Mineralogical and Kinetic Considerations for In-Situ Recovery of Sandstone-Hosted Uranium – Grants Uranium District, New Mexico

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2019 NMA Uranium Recovery Workshop
Jurassic setting: the Morrison Formation
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• 1950-2002: 340 million lbs U$_3$O$_8$
• > 300 million lbs of resources remain (McLemore, 2013)
• Conventional mining ceased by 1989
• Solution mining continued until 2002 (9.6 million lbs U$_3$O$_8$)
Could ISR work in the Grants?

Nichols Ranch mine, Wyoming (2016)
<table>
<thead>
<tr>
<th>Company</th>
<th>Project</th>
<th>Location</th>
<th>Approx. Depth(ft)</th>
<th>4/1/86 Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exxon</td>
<td>San Antonio Valley</td>
<td>21-12N-4W</td>
<td>925</td>
<td>Cancelled</td>
</tr>
<tr>
<td>Phillips</td>
<td>Section 32-Nose Rock</td>
<td>32-19N-12W</td>
<td>3400-3700</td>
<td>Cancelled</td>
</tr>
<tr>
<td>Conoco-WMC²</td>
<td>Borrego Pass</td>
<td>13-16N-11W</td>
<td>2000</td>
<td>See &quot;In-Situ Inc&quot; below</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18-16N-10W</td>
<td>2200</td>
<td></td>
</tr>
<tr>
<td>URI³/Saarberg</td>
<td>Interplan</td>
<td>12N-4W</td>
<td>1300-2100</td>
<td>Under negotiation</td>
</tr>
<tr>
<td>In-Situ, Inc</td>
<td>Borrego Pass</td>
<td>13-16N-11W</td>
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</table>

1 United Nuclear Corporation
2 Wyoming Mineral Corporation
3 Uranium Resources, Inc.
Hydrometallurgy + hydrogeology

Predominant method U mining

Distinct cost and environmental impact advantages

Uranium mining in NM has a contentious environmental and epidemiological legacy – could this be part of a more sustainable approach to the remaining resources?

https://www.aph.gov.au
The problem: Deposit mineralogy can confound leaching efforts

Figure 11a: BEI of a lignite with uranium enriched zones and tyuyamanite coating a small lignite particle.

Figure 8: BEI of pyrite and cryptocrystalline uranium. The black areas are quartz grains.
The problem: Deposit mineralogy can confound leaching efforts

Figure 11a: BEI of a lignite with uranium enriched zones and tyuyamanite coating a small lignite particle.

Figure 8: BEI of pyrite and cryptocrystalline uranium. The black areas are quartz grains.
So we need to investigate the ore’s geochemistry:
What are the fundamental controls on leaching?

McLemore, 2010
Methods

- 18 samples from four sub-districts
- Samples of good integrity are scarce beyond the New Mexico Bureau of Geology core archives
- This study: samples from core archives and St. Anthony Mine, near Bibo, NM
Methods

1. 48 hr batch leaching experiments
   - ALKALINE (2 g/L sodium bicarbonate + 1.98 g/L hydrogen peroxide, pH 8.2))
   - LOWER H₂O₂ (2 g/L sodium bicarbonate + 0.198 g/L hydrogen peroxide, pH 8.5)
   - GROUNDWATER (pH 7.5)

2. Mineralogy and Bulk Chemistry
Comparing redistributed- & primary-type ores

<table>
<thead>
<tr>
<th></th>
<th>C (%)</th>
<th>Organic C (%)</th>
<th>As (ppm)</th>
<th>Se (ppm)</th>
<th>U (ppm)</th>
<th>V (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Redistributed</strong></td>
<td>0.04</td>
<td>0.03</td>
<td>14.1</td>
<td>54</td>
<td>1500</td>
<td>90</td>
</tr>
<tr>
<td><em>(Borrego Pass)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Primary</strong></td>
<td>6.95</td>
<td>3.5</td>
<td>74</td>
<td>1</td>
<td>10,200</td>
<td>1960</td>
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<tr>
<td><em>(Saint Anthony)</em></td>
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## Redistributed-type

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### Mineral Composition

<table>
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<th>Mineral</th>
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<tr>
<td>Quartz</td>
<td>40.1</td>
</tr>
<tr>
<td>Kspar</td>
<td>10.3</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>43.1</td>
</tr>
<tr>
<td>Clay</td>
<td>0.4</td>
</tr>
<tr>
<td>Opaque</td>
<td>0.4</td>
</tr>
<tr>
<td>Sericite</td>
<td>8.9</td>
</tr>
<tr>
<td>Chlorite</td>
<td>5.3</td>
</tr>
<tr>
<td>Porosity</td>
<td>23.1</td>
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</tbody>
</table>
Pseudo first-order reaction rate constant

\[ k = \frac{1}{t} (\ln C_0 - \ln C) \]

