Characterization and comparison of mine wastes from legacy mines in NM

Presentation by: John Asafo-Akowuah

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Overview

Purpose
Study Area
Methodology
Results
Conclusions
Recommendations
Purpose

Determine and compare the mineralogical and geochemical composition of mine wastes in legacy gold (Au) and uranium (U) mines in the study areas.

Determine the possible release of trace elements from the waste rock piles into the environment, and their acid/neutralizing potential.
Relevance of Study

Understanding the chemistry and distribution of minerals in a waste rock pile is key to characterizing the waste rock pile, predicting the mobility of metals and trace elements into the environment, public health and safety, ecological risk, and risk to ecosystems.

- Reclamation efforts have not examined the long-term chemical effects from these mines.
- There is still potential for environmental effects long after remediation of the physical hazards, as found in several areas in NM including Jackpile mine, Laguna.
- Some of these observations only come from detailed electron microprobe studies.

Study Areas

Jicarilla Mountains district
Socorro district
Ladron Mountains district
Study Area
Jicarilla Mountains

- Apex Mine: Jic410
- Gold Stain Mine: Jic334
- Sally Mine: Jic413

Approximately 100 miles southeast of Albuquerque, NM

About 18 miles north-east of White Oaks, NM

About 155 miles north-northeast of El Paso, Texas
Study Area
Socorro District

Lucky Don mine

Little Davie mine

Bustos Well 7 1/2 quadrangle

About 10 miles east of San Antonio, NM

Little Davie is located about ¼ mile south-southwest of Lucky Don
Study Area

Ladron Mountains

Jeter mine

About 27 miles north of Socorro

Lies in section 35, T. 3N, R. 2W
Great Plains Margin Gold-Veins (alkaline-type Au veins) hosted by a late-Eocene or early-Oligocene granodiorite

Younger dikes, sills, and laccoliths intruded the granodiorite and the sedimentary rocks

Minor vein deposits of hematite and sulfides, and small disseminations of pyrite have been precipitated from hydrothermal solutions.

Placer-gold deposits are of local derivation, found in three separate sedimentary units.

Source: McLemore et al., 1991
Lucky Don & Little Davie mines

Rio Grande Rift Cu-Ag (U) vein type in Permian San Andres Formation

Mineralization is localized by a northeast-trending fault parallel to major fault, which lies immediately to the west

Total ore produced at both mines amounts to 964.94 tons ($\text{U}_3\text{O}_8$ and $\text{V}_2\text{O}_5$) worth $70,000

Lucky Don: 1955-1963

Source Cather et al, 2014
Jeter Mines

Rio Grande Rift Cu-Ag (U) vein type deposit along fault between Proterozoic capirote granite and sediments

Granite has been intruded by a host of fine-grained gray andesitic dikes.

Total ore produced from Jeter mine amounts to 8,826 tons ($U_3O_8$ and $V_2O_5$) worth over $500,000

Source Chamberlin et al, 2007
Methodology

Field Sampling
- Au Mine
  - GPS mapping
  - Waste rock pile sampling
- U Mine
  - GPS/Scintilometer mapping
  - Waste rock pile sampling

Laboratory Analyses
- Paste pH and paste conductivity
- Chemistry – Petrography, total whole rock chemistry, XRD and Electron microprobe
Approach

SAMPLE CHARACTERIZATION FLOW CHART

- Conduct field assessment of mine feature
  - Feature with large waste rock piles or tailings
    - All significant mine features
      - Enter information into NM Mines Database

- Collect sample
  - Specific Gravity

- Geochemistry
  - Acid-base Accounting (ABA)
    - If potentially acid generating
      - Long term Kinetic Testing
        - If potentially acid generating
          - If significant concentrations of metals present or potentially acid generating

- Leach tests
  - Bulk chemical analysis
    - If significant concentrations of metals present or potentially acid generating
      - Bulk Sample (bucket)
        - Particle size analysis
          - Geotech tests
            - Moisture content
            - Density
            - Atterburg limits
            - Shear box tests
              - Petrography, XRD
                - Mineral identification, element speciation, or understanding weathering textures
              - Electron microprobe
              - Field observations
                - Mineralogy
                  - If significant sulfide minerals or metals present or potentially acid generating
                    - Rock chip samples
                      - Major and trace element chemistry
Sampling

