THE GRANTS URANIUM DISTRICT: SOURCE AND DEPOSITION

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OUTLINE

• Introduction
• Description of the Grants uranium deposits
• Age of the deposits
• Source of uranium
• How did the deposits form?
• Comments and conclusions
• Future research
Historical Production from the Morrison Formation in Grants District

- 340 million lbs of $\text{U}_3\text{O}_8$ from 1948-2002
- Accounting for 97% of the total uranium production in New Mexico
- More than 30% of the total uranium production in the United States
- 4$^{th}$ largest district in total uranium production in the world
New Mexico is 2nd in uranium reserves 15 million tons ore at 0.277% $U_3O_8$ (84 million lbs $U_3O_8$) at $30/\text{lb}$ (2003)
Grants district

- 340 million lbs of U₃O₈ have been produced 1948-2002
- ~360 million lbs of U₃O₈ historic resources have been reported by various companies
- Probably another ~200 million lbs of U₃O₈ remain to be discovered
- The district contained more than 900 million lbs U₃O₈
DESCRIPTION OF THE GRANTS URANIUM DEPOSITS
<table>
<thead>
<tr>
<th>Age Era (Ma)</th>
<th>Period</th>
<th>Symbol</th>
<th>Lithology</th>
<th>Formation</th>
<th>Energy Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500 to 1750</td>
<td>Pre cambrian</td>
<td>P-C</td>
<td>Sandstone, limestone, igneous rocks</td>
<td>Middle and Lower Proterozoic metamorphic and igneous rocks</td>
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<tr>
<td>570</td>
<td>Lower Paleozoic</td>
<td>Pz</td>
<td>Leadville and Chuhuahuan limestones, Aneth and Elbert Formations, and Ignace Quartz</td>
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<td>250</td>
<td>Pennsylvania</td>
<td>P</td>
<td>Hermosa Group (subsurface), Inland Trail, Paradox, Pinawa Trail and Mesa Formations (northwest)</td>
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<td>240</td>
<td>Permian</td>
<td>P</td>
<td>Calico Formation (north), San Andres, Galleria, Yesso, and Ana Formations (south)</td>
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<tr>
<td>200</td>
<td>Triassic</td>
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<td>Rock Point Formation (south), Chaco Group</td>
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<tr>
<td>65</td>
<td>Jurassic</td>
<td>J</td>
<td>Morrison Formation, Wasatch Formation, Emancipation</td>
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<tr>
<td>5</td>
<td>Cretaceous</td>
<td>K</td>
<td>Mesaverde Group, Cretaceous Canyon Formation, Gallup Sandstone (southwest)</td>
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<td>Lewis Shale, Pinedale Chalk Sandstone</td>
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<td>Kirkland Shale and Fruitland Formation</td>
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<td>Ojo Alamo Sandstone</td>
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<tr>
<td>45</td>
<td>Tertiary</td>
<td>T</td>
<td>Nacimiento Formation and Animas Formation</td>
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<td></td>
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<td>San Jose Formation</td>
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<td>Lower Santa Fe Group</td>
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<td>Bighorn Formation (southwest), Cheyenne Sandstone</td>
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<td>Volcanic rocks</td>
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<td>Alluvium, basalt flows</td>
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Primary Tabular Deposits in Westwater Canyon Member

- Less than 2.5 m thick
- Grades exceed 0.2% $\text{U}_3\text{O}_8$
- Sharp boundaries
- Locally offset by Laramide (Late Cretaceous)-Tertiary faults
- Black to dark gray because of the associated humate
- Also called primary, trend, prefault, black banded, channel, blanket ore
Redistributed Deposits in Westwater Canyon Member, Dakota Sandstone

- 3-46 m thick
- Grades less than 0.2% $\text{U}_3\text{O}_8$
- Commonly localized by faults
- Form roll front geometries locally
- Diffuse ore to waste boundaries
- Dark, brownish gray to light gray
- Also called postfault, stack, secondary, roll front ore
Remnant-primary sandstone uranium deposits

- Surrounded by oxidized sandstone
- Where the sandstone host surrounding the primary deposits was impermeable and the oxidizing waters could not dissolve the deposit, remnant-primary sandstone uranium deposits remain
- Also called ghost ore bodies
AGE OF THE DEPOSITS
Possible episodes of primary uranium mineralization

• Early Jurassic (Todilto at 150-155 Ma, U/Pb, Berglof, 1992)

• During and soon after deposition of the Westwater Canyon sandstones
  • 148 Ma (Rb/Sr, Lee and Brookins, 1978) deposition age of Westwater Canyon Member
  • 130-140 Ma based on U/Pb data and Rb/Sr and K/Ar ages of clay minerals penecontemporaneous with uranium minerals
  • Jackpile Sandstone is younger at 110-115 Ma (Lee, 1976)
Possible episodes of redistributed uranium mineralization

