

# URANIUM RESOURCES IN THE GRANTS URANIUM DISTRICT, NEW MEXICO: AN UPDATE

VIRGINIA T. McLEMORE<sup>1</sup>, BRAD HILL<sup>2</sup>, NIRANJAN KHALSA<sup>2</sup>, AND SUSAN A. LUCAS KAMAT<sup>3</sup>

<sup>1</sup>New Mexico Bureau of Geology and Mineral Resources, NM Institute of Mining and Technology, Socorro, NM 87801, ginger@nmbg.nmt.edu

<sup>2</sup>Strathmore Res. US Ltd., 4001 Office Court Dr., Suite 102, Santa Fe, NM 87507

<sup>3</sup>New Mexico Environment Department, Albuquerque, NM 87185

**ABSTRACT**—The Grants uranium district, which extends from east of Laguna to west of Gallup in the San Juan Basin is probably 4<sup>th</sup> 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 U<sub>3</sub>O<sub>8</sub> 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 4<sup>th</sup> 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 U<sub>3</sub>O<sub>8</sub> were produced from the Grants deposits in New Mexico between 1950 and 2002, and more than 300 million lbs of U<sub>3</sub>O<sub>8</sub> 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).

The early history of uranium production in the Grants district is summarized by Chenoweth (1985a, b, 1989), Chenoweth and Holen (1979), and McLemore (1983). Table 3 summarizes the status of the uranium mills in the Grants district. Appendix 1 summarizes the important uranium deposits and mines in the Grants district and elsewhere in New Mexico and includes updates on the production and resource estimates. In 2001, Homestake Corp. merged with Barrick Gold Corp. Homestake completed surface reclamation of the Homestake mill at Milan in 2004. Groundwater remediation and corrective actions at the Homestake mill are on-going. Kermac Nuclear Fuels Corp., a partnership of Kerr-McGee Oil Industries Inc., Anderson Development Corp., and Pacific Uranium Mines Co., built the Kerr-McGee mill at

Ambrosia Lake in 1957-1958 and began milling in 1958. In 1983, Quivira Mining Co. became a subsidiary of Kerr-McGee Corp. and from 1985-2002, the mill produced only from mine waters recovered from the Ambrosia Lake underground mines. Total production from this mine-water recovery amounted to 9,635,869 lbs of U<sub>3</sub>O<sub>8</sub> from 1963-2002 (McLemore, 2011). Quivira Mining Corporation was bought by Rio Algom in 1989. Rio Algom was bought by Billiton (which later became BHP Billiton) in 2000

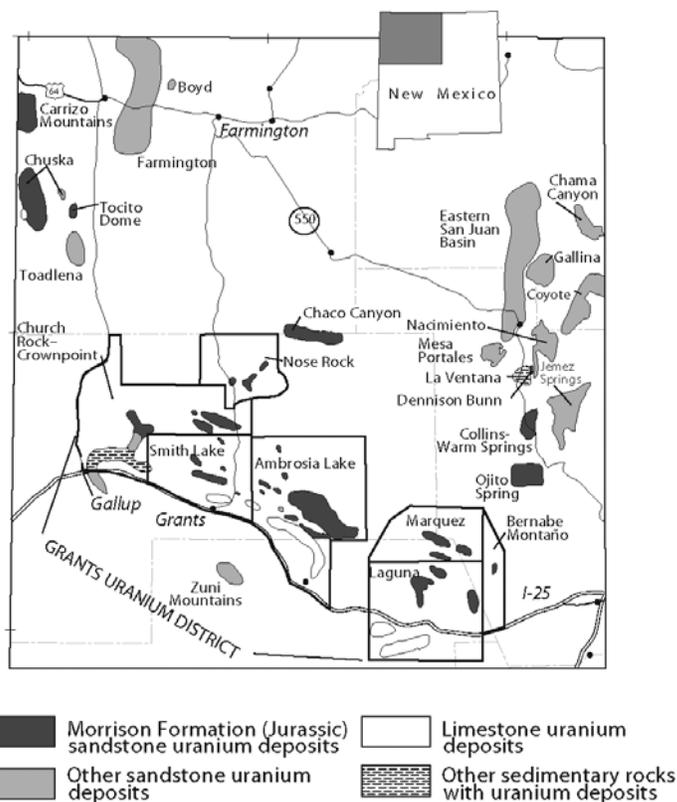


FIGURE 1. Subdistricts in the Grants uranium district listed in Table 1 and other districts in the San Juan Basin, New Mexico with uranium deposits. Polygons outline approximate areas of known uranium deposits.

