Uranium deposits in the Poison Canyon Trend, Ambrosia Lake Subdistrict, Grants Uranium District, McKinley and Cibola counties, New Mexico

Virginia T. McLemore, 2021, pp. 159-170

in:

Geology of the Mount Taylor area, Frey, Bonnie A.; Kelley, Shari A.; Zeigler, Kate E.; McLemore, Virginia T.; Goff, Fraser; Ulmer-Scholle, Dana S., New Mexico Geological Society 72nd Annual Fall Field Conference Guidebook, 310 p.

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New Mexico Geological Society Guidebook, 71st Field Conference, Geology of the Mount Taylor Area, 2021, p. 159-169.

URANIUM DEPOSITS IN THE POISON CANYON TREND, AMBROSIA LAKE SUBDISTRICT, GRANTS URANIUM DISTRICT, MCKINLEY AND CIBOLA COUNTIES, NEW MEXICO

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Abstract—The Poison Canyon uranium discovery was an important economic event in the Grants Uranium District, New Mexico. Not only was it the first sandstone-hosted uranium deposit discovered and mined that ultimately led to the larger Ambrosia Lake Trend, but the main types of uranium deposits, primary and redistributed, were first recognized in the Poison Canyon Trend. More than 10 million lbs of U_3O_8 were produced from mines in the Poison Canyon Trend and additional historic resources remain. The Poison Canyon Trend is south of the Ambrosia Lake Trend, north of Grants and Milan in the southern San Juan Basin. The uranium deposits are hosted by the Poison Canyon sandstone, an informal name (economic usage) of one of the uranium-bearing sandstone units at the top of the Westwater Canyon Member or the lower part of the overlying Brushy Basin Member of the Jurassic Morrison Formation. Many of the uranium deposits in the Poison Canyon Trend have been mined out and what uranium remained at these older mines is probably uneconomic to recover, especially in the western portion of the area. The mineral-resource potential for uranium in the unmined portions of the Poison Canyon Trend is high, especially in the eastern portion of the trend. However, it is unlikely that any of these deposits will be mined in the near future because of economic conditions and numerous challenges to mine uranium in New Mexico.

INTRODUCTION

Most of the economic uranium deposits in New Mexico are hosted by sandstones, and most of the uranium production in New Mexico has come from the Westwater Canyon and Brushy Basin members of the Jurassic Morrison Formation in the Grants Uranium District in McKinley and Cibola (formerly Valencia) Counties (Hilpert, 1969; McLemore, 1983; McLemore and Chenoweth, 1989, 1991, 2017). The Grants District represents one large area in the southern San Juan Basin, extending from east of Laguna to west of Gallup and consists of eight subdistricts (Fig. 1; McLemore and Chenoweth, 1989, 2017). During a period of nearly three decades (1951–1980), the Grants District yielded nearly 347 million lbs of U_3O_8, almost all of New Mexico's production, and more uranium than any other district in the United States (McLemore and Chenoweth, 1989, 2017). Although there are no operating mines in the Grants District today, numerous companies have acquired uranium properties and plan to explore and develop deposits in the district in the future.

The first economic discovery of uranium in sandstone in the Grants District was made on January 4, 1951, east of Haystack Butte in the southern Ambrosia Lake Subdistrict of the Grants District (Fig. 2). The area was named Poison Canyon for the abundance of locoweed, a poisonous plant. The host rock is either a tongue of the Westwater Canyon Member or the lower part of the overlying Brushy Basin Member of the Morrison Formation (Hilpert, 1969). This unit would later be called the Poison Canyon sandstone, an informal name of economic usage.

Many published and unpublished reports have been released before 1990 describing the uranium deposits in the Grants Dis-

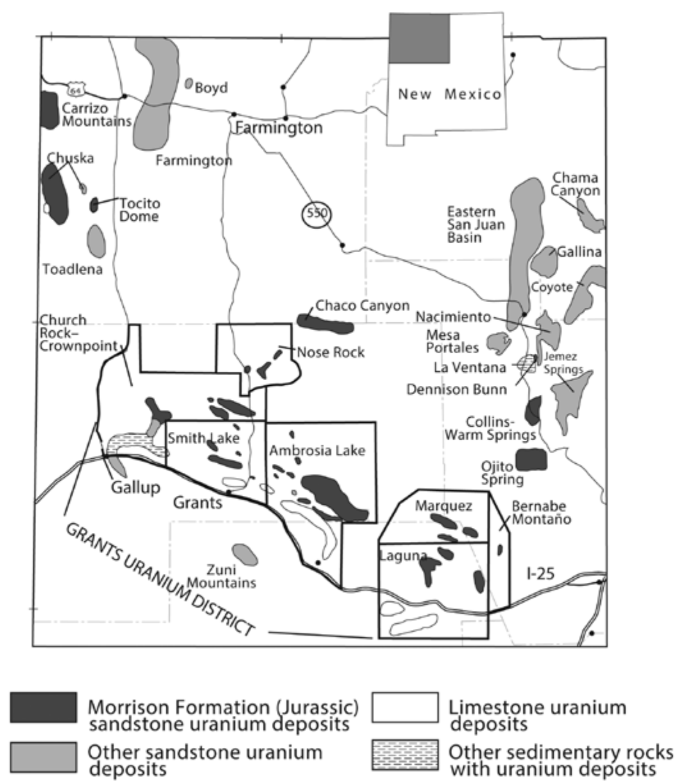

FIGURE 1. Subdistricts in the Grants Uranium District in the San Juan Basin, New Mexico (McLemore and Chenoweth, 1989, 1991). Polygons outline approximate areas of known uranium deposits.

