ABSTRACT — The Grants uranium district, which extends from east of Laguna to west of Gallup in the San Juan Basin is probably 4th in total historical world production behind East Germany, the Athabasca Basin in Canada, and South Africa. Sandstone uranium deposits account for the majority of the uranium production from the Grants district and the most significant deposits are those in the Morrison Formation, specifically the Westwater Canyon Member, where more than 169,500 short tons of U₃O₈ were produced from 1950 to 2002. At least 114 major mines and undeveloped deposits are found in eight subdistricts in the Grants district, but only four projects offer the potential to produce in the near-term: Roca Honda, Mount Taylor, La Jara Mesa, and Church Rock Section 8. Although deposits currently producing elsewhere tend to be higher grade and/or larger tonnage, the Grants district still contains a large enough resource to have a major impact on the global uranium supply. The economic feasibility of mining a number of these deposits will increase with the licensing and construction of a regional mill, improved in situ recovery technologies, decreasing production costs, and an increase in world-wide uranium consumption.

INTRODUCTION

During a period of nearly three decades (1951-1980), the Grants uranium district in northwestern New Mexico (Fig. 1) yielded more uranium than any other district in the United States (Table 1). Although there are no producing operations in the Grants district today, numerous companies have acquired uranium properties and plan to explore and develop deposits in the district using both conventional and in situ recovery technology. The Grants district is a single large area in the San Juan Basin, extending from east of Laguna to west of Gallup and consists of eight subdistricts (Fig. 1; McLemore and Chenoweth, 1989). The Grants district is probably 4th in total historical world production behind East Germany, the Athabasca Basin in Canada, and South Africa (T. Pool, General Atomics, written commun., 2002). More than 340 million pounds (lbs) of U₃O₈ were produced from the Grants deposits in New Mexico between 1950 and 2002, and more than 300 million lbs of U₃O₈ remain as unmined resources (Table 1; Appendix 1). Most of the uranium production in New Mexico has come from the Morrison Formation in the Grants district in McKinley and Cibola (formerly Valencia) Counties, mainly from the Westwater Canyon Member (Table 2; McLemore, 1983).


Appendix data for this paper can be accessed at:
http://nmgs.nmt.edu/repository/index.cfm?rid=2013002
and has since reclaimed the former Kerr-McGee mill and mines. United Nuclear Corp. is now owned by General Electric Corp. and is reclaiming their former mines and mill in Church Rock and Ambrosia Lake. The predominant companies in the Grants district currently conducting exploration and development include:

- Strathmore Resources US Ltd. (http://www.strathmoreminerals.com)
- Uranium Resources, Inc. (URI; http://www.uraniumresources.com/)
- Rio Grande Resources (http://www.ga.com/nuclear-fuel/rio-grande-resources)
- Laramide Resources Ltd. (http://www.laramide.com/)
- Uranium Energy Corp. (http://www.uraniumenergy.com/)
- Trans America Industries Ltd.
- Aus American Mining

In 2012, Cibola Resources LLC was purchased by Neutron Energy, Inc. in 2010. Neutron Energy, Inc. was purchased by Uranium Resources Inc.

The purpose of this report is to briefly describe the uranium deposits in the Grants district (Table 2), including their production, geology, resources, future potential, and environmental issues. The geology and descriptions of the uranium deposits in the Grants district are described by numerous geologists and summarized by McLemore (1983, 2007, 2009, 2011), McLemore and Chenoweth (1989), McLemore et al. (2002), Canadian National Instrument NI 43-101 reports, company web sites, and other reports as cited. Canadian National Instrument NI 43-101 is a standard guideline used for public disclosure of scientific and technical information concerning mineral properties in Canada (http://www.apgo.net/ni43-101.htm, accessed 3/31/13). The production figures in Table 1 are the best data available and were obtained from published and unpublished sources (NMBGMR file data). Production figures are subject to change as new data are obtained. Some of the resource and reserve data presented here and in Appendix 1 are historical and are provided for information purposes only, and do not conform to Canadian National Instrument NI 43-101 requirements. Other resource/reserve data do conform to NI 3-101 requirements and are specifically referenced as such. The mines and deposits are located on maps by McLemore and Chenoweth (1991).