Using composite sampling method by Munroe (1999) and USGS

Characterize waste rock piles

Determine the presence of trace elements from the waste rock piles

Determine the suitability of waste rock material to be used as backfill
Volume of waste rock pile: About 530 tons of jarosite rich material, 280 tons of porphyritic dacite material

Volume of waste rock pile: About 800 tons

Volume of waste rock pile: About 2500 tons
Field Characteristics of Potential Acid Rock Drainage

ARD forms when sulfide minerals are exposed to oxidizing conditions

Potential ARD waste rock piles in the field will generally have:
- pyrite
- jarosite
- low pH

The rate of sulfide oxidation depends on reactive surface area of sulfide, oxygen concentration and solution pH

Test to determine ARD include:
- Acid Base Accounting (ABA) – measures net acid potential
- Net Acid Generation (NAG) – generate a single value
# Field Observations - U

<table>
<thead>
<tr>
<th>Uranium Mine</th>
<th>Mine Feature</th>
<th>Depth of Workings (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucky Don</td>
<td>6 stub adits, loading bin, waste/rock pile, open pit</td>
<td>0–40</td>
</tr>
<tr>
<td>Little Davie</td>
<td>Pit, short adit, waste/rock pile</td>
<td>5–10</td>
</tr>
<tr>
<td>Jeter</td>
<td>Concrete platform, 3 waste piles, caved adit, open pit</td>
<td>300</td>
</tr>
</tbody>
</table>
## Field Observations - U

<table>
<thead>
<tr>
<th>Uranium Mine</th>
<th>Background Radiation (cps)</th>
<th>Min Radiation (cps)</th>
<th>Max Radiation (cps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucky Don</td>
<td>20-50</td>
<td>100</td>
<td>4,435</td>
</tr>
<tr>
<td>Little Davie</td>
<td>20-50</td>
<td>120</td>
<td>771</td>
</tr>
<tr>
<td>Jeter</td>
<td>10-30</td>
<td>80</td>
<td>1,640</td>
</tr>
</tbody>
</table>
Field Observations—\( ^{\text{U}} \) Mineralized Sample

- Samples of waste pile rocks with disseminated carnotite from Lucky Don mine (771 cps)
- A mineralized sample from Lucky Don mine (4,435 cps)
- A mineralized sample from Little Davie mine (771 cps)

Carnotite

\( ^{\text{U}},^{\text{V}} \) (uraninite ?)
## Field Observations – U Mines

<table>
<thead>
<tr>
<th>Uranium Mine</th>
<th>Ore Minerals</th>
<th>Field evidence of potential acid drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucky Don</td>
<td>tyuyamunite, carnotite, uraninite, Cu minerals, uranophane</td>
<td>No</td>
</tr>
<tr>
<td>Little Davie</td>
<td>tyuyamunite, carnotite, uraninite, Cu minerals, uranophane</td>
<td>No</td>
</tr>
<tr>
<td>Jeter</td>
<td>carnotite, tyuyamunite, alunite, pitchblende, malachite, Fe-Mn oxides, clay, azuritite, barite, calcite</td>
<td>No</td>
</tr>
</tbody>
</table>
Laboratory Analyses

**Paste pH**

Used to determine geochemical behavior of waste rock.
The paste conductivity values were converted to total dissolve solids (TDS).

**XRD Technique**

Conducted on to determine the mineralogy.
Samples were grinded into a well homogenized material.
A five minute absolute scan analysis was run.