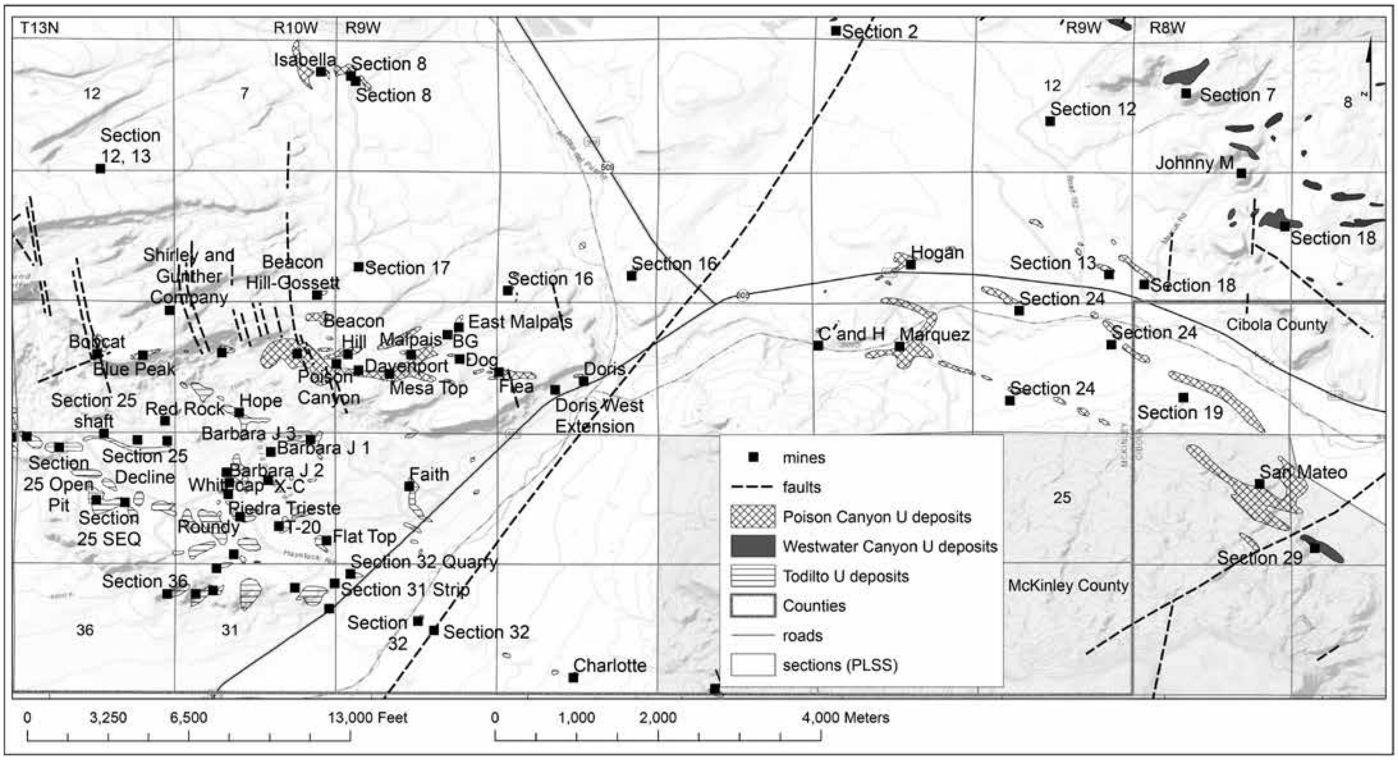

FIGURE 2. Uranium deposits in the Poison Canyon Trend, Ambrosia Lake Subdistrict (revised from Chapman, Wood and Griswold, Inc., 1979; McLemore and Chenoweth, 1991). A color version is in the color plates section of this guidebook and in supplemental material. PLSS=Public Land Survey System

trict (cited in McLemore, 1983; McLemore and Chenoweth, 1989, 2017), but few reports have updated the status of the deposits in the Poison Canyon area (McLemore et al., 2013). The Poison Canyon uranium discovery was an important economic event in the Grants District. Not only was it the first sandstone-hosted uranium deposit discovered and mined that ultimately led to the larger Ambrosia Lake Trend, but the main types of uranium ore deposits in the Grants District, primary and redistributed, were first recognized in the Poison Canyon Trend. More than 10 million lbs of U_3O_8 were produced from mines in the Poison Canyon Trend, and additional historic resources remain that could be mined in the future (Tables 1, 2). Most of the recent studies on the Grants District have focused on reclamation, while only a few recent reports have discussed the uranium geology and future economic potential of these deposits.

The purpose of this report is to summarize the history, stratigraphy, and mineralized deposits in the Poison Canyon Trend (including uranium production), as well as provide some insights into the age, source and future mineral-resource potential of the uranium deposits in the Poison Canyon Trend. Most of the mines in the Poison Canyon Trend have been or are being reclaimed, and studies on their reclamation are discussed elsewhere. The Poison Canyon Trend, as defined in this report, is from the Section 14 prospect near the Bobcat and Blue Peak mines (southeast of Mesa Montanosa) southeastward to the San Mateo Mine, which is west of the village of San Mateo (Fig. 2; Rapaport, 1963).

METHODOLOGY

All known uranium mines, mills, deposits, and occurrences are entered into the New Mexico Mines Database (McLemore et al., 2002). Since its creation in 1927, the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) has collected published and unpublished data on the districts, mines, deposits, occurrences, and mills, including uranium mines, and is slowly converting these data into a relational database, the New Mexico Mines Database, using Microsoft Access. The New Mexico Mines Database provides data available on mines and districts in New Mexico. The available data for this database is from a variety of published and unpublished reports (including theses and dissertations) and miscellaneous unpublished files in the NMBGMR mining archive, and includes information on location, production, reserves, resource potential, significant deposits, geology, geochemistry (rock, water, etc.), well data, mining methods, maps, ownership, and other data, if available. The New Mexico Mines Database provides detailed information on the mineralogy, host rock lithology, and metal association of each mine or mining district. The database also includes limited geochemical data of both solid (host rock, ore, mine wastes, tailings, stream sediments, etc.) and water (surface, ground, pit lakes, etc.) samples. New information is continuously becoming available and is incorporated into the database regularly. See McLemore et al. (2002) for a more detailed description of the database. Much of the information in this paper is summarized from the database, and includes information from field investigations, published papers

TABLE 1. Production from uranium mines in the Poison Canyon Trend 1951-1971 (revised from U.S. Atomic Energy Commission, production records; McLemore, 1983).