Redistributed-type: alkaline

Total Metals Leached

- Uranium: 50%
- Arsenic: 11%
- Selenium: 8%
- Vanadium: 17%
Redistributed-type: lower $\text{H}_2\text{O}_2$

$15 \times 10^{-3} \text{ hr}^{-1}$

$2 \times 10^{-3} \text{ hr}^{-1}$

$1.3 \times 10^{-3} \text{ hr}^{-1}$

$3 \times 10^{-3} \text{ hr}^{-1}$

Pseudo first-order reaction rate constant

\[ k = 1/t (\ln C_0 - \ln C) \]

Total Metals Leached

Uranium: 52 % (↑)
Arsenic: 10 % (↓)
Selenium: 6 % (↓)
Vanadium: 15 % (↓)
Pseudo first-order reaction rate constant

\[ k = \frac{1}{t} (\ln C_0 - \ln C) \]

Redistributed-type: groundwater

Total Metals Leached

- Uranium: 31 % (↓)
- Arsenic: 3 % (↓)
- Selenium: 3 % (↓)
- Vanadium: 5 % (↓)
Electron Microprobe analyses show an non-definitive mineralogy – possibly clay-associated, filling space in silicate grains.

Clay-associated U

Uranophane(?) in silicate grain
Clay-associated U
Here, uranium is not carbon-associated.
### Primary-type

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**Mineral Composition (%)**

- Quartz: 30.7
- Kspar: 1.7
- Plagioclase: 5.3
- Clay: 5
- Opaque: 54.7
- Porosity: 3
Primary-type: alkaline

Pseudo first-order reaction rate constant

\[ k = \frac{1}{t} (\ln C_0 - \ln C) \]

Total Metals Leached
- Uranium: 7.4%
- Arsenic: 14%
- Vanadium: 4%

\[ 1.5 \times 10^{-3} \text{ hr}^{-1} \]

\[ 0.5 \times 10^{-3} \text{ hr}^{-1} \]

\[ 0.6 \times 10^{-3} \text{ hr}^{-1} \]
Primary-type: lower $\text{H}_2\text{O}_2$

**Pseudo first-order reaction rate constant**

$$k = \frac{1}{t} (\ln C_0 - \ln C)$$

**Total Metals Leached**

- Uranium: 11% ($\uparrow$)
- Arsenic: 10% ($\downarrow$)
- Vanadium: 1.4% ($\downarrow$)
Primary-type: groundwater

Total Metals Leached
Uranium: 3 % (↓)
Vanadium: 0.04 % (↓)

Pseudo first-order reaction rate constant

\[ k = \frac{1}{t} (\ln C_0 - \ln C) \]
EMP analyses: highly carbonaceous, amorphous, non-mineral forms of uranium, as well as minor U-phosphates.

Odd botryoidal forms: bacteria? Humate? U-phosphate, autunite?
Here, uranium co-occurs with carbon (uraniferous humate?)
U also associated with K, V: carnotite-type mineral on edges?
Implications

- Order-of-magnitude less oxidant (H$_2$O$_2$) = more uranium, less potential contaminants (As, Se, V)
- Though lower proportion of U is released via alkaline leaching in primary-type deposits, higher amount of uranium in ore implies longer mine life
- Need to consider role of organic matter in leaching kinetics and closure plans
- The absence of true “minerals” needs to be considered – how would this affect yield, post-closure models?
Future Work
1. Use EMP data to develop paragenetic interpretation of U deposition
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2. Geochemical modeling in PhreeqC

- Allows the extrapolation of the leaching and geochemical results to the mining environment
  - Derive saturation indices, speciation, changes in fluid composition during reactive transport – why does less oxidant yield more U?
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• Bonnie Frey (New Mexico Bureau of Geology & Mineral Resources), EPSCoR Uranium Team PI – use of Geochemistry lab and ICP-MS instrument

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• PhD committee members: Dr. Virgil Lueth (New Mexico Bureau of Geology & Mineral Resources), Dr. Kierran Maher, Dr. Daniel Cadol and Dr. Jolante van Wijk (New Mexico Tech Earth and Environmental Science Department)
References


Thank you