*Appendix data for this paper can be accessed at:*

<http://nmgs.nmt.edu/repository/index.cfm?rid=2013002>

Table 1. Uranium production and types of deposits by subdistrict in the Grants uranium district, New Mexico (McLemore and Chenoweth, 1989, production from 1988-2002 estimated by the senior author). See Appendix 1, McLemore (1983, 2009), McLemore and Chenoweth (1989, table 3), and McLemore et al. (2002) for more details and locations of additional minor uranium occurrences. Types of deposits defined in Table 2. Subdistricts shown in Figure 1.

DISTRICT	PRODUCTION (lbs U <sub>3</sub> O <sub>8</sub> )	GRADE (U <sub>3</sub> O <sub>8</sub> %)	PERIOD OF PRODUCTION	TYPES OF DEPOSITS
Laguna	>100,600,000	0.1-1.3	1951-1983	A, C, E
Marquez	28,000	0.1-0.2	1979-1980	A
Bernabe Montaña	None			A
Ambrosia Lake	>211,200,000	0.1-0.5	1950-2002	A, B, C, E
Smith Lake	>13,000,000	0.2	1951-1985	A, C
Church Rock-Crownpoint	>16,400,000	0.1-0.2	1952-1986	A, B
Nose Rock	None			A
Chaco Canyon	None			A

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 U<sub>3</sub>O<sub>8</sub> 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 U<sub>3</sub>O<sub>8</sub> (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 pre-fault, 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% U<sub>3</sub>O<sub>8</sub>, and have sharp ore-to-waste boundaries. The largest deposits in the Grants uranium district contain more than 30 million lbs of U<sub>3</sub>O<sub>8</sub>.

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 U<sub>3</sub>O<sub>8</sub> with an average grade of 0.16% U<sub>3</sub>O<sub>8</sub>. 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

Table 2. Classification of uranium deposits in New Mexico (modified from McLemore and Chenoweth, 1989; McLemore, 2001, 2009). Deposit types in bold are found in the Grants uranium district.

---



---

I.	Peneconcordant uranium deposits in sedimentary host rocks
A.	<b>Morrison Formation (Jurassic) sandstone uranium deposits</b>
•	<b>Primary, tabular sandstone uranium-humate deposits in the Morrison Formation</b>
•	<b>Redistributed sandstone uranium deposits in the Morrison Formation</b>
•	<b>Remnant sandstone uranium deposits in the Morrison Formation</b>
•	Tabular sandstone uranium-vanadium deposits in the Salt Wash and Recapture Members of the Morrison Formation
B.	<b>Other sandstone uranium deposits</b>
•	<b>Redistributed uranium deposits in the Dakota Sandstone (Cretaceous)</b>
•	<b>Roll-front sandstone uranium deposits in Cretaceous and Tertiary sandstones</b>
•	Sedimentary uranium deposits
•	Sedimentary-copper deposits
•	<b>Beach placer, thorium-rich sandstone uranium deposits</b>
C.	<b>Limestone uranium deposits</b>
•	<b>Limestone uranium deposits in the Todilto Formation (Jurassic)</b>
•	Other limestone deposits
D.	<b>Other sedimentary rocks with uranium deposits</b>
•	<b>Carbonaceous shale and lignite uranium deposits</b>
•	Surficial uranium deposits
II.	Fracture-controlled uranium deposits
E.	Vein-type uranium deposits
•	Copper-silver (uranium) veins (formerly Jeter-type, low-temperature vein-type uranium deposits and La Bajada, low-temperature uranium-base metal vein-type uranium deposits)
•	<b>Collapse-breccia pipes (including clastic plugs)</b>
•	Volcanic epithermal veins
•	Laramide veins
III.	Disseminated uranium deposits in igneous and metamorphic rocks
F.	Igneous and metamorphic rocks with disseminated uranium deposits
•	Pegmatites
•	Alkaline rocks
•	Granitic rocks
•	Carbonatites
•	Miscellaneous

---

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  $U_3O_8$  at a grade of 0.20%  $U_3O_8$ .

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 uraniumiferous groundwater migrated into the Westwater Canyon sandstones and precipitated in the vicinity of

TABLE 3. Uranium mills in New Mexico (McLemore and Chenoweth, 20032). Mine id refers to Mine identification number and location in McLemore et al. (2002).