Mine ID	Mine Name	Ore (short tons)	Uranium (pounds)	Grade (%U_3O_8)	Vanadium (pounds)	Years
NMMK0012	Beacon Hill-Gossett	41,650	161,045	0.19	22,671	1956-1963, 1966-1967
NMMK0013	BG	30,033	128,644	0.22		1969-1971
NMMK0018	Blue Peak	12,051	44,020	0.19	18,707	1951-1961, 1964
NMMK0019	Bobcat	117	186	0.06	71	1956
NMMK0045	Davenport	7517	28,829	0.17		1957-1968
NMMK0048	Dog	244,177	906,235	0.19		1957-1975, 1978-1980
NMMK0049	Doris	33,487	122,872	0.18		1958-1961, 1979-1980
NMMK0050	Doris West Extension					1979-1981
NMMK0054	East Malpais	30,333	139,818	0.23		1958-1960
NMMK0082	Hogan	129,551	678,510	0.26		1959-1962
NMMK0086	Isabella	76,749	237,061	0.15		1959-1962, 1980
NMMK0099	Malpais	42,070	198,492	0.24		1958-1961
NMMK0105	Marquez	717,031	3,759,653	0.26		1958-1966
NMMK0107	Mesa Top	108,261	512,965	0.24	144,610	1954-1961, 1967-1968
NMMK0133	Poison Canyon	217,066	1,004,594	0.23	338,094	1952-1980
NMMK0172	Section 8	47,808	165,319	0.17		1958-1966, 1970, 1978-1980
NMMK0210	Section 24 (Chill Wills)	10,950	37,693	0.17		1960-1963
NMCI0053	San Mateo	842,463	2,863,024	0.17		1959-1971
Total		***2,591,314***	***10,988,960***		***524,153***	

TABLE 2. Estimates of the remaining uranium resources in the Poison Canyon Trend (revised from McLemore et al., 2013; Wilton, 2018). Some uranium resources remain at the Marquez mine. The resource and reserve data presented are historical and are provided for information purposes only. They do not conform to Canadian National Instrument NI 43-101 or U.S. Securities and Exchange Commission requirements.

Mine ID	Mine Name	Remaining Resource (short tons)	Grade (U_3O_8%)	Uranium (pounds)	Depth (m)	Year of resource
NMMK0210, NMMK0211, NMMK0212	Section 24 (Treeline)	1,500,000	0.13	593,448	137-183	1978
NMMK0727	Section 13	?	0.039-0.216	855,313	246-267	2008
Total		***>1,500,000***		***1,448,761***		

(Rapaport, 1963; Holmquist, 1970; McLemore, 1983), and NMBGMR file data.

A detailed mineral deposit map of the Poison Canyon Trend was compiled in ArcMap using USGS topographic maps as the map base at a scale of approximately 1:12,000, the New Mexico Mines Database, as well as digitized outlines of mineralized deposits from NMBMGMR file data, published reports, and unpublished company data (Fig. 2; color version is in the color plates section of this guidebook and in supplemental material). Most of the outlines of the ore deposits were obtained from the mining companies in the mid-1980s (Rapaport, 1963; Chapman, Wood and Griswold, Inc., 1979; McLemore and Chenoweth, 1989, 1991) and updated by recent reports.

The production and resources figures in Tables 1 and 2 are the most recent data available and were obtained from published and unpublished sources (NMBGMR file data). Production and resources figures are subject to change as new data are obtained. The resource and reserve data presented in Table 2 are historical and are provided for information purposes only, and do not conform to Canadian National Instrument NI 43-101 or U.S. Securities and Exchange Commission requirements.

GEOLOGIC SETTING

The Morrison Formation is Late Jurassic (Kimmeridgian-Tithonian) and extends throughout much of western United States (Hilpert, 1969; Dunagan and Turner, 2004; Dickinson, 2018). Sedimentary units within the formation were deposited in a variety of environments, including alluvial plain, eolian, lacustrine, and nearshore marine. The formation is divided into the Salt Wash (oldest), Recapture, Westwater Canyon, and Brushy Basin (youngest) members; overlies the Jurassic Bluff Sandstone and Summerville Formation; and is overlain by the Cretaceous Dakota Formation (see stratigraphic chart, back cover). The Salt Wash Member is not found in the Ambrosia Lake Subdistrict. The Ambrosia Lake Subdistrict is one of the most faulted areas of the Grants District where high-angle normal faults either trend north to northeast, northeast to east, or northwest. Most of the faults are younger than the Dakota Formation and have displacements of 15 to 30 m.

The Poison Canyon sandstone is an informal name (economic usage) of one of the uranium-bearing sandstone units in the Morrison Formation (Fig. 3; Zitting et al., 1957; Hilpert and Corey, 1956; Hilpert and Freeman, 1956; Hilpert, 1969). There has been a controversy among economic geologists as to whether the Poison Canyon sandstone is the uppermost sandstone unit at the top of the Westwater Canyon Member (Santos, 1963; Tessendorf, 1980; Condon, 1989) or the lowermost sandstone at the base of the Brushy Basin Member (Hilpert, 1963; Turner-Peterson et al., 1980; Turner-Peterson, 1985; Bell, 1986; Dahlkamp, 2010). Furthermore, other economic geologists (Hoskins, 1963) use this name to designate any persistent sandstone in the Brushy Basin Member in the Ambrosia Lake and Smith Lake subdistricts. The relationship between the Westwater Canyon and Brushy Basin contact is a stratigraphic difficulty inherent with interfingering fluvial units, and picking the contact between the two units can be difficult and arbitrary. However, for the purposes of this report, the Poison Canyon sandstone refers to the specific sandstone found in the Poison Canyon Trend that is separated from lower Westwater Canyon sandstones by a regional, 4.6- to 7.6-m thick, greenish shale, often called the K shale (Fig. 3). Stratigraphic relationships can be confusing because the Poison Canyon sandstone is a braided-stream deposit formed at the top of the Westwater Canyon wet alluvial fan system (Galloway, 1980) prior to the deposition of the predominantly shale units of the Brushy Basin Member that has local persistent streams cutting through the shale sequences (Fig. 3). These stratigraphic naming problems are in part, a result of the depositional nature of the units and some geologists use geophysical logs and cuttings in addition to outcrops and measured sections to determine the stratigraphic relationships, whereas other geologists use only outcrops and measured sections.

