Abstract

The Crownpoint and Churchrock uranium deposits, San Juan Basin, New Mexico are currently being developed by Uranium Resources, Inc. (URI) and its subsidiary Hydro Resources, Inc. (HRI) with an anticipated start-up in 1998. Both deposits will be developed using advanced in situ leach (ISL) mining techniques. URI/HRI currently has about 14,583 t U (37.834 million pounds U₃O₈) of estimated recoverable reserves at Crownpoint and Churchrock, at a cost less than $39/kg U ($15/lb U₃O₈). The uranium endowment of the San Juan Basin is the largest of any province in the USA. In March, 1997, a Final Environmental Impact Statement (FEIS) for the Crownpoint and Churchrock sites was completed by the Nuclear Regulatory Commission which recommends the issuance of an operating license. The FEIS is the culmination of a 9 year effort to license and develop the deposits. The Westwater Canyon Member of the Jurassic Morrison Formation is an arkosic, fine to coarse grained sandstone bounded by near basinwide confining clays deposited in a wet alluvial fan environment within the San Juan Basin. The primary, trend-ore deposits are hosted by the Westwater Canyon Member as humate-rich, syngenetic tabular deposits which were subsequently remobilized into roll fronts. Since deposition in the Jurassic, two phases of remobilization have occurred in the basin causing the formation of in situ leach amenable monometallic uranium rolls free of organic debris. Following in situ mining, ground water restoration of the Crownpoint and Churchrock mines is required to provide a water quality consistent with pre-mining baseline conditions. The development of in situ mining offers an environmentally sound and cost-effective method for uranium extraction. URI/HRI anticipates a production of 385-1,156 Tonnes U/year (1-3 million pounds U₃O₈) from the New Mexico properties.

1. STRUCTURAL SETTING

The Crownpoint and Churchrock uranium deposits are located in northwestern New Mexico and are part of the Grants Uranium Region in the San Juan Basin (Fig. 1). The San Juan Basin, regionally part of the Colorado Plateau, is bounded on the north by the San Juan Uplift, to the west by the Defiance Uplift, to the south by the Zuni Uplift, and to the east by the Nacimiento Uplift and the Archuleta Arch. Fig. 2 presents an index map of the five mining districts within the region including the Churchrock, Crownpoint, Smith Lake, Ambrosia Lake, and Laguna districts as well as the locations of the three URI/HRI sites. Historically, the Grants Uranium Region represents the largest of all uranium-bearing provinces in the USA. Crownpoint is located in the central portion of the Chaco Slope and Churchrock is located 30 km to the west, also on the Chaco slope. The location of the three URI/HRI properties is also shown in Fig. 2 and are referred to as Churchrock, Crownpoint, and Unit 1.

2. DEPOSITIONAL FRAMEWORK

The Jurassic Morrison Formation is the single most important uranium producer in the USA and is the host for uranium deposits not only in the San Juan Basin, but also throughout the Colorado Plateau which covers 500,000 km² (200,000 mi²) including portions of Arizona, Colorado, New Mexico and Utah. The deposition of Morrison Formation occurred at a time in which large quantities of volcanic ash provided a source for uranium as the favorable
sandstone hosts of the Westwater Canyon Member were being deposited. In the San Juan Basin, sub-aerial alluvial fans draining the Zuni Uplift to the south developed over Recapture Member clays. Following the basin-wide development of the Westwater Canyon Member sandstones, Brushy Basin Member bentonitic claystones and mudstones containing large quantities of volcanic ash were deposited [1, 2, 3, 4, 5, 6].

Humate from the sediments was mobilized sygenetically [2, 3] and was reconcentrated into the Westwater Canyon Member sandstones. This provided a reductant for the large quantities of uranium in the Morrison system and gave rise to the humate-rich, tabular “trend-ores” throughout the San Juan Basin. The geometric mean of the total carbon content of the Ambrosia Lake “trend ores” is 0.60% [4]. Background concentrations at Ambrosia Lake is 0.14% [4].