### DESCRIPTION OF URANIUM DEPOSITS

Sandstone uranium deposits account for the majority of the uranium production from the Grants district and the most significant deposits are those in the Morrison Formation, specifically the Westwater Canyon Member, where more than 169,500 short tons of UO₃ were produced from 1950 to 2002 (McLemore and Chenoweth, 1989). In contrast, production from other sandstone uranium deposits in New Mexico amounts to 234 short tons UO₃ (1948-1970, McLemore and Chenoweth, 1989). There are three types of deposits in the Westwater Canyon Member of the Morrison Formation: primary (trend or tabular), redistributed (stack), and remnant-primary sandstone uranium deposits (Hilpert, 1969; Hilpert and Moench, 1960; Adams and Saucier, 1981). A stratigraphic column is found elsewhere in this guidebook.

Primary sandstone-hosted uranium deposits, also known as prefault, trend, blanket, and black-band ores, are found as blanket-like, roughly parallel ore bodies along trends, mostly in sandstones of the Westwater Canyon Member. These deposits are characteristically less than 2.4 m thick, average more than 0.20% UO₃, and have sharp ore-to-waste boundaries. The largest deposits in the Grants uranium district contain more than 30 million lbs of UO₃.

Redistributed sandstone-hosted uranium deposits, also known as post-fault, stack, secondary, and roll-type ores, are younger than the primary sandstone-hosted uranium deposits. They are discordant, asymmetrical, irregularly shaped, characteristically more than 2.4 m thick, have diffuse ore-to-waste contacts, and cut across sedimentary structures. The average deposit contains approximately 18.8 million lbs UO₃ with an average grade of 0.16% UO₃. Some redistributed uranium deposits are vertically stacked along faults.

Remnant sandstone-hosted uranium deposits were preserved in sandstone after the oxidizing waters that formed redistributed
uranium deposits had passed. Some remnant sandstone-hosted uranium deposits were preserved because they were surrounded by or occur within less permeable sandstone and could not be oxidized by the oxidizing groundwaters. These deposits are similar to primary sandstone-hosted uranium deposits, but are difficult to locate because they occur sporadically within the oxidized sandstone. The average size is approximately 2.7 million lbs U₃O₈ at a grade of 0.20% U₃O₈.

Although, there is no consensus on details of the origin of the Morrison primary sandstone uranium deposits (Nash et al., 1981; Sanford, 1982, 1992; McLemore, 2011), the majority of the proposed models for their formation suggest that deposition occurred at a groundwater interface between two fluids of different chemical compositions and/or oxidation-reduction states. Subsequent models, such as the lacustrine-humate (Turner-Peterson, 1985; Turner-Peterson and Fishman, 1986) and brine-interface (Granger and Santos, 1986; Sanford, 1982, 1992) models have refined or incorporated portions of these early theories.

The primary tabular sandstone uranium deposits formed during Jurassic Westwater Canyon time. Subsequently, oxidizing solutions moved down-dip, modifying tabular deposits into roll-front and fault-related deposits. Evidence, including age dates and geochemistry of the deposits, suggests that roll-front and fault-related deposits were formed possibly during the Early Cretaceous and from a second oxidation front during the mid-Tertiary (McLemore, 2011). A potential source of the uranium, the Zuni Mountains, a granitic highland enriched in uranium (as much as 11 ppm), has high heat flow, and lies south of the district. Another source is Jurassic arc volcanism southwest of the San Juan Basin. It is likely that uranium was leached from both the Jurassic volcanic rocks and the Proterozoic granites (McLemore, 2011), and these waters migrated into the San Juan Basin. These waters likely could have mixed with uranium leached from the volcanic ash that covered much of the area during Jurassic times. The uraniferous groundwater migrated into the Westwater Canyon sandstones and precipitated in the vicinity of
humate and other organic material to form the tabular uranium deposits. During the Late Cretaceous (?) and Tertiary, after formation of the primary sandstone uranium deposits, oxidizing groundwater migrated through the uranium deposits and remobilized some of the primary sandstone uranium deposits (Saucier, 1981; McLemore, 2011). Uranium was reprecipitated ahead of the oxidizing waters forming redistributed sandstone uranium deposits. 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.