The Poison Canyon sandstone generally consists of three units: a lower sandstone, middle shale, and upper sandstone. The sandstone is yellow to gray, fine- to coarse-grained, poorly sorted, cross-bedded arkosic sandstone approximately 15 m thick at the Poison Canyon Mine, and varies from 10 to 25 m thick elsewhere. Volcanic rock fragments are common along with clay balls and lenses. It extends to the east and north from the mine and vertically grades upwards into the Brushy Basin Member. Most of the uranium deposits are near the base of the sandstone, and most of the deposits are found where the Poison Canyon sandstone is greater than 15 m thick (Hilpert, 1969). Paleocurrent studies of the Poison Canyon sandstone indicate predominantly east to northeast current directions, whereas the older upper Westwater Canyon sandstones indicate predominantly east to southeast current directions (Turner-Peterson et al., 1980; Turner-Peterson, 1985). The lower Westwater Canyon sandstones flowed east-southeast (Turner-Peterson et al., 1980; Turner-Peterson, 1985).

The regional presence of extensive zeolites in the Brushy Basin Member was previously interpreted to represent deposition in a shallow alkaline lake (Lake T'oo'dichi'; Turner-Peterson, 1980, 1985; Turner-Peterson and Fishman, 1991; Demko et al., 2004; Turner, 2010a,b), but re-evaluation of the geochemistry and sedimentology has led to a revised interpretation. Revised interpretations have redefined Lake T'oo'dichi' as widespread, discontinuous wetlands of isolated ponds and marshes (Anderson and Lucas, 1997; Turner, 2004) fed by groundwater from a regional aquifer (Dunagan and Turner, 2004; Turner, 2010a,b; Dickinson, 2018). The Poison Canyon sandstone is interpreted as a local fluvial sandstone flowing into or across the Lake T'oo'dichi'. The gray smectite mudstones were deposited marginally to the lake.

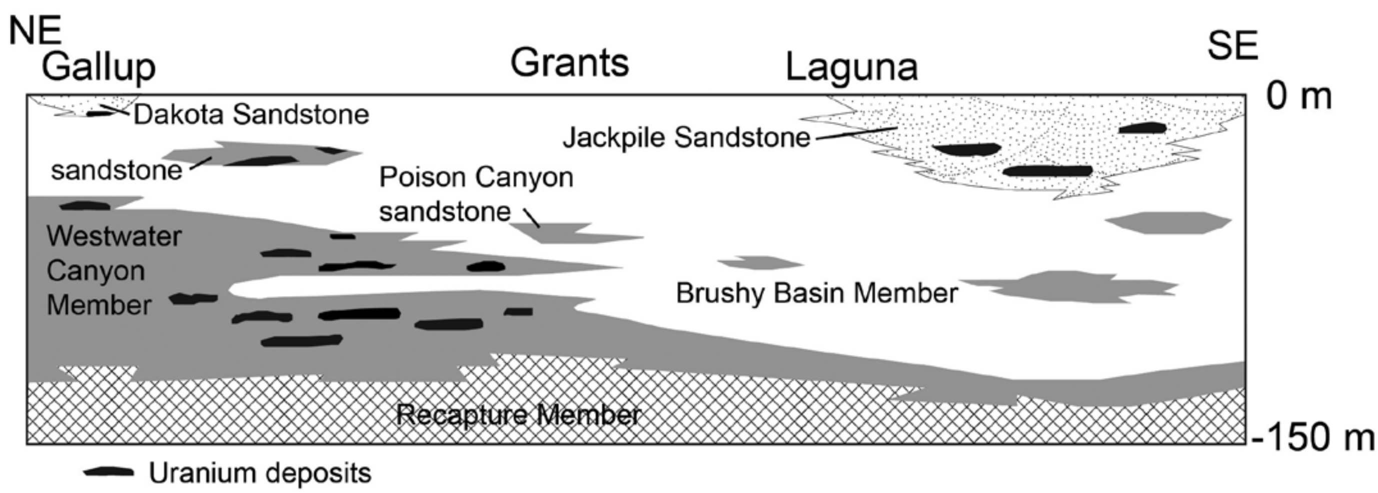

FIGURE 3. Schematic cross-section from Gallup to east of Laguna showing relationship of the Poison Canyon sandstone to the Westwater Canyon and Brushy Basin Members of the Morrison Formation (modified from Hilpert, 1969).

Three types of uranium deposits are found in the Morrison Formation (including the Westwater Canyon Member, Poison Canyon sandstone, Brushy Basin Member, Jackpile Sandstone, and extending into the Cretaceous Dakota Formation in the Church Rock-Crownpoint Ssubdistrict): 1) primary, tabular (also called trend or blanket), 2) redistributed (also called roll-type or stack), and 3) remnant-primary sandstone uranium deposits (Hilpert, 1969; Saucier, 1981; Adams and Saucier, 1981; McLemore and Chenoweth, 1989, 2017). A fourth type of uranium deposit, tabular sandstone uranium-vanadium deposits are found in the Salt Wash and Recapture members of the Morrison Formation in the western San Juan Basin (McLemore and Chenoweth, 1989, 2017). It is important to note that the older Jurassic Todilto Limestone is mineralized south of the Poison Canyon Trend (Berglof and McLemore, 2003; McLemore, 2020). The descriptions of the economic geology and uranium deposits are found in numerous reports, many cited in McLemore (1983), Hilpert (1969), McLemore and Chenoweth (1989, 1991, 2017), McLemore et al. (2013), and Dahlkamp (2010).