Mine id	Mill Name	Year built	Year first operated	Year last operated	Maximum Milling Capacity (short tons of ore per day)	Amount of tailings (estimated in million short tons)	Mill owner	Current status
NMCI0110	Homestake	1957	1958	1990	3500	22.225	Homestake Mining Co	Decommissioned in 1993, reclamation completed
NMMK0349	Ambrosia Lake (Kerr-McGee Corp., Rio Algom Mining)	1957	1958	2002	7000	?	Quivira Mining Co., subsidiary of BHP-Bulliton	reclamation nearly completed
NMCI0109	Bluewater	1953	1953	1982	6000	24	ARCO (Anaconda)	Decommissioned, reclamation completed
NMMK0125	Church Rock	1977	1977	1982	3000	3.5	United Nuclear	Decommissioned in 1993
NMMK0353	Phillips (Ambrosia Lake)	1958	1958	1963	1750	6.931	Phillips Petroleum Company, United Nuclear Corp.	Decommissioned, reclamation completed under UMTRCA
NMMK0354	Bokum	1980	none	none	?	none	Bokum Resources	declared bankruptcy in 1981
NMSJ0115	Shiprock (Navajo)	1954	1954	1968	500	2.52	Foote Mineral Co.	Decommissioned, reclamation completed under UMTRCA in 1986
NMCI0108	L-Bar	1976	1976	1981	1600	?	Kennecott Energy Co. (formerly Sohio)	

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). 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%  $U_3O_8$ , and production from Mount Taylor averaged 0.5%  $U_3O_8$  (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  $U_3O_8$  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

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

NM Mines Database Id No	Deposit Name	Latitude (DD)	Longitude (DD)	Resource (tons ore)	Grade (%U)	U lbs	Date of Estimate	Type of Estimate	Operator
NMMK0020	Borrego Pass	35.620119	107.94362	45,000,000	0.15		1983	historic	Conoco
NMMK0035	Cliffside (Frosty Ox)	35.395569	107.74929		see NM MK0239	1985	historic	Trans America Industries, Neutron Energy	Uranium Resources Inc.
NMCI0251	East Area	35.279174	107.74755	388,434	0.25		2006	NI 43-101 measured and indicated	Laramide Resources
NMMK0712	East Roca Honda	35.373201	107.65319	2,750,000	0.175	9,625,000	1985	historic	Trans America Industries Ltd
NMCI0020	La Jara Mesa	35.280139	107.74489	1,555,899	0.23	7,257,817	2007	NI 43-101 measured and indicated	Laramide Resources
NMCI0027	Mount Taylor 2012	35.334977 historic	107.63558 Rio Grande Resources Corp, General Atomics	4,800,000	0.15-0.2 0.16	100,000,000 15,300,000	2002 2011	historic reported	Mobil-TVA Uranium Resources Inc.
NMMK0142	Roca Honda	35.365717	107.6966	2,077,000	0.404	16,783,000	2012	NI 43-101 measured and indicated	Strathmore
NMMK0143	Roca Honda	35.363139	107.69961	3,900,000	0.19	14,700,000	2011	reported	Uranium Resources Inc.
NMMK0179	Section 13	35.348778	107.63547	710,000	0.17	2,400,000	2011	reported	Uranium Resources Inc.
NMMK0210	Section 24 (Treeline)	35.347278	107.74672		0.11	577,000		historic	Western Uranium Corp
NMMK0222	Section 26 (Elizabeth)	35.408972	107.76286	924,198	0.24	4,440,605			Trans America Industries Ltd
NMMK0239	Section 31 (Frosty Ox)	35.398194	107.72336	303,695	0.165	1,002,160	1985	historic	Trans America Industries Ltd
NMMK0250	Section 35 (Elizabeth)	35.398861	107.75842	838,418	0.24	2,014,225	1985	historic	Trans America Industries Ltd
NMMK0340	West Largo	35.5257	107.92151	2,800,000	0.3	17,200,000	2011	reported	Uranium Resources Inc.

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 Montaña subdistrict

The Bernabe Montaña 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 Montaña. 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-Crownpoint 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% U<sub>3</sub>O<sub>8</sub> (Hicks et al., 1980; Bendix Field Engineering Corp., 1979). The economic feasibility of these mineralized zones remains to be proven.

Table 5. Resource estimates of major deposits in the Church Rock-Crownpoint subdistrict. See Appendix 1 for references and other information.