Sandstone uranium deposits occur in other formations in the Colorado Plateau. Tabular sandstone uranium-vanadium deposits in the Salt Wash and Recapture Members of the Morrison Formation are restricted to the east Carrizo (including the King Tutt Mesa area) and Chuska Mountains subdistricts of the Shiprock district, western San Juan Basin and in Utah and Arizona (McLemore, 1983; Chenoweth and McLemore, 2010). Roll-front sandstone uranium deposits are found in several areas on the Colorado Plateau. Another type of sedimentary sandstone uranium deposits include stratabound deposits associated with syngenetic organic material or iron oxides, or both, such as at the Boyd deposit near Farmington and in the Chinle Formation throughout northern New Mexico and Arizona (McLemore, 1983; Chenoweth and McLemore, 2010). The C de Baca sandstone uranium deposit is in the Riley area of Socorro County and controlled by Max Resources Corp. (Appendix 1; Bersch, 2008). Recent drilling has occurred in the Datil area but did not delineate any ore bodies. Stratabound, sedimentary-copper deposits containing Cu, Ag, and locally Au, Pb, Zn, U, V, and Mo (also known as “red-bed” or “sandstone” copper deposits) are found throughout New Mexico and Arizona (McLemore, 1983).

### SUMMARY OF THE GRANTS URANIUM DISTRICT BY SUBDISTRICT

#### Ambrosia Lake subdistrict

More than 200 mines, deposits, and occurrences are found in the Todilto Limestone, Morrison Formation and Cretaceous sediments in the Ambrosia Lake subdistrict and more than 50 of these have yielded uranium production since the initial discovery in the Poison Canyon area in 1951 (Appendix 1; McLemore, 1983). The Ambrosia Lake-Mount Taylor trend is the largest mineralized area in the Grants district and includes resources at Mount Taylor and Roca Honda. Uranium mineralization in the Mount Taylor and Roca Honda deposits are primary tabular sandstone deposits within the Westwater Canyon Member. Ore grades range from 0.15% to over 2.0% U₃O₈, and production from Mount Taylor averaged 0.5% U₃O₈ (Table 4; Appendix 1). Major deposits under exploration are listed in Table 4 and Appendix 1. The Mount Taylor mine contains an in-place resource of more than 100 million lbs U₃O₈ and presently, the deposit is being evaluated for development by Rio Grande Resources.

The Roca Honda deposit, located about 3.2 km northwest from the Mount Taylor deposit, is currently controlled by Strathmore, Uranium Resources Inc., Neutron (URI) and private ownership. Kerr-McGee completed a shaft to just above the Westwater...
GRANTS URANIUM DISTRICT

TABLE 4. Resource estimates of major deposits in the Ambrosia Lake subdistrict. See Appendix 1 for references and other information.

<table>
<thead>
<tr>
<th>NM Mines Database Id No</th>
<th>Deposit Name</th>
<th>Latitude (DD)</th>
<th>Longitude (DD)</th>
<th>Resource (tons ore)</th>
<th>Grade (%U)</th>
<th>U lbs</th>
<th>Date of Estimate</th>
<th>Type of Estimate</th>
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<td>reported</td>
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</table>

Canyon Member (approximately 518 m deep) in the 1980s but abandoned the project due to poor market conditions. Currently, Strathmore is the only company developing and permitting their portion of the deposit (T13N, R08W, Secs. 9, 10, and 16). Details regarding Strathmore’s proposed Roca Honda mine are by Khalsa et al. (this volume) and Nakai-Lajoie et al. (2012). Other potential properties are described by Carter (2007, 2008), Bersch (2008), Peters (2007) and summarized in Appendix 1.