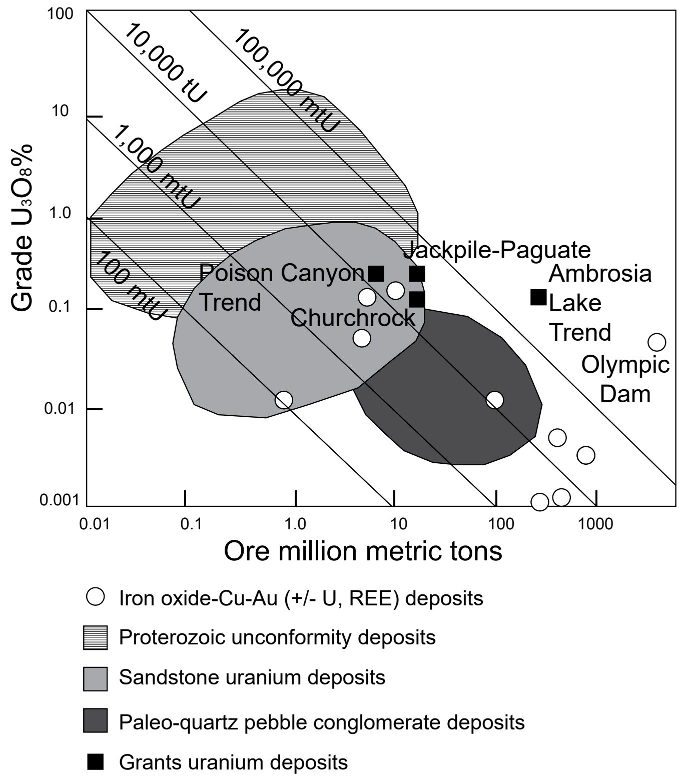

FIGURE 4. Grade-tonnage of major uranium deposits, showing major Grants uranium deposits. Fields are modified from Hitzman and Valenta (2005) and Thakur et al. (2018) with specific deposit data from Holen and Finch (1982), McLemore (1983), Chenoweth (1989), and McLemore et al. (2013).

DESCRIPTION OF SELECTED URANIUM DEPOSITS

Sandstone uranium deposits in the Poison Canyon Trend are a cluster of similar ore bodies that are spatially close together, that formed by similar geologic processes, and that could have been mined as one to three large mine operations (Holen and Finch, 1982). But the ownership of the Poison Canyon Trend deposits was complicated with various sections owned by private owners, state of New Mexico, Navajo Indian allotments, and federal lands (referred to as checkerboard ownership), resulting in the numerous underground operations (albeit no longer operating). Therefore, the entire Poison Canyon Tend could be considered one large uranium deposit (similar to a mine producing multiple ore shoots along one vein) that was operated by different mining companies.

Appendix 1 is a summary of the location and other data of the uranium mines, prospects, and unmined deposits in the Poison Canyon Trend. Production from the uranium mines in the Poison Canyon Trend is in Table 1, and estimates of the remaining uranium resources are in Table 2. Figure 2 shows the trend of the uranium deposits (a color version of this figure is in the color plates portion of this volume). Figure 4 shows grade-tonnage relationships of uranium deposits, comparing the Grants uranium deposits with other world-class uranium deposits. Descriptions and mining history of selected Poison Canyon Trend mines are below.

Blue Peak Mines

In 1951, yellow uranium minerals (predominantly carnotite, tyuyamunite, autunite, schroeckingerite; Dodd, 1955; Rapaport, 1963) were found associated with black carbonaceous material (humates) in limonitic sandstone outcrops, just above the K shale layer. Blue Peak Mining Co. began operating the Blue Peak mines in March 1951 from seven adits and stripping along the rim (Holmquist, 1970). The Blue Peak mines were the first sandstone operations in the Ambrosia Lake Subdistrict (Rapaport, 1963; McLemore, 1983). Several different operators developed and mined the deposits (Table 3; Holmquist, 1970). Total production amounted to 12,051 short tons of ore yielding 44,020 lbs U_3O_8 (grade 0.19%) and 18,707 lbs of V_2O_5 from 1951 to 1964 (Table 1, 3). Most of the uranium deposits were mined, but small isolated mineralized bodies remained that would be difficult and uneconomic to recover (U.S. Atomic Energy Commission files).

The entire mined deposit was approximately 213 m long and 10-30 m wide. Mineralized stopes exhibited 10 to 100 fractures per hundred linear meters, whereas barren and low-grade stopes exhibited 1.5 to 3 fractures per hundred linear meters. This correlation between fractures and mineralization provided a definitive guide to locating uranium deposits in the Poison Canyon Trend (Rapaport, 1963).

Poison Canyon Mine

Open-pit mining began at the Poison Canyon Mine in December 1951, and the first ore shipped in early 1952 (U.S. Atomic Energy Commission production records). A series of north-trending faults slightly offset the ore bodies and subsequently redistributed the uranium along the faults (Fig. 2; Mathewson, 1953; Konigsmark, 1958; Rapaport, 1963; Tessendorf, 1980). Uranium grade and thickness increase adjacent to the faults (Dodd, 1955). The primary uranium deposits were 3.6 m thick, and coffinite, tyuyamunite, and autunite were

TABLE 3. Uranium production from the Blue Peak Mine, 1951-1964 (from U. S. Atomic Energy Commission, production records; McLemore, 1983).

Year	Shipper	Ore (short tons)	Uranium (pounds)	Grade (% U_3O_8)	Grade (% V_2O_5)
1951	Blue Peak Mining Co.	766	5488	0.36	0.15
1952	Blue Peak Mining Co.	3998	12,474	0.16	0.08
1953	Shattuck Denn Corp.	1039	3826	0.18	0.09
1955	Blue Peak Mining Co., San Michaels College Foundation	148	867	0.29	0.08
1956	Colohoma Uranium, Inc.	347	2180	0.31	0.13
1957	Three Jacks Mining	549	2676	0.25	
1958	Three Jacks Mining	219	861	0.20	
1959	Farris Mining Co.	3751	11,146	0.15	
1960	Farris Mining Co., Lloyd O. Sutton	726	3113	0.21	
1961	Lloyd O. Sutton	417	1234	0.15	
1964	Lee Garcia	91	155	0.09	
Total 1951-1964		***12,051***	***44,020***	***0.19***	

the primary uranium minerals (Konigsmark, 1958); pascoite, a vanadium mineral, and ilsemannite, a molybdenum mineral, also are reported (Tessendorf, 1980). Some of the redistributed uranium was vertically distributed or stacked along the fault and was up to 12 m thick. The uranium bodies were 3-15 m to 137 m wide in the shear zone. Underground mining started in 1955 (Holmquist, 1970), and Farris Brothers continued operations in 1960. Subsequently, Reserve Oil and Minerals Corp. located additional uranium deposits in 1976 and mined underground at the mine through 1980 (Tessendorf, 1980). Total production from all companies amounted to 217,066 short tons of ore yielding 1,004,594 lbs U_3O_8 (0.23% U_3O_8) and 338,094 lbs V_2O_5 from 1952 to 1980 (Table 1). Not all production was reported between 1970 and 1980, although most of the uranium deposits were mined out.