NM Mines Database Id No	Deposit Name	Latitude (DD)	Longitude (DD)	Resource (tons ore)	Grade (%U)	U lbs	Date of Estimate	Type of Estimate	Operator
NMMK0025	Canyon	35.65699	108.20692	600,000	0.12		1983	historic	
NMMK0034	Church Rock (Section 17)	35.62221	108.55273	8,443,000			2002	historic	Uranium Resources Inc.
NMMK0128	Church Rock ISL (Section 8)	35.63031	108.55064	3,060,000	0.11	6,500,000	2012	proven and probable reserves	Uranium Resources Inc.
NMMK0316	Church Rock-Section 4	35.6423	108.53346	2,564,000	0.11	5,502,000	1995	historic	Strathmore
NMMK0036	Crownpoint	35.68475	108.16042	9,477,000	0.102	19,205,000	2012	indicated	originally Conoco, Uranium Resources Inc.
NMMK0040	Crownpoint ISL (Unit 1)	35.70668	108.22052	27,000,000			2002	historic	Mobil-TVA
NMMK0346	Crownpoint-Section 24	35.68459	108.1677	4,800,000	0.16	15,300,000	2011	reported	Uranium Resources Inc.
NMMK0043	Dalton Pass	35.67849	108.26496	600,000	0.12		1983	historic	United Nuclear-TVA
NMMK0044	Dalton Pass	35.6813	108.27829	200,000	0.1		1983	historic	United Nuclear-TVA
NMMK0101	Mancos-Section 12	35.62645	108.58327	11,300,000	0.11			historic	Uranium Resources Inc.
NMMK0100	Mancos-Section 7	35.62894	108.58055	5,200,000	0.11	11,300,000	2011	reported	Uranium Resources Inc.
NMMK0111	Narrow Canyon	35.64484	108.29841	828,000	0.12		1983	historic	Pioneer Nuclear
NMMK0117	NE Church Rock	35.65841	108.50853	2,250,000	0.15		1969	historic	United Nuclear Corporation
NMMK0112	NE Church Rock 1	35.6665	108.50273	708,589	0.247		1983	historic	Navajo Indian Reservation
NMMK0114	NE Church Rock 2	35.67663	108.52621	2,850,000	0.19		1979	historic	Navajo Indian Reservation
NMMK0115	NE Church Rock 3	35.69756	108.54866	4,200,000	0.2		1983	historic	Navajo Indian Reservation
NMMK0126	Section 32-Dalton Pass	35.66422	108.23567	1,622,650	0.095	3,070,726	2009	NI 43-101 measured and indicated	Strathmore

### Church Rock-Crownpoint subdistrict

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 U<sub>3</sub>O<sub>8</sub> (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 U<sub>3</sub>O<sub>8</sub> 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

Mining Company, drilled more than 130 exploration holes and was studying the economic feasibility and amenability of an in situ recovery facility before abandoning the property in the 1980s. Strathmore has completed a NI 43-101 compliant resource for the property, which shows a measured and indicated resource of 3.017 million lbs of  $U_3O_8$  at a grade of 0.10%  $U_3O_8$ . An additional 1.530 million lbs  $U_3O_8$  at a grade of 0.08%  $U_3O_8$  is inferred (Alief, 2009a).

#### **Laguna subdistrict**

Uranium was discovered in the Laguna subdistrict in 1951 by aerial reconnaissance at the Jackpile-Paguete mine, one of the largest open pit uranium mines in the world. More than 80 million lbs of  $U_3O_8$  was produced from 1952 to 1982. Most of the larger deposits, including the Jackpile-Paguete, 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 Todilto 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  $U_3O_8$  at a grade of 0.126%  $U_3O_8$  and an additional inferred resource of 4.906 lbs of  $U_3O_8$  at a grade of 0.114%  $U_3O_8$  (Alief, 2010).

#### **Nose Rock subdistrict**

The northern-most uranium deposits are found in the Westwater Canyon Member in the Nose Rock subdistrict at depths of 9140 to 1219 m, where more than 25 million lbs of  $U_3O_8$  were delineated by Phillips Petroleum Company, but never mined (McLemore, 1983). Drilling in the Chaco Canyon area, north of Nose Rock deposits found uranium-bearing horizons (0.015-0.125% radiometric equivalent  $U_3O_8$ ) in the Westwater Canyon Member at depths of 1280 to 1585 m (Hicks et al., 1980; Bendix Field Engineering Corp., 1979).

Currently, the Nose Rock deposit is held in fee by Uranium Resources, Inc. (T19N, R11W, Secs. 10, 11, 15, 17, 18, 19, 20, 29, 30, and 31; Uranium Resources, Inc., 2011; <http://www.uranium-resources.com/projects/new-mexico/nose-rock>) and as 102 lode mining claims and six State of New Mexico Mineral Leases by Strathmore (located in T19N R11W, Sec. 16, T19N, R12W Sec. 36, and T18N, R12W, Secs. 1, 2, 11, 14, 16, 32, and 36). Section 1 of the Strathmore portion of the deposit contains a measured and indicated NI 43-101 compliant resource of 2.593 million lbs of  $U_3O_8$  at 0.147%  $U_3O_8$  grade and an additional inferred resource of 0.452 million lbs of  $U_3O_8$  at 0.135%  $U_3O_8$  (Alief, 2009b).