Bernabe Montaño subdistrict

The Bernabe Montaño subdistrict lies northeast of the Laguna subdistrict in McKinley, Cibola, and Sandoval Counties. Only one mine has yielded ore production, the Rio Puerco mine in 1979-1980. However, several large, low-grade deposits are found in the subdistrict (Appendix 1). The Westwater Canyon Member is approximately 60-91 m thick and the depth of uranium mineralization is approximately 244 m at the Rio Puerco mine and approximately 305-732 m at Bernabe Montaño. Most of the uranium deposits are primary tabular deposits in multiple horizons (Moore and Lavery, 1980; Kozusko and Saucier, 1980).

Chaco Canyon subdistrict

The Chaco Canyon subdistrict is north of the Church Rock-Crowpoint subdistrict. Although no uranium production has occurred from the subdistrict, drilling by Bendix Field Engineering Corp. identified nine mineralized zones in the Westwater Canyon and lower Brushy Basin Members that contained 0.015 to 0.125% U₃O₈ (Hicks et al., 1980; Bendix Field Engineering Corp., 1979). The economic feasibility of these mineralized zones remains to be proven.
The Church Rock-Crownpoint subdistrict is located at the western edge of the Grants uranium district and is also known as the Gallup subdistrict. There are more than 50 uranium occurrences, most of which are found in the Westwater Canyon Member of the Morrison Formation (McLemore, 1983). Several occurrences also have been found in the Brushy Basin Member of the Morrison Formation and the overlying Cretaceous Dakota Sandstone. Uranium in the district is found at average depths of 457-610 m below ground surface. Uranium was first discovered in the early 1960’s. Potential uranium resources in the subdistrict have historically been estimated at approximately 60 million lbs of U₃O₈ (Appendix 1); major deposits under exploration are listed in Table 5. Mineralized zones are both primary tabular ore deposits as well as redistributed, roll-front morphology deposits (McLemore, 1983; Fitch, 2005; Myers, 2006a, b, c; Beahm, 2012).

Uranium Resources, Inc. recently released a Feasibility Study for their Church Rock property (T16N, R16W, Sec 8) indicating a recovery of 4.4 million lbs of U₃O₈ via in situ recovery over a six year production life (Uranium Resources, Inc. press release, December 31, 2012).

Strathmore currently controls the mineral claims on sec. 4, T16N, R16W within the Church Rock subdistrict. Strathmore purchased the property in 2004 from Rio Algom Mining, who had acquired the property from Kerr-McGee, who originally staked the claims in 1965. Strathmore is currently evaluating the property for in situ recovery.

Strathmore also holds mining claims at Dalton Pass covering approximately 640 acres. The previous operator, Pathfinder

<table>
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<th>NM Mines Database Id No</th>
<th>Deposit Name</th>
<th>Latitude (DD)</th>
<th>Longitude (DD)</th>
<th>Resource (tons ore)</th>
<th>Grade (%U)</th>
<th>U lbs</th>
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Table 5. Resource estimates of major deposits in the Church Rock-Crownpoint subdistrict. See Appendix 1 for references and other information.
Laguna subdistrict

Uranium was discovered in the Laguna subdistrict in 1951 by aerial reconnaissance at the Jackpile-Paguate mine, one of the largest open pit uranium mines in the world. More than 80 million lbs of UO₂ was produced from 1952 to 1982. Most of the larger deposits, including the Jackpile-Paguate, are primary tabular sandstone deposits found in the Jackpile sandstone, above the Brushy Basin Member, and tend to align in a northeast-trending belt subparallel to the axis of the Jackpile sandstone (Appendix 1; McLemore, 1983). Uranium deposits also are found in breccia pipes, the Westwater Canyon and Recapture Members of the Morrison Formation, and the Todito Limestone. Five mines or mine complexes produced from 1952 to 1982 and resources remain in the subdistrict (Appendix 1).