**Whole Rock Chemistry**

Analytical methods include whole rock by fusion, ICP-MS, Leco and ICP-AES.
Electron Microprobe Analyses

Qualitative and quantitative analyses

Heavy minerals were first viewed in backscatter electron image (BSE)

Quantitative and qualitative analyses were used to determine textures and chemical composition of the minerals
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Range in common soil (ppm)</th>
<th>Range in Ladron sediments (ppm)</th>
<th>Anomaly Threshold (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>0.6-4.8</td>
<td>1.93-6.62</td>
<td>4.5</td>
</tr>
<tr>
<td>V</td>
<td>15-250</td>
<td>34-358</td>
<td>225</td>
</tr>
<tr>
<td>Cu</td>
<td>10-100</td>
<td>11-163</td>
<td>45</td>
</tr>
<tr>
<td>Au</td>
<td>0.004-0.005</td>
<td>All&lt;0.4-0.1</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Resident soil (mg/kg)</th>
<th>Industrial (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>230</td>
<td>3,500</td>
</tr>
<tr>
<td>V</td>
<td>460</td>
<td>380,000,000</td>
</tr>
<tr>
<td>Cu</td>
<td>3,100</td>
<td>47,000</td>
</tr>
<tr>
<td>As</td>
<td>0.68</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: Chamberlin, 1982
### Paste pH and chemistry – Au Mines

**EPA – Regional Screening Level (RSL) Summary table, 2016**

<table>
<thead>
<tr>
<th>Mineral</th>
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</tr>
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</table>

<table>
<thead>
<tr>
<th>Waste Rock Pile</th>
<th>Paste pH</th>
<th>Total Dissolve Solids (ppm)</th>
<th>Au (ppm)</th>
<th>As (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex mine</td>
<td>5.92</td>
<td>119</td>
<td>0.030</td>
<td>0.8</td>
</tr>
<tr>
<td>Gold Stain mine-A</td>
<td>4.40</td>
<td>81</td>
<td>0.341</td>
<td>5.1</td>
</tr>
<tr>
<td>Gold Stain mine-B</td>
<td>4.71</td>
<td>55</td>
<td>0.229</td>
<td>10.9</td>
</tr>
<tr>
<td>Jic410</td>
<td>7.13</td>
<td>79</td>
<td>0.067</td>
<td>0.7</td>
</tr>
<tr>
<td>Jic413-A</td>
<td>3.03</td>
<td>152</td>
<td>0.820</td>
<td>0.6</td>
</tr>
<tr>
<td>Jic413-B</td>
<td>7.46</td>
<td>209</td>
<td>1.290</td>
<td>0.7</td>
</tr>
<tr>
<td>Jic334</td>
<td>6.78</td>
<td>253</td>
<td>0.049</td>
<td>0.7</td>
</tr>
<tr>
<td>Sally mine</td>
<td>3.43</td>
<td>156</td>
<td>1.400</td>
<td>0.8</td>
</tr>
</tbody>
</table>

- **Represent pH 4-3**
- **Represent pH 5-4**
- **Au >1ppm**
Paste pH graph – Au mines
Geochemical value plot for Au, Cu, As, Zn & Pb – Au mines

EPA – Regional Screening Level (RSL)
Summary table, 2016

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<td>3,100</td>
<td>47,000</td>
</tr>
<tr>
<td>As</td>
<td>0.68</td>
<td>3</td>
</tr>
<tr>
<td>Zn</td>
<td>23,000</td>
<td>350,000</td>
</tr>
<tr>
<td>Pb</td>
<td>400</td>
<td>800</td>
</tr>
</tbody>
</table>

GEOCHEMICAL PLOT FOR Au, Cu, As, Zn and Pb

GEOCHEMICAL VALUE

WASTE ROCK PILE

- Apex Mine
- Gold Stain-A
- Gold Stain-B
- Jic334
- Jic410
- Jic413-B
- Jic413-A
- Sally mine
Ternary plot for Au, Ag & As– Au mines

Number of samples (n) = 8
### Paste pH, and chemistry Analyses – U mines

**EPA – Regional Screening Level (RSL) Summary table, 2016**

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<thead>
<tr>
<th>Waste Rock Pile</th>
<th>Paste pH</th>
<th>Total Dissolve Solids (ppm)</th>
<th>U (ppm)</th>
<th>V (ppm)</th>
<th>Th (ppm)</th>
<th>As (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeter1</td>
<td>7.77</td>
<td>1</td>
<td>23.7</td>
<td>93</td>
<td>14.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Jeter29</td>
<td>7.85</td>
<td>1</td>
<td>75.1</td>
<td>101</td>
<td>12.4</td>
<td>5.1</td>
</tr>
<tr>
<td>Jeter31</td>
<td>7.50</td>
<td>428</td>
<td>138</td>
<td>74</td>
<td>13.8</td>
<td>7.5</td>
</tr>
<tr>
<td>Little Davie</td>
<td>8.24</td>
<td>98</td>
<td>160.5</td>
<td>457</td>
<td>1.32</td>
<td>50</td>
</tr>
<tr>
<td>Lucky Don</td>
<td>8.16</td>
<td>92</td>
<td>126.5</td>
<td>563</td>
<td>1.96</td>
<td>241</td>
</tr>
</tbody>
</table>
Geochemical value plot for U, Th & V–U mines