#### **Smith Lake subdistrict**

Eight mines in the Smith lake subdistrict have produced uranium and additional, unmined deposits are found in the subdistrict (Appendix 1). Only the Black Jack No. 1 and several uranium occurrences are found in the Westwater Canyon Member; both primary tabular and redistributed sandstone deposits are found at the Black Jack No. 1 mine. The remaining deposits in the Smith Lake subdistrict are found in the Brushy Basin Member and are aligned in a northwest-southeast trend.

### **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).

In the Ambrosia Lake subdistrict, approximately 80 billion gallons of mine water was extracted from the subsurface from mine dewatering and aquifer depressurizing operations. Most of the mine waters received little or no treatment before discharge

to the ground or surface drainages, creating perennial stream flows in major drainages (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 stope-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 natural background concentrations was present. The terrestrial background exposure rate in the area ranged between 5 to 10  $\mu\text{R}/\text{h}$ . Results indicate that areas associated with elevated radiation levels ranged from 20  $\mu\text{R}/\text{h}$  to 435  $\mu\text{R}/\text{h}$  (US EPA, 2011a; b).

Since the 1980s, several federal, state and tribal agencies and former mining companies have pursued clean-up 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 Montaña, 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  $\text{U}_3\text{O}_8$ . 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 companys' 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 Fuel's 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.

### ACKNOWLEDGMENTS

This report is part of on-going studies of mineral resources in New Mexico, supported by the New Mexico Bureau of Geology and Mineral Resources (NMGMMR), a division of New Mexico Institute of Mining and Technology, L. Greer Price, Director and State Geologist and by the New Mexico Environment Department. Thanks to Rick Edge, William Chenoweth, and Dan Kapostasy who reviewed an earlier version of this manuscript.