Following deposition of the Morrison, transgressive Dakota seas enveloped much of the western USA depositing beach, barrier bar, and distributary deltaic sediments unconformably over the Morrison Formation. This was followed by deposition of the thick offshore sediments of the Mancos Shale.
Structural re-development of the San Juan Basin during Cretaceous and Tertiary times allowed for the redistribution of the tabular trend ores into the remobilized ores occurring at Crownpoint and Churchrock. This remobilization is responsible for the segregation of vanadium, selenium, and molybdenum from the remobilized ores such as Churchrock [4]. The total carbon is very low [4].

3. LOCATION

3.1. Crownpoint and unit 1

The Crownpoint and Unit 1 sites covers 877 ha (2,192 acres) and is located on Sections 15, 16, 19, 21, 22, 24, and 25 of Township 17 North, Range 13 West and Section 29, Township 17 North, Range 12 West adjacent to the town limits of Crownpoint (Fig. 3). The Crownpoint Trend lies on the central portion of the Chaco Slope to the south of the interior part of the San Juan Basin near the regional redox front at a depth of about 700 m. The Crownpoint trend was discovered in the late 1970s by Conoco and Mobil. Conoco began engineering studies of for a major underground mine in the late 1970s and three deep shafts were completed in 1982.

Unit 1 is located 3.2 km west of the town Crownpoint and covers 512 ha (1,280 acres) in Sections 15, 16, 21, and 22 of Township 17 North, Range 13 West and has very similar geological characteristics to the Crownpoint site. The Unit 1 Site is shown in Fig. 3. This forms a portion of the area leased by Mobil which explored and discovered over 38,500 t U (100 million pounds U3O8) within their leases.

Because of the leachable nature of portions of the ore in the area, Mobil completed an in situ pilot operation near what HRI calls the Unit 1 area. This pilot demonstrated the economic viability for ISL production of the Crownpoint ores as well as demonstrating the ability for restoration.
3.2. Churchrock

The Churchrock site is located in the northwest corner of the Zuni Uplift near the boundary of the Chaco Slope and the depth to ore is approximately 250 m. The site is located in Sections 8 and 17 of Township 16 North and Range 16 West and covers an area, as shown in Fig. 4, of 145 ha (360 acres). HRI's mineral rights include 65 ha (160 acres) of patented claims in Section 8, and 80 ha (200 acres) of leases on Section 17. A portion of the Churchrock site in the northeast corner of Section 17 was previously mined for uranium.

4. RESERVES AND PRODUCTION IN THE GRANTS URANIUM REGION

In the Grants Uranium Region, the estimated total endowment of the Westwater Canyon Member is $3.5 \times 10^6$ Tonnes U [6]. Cumulative production of uranium from the Grants Uranium Region by January 1, 1997 has been 131,450 t U (341.8 million pounds U$_3$O$_8$) [5, 7, 8, 9]. URI/HRI currently has about 14,583 t U (37.834 million pounds U$_3$O$_8$) of estimated recoverable reserves at Crownpoint and Churchrock at a cost less than $39/kg U ($15/lb U$_3$O$_8$). About 40% of all uranium produced in the USA is from the Grants Mineral Belt [5].

5. REGIONAL GEOLOGY

The San Juan Basin has been a regional depocenter since the Paleozoic. Approximately 3,000 m of section are present and range in age from Precambrian to Holocene. Strata from Permian to upper Cretaceous are identified including the Jurassic Morrison formation which hosts most of the uranium deposits in the basin. Formation of minor importance are the Cretaceous Dakota Sandstone and the Jurassic Todilto Limestone. Figure 5 is a cross-section between Gallup and Grants, New Mexico showing the regional relationships of the Jurassic Morrison [1].

FIG. 3. Crownpoint and Unit 1 site map.
FIG. 4. Churchrock site map.

FIG. 5. Cross-section between Gallup and Grants, New Mexico [1].
5.1. Morrison formation

The Morrison Formation consists of the Recapture, Westwater Canyon, and Brushy Basin Members and may attain a total thickness of about 225 m. A typical section in the Westwater Canyon Member along with a geophysical log is presented in Fig. 6 [1].