- During the Dakota time (Late Cretaceous, 80-106 Ma)
- During the present erosional cycle (which started in late Miocene or early Pliocene)
  - Secondary Todilto uranophane yields U/Pb ages of 3 to 7 Ma (Berglof, 1992)
  - Redistributed (stack) ore and an oxidized uranium mineral (uranophane) at Ambrosia Lake have late Tertiary U/Pb ages of 3 to 12 Ma
The primary uranium deposits are associated with humates. Therefore we need to understand the origin of the humates as well as the uranium.
Origin of humates

- Organic matter, not petroleum derived
  - Plant debris incorporated into the alluvial fans at the time of deposition
  - Plant material associated with the overlying lacustrine units
  - Dakota and pre-Dakota swamps (????)
- Locally it is detrital (L-Bar deposits)
- At most places, humates were deposited just after the sandstones were emplaced but before the uranium
- Brushy Basin contains little organic material
There is no consensus on details of the origin of the Morrison primary sandstone uranium deposits

- Ground water derived from a granitic highland to the south
- Ground water derived from a volcanic highland to the southwest (Jurassic arc)
- Alteration of volcanic detritus and shales within the Brushy Basin member (Lacustrine-humate model)
- Older uranium deposits
- Combination of the above
Granitic highland

- Zuni Mountains
- High heat flow (2-2.5 HFU; Reiter et al., 1975)
- Precambrian granites in the Zuni Mountains contain as much as 11 ppm (Brookins, 1978)
Volcanic highland

- Jurassic volcanic and plutonic rocks in the southwest
- Meteoric water dissolves uranium from volcanic and plutonic rocks and transport into the San Juan Basin
Jurassic arc (Kowallis et al., 2001)

Subduction zone

Jurassic plutons
(Kowallis et al., 1999; du Bray, 2007)

Jurassic caldera (Lawton and McMillan, 1999)

Approximate direction of sedimentation

Limit of Morrison Basin (Turner and Peterson, 2004)
Alteration of volcanic detritus and shales

- Ash fall and other volcanic detritus erupts from the volcanic arc and deposits into the San Juan Basin
- Mechanical weathering of the volcanic arc deposits detritus into the San Juan Basin
- Subsequent weathering of the ash fall deposits immediately after deposition and during diagenesis releases uranium
HOW DID THE DEPOSITS FORM?
Lacustrine-humate model

• Ground water was expelled by compaction from lacustrine muds formed by a large playa lake
• Humate or secondary organic material precipitated as a result of flocculation into tabular bodies
• During or after precipitation of the humate bodies, uranium was precipitated from ground water
Fluvial facies

Mudflat facies

Playa-lake facies

Detrital magnetite and ilmenite

Ti oxides (Fe leached)

Diagenetic U in organic-rich lenses

Less permeable sandstone

10 m

2 to 10 km

from Turner-Peterson and Fishman (1986)
Brine-interface model

- Uranium and humate were deposited during diagenesis by reduction at the interface of meteoric fresh water and basinal brines or pore water.
- Uranium precipitated in the presence of humates at a gravitationally stable interface between relatively dilute, shallow meteoric water and saline brines that migrated up dip from deeper in the basin.
- Ground-water flow was impeded by upthrown blocks of Precambrian crust and forced upwards.
- These zones of upwelling are closely associated with uranium-vanadium deposits.
Roll-front uranium deposits

• After formation of the primary sandstone uranium deposits, oxidizing ground waters migrated through the uranium deposits and remobilized some of the primary sandstone uranium deposits.

• Uranium was reprecipitated ahead of the oxidizing waters forming redistributed or roll front sandstone uranium deposits.

• Evidence suggests that more than one oxidation front occurred in places (Cretaceous and a Tertiary oxidation front).
Secondary roll-front ore

Diagenetic U ore lenses (not essential to form roll-front deposit)

Molybenite, pyrite, calcite

Hematite, limonite (magnetite) core

Sidereite, goethite, S

Uraninite, pyrite, Se

Oxidized rocks (diagenetic hematite and limonite)

Reduced sandstone (diagenetic pyrite, marcasite, calcite, organic material)

Ground water movement in permeable sandstone

20 to 100 m

From Nash et al. (1981) and Devoto (1978)
FIGURE 4  Map showing distribution of Tertiary-Quaternary oxidation in sandstone of Westwater Canyon Member, Morrison Formation. See Saucier (11), from which this figure is taken, for full discussion of details shown on map.
COMMENTS

• None of the uranium mills remain in the Grants region.
• Current plans by some companies are to mine uranium by ISR or heap leaching.
• Most conventional mining of uranium will require shipping to an existing mill in Utah or Colorado or licensing and building a new mill in New Mexico.
• The Navajo Nation has declared that no uranium production will occur in Indian Country.
CONCLUSION

- Grants district primary uranium deposits formed shortly after deposition coincident with Jurassic arc volcanism to the southwest
- Grants district redistributed uranium deposits formed during periods when oxidizing ground waters could enter the mineralized sandstones and remobilize the older primary uranium deposits
  - During the Cretaceous Dakota deposition ??????
  - During the mid-Tertiary to modern erosional cycle
FUTURE RESEARCH

• More age determinations
• Better understanding of the regional Jurassic tectonics
• Geochemical analyses of the Jurassic sediments and ore deposits
• Determining the age of remobilization or redistributed deposits