Hogan Mine

The Hogan Mine, discovered by drilling in 1957, operated between 1959 and 1979 through a 103.6 m shaft in a thick portion of the Poison Canyon sandstone (24 m thick). Three redistributed, vertical uranium deposits (designated basal, intermediate, and upper zones) in the Hogan Mine were found along an anticlinal fold that is parallel to the San Mateo fault (Rapaport, 1963). The deposit was developed by underground methods typical of the times (Mining World, 1959), and total production amounted to 129,551 short tons of ore containing 678,510 lbs U_3O_8 at a grade of 0.26% U_3O_8 from 1959 to 1962; an unknown amount of uranium was produced from 1963-1979. Most, if not all of the uranium deposits were mined out.

Marquez Mine

The Marquez (Marcus) Mine, discovered by drilling in 1955, operated through a 571.5-m incline (Weege, 1963) from 1958 to 1966 and was the largest deposit in the Poison Canyon Trend (Rapaport, 1963) with a production of 717,031short tons of ore containing 3,759,653 lbs U_3O_8 at a grade of 0.26% U_3O_8 (Table 4). The deposit consisted of northeast-trending, narrow, elongated ore bodies, more than 1.6 km long, mostly at the base of the Poison Canyon sandstone. Uranium is associated with organic matter that consists of humates, coal fragments, and silicified wood fragments within the 7.6-m-thick, upper, medium- to fine-grained, arkosic sandstone. Uranium is associated with humates. During retreat mining and recovery of pillars, the workings started to cave, and some uranium was lost (Johnston, 1963; Holmquist, 1970). Although, some uranium probably remains, it will be difficult and dangerous to mine by conventional techniques.

Mesa Top Mine

The Mesa Top Mine, discovered by drilling in 1954, operated between 1959 and 1968 through a 45.7 m shaft. The Mesa Top shaft closed in 1959, and the ore was hoisted through the nearby Malpais shaft. The mine yielded 108,261 short tons of ore containing 512,965 lbs U_3O_8 (grade of 0.24% U_3O_8) and 144,610 lbs V_2O_5 from 1954 to 1961 (Table 1); an unknown amount of uranium was produced from 1967 to 1968. Most, if not all of the uranium deposits were mined.

San Mateo Mine

The San Mateo deposit is the easternmost deposit in the Poison Canyon Trend and was discovered in 1957 with more than 83,820 m of drilling in 250 holes in 1957-1958 (Holmquist, 1970). The 337-m three-compartment shaft was sunk in 1958 by Centennial Dev. Co. and operated by Rare Metals Co. Water was encountered at 213 m (Holmquist, 1970). Total production from 1959 to 1971 amounted to 842,463 short tons of ore containing 2,863,024 lbs U_3O_8 (Table 5). In 1964, United Nuclear acquired the property, and in 1981, Homestake obtained ownership of the property. There could be additional, unmined uranium deposits in the area.

TABLE 4. Uranium production from the Marquez Mine, 1959-1966 (from U. S. Atomic Energy Commission, production records; McLemore, 1983). There may have been additional, unreported production in 1971.

Year	Shipper	Ore (short tons)	Uranium (pounds)	Grade (%U_3O_8)
1958	Calumet and Hecla	75,393	402,968	0.27
1959	Calumet and Hecla	139,958	786,122	0.28
1960	Calumet and Hecla	132,467	657,674	0.25
1961	Calumet and Hecla	103,435	609,362	0.28
1962	Calumet and Hecla	106,933	555,840	0.26
1963	Calumet and Hecla	104,984	529,468	0.25
1964	Calumet and Hecla	16,558	92,997	0.28
1965	United Nuclear	5145	18,268	0.18
1966	United Nuclear	32,158	106,954	0.17
Total 1958-1966		***717,031***	***3,759,653***	***0.26***

Section 24 (Chill Wills, Treeline) Deposits

Several, small uranium deposits were discovered in the Poison Canyon sandstone in Section 24 by drilling in the late 1970s. The Section 24 (also known as Chill Wills) Mine yielded 10,950 short tons of ore containing 37,693 lbs of U_3O_8 (0.17% U_3O_8) from 1960 to 1963. In 1978, Conoco identified an historic resource of 593,448 short tons of ore grading 0.13% U_3O_8 elsewhere in Section 24 (also known as Treeline; Table 2; Fig. 2). Currently, enCore Energy Corp. owns the property and is examining it for potential in situ recovery (*https://www.encoreenergycorp.com/uranium-assets/isr-projects/treeline/*, accessed 1/18/20).

AGE AND SOURCE OF URANIUM MINERALIZATION

The age of the uranium deposits in the Grants District is constrained by numerous isotopic studies (Table 6, Fig. 5; McLemore, 2011) and supports a potential Jurassic volcanic arc as a source of uranium (Christiansen et al., 2015). Jurassic volcanism, intra-arc sedimentation and plutonism are well documented throughout the Jurassic volcanic arc west and southwest of the San Juan Basin (Fig. 6; Saleeby and Busby-Spera, 1992; Miller and Busby, 1995; Blakey and Parnell, 1995; Lawton and McMillan, 1999; Kowallis et al., 2001; du Bray, 2007). Uranium and vanadium concentrations show a decrease in the volcanic ash beds, consistent with uranium and vanadium being derived from volcanic ash from the Jurassic arc (Christiansen et al., 2015). Zircon ages from the Brushy Basin and Westwater Canyon members are consistent with the Jurassic volcanic arc as a source, as well as Proterozoic basement rocks (Dickinson and Gehrels, 2008). The uranium also could be from groundwater derived from a volcanic highland to the southwest (Sanford, 1982, 1992).