5.1.1. Recapture Member

The Recapture Member of the Morrison Formation is composed dominantly of two facies: aeolian and lacustrine. The eolian portion can be up 90 m thick and consists of white, tan, and yellowish-gray, fine- to medium-grained, well sorted, large-scale trough crossbedded

FIG. 6. Typical section of the Westwater canyon Member.
sandstone [1]. The lacustrine facies is an interbedded sequences of alternating red and maroon mudstones and white, light-gray, and reddish-brown, fine- to medium-grained, moderately well sorted sandstone. It ranges in thickness in the San Juan Basin from 0 to 152 m [1].

5.1.2. Westwater Canyon Member

The Westwater Canyon Member is an artesian aquifer with a transmissivity of $3.676 \times 10^{-4}$ to $3.880 \times 10^{-4}$ m$^2$/s (2,556–2,698 gal/day/ft) [8] and is tightly confined by aquicludes of the overlying Brushy Basin clays and underlying Recapture Shale. As described by Kirk & Condon [1], the Westwater Canyon Member is a sequence of vertically stacked and laterally coalesced fine- to coarse-grained, arkosic to felspathic, poorly sorted, sandstone beds interbedded with thin, discontinuous mudstone beds. The color ranges from pink to red, grayish-green, and yellowish gray. The Westwater Canyon Member was deposited in a braided fluvial framework and ranges in thickness from 30 to over 125 m and deposited in a synclinal area between the Mogollon and Uncompahgre uplifts [3]. At Crownpoint, the Westwater Canyon Member ranges in thickness from 72 to 105 m. At Churchrock, the average thickness of the Westwater is 80 m. A shown in Fig. 2, the source of the sediment was from the southwest across the area of the Zuni Uplift.

5.1.3. Brushy Basin Member

The Westwater Canyon Member interfingers locally and regionally with the overlying Brushy Basin Member mudstones which also serve as a regional aquiclude. Locally, the Brushy Basin Member hosts braided fluvial sandstones sometimes referred to as “Poison Canyon”. The Brushy Basin Member is composed of light greenish-gray bentonitic claystone and mudstone and ranges in thickness from 12 to 40 m [1, 8]. At Crownpoint, the Brushy Basin ranges from 20 to 35 m.

5.2. Dakota Sandstone

The Dakota Sanstone unconformably overlies the Morrison Formation and consists of two distinctive units. The lower portion is a paludal shale and mudstone overlying the Brushy Basin Member occasionally containing fluvial sandstone and locally coal. The upper portion of the Dakota is a well-developed white to light-brown, transgressive beach and barrier-bar marine sandstone unit occasionally containing distributary sandstone channels which are occasionally conglomeratic. These channels occasionally scour into the underlying Brushy Basin Member [1]. The thickness of the Dakota Sandstone is up to 60 m.

5.3. Mancos Shale

The Mancos shale was deposited in a transgressive offshore marine environment and is a dark-gray claystone, mudstone and very-fine sandstone system and is up to 600 m thick [1, 8]. At the Churchrock site, the Mancos shale is present at the surface.

6. DEVELOPMENT OF URANIUM DEPOSITS IN THE WESTWATER CANYON MEMBER

Uranium was deposited in the Westwater Canyon Member penecontemporaneously with the deposition of volcanic ash in a humate rich environment. Syngentic concentration of humate and uranium within tabular sandstone masses created the tabular “trend-ore” deposits.
Following structural changes in the basin during Cretaceous times, the trend-ore containing vanadium, molybdenum, and humate was redistributed into secondary "stacked" ore rolls virtually free of organics but containing some molybdenum. A later stage of basin development during Tertiary further redistributed the uranium into monometallic stacked ores. Both Crownpoint and Churchrock are Tertiary stacked-ore deposits.

The Cretaceous and Tertiary remobilized uranium rolls are considered favorable for bicarbonate-oxygen ISL methods currently employed by URI's Kingsville Dome and Rosita plants.

6.1. Regional ore controls

Clear regional controls of the uranium deposits in the San Juan Basin are evidenced by the strong correlation between the regional redox fronts and the location of the ore deposits [1, 2, 3]. This regional redox front is presented in Fig. 7 [1]. The regional redox front is accompanied by discrete zones of hematitic and limonitic alteration within the basin, the hematitic zone being updip of the limonitic zone. Gray, reduced Westwater Canyon Member sandstones occur downdip of the regional redox front. The remobilized ore lies in the limonitic zone downdip of the more intensely oxidized zone of hematitic alteration.