Marquez subdistrict

Uranium deposits in the Marquez subdistrict are almost exclusively in the lower Westwater Canyon Member, although some low-grade uranium is found in the Jackpile sandstone and in the Brushy Basin and Recapture Members (Livingston, 1979; Moore and Lavery, 1980). Very little uranium was produced from the subdistrict (Table 1), but significant resources have been delineated and potential targets exist (Appendix 1). The mineral deposits, discovered in the late 1960s and 1970s, are mostly primary tabular sandstone types found in three distinct sandstone horizons, although minor redistributed sandstone deposits are found along faults. Bokum Resources sank a shaft at the Marquez mine in 1977-1980, but never completed it. Kerr-McGee sank a 250 m shaft at the Rio Puerco deposit and extracted 10,160 short tons for milling, then terminated the lease (Randabel and Vukovic, 2009). Kerr-McGee also drilled a Marquez deposit in 1973-1977 and in 1978, sold a 50% interest to the Tennessee Valley Authority (TVA). In 1980 Kerr-McGee returned the Marquez property to the claim owners. Aus American Mining controls the Rio Puerco deposit.

Neutron Energy, purchased by Uranium Resources Inc. in 2012, controls the portion of the Marquez deposit formerly owned by Bokum Resources. Strathmore controls the Kerr-McGee portion of the Marquez deposit through a mineral lease acquired in 2007 (Alief, 2010). The Strathmore portion of the Marquez deposit contains a measured and indicated NI 43-101 compliant resource of 9.130 million lbs of UO₂ at a grade of 0.126% UO₂ and an additional inferred resource of 4.906 lbs of UO₂ at a grade of 0.114% UO₂ (Alief, 2010).

Summary of Environmental Issues

The substantial development of uranium in New Mexico during the mid-twentieth century left a legacy of former mining properties scattered throughout the Grants uranium district. Most uranium mines and mills closed with few requirements for reclamation or remediation. Federal and state water quality laws only began enacting significant regulatory requirements in the 1970s; state surface reclamation laws were not passed until the New Mexico Mining Act of 1993.

Historical releases to groundwater and surface water, soil, and air have been documented from legacy uranium mine and mill sites throughout the Grants district (McLemore, 2010a, b; US EPA, 2010a), and have the potential to release contaminants to the environment from the present and into the future. Physical hazards, including open adits and shafts and uncontrolled waste rock and ore piles, remain at many mine sites (Anderson, 1980; McLemore, 1983; US EPA, 2010a).
to the ground or surface drainages, creating perennial stream flows in major drains (NMED, 2010). The extensive dewatering operations significantly changed area hydrologic conditions, resulting in continuing influx of oxygenated groundwater to the dewatered areas (US EPA, 2010a). Process waters from unlined leach pads, evaporation and tailing ponds, heap- and stopet-leaching and uranium milling operations also were discharged to the surface. Impacts to groundwater from these discharges were noted both in a 1975 Environmental Protection Agency document titled “Summary of Ground-Water Quality Impacts of Uranium Mining and Milling in the Grants Mineral Belt, New Mexico” and a 1986 New Mexico Environmental Improvement Division document (NMED, 2010).

Aerial surveys were conducted near Ambrosia Lake and Grants, New Mexico, during August and October, 2011, to determine if residual surface contamination exceeding normal background concentrations was present. The terrestrial background exposure rate in the area ranged between 5 to 10 μR/h. Results indicate that areas associated with elevated radiation levels ranged from 20 μR/h to 435 μR/h (US EPA, 2011a; b).

Since the 1980s, several federal, state and tribal agencies and former mining companies have pursued cleanup and reclamation activities under various laws. Contamination associated with former uranium extraction activities within the Shiprock district and the Church Rock-Crownpoint, Nose Rock and Smith Lake subdistricts and part of the Ambrosia Lake subdistrict are partly under the jurisdiction of the Navajo Nation and are being addressed by U.S. Environmental Protection Agency (EPA) Region 9. Details of the EPA Region 9 and Navajo Nation activities can be found in the Health and Environmental Impacts of Uranium Contamination in the Navajo Nation Five-Year Plan, website (US EPA, 2010b). The remainder of the Ambrosia Lake subdistrict, as well as the Bernabe Montaño, Laguna and Marquez subdistricts contain legacy uranium sites that are under the jurisdiction of EPA Region 6 and the State of New Mexico. Details of the EPA Region 6 and State of New Mexico activities can be found in the five-year plan for the Grants district (US EPA, 2011b).

