DOE) Total System Performance Assessment - Viability Assessment

(DOE, 1998; TRW, 1998) to predict the evolution of water chemistry resulting from geochemical interactions in emplacement drifts.

Communication applications: The CNWRA maintains a comprehensive website [<http://www.swri.edu/4org/d20/ghs/PBlanca/index.html>] as a vehicle to distribute information and promote natural analogue studies related to nuclear waste management.

References:

For a Peña Blanca bibliography, see the CNWRA website:
<http://www.swri.edu/4org/d20/ghs/PBlanca/biblio.html>

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Added value comments: None to add.

Potential follow-up work: Mapping, sampling, and analyses of U-rich opal and caliche deposits at Nopal I are currently being conducted by CNWRA scientists. The purpose of this work is to evaluate the most recent radionuclide release and transport because of their particular relevance to potential processes in the proposed repository at Yucca Mountain.

Keywords: uraninite, oxidation, dissolution, spent fuel, unsaturated zone, volcanic tuff, fractures

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