Another important regional and local control for the concentration of uranium is the development of highly transmissive zones in the Westwater Canyon Member fan system which allowed large quantities of uranium bearing solutions to pass through regional redox fronts and be precipitated.

![FIG. 7. Regional Redox Interface — From [1].](image-url)
6.2. Local ore controls

Local ore controls for the individual rolls within the Westwater Canyon Member appear to be the thin, laterally discontinuous clays within the sandstone. As shown in Fig. 8 of the Crownpoint site, multiple, stacked ore bodies are present throughout the Westwater Canyon Member, each within an individual geochemical cell. Accurate interpretation and delineation of these ore rolls is required to design an effective well field.

FIG. 8. Stacked roll fronts in the SE¼ of section 24 at Crownpoint.

7. ISL PROCESS

In order to develop the Crownpoint and Churchrock ore deposits, two distinct producing elements are necessary: the Well Field, and the Ion Exchange Plant. The plant consists of ion exchange columns containing resins with an affinity for uranyl carbonate ions. The flow of dilute solutions of uranyl carbonate (about 50–150 mg U/L) from the extraction wells is maintained at a rate of 10,000–20,000 L/m (2,500–5,000 gallons/m) through the plant. This yields between 230 kg U to 4,615 kg U per day (600 to 12,000 pounds of U3O8) for an annual production of 263–1,577 t U per year. Following extraction of uranium, oxygen and complexing agent such as sodium bicarbonate is added and the solution is reinjected. Of course, the true key to ISL development is the well field design.

7.1 Well field design

The well field is the mechanism by which the leaching solutions, or lixiviant, is circulated through the ore body (Fig. 9). Well field design for the in situ leach mines at Crownpoint and Churchrock will include up to 1,000–2,000 injection and extraction wells for each mine site located as close as possible to the ore. Because of the sinuosity of each individual roll front, wells as closely spaced as 10–50 meters will be used to extract the uranium. Each well field will be surrounded by a ring of monitoring wells not more than 120 m (400 ft) from the
nearest production well and not farther than 120 m from each other. Leachate migration to the monitoring wells is called an excursion. Excursion controls consist primarily of the initial engineering design of the wellfield, balancing lixiviant flow in the wellfield, and maintaining a slight production bleed of 1% to create a cone of depression around the ore zone. URI has never had an excursion in its operating history.

![TYPICAL WELLFIELD DESIGN](image)

**FIG. 9. Typical wellfield design.**

8. LICENSING

URI/HRI is currently in the process of obtaining source material license as authorized by the Atomic Energy Act for the Crownpoint, Churchrock, and Unit 1 sites. With the issuance of the FEIS [8] in February, the lengthy re-evaluation by the U.S. Nuclear Regulatory Agency (NRC) [10], the Bureau of Indian Affairs (BIA), and the U.S. Bureau of Land Management (BLM) was completed with a recommendation to issue a combined source and by-product material license from the NRC and minerals operating leases from the BLM and BIA. The FEIS recommended that the license and leases should be conditioned on the commitments made by HRI in the license application and related submittals as well as various recommendations made by the NRC [8]. The FEIS is the culmination of a 9 year effort by HRI to license and develop the deposits. The NRC license will be conditioned on a Safety Analysis Report (SAR) currently being prepared by the NRC and Consolidated Operating Plan (COP) which is currently undergoing review by the NRC.

Other required licenses and conferred rights include the Underground Injection Control (UIC) License, and Surface Discharge Permit, land disposal of treated waste water, and air quality licenses.

8.1. Underground injection control license

In addition to a source material license, URI/HRI has obtained a UIC license from the State of New Mexico Environmental Department. A UIC license allows for the injection of mining fluids into an aquifer for the purpose of extraction of uranium.
8.2. Land application of discharged water

Surface application of treated discharge waters is licensed by the State of New Mexico Environmental Department or the U.S. Environmental Protection Agency depending on the land status.