### REFERENCES

- Adams, S.S. and Saucier, A.E., 1981, Geology and recognition criteria for uraniferous humate deposits, Grants uranium region, New Mexico—final report: U.S. Department of Energy, Open-file report GJBX-2(81), 225 p.
- Alief, M.H., 2009a, Technical report on Section 32, T17N, R13W, Dalton Pass uranium property, McKinley County, New Mexico: NI 43-101 Mineral Resource Report prepared for Strathmore Minerals Corp., 22 p., <[http://www.strathmoreminerals.com/i/pdf/DPStrathmore43101\\_30jan09.pdf](http://www.strathmoreminerals.com/i/pdf/DPStrathmore43101_30jan09.pdf)>
- Alief, M.H., 2009b, Technical report on Section 1, T18N, R12W, Nose Rock uranium property, McKinley County, New Mexico: NI 43-101 Mineral Resource Report prepared for Strathmore Minerals Corp., 27 p., <[http://www.strathmoreminerals.com/i/pdf/NRStrath43101Final\\_09feb09.pdf](http://www.strathmoreminerals.com/i/pdf/NRStrath43101Final_09feb09.pdf)>
- Alief, M.H., 2010, Marquez uranium property, McKinley and Sandoval Counties, New Mexico: NI 43-101 Mineral Resource Report prepared for Strathmore Minerals Corp., 35 p., <[http://www.strathmoreminerals.com/i/pdf/MARQUEZ\\_Strathmore\\_43-101-FINAL\\_10june2010.pdf](http://www.strathmoreminerals.com/i/pdf/MARQUEZ_Strathmore_43-101-FINAL_10june2010.pdf)>
- Anderson, O.J., 1980, Abandoned or inactive uranium mines in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Report OF-18, 778 p.
- Beahm, D.L., 2012, Crownpoint and Hosta Butte uranium project, McKinley County, New Mexico, USA: Tigris Uranium Corp., 81 p.
- Bendix Field Engineering Corp., 1979, Engineering report on the drilling in the east Chaco Canyon area of New Mexico: U.S. Department of Energy, Report, GJBX-101(79), 47 p.
- Bersch, M.G., 2008, Technical Report on the C de Baca uranium project, Socorro County, New Mexico, USA: NI 43-101 report for Max Resource Corporation, 53 p., <[http://www.maxresource.com/i/pdf/2008-03-05\\_NI43-101\\_CdeBaca.pdf](http://www.maxresource.com/i/pdf/2008-03-05_NI43-101_CdeBaca.pdf)>
- Carter, G.S., 2007, Technical report on the uranium resources on the Cebolleta uranium project, Cibola County, New Mexico, USA: NI 43-101 Mineral Resource Report prepared for Cebolla Resources LCC, c/o Neutron Energy Inc., 46 p.
- Carter, G.S., 2008, Technical report on the uranium resources at Ambrosia Lake uranium project, McKinley County, New Mexico: NI 43-101 Mineral Resource Report prepared for Trans America Industries Ltd., 51 p.
- Chenoweth, W.L., 1985a, Historical review of uranium production from the Toddlito Limestone, Cibola and McKinley Counties, New Mexico: *New Mexico Geology*, v. 7, p. 80-83.
- Chenoweth, W.L., 1985b, Raw materials activities of the Manhattan Project in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Report OF-241, 12 p.
- Chenoweth, W.L., 1989, Geology and production history of uranium deposits in the Dakota Sandstone, McKinley County, New Mexico: *New Mexico Geology*, vol. 11, p. 21-29.
- Chenoweth, W.L. and Holen, H.K., 1979, Exploration in Grants uranium region since 1963; in C.A. Rautman, compiler, *Geology and mineral technology of the Grants uranium region 1979*: New Mexico Bureau of Mining and Mineral Resources, Memoir 38, p. 17-21.
- Chenoweth, W.L. and McLemore, V.T., 2010, Uranium in the Sanostee district, San Juan County, New Mexico: *New Mexico Geological Society Guidebook 61*, p. 213-220.
- Fitch, D., 2005, Technical report of the Strathmore Church Rock uranium property, McKinley County, New Mexico: Technical Report for SEDAR, 59 p.
- Granger, H.C., and Santos, E.S., 1986, Geology and ore deposits of the Section 23 mine, Ambrosia Lake district, New Mexico; in Turner-Peterson, C. E., Santos, E. S., and Fishman, N. S., eds., *A basin analysis case study: The Morrison Formation, Grants uranium region, New Mexico*: American Association of Petroleum Geologists, *Studies in Geology* 22, p. 185-210.
- Hicks, R.T., Lowry, R.M., Della Valle, R.S., and Brookins, D.G., 1980, Petrology of Westwater Canyon Member, Morrison Formation, East Chaco Canyon drilling project, New Mexico—comparison with Grants mineral belt; in C.A. Rautman, compiler, *Geology and mineral technology of the Grants uranium region 1979*: New Mexico Bureau of Mining and Mineral Resources, Memoir 38, p. 208-214.
- Hilpert, L.S., 1969, Uranium resources of northwestern New Mexico: U.S. Geological Survey, Professional Paper 603, 166 p.
- Hilpert, L.S. and Moench, R.H., 1960, Uranium deposits of the southern part of the San Juan Basin, New Mexico: *Economic Geology*, v. 55, no. 3, p. 429-464.
- Khalsa, N.K., Hill, B. and Kapostasy, D., 2013, The Roca Honda mine project—a summary: *New Mexico Geological Society*, this guidebook.
- Kozusko, R.G. and Saucier, A.E., 1980, The Bernabe Montañño uranium deposit, Sandoval County; in C.A. Rautman, compiler, *Geology and mineral technology of the Grants uranium region 1979*: New Mexico Bureau of Mining and Mineral Resources, Memoir 38, p. 263-268.
- Livingston, Jr., B.A., 1979, Geology and development of Marquez, New Mexico, uranium deposit; in C.A. Rautman, compiler, *Geology and mineral technology of the Grants uranium region 1979*: New Mexico Bureau of Mining and Mineral Resources, Memoir 38, p. 252-261.
- McLemore, V.T., 1983, Uranium and thorium occurrences in New Mexico: distribution, geology, production, and resources; with selected bibliography: New Mexico Bureau of Mines and Mineral Resources, Open-file Report OF-182, 950 p., also U.S. Department of Energy Report GJBX-11(83).
- McLemore, V.T., 2001, Silver and gold resources in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resource Map 21, 60 p.
- McLemore, V.T., 2007 Uranium resources in New Mexico: Society for Mining, Metallurgy, and Exploration Inc. (SME) preprint, 2007 annual meeting, 18 p., <<http://geoinfo.nmt.edu/staff/mclemore.htm>> (accessed December 06, 2007).
- McLemore, V.T., 2009, In-situ recovery of sandstone uranium deposits in New Mexico: Past, present, and future issues and potential: Society for Mining, Metallurgy and Exploration Inc., Annual Convention, Denver, Feb 2009, Preprint 09-21.
- McLemore, V.T., 2010a, Use of the New Mexico Mines Database and ArcMap in uranium reclamation studies: Society for Mining, Metallurgy and Exploration Inc., Transactions, v. 328.
- McLemore, V.T., 2010b, Use of the New Mexico Mines Database and ArcMap in uranium reclamation studies: Society for Mining, Metallurgy and Exploration Inc., Annual Convention, Phoenix, Feb 2010, Preprint 10-125
- McLemore, V.T., 2011, The Grants uranium district: Update on source, deposition, exploration: *The Mountain Geologist*, v. 48, p. 23-44.
- McLemore, V.T. and Chenoweth, W.L., 1989, Uranium resources in New Mexico: New Mexico Bureau of Mines and Minerals Resources, Resource Map 18, 36 p.
- McLemore, V.T. and Chenoweth, W.L., 1991, Uranium mines and deposits in the