<table>
<thead>
<tr>
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<td>47,000</td>
</tr>
<tr>
<td>As</td>
<td>0.68</td>
<td>3</td>
</tr>
</tbody>
</table>

EPA – Regional Screening Level (RSL) Summary table, 2016
Ternary plot for U, Th & V– U mines

Number of samples (n) = 5
Figures a) Backscattered electron images of quartz grain replacing Fe-oxide in sample Jic410. This is likely supergene replacement.

b) Backscattered electron images of Fe grain in sample Jic412. Note how altered and pitted the grain is.

c) Backscattered electron images of pyrite grain in sample Jic412 c. Note how pristine the pyrite grain is.
Figures d, e & f) Backscattered electron images of pyrite and Fe-oxide grains distribution in sample Jic802. Note how pristine the pyrite is in Figure d, but pitted in Figures e and f.
Quantitative scan for pyrite

High S and F percentages

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>S(%)</th>
<th>Fe(%)</th>
<th>Cu(%)</th>
<th>As (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold Stain-A-01</td>
<td>53.07</td>
<td>47.36</td>
<td>0.08</td>
<td>0.03</td>
</tr>
<tr>
<td>Gold Stain-A-02</td>
<td>33.63</td>
<td>31.11</td>
<td>32.90</td>
<td>0.02</td>
</tr>
<tr>
<td>Gold Stain-A-03</td>
<td>54.67</td>
<td>45.84</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>Gold Stain-B-01</td>
<td>52.56</td>
<td>47.50</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Gold Stain-B-02</td>
<td>52.52</td>
<td>47.59</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Gold Stain-B-03</td>
<td>52.68</td>
<td>47.09</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>Jic413A-01</td>
<td>53.69</td>
<td>47.39</td>
<td>0</td>
<td>0.02</td>
</tr>
<tr>
<td>Jic413A-02</td>
<td>53.02</td>
<td>47.47</td>
<td>0</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Microprobe Analysis (BSE) images of U Samples

Pristine uranium and vanadium minerals
Microprobe Analysis (BSE) images of U Samples

Dissolved uranium and vanadium minerals
Microprobe Analysis (BSE) images of U Samples

BSE images of CaCO$_3$ and Fe-Oxide grains
### Net Neutralization Potential (NNP) - U

AP (Kg CaCO₃/tonne) = 31.25 x S (%), NP (total C) = C (%) x 83.3, NNP = NP – AP, NPR = NP/AP  

**Assuming all C in sample are CaCO₃**

<table>
<thead>
<tr>
<th>Waste Rock Pile</th>
<th>S (%)</th>
<th>C (%)</th>
<th>AP (Kg CaCO₃/tonne)</th>
<th>NP (total C)</th>
<th>NNP</th>
<th>NPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeter1</td>
<td>0.05</td>
<td>0.13</td>
<td>1.5575</td>
<td>10.829</td>
<td>9.2715</td>
<td>6.95</td>
</tr>
<tr>
<td>Jeter29</td>
<td>0.24</td>
<td>0.75</td>
<td>7.476</td>
<td>62.475</td>
<td>54.999</td>
<td>8.36</td>
</tr>
<tr>
<td>Jeter31</td>
<td>0.05</td>
<td>0.21</td>
<td>1.5575</td>
<td>17.493</td>
<td>15.9355</td>
<td>11.23</td>
</tr>
<tr>
<td>Little Davie</td>
<td>0.03</td>
<td>10.45</td>
<td>0.9345</td>
<td>870.485</td>
<td>869.5505</td>
<td>931.50</td>
</tr>
<tr>
<td>Lucky Don</td>
<td>0.05</td>
<td>5.45</td>
<td>1.5575</td>
<td>453.985</td>
<td>452.4275</td>
<td>291.48</td>
</tr>
</tbody>
</table>
Acid Rock Drainage (ARD) U waste rock pile Classification Plot