$^{40}Ar/^{39}Ar$ ages of plagioclase and alkali feldspar from the younger Brushy Basin Member of the Morrison Formation range from 145 to 153 Ma (Kowallis et al., 1991, 1999). Rb/Sr isochrons of clay minerals from the Poison Canyon sandstone indicated minimum ages of 105 Ma and 130 Ma (Brookins, 1980, 1989), but the isochrons are disturbed because of alteration. Primary, tabular uranium deposits in the older Westwater Canyon Member of the Ambrosia Lake and Smith Lake subdistricts are 130-140 Ma (references in Table 6; Fig. 5). The primary, tabular uranium deposits in the Poison Canyon Trend are likely of similar age. Younger, redistributed uranium deposits in the Ambrosia Lake Subdistrict are much younger, 3-12 Ma in age (references in Table 6; Fig. 5).

TABLE 5. Uranium production from the San Mateo Mine, 1959-1971 (from U. S. Atomic Energy Commission, production records; McLemore, 1983). There may have been additional, unreported production in 1971.

Year	Shipper	Ore (short tons)	Uranium (pounds)	Grade (%U_3O_8)
1959	Rare Metals Corp.	5532	19,248	0.17
1960	Rare Metals Corp.	4077	12,865	0.16
1961	Rare Metals Corp.	74,662	234,570	0.16
1962	Rare Metals Corp., El Paso Natural Gas Co.	85,798	334,288	0.19
1963	El Paso Natural Gas Co.	100,811	409,609	0.20
1964	El Paso Natural Gas Co., United Nuclear Corp.	42,220	173,357	0.21
1965	United Nuclear Corp.	48,508	199,000	0.21
1966	United Nuclear Corp.	73,934	294,025	0.20
1967	United Nuclear Corp.	144,102	484,206	0.17
1968	United Nuclear Corp.	86,345	239,707	0.14
1969	United Nuclear Corp.	118,989	296,096	0.12
1970	United Nuclear Corp. (Reserve Oil and Minerals Corp.)	52,134	152,828	0.15
1971	United Nuclear Corp.	5351	13,225	0.17
Total 1959-1971		***842,463***	***2,863,024***	***0.17***

ORIGIN OF URANIUM MINERALIZATION

There is no consensus on the origin of the primary, tabular sandstone uranium deposits (Sanford, 1992; McLemore and Chenoweth, 2017). The majority of the proposed models for formation of the Ambrosia Lake sandstone uranium deposits 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 and brine-interface models, have refined or incorporated portions of these early theories. In the lacustrine-humate model, groundwater was expelled by compaction from lacustrine muds formed by a large playa lake (Turner-Peterson, 1985; Turner-Peterson and Fishman, 1986). The ground-

TABLE 6. Sequence of uranium deposition in the Grants Uranium District (from youngest to oldest; modified from McLemore, 2011). The age of the mineralizing event is from isotopic dating (Fig. 5) or is estimated by the author based upon stratigraphic position.

Depositional Event	Age	Reference
Secondary Todilto limestone deposits	Tertiary, 3-7 Ma	Berglof (1989)
Redistributed uranium deposits (Cretaceous Dakota Sandstone, Jurassic Brushy Basin and Westwater Canyon Sandstone members)	Tertiary, 3-12 Ma	Miller and Kulp (1963), Nash and Kerr (1966), Nash (1968), Brookins et al. (1977), Brookins (1980), Ludwig et al. (1982), Hooper (1983)
Redistributed uranium deposits (Cretaceous Dakota Sandstone, Jurassic Brushy Basin and Westwater Canyon Sandstone members)	Cretaceous, 80-106 Ma	Smith, R., and McLemore, V.T. (unpublished)
Uranium in the Jackpile sandstone	110-115 Ma	Lee (1976)
Uranium in the Brushy Basin Sandstone Member	Unknown, estimated 130-115 Ma	
Uranium in the Poison Canyon sandstone	Unknown, estimated 140-115 Ma	
Uranium in the Westwater Canyon Sandstone Member	148-130 Ma	Miller and Kulp (1963), Nash and Kerr (1966), Nash (1968), Brookins et al. (1977), Brookins (1980), Ludwig et al. (1982), Hooper (1983)
Deposition of the Morrison Formation units	Unknown, estimated before 130 Ma	
Todilto limestone uranium deposits	155-150 Ma	Berglof (1970, 1989)
Deposition of the Todilto limestone	Before 155 Ma	

water was expelled into the underlying fluvial sandstones where humate or secondary organic material precipitated as a result of flocculation into tabular bodies within sandstone hosts. During or after precipitation of the humate bodies, uranium was precipitated from groundwater (Turner-Peterson, 1985; Turner-Peterson and Fishman, 1986). This model proposes the humate bodies were formed prior to uranium deposition.

In the brine-interface model, uranium and humate were deposited during diagenesis by reduction at the interface of meteoric fresh water and groundwater brines (Granger and Santos, 1986). In another variation of the brine-interface model, groundwater flow is driven by gravity, not compaction (Sanford, 1982, 1992). Groundwater flowed down dip and discharged in the vicinity of the uranium deposits. Uranium

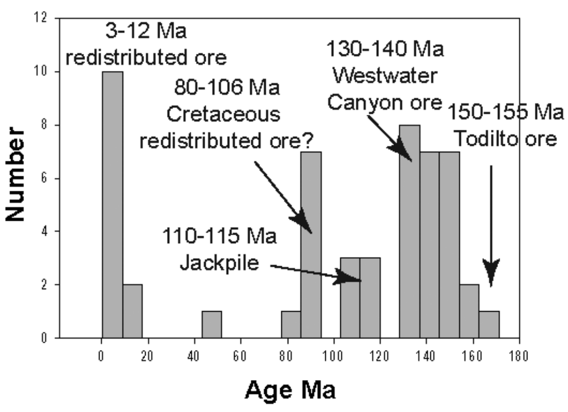

FIGURE 5. Age determinations of Grants District mineralization (from McLemore, 2011). Includes Pb/U, K/Ar, Rb/Sr, and fission track dates from Miller and Kulp (1963), Nash and Kerr (1966), Nash (1968), Berglof (1970, 1989), Brookins et al. (1977), Brookins (1980), Ludwig et al. (1982), Hooper (1983) and is summarized by Wilks and Chapin (1997). The Brushy Basin Member is 153 to 145 Ma (Kowallis et al., 1991, 1999) and the uranium ore ranges from 130 Ma to 105 Ma (Brookins, 1980).