- Grants district, Cibola and McKinley Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open File Report 353, 22 p.
- McLemore, V.T. and Chenoweth, W.L., 2003, Uranium resources in the San Juan Basin, New Mexico: New Mexico Geological Society, Guidebook 54, p. 165-178.
- McLemore, V.T., Donahue, K., Krueger, C.B., Rowe, A., Ulbricht, L., Jackson, M.J., Breese, M.R., Jones, G., and Wilks, M., 2002, Database of the uranium mines, prospects, occurrences, and mills in New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open file Report 461, CD-ROM.
- Moore, S.C. and Lavery, N.G., 1980, Magnitude and variability of disequilibrium in San Antonio Valley uranium deposit, Valencia County; in C.A. Rautman, compiler, Geology and mineral technology of the Grants uranium region 1979: New Mexico Bureau of Mining and Mineral Resources, Memoir 38, p. 276-283.
- Myers, G., 2006a, Technical report of the Section 24 portion of the Crownpoint property, McKinley County, New Mexico: NI 43-101 Mineral Resource Report prepared for Strathmore Minerals Corp., 71 p.
- Myers, G., 2006b, Technical report of the Section 19 and 29 portions of the Crownpoint property, McKinley County, New Mexico: NI 43-101 Mineral Resource Report prepared for Strathmore Minerals Corp., 79 p.
- Myers, G., 2006c, Technical report of the Hosta Butte property, McKinley County, New Mexico: NI 43-101 Mineral Resource Report prepared for Strathmore Minerals Corp., 58 p.
- Nakai-Lajoie, P., Michaud, R., Collins, S.E., and Smith, R.C., 2012, Technical report on the Roca Honda project, McKinley County, New Mexico, USA: NI 43-101 Mineral Resource Report prepared for Strathmore Minerals Corp., 264 p., <[http://www.strathmoreminerals.com/i/pdf/RPA-RHR-Roca\\_Honda-NI-43-101-PEA-Aug\\_6\\_2012-FI.pdf](http://www.strathmoreminerals.com/i/pdf/RPA-RHR-Roca_Honda-NI-43-101-PEA-Aug_6_2012-FI.pdf)>
- Nash, J.T., Granger, H.C., and Adams, S.S., 1981, Geology and concepts of genesis of important types of uranium deposits; in Skinner, B. J. (ed.), 75th anniversary volume, 1905-1980: Economic Geology, p. 63-116.
- Navajo Nation, 2005, Dine natural resources protection act of 2005. 6 p., <<http://www.navajocourts.org/Resolutions/CAP-18-05.pdf>>
- New Mexico Environment Department (NMED), 2010, Geochemical analysis and interpretation of ground water data collected as part of the Anaconda Company Bluewater Uranium Mill Site Investigation (CERCLIS ID NMD007106891) and San Mateo Creek Site Legacy Uranium Sites Investigation (CERCLIS ID NMN00060684), McKinley and Cibola County, New Mexico, 128 p., <<http://www.nmenv.state.nm.us/gwb/documents/FinalPublicDraftofGeochemofBluewaterandSMCGroundWaterSamples.pdf>>
- Pelizza, M. and McCarn, D.W., 2003a, Licensing of in situ leach recovery operations for the Crownpoint and Church Rock uranium deposits, New Mexico: A case study, part 1 of 2: The Professional Geologist, vol. 40, n. 3, p. 5-10.
- Pelizza, M. and McCarn, D.W., 2003b, Licensing of in situ leach recovery operations for the Crownpoint and Church Rock uranium deposits, New Mexico: A case study, part 1 of 2: The Professional Geologist, vol. 40, n. 3, p. 6-12.
- Pelizza, M. and McCarn, D. W., 2004, Licensing of in situ leach recovery operations for the Crownpoint and Church Rock uranium deposits, New Mexico: A case study, in: Recent developments in uranium resources and production with emphasis on in situ leach mining. Proceedings of a technical meeting organized by the IAEA in co-operation with the OECD Nuclear Agency, the Bureau of Geology, China National Nuclear Corporation, Proceedings of a technical meeting organized by the IAEA in co-operation with the OECD Nuclear Agency, the Bureau of Geology, China National Nuclear Corporation held in Beijing, 18-23 September 2002, v. IAEA-TEC-DOC-1396, p. 153-173.