Assumption: pH = pH after reaction (NAG pH)

- Lucky Don & Little Davie samples
- Jeter mine samples
<table>
<thead>
<tr>
<th>Waste Rock Pile</th>
<th>S (%)</th>
<th>C (%)</th>
<th>AP (Kg CaCO3/tonne)</th>
<th>NP (total C)</th>
<th>NNP</th>
<th>NPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex mine</td>
<td>0.08</td>
<td>0.33</td>
<td>2.492</td>
<td>27.489</td>
<td>24.997</td>
<td>11.031</td>
</tr>
<tr>
<td>Gold Stain mine-A</td>
<td>0.36</td>
<td>0.26</td>
<td>11.214</td>
<td>21.658</td>
<td>10.444</td>
<td>1.931</td>
</tr>
<tr>
<td>Gold Stain mine-B</td>
<td>0.35</td>
<td>0.24</td>
<td>10.903</td>
<td>19.992</td>
<td>9.090</td>
<td>1.834</td>
</tr>
<tr>
<td>Jic410</td>
<td>0.01</td>
<td>0.53</td>
<td>0.312</td>
<td>44.149</td>
<td>43.838</td>
<td>141.730</td>
</tr>
<tr>
<td>Jic413-A</td>
<td>0.85</td>
<td>0.26</td>
<td>26.478</td>
<td>21.658</td>
<td>-4.820</td>
<td>0.818</td>
</tr>
<tr>
<td>Jic413-B</td>
<td>0.5</td>
<td>0.51</td>
<td>15.575</td>
<td>42.483</td>
<td>26.908</td>
<td>2.728</td>
</tr>
<tr>
<td>Jic334</td>
<td>0.01</td>
<td>0.2</td>
<td>0.312</td>
<td>16.660</td>
<td>16.349</td>
<td>53.483</td>
</tr>
<tr>
<td>Sally mine</td>
<td>0.43</td>
<td>0.36</td>
<td>13.395</td>
<td>29.988</td>
<td>16.594</td>
<td>2.239</td>
</tr>
</tbody>
</table>
Acid Rock Drainage (ARD) Au waste rock pile Classification Plot

Assumption: pH = pH after reaction (NAG pH)

- Jicarilla samples
Acid Rock Drainage (ARD) Au & U Comparison

Assumption: $\text{pH} = \text{pH after reaction (NAG pH)}$

- Lucky Don & Little Davie samples
- Jeter samples
- Jicarilla samples
Conclusion – U Mines

No evidence of potential acid drainage from field observations (hosted by limestone)

No pyrite identified in XRD and electron microprobe analysis

Waste rock pile samples from all U mines plotted in the non-acid forming zone on the ARD classification plot inferring non-acid producing rock piles

Dissolved U and V grains in electron microprobe analysis

Elevated radioactivity (scintillometer mapping) in some waste rock piles

Waste piles with high radioactivity from scintillometer should be covered
Conclusion – Au Mines

Jarosite was observed in sample Jic413A, pyrite was identified in numerous waste rock piles during field investigations.

XRD and electron microprobe analyses identified pyrite grains in waste rock pile samples with pH < 5, some with whole rock arsenic (As) values between 0.8-10.9 ppm.

Pitted textures in microprobe analyses are consistent with arsenic being leached from pyrite.

Jic413A plotted in the potentially acid forming zone, Sally and Gold Stain-A mines plotted in uncertain zone and the rest of the Au samples plotted in the non-acid forming zone on the ARD classification plot.

Waste rock piles with pH > 5, and plotting in non-acid forming zone can be used as backfill.
Recommendations

Leaching tests are recommended to determine the leachability of acid from Jic413A, Sally and Gold Stain-A waste rock piles into the environment.

Sediment survey to determine the movement of U, V and trace elements into the environment.

Further field studies needed to determine the mineral potential of rock piles with elevated Au values.
Appreciation

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Questions