**FUTURE POTENTIAL**

Of the properties mentioned above (Appendix 1), a few have the potential to be advanced to a recovery state in the near-term under current or projected market conditions. These projects include existing mines coming back into production, new underground conventional mines, and in situ recovery projects. While some of the mines and districts mentioned above and in Appendix 1 could be economic under current conditions, they are currently not being moved forward by their current owners and will not be discussed here.

There are four projects that offer the potential to produce in the near term. These projects account for a combined resource in excess of 145 million lbs of U₃O₈. Strathmore’s Roca Honda project has completed a Preliminary Economic Assessment, submitted a mine permit to the State of New Mexico, and has received a draft Environmental Impact Statement (EIS) from the U.S. Forest Service. Rio Grande Resources’ Mount Taylor project, currently on standby, has the largest resource. Laramide Resources’ La Jara Mesa has submitted a mine Plan of Operations to the U.S. Forest Service and has subsequently received a draft EIS. Uranium Resources’ Church Rock Section 8 holds a radioactive materials license and has been granted water rights for the life of the mine by the New Mexico Office of the State Engineer. Recognizing the importance of a regional mill in bringing additional mines on line, Strathmore is currently gathering baseline data for the purpose of submitting an application to the U.S. Nuclear Regulatory Commission for licensing of their Peña Ranch mill.

It is possible that additional mines will be brought into production in the Grants uranium district as global demand increases. These properties include those owned by Strathmore and Uranium Resources/Neutron Energy at Marquez as well as both companies’ Nose Rock properties. The feasibility of mining lower grade, smaller tonnage deposits in the region depends largely on the price of uranium and the availability of a regional mill. Currently the closest mill to the Grants uranium district is Energy Fuels’ White Mesa mill in Blanding, UT (322 km away). Current uranium prices prohibit shipment of ore to this mill. Strathmore is in the process of submitting a mill license application to the U.S. Nuclear Regulatory Commission for their Peña Ranch mill, located near Ambrosia Lake. Future development of these reserves and resources will depend upon the lowering of production costs, perhaps by in situ recovery techniques.

**SUMMARY**

Sandstone uranium deposits in the Grants uranium district, New Mexico have played a major role in world historical uranium production. Although other types of uranium deposits in the world are higher in grade and larger in tonnage, the Grants uranium district could again become a significant source of uranium:

- When a mill is built in the district
- As in situ recovery technologies improve, decreasing production costs
- As demand for uranium increases world-wide, increasing the price of uranium.

However, several challenges need to be overcome by the companies before uranium can be produced once again from the Grants uranium district:

- There are no conventional mills remaining in New Mexico to process the ore, which adds to the cost of producing uranium in the state. New infrastructure will need to be built before conventional mining can resume.
- Permitting for new in situ recovery and especially for conventional mines and mills will possibly take years to complete (Pelizza and McCarn, 2003a, b, 2004).
- Operational, monitoring, contingency and closure plans, including reclamation must be developed before mining or in situ recovery begins. Modern regulatory costs will add to the cost of producing uranium in the U.S.
• Some communities, especially the Navajo Nation communities, do not view development of uranium properties as favorable. The Navajo Nation has declared that no uranium production will occur on Navajo lands (Dine Natural Resources Protection Act of 2005; Navajo Nation, 2005).

• The Pueblo of Acoma, the Hopi Tribe, Pueblo of Laguna, Navajo Nation and Pueblo of Zuni petitioned the New Mexico Historic Preservation Division to recognize Mount Taylor as a Traditional Cultural Property (TCP). The Cultural Properties Review Committee permanently listed Mount Taylor as a TCP in the State Register of Cultural Properties in June 2009 (NM Department of Cultural Affairs press release, June 5, 2009).

• High-grade, low-cost uranium deposits in Canada and Australia are sufficient to meet current international demands; but additional resources will be required to meet near-term and future requirements.

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