8.3. Water rights

Water rights in the State of New Mexico is administered through the New Mexico State Engineer. Applications for water rights are required to be published and are subject to a hearing if protested. Water rights may be approved subject to three conditions: That the application (1) not impair existing water rights, (2) not be contrary to the conservation of water within New Mexico, and (3) not be detrimental to the public welfare. URI/HRI is currently in the process of obtaining water rights for the anticipated projects.

8.4. Comparative consumptive water use

Agricultural use of consumed water in McKinley County, New Mexico for 50 hectares (123.5 acres) is compared to the total consumptive water use for all three proposed ISL projects. As can be seen in Fig. 10, the consumed water use for to support 50 ha of all commercial agricultural products is greater than the average use for in situ uranium mining. By comparison, water use for the former Churchrock mines required at least 6 million m$^3$ (5,000 acre feet) per annum to dewater the mines or at least 36 times the ISL water requirements.

![Comparative consumptive water use 50 hectares of crops and ISL mining.](image)

Based on 3.3 x 10$^6$ m$^3$ water requirement for all foreseen mining projects over 20 years
Restoration by reverse osmosis - 4 pore volumes
Source: USDA, Natural Resources Conservation Service, Grants, New Mexico, 1997

9. RESTORATION

Based on the experience gained in the industry, three strategies (Table I) are considered in ground water restoration including (a) groundwater sweep (GS); (b) reverse osmosis (RO); and (c) brine concentration (BC) depending on the water budget. Total water use is estimated
to be 13–29 million m$^3$ for groundwater sweep, 3.3–7.7 million m$^3$ for RO, and 0.03–0.07 million m$^3$ for BC. This represents the total water requirements for all currently foreseen projects.

### TABLE I. WATER REQUIREMENTS FOR CROWNPOINT, UNIT 1 AND CHURCHROCK [8]

<table>
<thead>
<tr>
<th>Restoration Method</th>
<th>4 Pore Volumes (millions M$^3$)</th>
<th>9 Pore Volumes (millions M$^3$)</th>
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<tbody>
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<tr>
<td>Brine Concentrator</td>
<td>0.03</td>
<td>0.07</td>
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10. RESOURCE & PRODUCTION BASE OF URI/HRI

10.1. Santa Fe Pacific Gold Corporation Agreement

URI/HRI recently signed an agreement with Santa Fe Pacific Gold Corporation in which certain mineral rights were acquired covering 200,000 ha (500,000 acres). These rights were obtained in exchange for 1.2 million shares of URI's common stock and a commitment for $200,000 per year in exploration expenditures for the next 10 years [11, 12]. URI estimates there is approximately 5,700 t U (14.7 million pounds U$_3$O$_8$) of proven in-place uranium reserves approximately 3,700 t U (9.6 million pounds U$_3$O$_8$) recoverable] that were drilled-out on the acquired land. The potential for further development is very large based on the USGS endowment study of the San Juan Basin completed in 1986 [6]. It is estimated from this study that the endowment at a cutoff grade of 0.10% of the Westwater Canyon Member is 1,392,000 t U (3,280 million pounds of U$_3$O$_8$) at ISL minable depths.

10.2. URI/HRI Operations and Production

URI and its subsidiary HRI currently has uranium production operations in South Texas in the Kingsville Dome and Rosita plants. Production in 1996 amounted to 524 t U (1.36 million pounds U$_3$O$_8$) making URI one of the largest domestic producer of uranium in the USA [11].

Based on the recent acquisition of Alta Mesa in Texas, the development of the Vasquez, Texas property, a favorable FEIS for three uranium properties in New Mexico, and recent agreements with Santa Fe Pacific Gold Corporation (SFPGC), the in-place uranium reserves of the company are 34,000 t U (88 million pounds U$_3$O$_8$) of which 22,000 t U (57 million pounds U$_3$O$_8$) are recoverable [12]. URI/HRI has been extremely active in licensing the Alta Mesa, Texas and New Mexico deposits for production as early as 1998.

ACKNOWLEDGMENTS

The author gratefully acknowledges the generous support and technical review by Richard Clement, Craig Bartels, and Frank Lichnovsky of Hydro Resources, Inc. and Mark Pelizza of Uranium Resources, Inc. in the preparation of this paper.
REFERENCES