- Peters, D.C., 2007, Technical report on La Jara Mesa uranium property, Cibola County, New Mexico: NI 43-101 Mineral Resource Report prepared for Laramide Resources Ltd., 81 p., <<http://www.laramide.com/images/pdf/propertyinfo/laramidetech0724.pdf>>
- Randabel, J. and Vukovic, D., 2009, Rio Puerco deposit, Sandoval County, New Mexico, USA, Geological Review and Estimate: Monaro Mining NL, 59 p., <[http://www.ausamerican.com/my/downloads/RioPuerco\\_Resource%20study2009\\_JR\\_ASXVersion.pdf](http://www.ausamerican.com/my/downloads/RioPuerco_Resource%20study2009_JR_ASXVersion.pdf)>
- Sanford, R.F., 1982, Preliminary model of regional Mesozoic ground water flow and uranium deposition in the Colorado Plateau: Geology, v. 10, p. 348-352.
- Sanford, R.F., 1992, A new model for tabular-type uranium deposits: Economic Geology, v. 87, p. 2041-2055.
- Saucier, A.E., 1981, Tertiary oxidation in Westwater Canyon Member of the Morrison Formation; in Rautman, C.A., compiler, Geology and mineral technology of the Grants uranium region 1979: New Mexico Bureau of Mines and Mineral Resources, Memoir 38, p. 116-121.
- Turner-Peterson, C.E., 1985, Lacustrine-humate model for primary uranium ore deposits, Grants uranium region, New Mexico: American Association of Petroleum Geologists, Bulletin, v. 69, no. 11, p. 1999-2020.
- Turner-Peterson, C.E. and Fishman, N.S., 1986, Geologic synthesis and genetic models for uranium mineralization in the Morrison Formation, Grants uranium region, New Mexico; in Turner-Peterson, C.E., Santos, E.S. and Fishman, N.S., eds., A basin analysis case study: The Morrison Formation, Grants uranium region, New Mexico: American Association of Petroleum Geologists, Studies 22, p. 357-388.
- U.S. Environmental Protection Agency (US EPA), 2010a, Assessment of health and environmental impacts of uranium mining and milling: Five-year plan Grants mining district, New Mexico, 52 p. <[http://www.epa.gov/region6/6sf/newmexico/grants/nm\\_grants\\_5yr\\_plan.pdf](http://www.epa.gov/region6/6sf/newmexico/grants/nm_grants_5yr_plan.pdf)>
- U.S. Environmental Protection Agency (US EPA), 2010b, Grants mining district draft five-year plan, 6 p. <[http://www.epa.gov/region6/6sf/newmexico/grants/nm\\_grants\\_5yr\\_factsheet.pdf](http://www.epa.gov/region6/6sf/newmexico/grants/nm_grants_5yr_factsheet.pdf)>
- U.S. Environmental Protection Agency (US EPA), 2011a, Aerial radiological surveys Ambrosia Lake uranium mines, Cibola and McKinley Counties, New Mexico, 33 p., <[http://www.epa.gov/region6/6sf/newmexico/grants/nm\\_grants\\_aerial-radiological-survey-of-the-ambrosia-lake-uranium-mines.pdf](http://www.epa.gov/region6/6sf/newmexico/grants/nm_grants_aerial-radiological-survey-of-the-ambrosia-lake-uranium-mines.pdf)>
- U.S. Environmental Protection Agency, 2011b, Aerial radiological surveys Poison Canyon uranium mines, Cibola and McKinley Counties, NM, 41 p., <[http://www.epa.gov/region6/6sf/newmexico/grants/nm\\_grants\\_aerial-radiological-surveys-of-the-poison-canyon-uranium-mines.pdf](http://www.epa.gov/region6/6sf/newmexico/grants/nm_grants_aerial-radiological-surveys-of-the-poison-canyon-uranium-mines.pdf)>
- Uranium Resources, Inc., 2011, Uranium Resources, Inc. annual report: 96 p., <[http://files.shareholder.com/downloads/URRE/2330303543x0x564568/9430bba2-2cbf-4281-93a0-0da5ca6893dd/URI\\_2011\\_AR\\_for\\_WebPosting.pdf](http://files.shareholder.com/downloads/URRE/2330303543x0x564568/9430bba2-2cbf-4281-93a0-0da5ca6893dd/URI_2011_AR_for_WebPosting.pdf)>