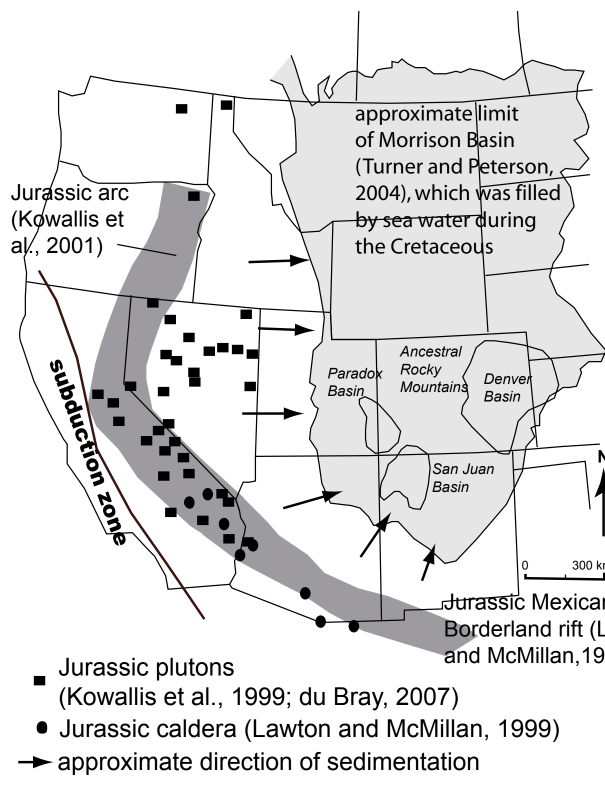

FIGURE 6. Approximate location of the Jurassic arc in relation to the Morrison Basin (from McLemore, 2011; McLemore and Chenoweth, 2017). The gray polygon represents the chain of volcanoes formed during the Jurassic Period, with the Morrison Basin in beige. Three subbasins also are delineated, including the Grants District in the southern San Juan Basin. From Kowallis et al. (1999), du Bray (2007), and Lawton and McMillan (1999).

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 (Sanford, 1982, 1992). Modeling of the regional groundwater flow in the Colorado Plateau during Late Jurassic and Early Cretaceous times supports the brine-interface model (Sanford, 1982). The groundwater flow was impeded by up-thrown blocks of Proterozoic crust and forced upwards. These zones of upwelling are closely associated with uranium-vanadium deposits throughout the Colorado Plateau (Sanford, 1982).

Uranium leached from the altered volcanic ash and from erosion of the Proterozoic granitic highland could have been carried by groundwater and surface waters into the Morrison Formation, forming the uranium deposits found in the Ambrosia Lake Subdistrict. The presence of organic material caused the precipitation of the uranium in the deposits. After formation of the primary, tabular sandstone uranium deposits during Tertiary time, oxidizing groundwater migrated through the uranium deposits and remobilized some of the primary, tabular sandstone uranium deposits (Saucier, 1981). 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.

MINERAL-RESOURCE POTENTIAL

Many of the uranium deposits in the Poison Canyon Trend have been mined out and what uranium mineralization remained at these mines is probably uneconomic to recover, especially in the western portion of the Poison Canyon Trend. Historic resources were determined in a few deposits that were never mined (Table 2; McLemore et al., 1986, 2013, this report). The mineral-resource potential for uranium in the unmined portions of the eastern portion of the Poison Canyon Trend is high (Table 2). However, it is unlikely that any of these deposits will be mined in the near future because of economic conditions and numerous challenges to mine uranium in New Mexico, as summarized by McLemore et al. (2013).

SUMMARY

The Poison Canyon Trend is from the Section 14 prospect near the Bobcat and Blue Peak mines (southeast of Mesa Montanosa) southeastward to the San Mateo Mine, which is west of the village of San Mateo. The first economic discovery of uranium in sandstone in the Grants District was made in the Poison Canyon Trend of the Ambrosia Lake Subdistrict. Not only was it the first sandstone-hosted uranium deposit discovered and mined that ultimately led to the larger Ambrosia Lake Trend, but the main types of uranium ore deposits in the Grants District, primary and redistributed, were first recognized in the Poison Canyon Trend. More than 10 million lbs of U_3O_8 were produced from mines in the Poison Canyon Trend, and additional historic resources remain that could be mined in the future. The primary, tabular uranium deposits in the Poison Canyon Trend are likely 130-140 Ma. Younger, redistributed uranium deposits in the Poison Canyon and Ambrosia Lake Trends are much younger, 3-12 Ma in age. There is no consensus on the origin of the primary, tabular sandstone uranium deposits; however, the majority of the proposed models for formation of the Ambrosia Lake sandstone uranium deposits suggest that deposition occurred at a groundwater interface between two fluids of different chemical compositions and/or oxidation-reduction states. The mineral-resource potential for uranium in the unmined portions of the eastern portion of the Poison Canyon Trend is high, but, it is unlikely that any of these deposits will be mined in the near future because of economic conditions and numerous challenges to mine uranium in New Mexico.

ACKNOWLEDGMENTS

This paper is part of an on-going study of the mineral resources of New Mexico at NMBGMR, Dr. Nelia Dunbar, Director and State Geologist. This report benefited from many past discussions with William Chenoweth, Bob Smith, Ted Wilton, James Bonner, Bill Bergloff, David Fitch, and many others; thanks to all of you. Steve Cather and David Fitch provided some insight into the stratigraphic position of the Poison Canyon sandstone. Ted Wilton and Alva Saucier reviewed an earlier version of this manuscript, and their comments are appreciated.

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Appendices can be found at http://nmgs.nmt.edu/repository/index.cfml?rid=2020002